

Proceedings of the VII Ibero-American

Congress of Smart Cities

ICSC-CITIES 2024

San Carlos, Costa Rica, November 12th to 14th

Hosted and sponsored by

Tecnológico de Costa Rica

Editors:

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Luis Hernández-Callejo
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CITIES

CIUDADES INTELIGENTES TOTALMENTE INTEGRALES, EFICIENTES Y SOSTENIBLES

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Elaborated by the Organizing Committee of the VII Ibero-American Congress of Smart Cities (ICSC-CITIES 2024).

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How to cite this book: Moreno-Bernal, P., Hernández-Callejo, L., Nesmachnow, S., Rossit, D., Torres-Aguilar, C. and Cardinale-Villalobos, L. (Eds). (2024). Proceedings of the VII Ibero-American Congress of Smart Cities. CITIES.

Cover: Carlos Torres-Aguilar

ISBN: 978-9930-617-71-7



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Preface

The Ibero-American Congress of Smart Cities (ICSC-CITIES), a forum for Smart Cities discussion, presents this book of articles from its seventh conference, held in presential and virtual mode format in San Carlos, Costa Rica, from November 12-14, 2024.

A Smart City is a framework composed mainly of Internet of Things systems and Information and Communication Technologies integrated to develop, implement, and promote sustainable development practices and face the challenges of urbanization. ICSC-CITIES aims to create synergies among different research groups to promote the development of Smart Cities and contribute to their knowledge and integration in different scenarios.

The conference has been held yearly since 2018. The first and second editions, 2018 and 2019, were celebrated in Soria, Spain. The third edition was celebrated virtually but hosted by Teconológico de Costa Rica. The fourth edition was hosted by Instituto Politécnico Nacional of Mexico and celebrated in presential and virtual mode in Cancún, México. The fifth edition was hosted by Universidad de Cuenca and celebrated in presential and virtual mode in Cuenca, Ecuador. The sixth edition was held in presential and virtual mode format in Ciudad de México and Cuernavaca, México, from November 13-17, 2023.

The VII Ibero-American Congress of Smart Cities (ICSC-CITIES 2024) was held in a hybrid way (presential and virtual) from November 12th to 14th, 2024, in San Carlos, hosted and sponsored by Teconológico de Costa Rica. Researchers from 34 countries gave 93 technical presentations during the ICSC-CITIES 2024. Fourteen papers were included as posters. Papers were divided into twelve tracks, i.e., Energy Efficiency and Sustainability, IoT and ubiquitous devices, Energy, Electric systems and real-world experiences, Smart Public Services, Artificial Intelligence for Smart Cities, Urban Informatics, Big Data, Data Management and Analytics, Governance and Citizenship, Smart Mobility, Smart Industry and Other developments for Smart Cities; those contributions were selected from a pool of 129 submitted papers, yielding an acceptance rate of 82.9%.

ICSC-CITIES 2024 was enriched by three-panel discussions focusing on specific aspects of Smart Cities. The first panel explored smart cities' energy transition. The second panel discussed artificial intelligence in business and its benefits. The final panel examined cyber security for smart cities.

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Program

ICSC-CITIES 2024 coincided in more than twelve countries throughout Latin America, Spain, and Portugal. The event was scheduled for a suitable period of the day to facilitate the attendance of students, researchers, and professionals from different countries. The conference program is shown below at the local time of the hosting institution (UTC-6).

Martes 12 de noviembre Auditorio Principal (CTEC) Enlace público en general: https://www.youtube.com/playlist?list=PLIPXhVPKZFTyDXWTsqo9L0VJTABLTKu-q			
Hora (UTC-6)	**Participantes**	**Artículo / Panel**	**Track**
7:30 - 8:00	**Registro de participantes**		
8:00 - 8:40	Inauguración: Juan Diego González, Luis Hernández Callejo, Oscar López, Leonardo Cardinale		
8:40 - 10:10	Duque, Zhingre, Montero, Amaya, Pinos	7. Inactivation of E. coli using ZnO and UV-LED technology: A promising approach for water treatment	Energy Efficiency and Sustainability Track Chair: Carlos Torres Aguilar
	Wang	31. Benchmarking Building Energy Efficiency with Bayesian Regression on Incomplete Data	
	Alcántara, Rincón, Mercedes, Méndez, Ruiz, Aybar Mariano	46. Comparative Analysis of Different Passive Technologies for Improving the Energy Performance of Buildings	
	Aguilar, Torres, Macias, García, Torres, Hernández, Serrano	94. Parabolic cylinder collector for roasting cocoa beans	
	Murcia, Correa, Hernández, Alonso, Navas	96. Life Cycle Assessment of Photovoltaic Glass in Greenhouse Systems: Environmental Trade-offs Between Energy Generation and Material Production	
	Dittmann, Tosello, Meza, Sanchez, Klein, Thalmann, Tischew	98. The Energy Transition of a University Campus through Photovoltaic and Battery Storage Systems	
10:10 - 10:30	**Receso**		
10:30 - 11:15	Vásquez, Batista, Ramirez	115. Alternatives to reduce the carbon footprint of port operations in LNG terminals	Energy Efficiency and Sustainability Track Chair: Carlos Torres Aguilar
	Piantanida, Pilar, Vottari	128. From Modules to Communities: Fostering Flexibility and Aggregation in School Infrastructure for Sustainable Smart Territories	
	Carbono, Gómez, Sanchez, Ospino, Mantilla, Alonso	48. Spectral analysis for anticipating critical failures in lithium-ion batteries spectral analysis for anticipating critical failures in lithium-ion batteries: a wavelet approach	
11:15 - 11:40	Carlos Cordero Vega	Descarbonización e infraestructura sostenible	
11:40 - 12:30	Panel de Discusión. Transición Energética de las Smart Cities. Retos y tendencias. Randall Zúniga, Donald Hidalgo, Luis Hernández Callejo, Alexandra Arias Alvarado		
12:30 - 13:30	**Almuerzo**		
13:30 - 13:55	Juan Celin Chacón García	Cooperativismo Inteligente	
13:55 - 14:20	Danny Briones Jiménez	Smart Cities: hacia una nueva era de digitalización de servicios y empoderamiento ciudadano	
14:20 - 15:35	Fayyaz, Zafar, Wasim, Shoaib, Ahad, Nunes, Coelh, Pires	6. Cricket Score Prediction using Machine Learning Techniques	IoT and ubiquitous devices Track Chair: José Alberto Hernández
	Murillo, Meza, Calderón	29. Distributed detection algorithm for photo-voltaic solar arrays based on least significant difference test	
	Lara, Ruzicka, Rodriguez, Quesada	113. A Home Assistant-based Platform for Ambient Intelligence in Smart Buildings	
	Cardinale, Murillo, Brénes	83. Low-cost IoT system to detect supbotimal conditions in PV arrays	
15:35 - 15:55	**Receso**		
15:55 - 18:10	Bernal, Muñoz, Paz, Galán	40. Coordinated tuning of STATCOM-POD controllers using PSO and NBA: a case study in DIgSILENT PowerFactory	Energy Track Chair: Víctor Alonso Gómez
	Morales, Hernández, Alonso, Redondo, de Almeida, Araujo	45. One Diode model intrinsic parameter extraction from solar module dark I/V curves with low computational cost	
	Del Ángel, Morales, Tejeda, Arenas	51. Modelling and validation of the pine pellet gasification process in a downdraft fluidised bed reactor using the application of free-to-use software	
	García, Alonso, Aguilar, de Godos	52. Renewable Communities Combining Anaerobic Digestion and Solar Energy: A Case Study in the Province of Soria (Spain)	
	Aguilar, Islas, Velázquez, Ríos, Cásares, Suástegui, Gámez, Pérez	62. Technical and Economic Analysis of an Off-Grid Microgrid with Solar PV and Battery Storage: A Case Study for Rural Communities in Mexico	
	Ríos, Velázquez, Aguilar, Islas, Bejarano, Rojas	65. Performance evaluation of an earth-water heat exchanger integrated to a solar absorption cooling system	

	Jimenez, Rodriguez	79. Strategy against energy poverty: analysis of the ventilation potential of a ground-air heat exchanger	
	Risso, Nesmachnow, Porteiro, Vignolo, Sierra, Ibarburu	93. A Mixed Combinatorial Optimization model for the Río Negro Hydroelectric Complex	
	Irurtia, Porteiro, Ibarburu	95. Direct demand side management of residential electric water heaters in Uruguay's electric grid	
18:10	**Fin de actividades**		

Aula Tecnoaulas

Enlace público en general: https://www.youtube.com/playlist?list=PLlPXhVPKZFTyDXWTsqo9L0VJTABLTKu-q

Hora (UTC-6)	Participantes	Artículo / Panel	Track
11:15 - 12:30	Muraña, Nesmachnow, Durillo	101. WGAN to augment tabular energy consumption data of high performance computing nodes	Energy Efficiency and Sustainability Track Chair: Diego Rossit
	Ponce, Moreano, Rus, Segovia	69. Smart Cities Strategies: Data-Driven Urban Energy Transition Using QGIS Heat Maps to Foster Photovoltaic Micro-Generation in Manta, Ecuador	
	Alchapar, Giancola, Pérez, Pezzuto	72. Facade Construction Technologies and Their Impact on the Urban Microclimate: A Comparative Study between the Cities of Madrid and Mendoza	
	Torres	75. Reliability, Availability and Maintainability Analysis for Grid-Connected Solar Photovoltaic Systems	
	Torres, Moreno, Nesmachnow, Rossit, Aguilar, Macias	76. Regression analysis for prediction of solar chimney performance	
12:30 - 13:30	**Almuerzo**		
13:30 - 14:15	Islas, Velázquez, Aguilar, Ríos, Gámez, Pérez	87. Optimization of a Fixed-Focus Scheffler Dish with Dual-Axis Tracking System for Solar Concentration in Northwestern Mexico	Energy Efficiency and Sustainability Track Chair: Diego Rossit
	Flores, Lara, Hernández, Guerrero, Sotelo	90. Sustainable management of urban solid waste in smart cities for energy generation and carbon credits	
	Redondo, Kupolati, Ndeti, Morales, Alonso, Njoroge, Hernández	10. Passive Electroluminescence and Photoluminescence in Photovoltaic Modules: Synchronous and Asynchronous Lock-In Approaches	
14:15	**Fin de actividades en Tecnoaulas**		

Miércoles 13 de noviembre

Auditorio Principal (CTEC)

Enlace público en general: https://www.youtube.com/playlist?list=PLlPXhVPKZFTyDXWTsqo9L0VJTABLTKu-q

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Hora (UTC-6)	Participantes	Artículo / Panel	Track
8:00 - 8:10	**Bienvenida**		
8:10 - 10:10	Díaz, Grisales, Cortés, Guzmán, Bolaños, Montoya, Hernandez	92. Operación inteligente de sistemas de generación fotovoltaicos en microrredes eléctricas aisladas de corriente alterna para reducción de costos y mejora de condiciones operativas	Electric systems Track Chair: Joao André Pinto Soares
	Rojas, Baier, Marciel, França, Hernandez	102. H-Bridge Cell Fault Clearing Algorithm for Cascaded Multilevel Converter Operating as Grid-Forming Inverter	
	Monteiro, Couto, Abud, França, Hernandez	114. Phase commutation strategy to mitigate overvoltage in distribution networks with high photovoltaic penetration	
	De León, Tzoc, Medinilla, Hernandez	122. Implementación de microrredes con componentes solares y de baterías en zonas rurales en Guatemala	
	Serra, Esteban, Mezzano, Baier, Espinoza, Montoya	28. IDA-PBC controller design for grid-connected Quasi-Z-Source Three-Phase Inverter	
	Silva, Dias, Bandória, de Almeida, Hernandez	38. Clustering of real load curves at a public university: Steps towards a sustainable campus	
	Marciel, Baier, Rojas, Quinteros, Esteban	60. Single-phase Cascaded Multilevel Inverter Operating as a Grid Forming Converter under dVOC Control using SOGI Strategy	
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14:15 - 14:55	Michael Ballestero, Productivity Strategy & AI Mentor	Casos de éxito con IA. Coffee analytic (Mercadeo, comercialización)	
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15:10 - 15:25	Almeida, Soares, Aliyan, Limmer, Faia, Ramos	127. Fairness Index Analysis in Local Energy Communities Considering Electric Vehicles and Energy Storage	
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	Jiménez, Sánchez, Fernández, Rus, Hernandez, Muñoz	41. Analysing the Performance of Electricity Generation through PV Rooftop Systems in Food Industry Facilities	
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18:15	**Fin de actividades en auditorio**		

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	Ruzafa, Cano, Sánchez, Hernandez, Baier	33. Design and implementation of DC meter for PV plants	
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	Montoya, Serra, Esteban, Gil, Hernandez	49. A Backstepping Control Design for Output Voltage Regulation in an Unknown Linear Load Interfaced through a Buck DC-DC Converter	
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	Gil, Montoya, Hernandez	55. Optimizing Household Appliance Usage to Minimize Energy Expenses: A Demand Management Approach	
	Baier, Serra, Aybar, Espinosa, Melin, Hernandez	57. Non-Linear Control Strategy for a Bidirectional DC-DC Converter in an Energy Storage System Operating in Conjunction with a Grid-Forming Inverter	
	Quintal, Puc, Flota, Hernandez	67. Voltage stability in the WSCC power system for large scale integration of renewable energy	
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	Nivia, Montoya, Gil, Serra, Hernandez	81. A PI-PBC Method for Voltage Support Using a PWM-CSC with Adaptive Load Estimation	
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	Cardoso da Silva, Do Nascimento, González, de Almeida	89. Evaluating the Social Impact of Electrical Vehicle Towards a Sustainability Transition: A Critical Analysis of Tesla, BYD, and EU environment reports	

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	Guerra, Perez, Juárez	35. A reference model for the formulation of citizen science projects	
	Boukharta, Navas, Chico	100. Examination of citizens' perceptions towards urban agriculture and its contribution to food security–worldwide and two cases evaluated in Spain	
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	Hernandez, Martinez, Muñiz, Guzman, Porcayo , Escamilla	121. FREM: Information Extraction System for Generating Phytosanitary Risk Alerts	
	Velasquez, Lozoya, Jimenez	124. Assessing Smart Cities in Developing Countries: Multi-dimensional Approaches	
	Landa, Gonzalez, Urra	56. The Challenges of Citizen Participation in the Develop-ment of Citizen-centered Smart Cities: Lessons Learnt from two European initiatives	
10:10 - 10:30	**Receso**		
10:30 - 10:45	Valle, Ramirez	59. Activismo urbano y ciudadanía inteligente en San José, Costa Rica: la tecnología cívica al servicio de la transformación del espacio público entre el 2012 y el 2022	Governance and Citizenship Track Chair: Luis Manuel Navas Gracia
10:45 - 11:00	Leandro-Elizondo	61. A SYSTEMIC PERSPECTIVE ON EDUCATION 3.0: NAVIGATING 4TH INDUSTRIAL ERA AND NURTURING EMERGING DIGITAL COMPETENCIES – STUDY CASES ON UNIVERSITY-BUSINESS STRATEGIC ALLIANCES	
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14:35 - 14:50	Garcia, Villafáfila, Codina	58. Comparison of charging infrastructure for electric vehicles in multi-unit residential buildings in Spain	
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15:10 - 16:30	Balladares, Torres, Angeles, Lopez, Ramírez	116. Smart industry solutions: finite element solver comparison for FEM vehicle cabin analysis	Smart Industry & Other developments for Smart Cities Track Chair: José Ignacio Morales
	Holguin, Herrera	103. CIUDADES INTELIGENTES DESDE LA PERSPECTIVA DE LOS SISTEMAS REGIONALES DE INNOVACIÓN	
	Martínez, Caso, Mila, Guzman	99. The other SOTA for DOTA: assessing general object detectors for aerial surveillance	
16:30	**Clausura y premiación mejores artículos**		

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	Arias, Aparicio, Gonzalez, Melendes, Suarez	37. Modeling of a water saving and heating system to meet urban and rural needs in Colombia	
	Monteiro, Fernandes, de Almeida, Henrique	104. Transformação de Escolas Estaduais em Escolas Técnicas: Uma Abordagem na Cidade de São Paulo Através de Programação Inteira	

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	Fuentes, Rivero, Gallegos	108. Lightweight Consensus Cryptographic Protocol for Biosignal Monitoring in Wireless Body Area Networks	
12:30 - 13:30	**Almuerzo**		
13:30 - 14:15	Caro, Rossit, Santiviago, Ferreira, Nesmachnow	17. Multi-objective optimization for the operation of a physicochemical phosphorus removal system	Smart Environment
	Porcayo, Martinez, León, Guzmán, Hernandez, Escamilla	112. ZREM: sistema de extracción de noticias para el Monitoreo Nacional e Internacional de Amenazas Zoosanitarias	Track Chair: Gilberto Martínez
14:15	**Fin de actividades en Tecnoaulas**		

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Oliveira, Hernández, Sodré, Mancebo	27. Economic Analysis of a Hybrid Wind-Solar System for Electric Vehicle Supply in Brazil	
Medina, Burlak, Martínez, Bonilla, Moreno, de-la-Cruz, Hernández	80. Intrusion detection system through mobile notifications using the Internet of Things	
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Energy, energy efficiency and sustainability

Carbon Footprint Analysis of CEDER Microgrid

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Abstract.

Global warming is considered one of the major issues facing current society. It is caused by greenhouse gas emissions, which are being targeted for reduction internationally. Given the magnitude and significance of global warming, it becomes imperative to estimate carbon emissions, particularly in sectors that contribute significantly to greenhouse gas emissions, such as the electricity sector. The present study aims to calculate the carbon footprint of electricity within a microgrid called CEDER-CIEMAT. Located in Soria, Spain, this microgrid, which is connected to the main grid, consists of a cluster of loads, generation units, and storage systems. The study has estimated an average carbon footprint of 91 g CO_2eq/kWh for the electricity within CEDER, compared to 128 g CO_2eq/kWh for electricity from the grid. This results in a total of 16.7 tons CO_2eq avoided per year in CEDER microgrid. A future improvement in the carbon footprint could be attributed to a lower dependence on the grid (65% actually), which can be further enhanced by increasing the number of generation units and, especially, by optimizing the use of storage units, which are currently underutilized.

Keywords: Carbon footprint, microgrids, global warming, carbon emissions, electricity generation, renewable energy and sustainability.

1 Introduction

Global warming has led to an increase in the average global temperature of approximately 1 ºC [1,2]. This sharp increase in global temperature is attributed to anthropogenic greenhouse gas emissions, mainly carbon dioxide (CO_2). Carbon emissions have increased over the last 50 years, reaching a total of 35.6 Gt CO_2 equivalent in 2023 [3]. Although this represents only a 0.1% increase compared to 2022, more efforts are required to limit greenhouse gas emissions. The Paris Agreement is an international

ISBN 978-9930-617-71-7

accord aimed at limiting global warming to below 2 ºC, preferably 1.5 ºC [4]. To achieve this, it is necessary to reach a net-zero carbon emissions scenario by mid-century, requiring a deep transformation of the economy and society.

Regarding the sectoral contribution to global warming, power sector accounted 38.4% of total emissions, industry for 29.0%, ground transportation for 18.6%, residential sector for 9.4%, and aviation and shipping for 4.5% [3]. Power sector still being the main contributor to global warming in 2023, evidencing the need of a transition from a power sector based on fossil fuels burning to a power sector based on renewable energies deployment.

Electricity demand continues to increase, reaching a global demand of 27,500 TWh in 2023 [5]. Moreover, the demand is expected to rise, growing by an average of 3.4% annually through 2026 [5]. The main source of electricity remains fossil fuel combustion, accounting for 61%, while renewable energy contributes 30% and nuclear energy 9% [6]. This global electricity mix results in a global CO_2 intensity in the electricity sector of around 455 g CO_2eq/kWh [5]. Therefore, the integration of new renewable electricity capacity is necessary, which can be sometimes challenging.

The two main renewable electricity sources in the world are solar and wind energy, which produced 5.5% and 7.8% of the total electricity in 2023 [6]. Renewable energies such as solar and wind have several advantages, including significant potential, low carbon emission rates, and competitive prices compared to fossil fuels. In fact, renewable energies produce the cheapest electricity. The levelized cost of electricity (LCOE) for photovoltaic energy ranges from 24 $ to 96 $ per MWh for utility-scale power plants, while wind energy has an LCOE between 24 $ and 75 $ per MWh for onshore power plants. In contrast, gas combined cycle plants have an LCOE of 39 $ to 101 $ per MWh, coal plants range from 68 $ to 166 $ per MWh, and nuclear plants range from 141 $ to 221 $ per MWh [7].

However, unlike conventional electricity sources, renewable energies such as solar and wind are intermittent and produce varying yields depending on weather conditions [8]. These fluctuations in production, along with the inability to control the power output from zero to full capacity throughout all operational hours of the power plants, have a significant impact on grid performance, limiting the integration of new power plants.

Microgrids (MGs) are clusters of electricity generation units, energy storage elements, and loads that function as a cohesive entity and can operate in either grid-connected or standalone mode depending on various factors [9–11]. One of the main advantages of MGs is their feasibility as a solution for integrating distributed renewable electricity generation and distributed energy storage systems into the main grid [9]. Therefore, MGs are considered valuable tools for improving grid stability and addressing some of the challenges associated with the widespread deployment of distributed renewable power plants. Moreover, MGs offer significant potential in smart cities, enabling the integration of electricity generation and storage systems in urban areas [12].

In parallel, the estimation and tracking of greenhouse gas emissions across various processes have become crucial topics. This estimation helps determine the total emissions associated with a product, energy unit, sector, etc., and is commonly referred to as the carbon footprint [13]. In the context of electricity, analyzing the carbon footprint allows for the quantification of its impact on global warming and enables the

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comparison of different electricity sources. Since microgrids (MGs) can be considered a tool to limit global warming and reduce greenhouse gas emissions, it is important to analyze the carbon footprint of MGs [14,15].

This article analyzes the evolution of carbon emissions in a real microgrid (MG) named CEDER over the period from 2020 to 2023. The second section of the paper presents the materials and methodology, where data from the microgrid, obtained through monitoring of various units, and data from the literature have been combined to calculate carbon emissions. The third section displays the results, comparing the carbon footprint of CEDER MG with that of the main grid, which allows for the determination of the carbon emission savings of the MG. Finally, the conclusion and discussion are presented in the last section.

2 Materials and methods

2.1 Energy flows in the MG units

CEDER MG, placed in Soria (Spain), has a 1000 kVA main electrical transformer which is used to reduce the voltage of the 45 kV distribution network which the MG is connected. The transformer supplies power to a closed-ring grid operating at 15 kV. This 15 kV ring contains eight transformation centers that step down the voltage to 400 V, connecting all generators, storage systems, and loads. All the generation units, storage systems and loads are summarized in Table 1.

Table 1. Elements of CEDER microgrid.

Generation units (504.1 kWp)		
Source	**Description**	**Power capacity**
Photovoltaic (PV)	11 distributed photovoltaic systems	181.9 kWp
Wind	Five small-scale wind turbines	162.2 kWp
Diesel	Diesel generator	100 kWp
Storage units (696.5 kWh)		
Category	**Description**	**Storage capacity**
Lead-Acid Battery	System I with Inverter (50 kWp)	259.2 kWh
	System II with Inverter (20 kWp)	183.6 kWh
	System III with Inverter (5 kWp)	156.0 kWh
LFP Battery	System with Inverter (30 kWp)	62.7 kWh
Pumped-storage Hydropower	Pelton Turbine (60 kWp), pumping system (30 kWp) and water tanks (2,000 m^3 and 70 m water head).	35 kWh
Loads		
Type	**Description**	**Average load**
AC	8 transformation centers (15 kV-400 V)	1,267 kWh/day

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Monitoring all the units that make up the CEDER MG has allowed for the calculation of the energy yield of each generation system, the energy storage by each storage facility, as well as the total load, energy purchased from the main grid, and energy injected into the main grid. Note that data with a 15-minute resolution have been used in the present study.

2.2 Emission Rates of technologies and main grid

Carbon emission rates (CER) refer to carbon emissions per energy unit. These rates have been obtained from other studies that, through a life cycle assessment of various energy sources and technologies, provide data which can be extrapolated to CEDER facilities. Note that all emission rates will be used as static values throughout the calculation process except for the Spanish national grid CER, which varies monthly due to changes in the energy mix across the study period.

Table 2. Carbon Emission Rates (CER) of several energy sources in CEDER MG.

Carbon emission source	Reference	CER
Photovoltaic	[16]	43 g CO_2 eq/kWh
Wind Energy	[16]	13 g CO_2 eq/kWh
Diesel	[16]	840 g CO_2 eq/kWh
Lead-acid batteries	[17]	150 g CO_2 eq/kWh
LFP batteries	[17]	14 g CO_2 eq/kWh
Pumped-storage Hydropower	[16]	7 g CO_2 eq/kWh
Spanish Grid (2020-2023)	[18]	70-160 g CO_2 eq/kWh

2.3 Calculation process

To calculate the total carbon emissions of the CEDER MG each month, three different factors are considered. First, the carbon emissions associated with the energy purchased by the MG from the main grid. Second, the emissions related to the generation and storage systems within the MG. Finally, the impact on carbon emissions of the energy injected into the main grid. This concept is represented in Equation 1.

$$CE_{CEDER} = CE_{Grid-P} + CE_{CEDER-units} + CE_{Grid-S} \quad (1)$$

Where CE_{CEDER} represents the total carbon emissions of the CEDER MG, CE_{Grid-P} denotes the emissions associated with energy purchases from the main grid, and CE_{Grid-S} refers to the carbon emissions related to energy sales to the main grid.

The calculation of emissions associated with energy purchased from the grid involves multiplying the total amount of energy required from the grid by the carbon emission rate of the main grid, as shown in Equation 2. On the other hand, the calculation of emissions associated with CEDER MG facilities is based on multiplying the energy supplied by each unit by its carbon emission rate, and then summing the carbon emissions of all CEDER MG units, as shown in Equation 3.

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$$CE_{Grid-P} = E_{Grid-P} \cdot CER_{Grid} \quad (2)$$

$$CE_{CEDER-units} = \sum(E_{unit} \cdot CER_{unit}) \quad (3)$$

Where $E_{Grid\text{-}P}$ represents the total amount of energy purchased from the main grid, and CER_{Grid} denotes the carbon emission rate of the main grid. E_{unit} refers to the total energy supplied by each generation or storage unit in the microgrid, while CER_{unit} is the associated carbon emission rate of each unit, obtained from literature (see Table 2).

Carbon emissions associated with the energy injected and sold to the grid are shown in Equations 4 and 5. This factor is obtained by multiplying the total energy injected into the grid by the difference between the carbon emission rate of the energy generated within the MG and the carbon emission rate of the grid. Therefore, if the electricity generated in the MG has a lower emission rate than that of the grid, the emissions associated with grid sales would be negative, indicating carbon emission savings.

$$CE_{Grid-S} = E_{Grid-S} \cdot (CER_{EG-CEDER} - CER_{Grid}) \quad (4)$$

$$CER_{EG-CEDER} = (\sum(E_{unit} \cdot CER_{unit}))/(\sum E_{unit}) \quad (5)$$

Where $E_{Grid\text{-}S}$ is the total energy injected into the grid, and $CER_{EG\text{-}CEDER}$ is the carbon emission rate of the energy generated within the MG. Finally, it is also possible to calculate the average carbon emission rate of the electricity in CEDER MG and total carbon emissions avoided in comparison with a scenario where all the energy comes from the grid, as Equation 6 and 7 display.

$$CER_{CEDER} = CE_{CEDER}/E_{Consumption} \quad (6)$$

$$CE_{Avoided} = CE_{CEDER} - (E_{Consumption} \cdot CER_{Grid}) \quad (7)$$

Where $E_{Consumption}$ means the total energy consumption of the loads in the MG.

3 Results

After processing the data, it is possible to analyze the contribution of the different electricity sources in CEDER MG. During the period analyzed, CEDER MG had a dependency on the main grid for 65% of its electricity. Therefore, 35% of the energy demand was met by the generation and storage system within the microgrid. A detailed plot of electricity flows for 2020, 2021, and 2022 can be seen in Fig. 1. As previously explained, there is a high dependency on the main grid. Photovoltaic (PV) is the main source of electricity in all the years, followed by wind energy. It is important to note the very low contribution of the Diesel Generator, hydro-pumped storage system, and batteries in the MG, despite the considerable capacity and power of the storage systems.

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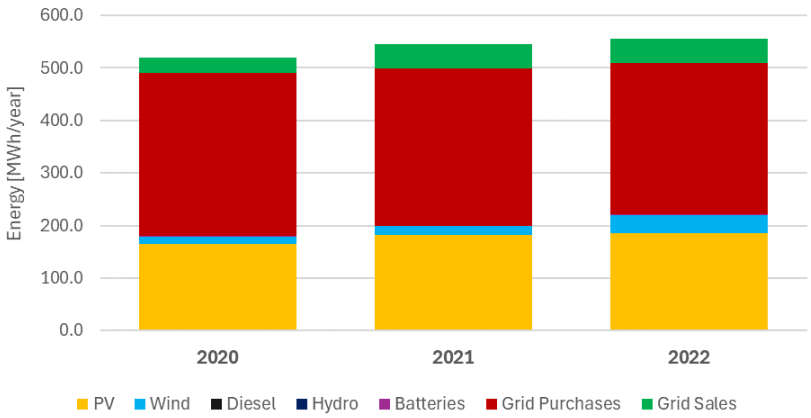


Fig. 1. Energy flow of electricity in CEDER MG.

The monthly comparison between the carbon emission rates of the main grid (CER_{Grid}) and the average carbon emission rate of the electricity consumed in CEDER MG (CER_{CEDER}) is important to analyze. Due to the high dependence on electricity purchased from the grid, the carbon emission rate of CEDER MG electricity is highly influenced by that of the grid, as shown in Fig. 2. However, the carbon emission rate of CEDER electricity always remains lower than that of the grid. On average, electricity from the grid involves 128 g CO_2eq/kWh, while CEDER electricity accounts for 91 g CO_2eq/kWh, which means a 29% lower carbon footprint.

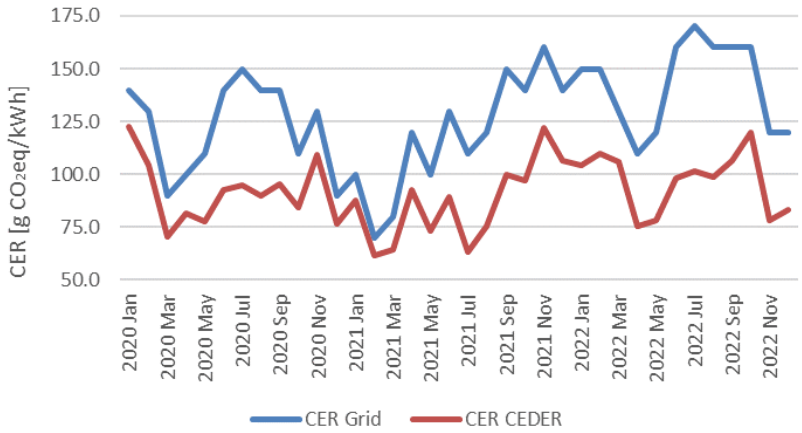


Fig. 2. Comparison of the carbon emission rate of the main grid (CER_{Grid}) and CEDER MG (CER_{CEDER}) electricity.

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Finally, the different sources of carbon emissions can be seen in Fig. 3 and Table 3 over the three years. Most of the emissions are associated with the energy purchased from the main grid. Among the generation units, PV is the only one with a significant impact on global warming, as it is also the main energy source. Wind energy presents a very low impact since its emission rate is even lower than that of PV. Due to the underuse of storage systems and the Diesel generator, the impact of these units is practically negligible. It is also important to note that energy injected into the grid has a positive impact on global warming, as this energy has a lower carbon emission rate than grid electricity, which means carbon emissions are avoided in another load of the main grid. This injection of electricity reduces the total emissions of CEDER MG by 8%, having a significant impact.

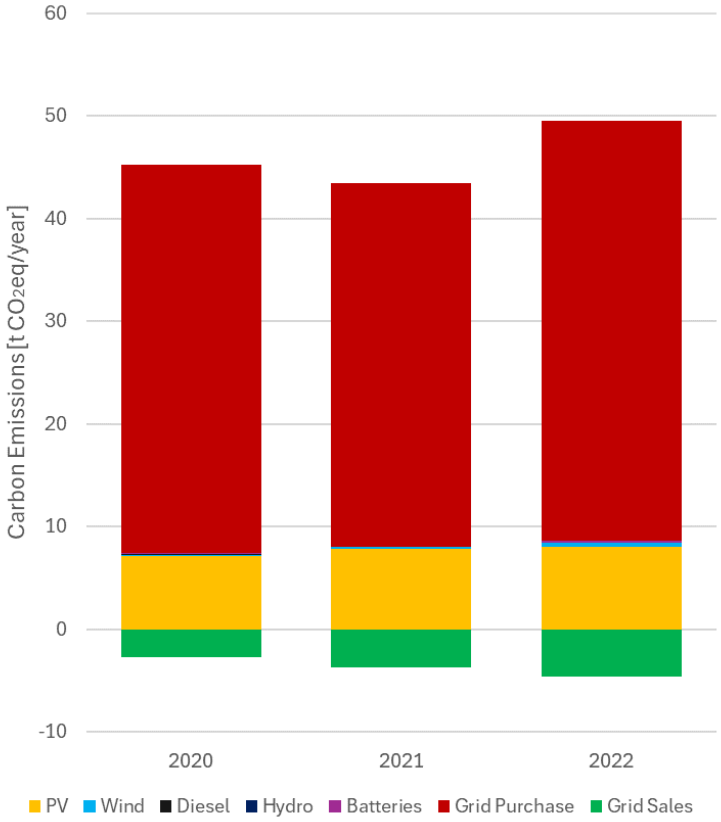


Fig. 3. Carbon emission sources in CEDER MG.

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Table 3. Carbon emission sources in CEDER MG.

Carbon emissions [t CO_2eq/year]			
Source	**2020**	**2021**	**2022**
PV	7.089	7.804	7.975
Wind	0.176	0.229	0.439
Diesel	0.068	0.000	0.017
Hydro	0.006	0.002	0.001
Batteries	0.091	0.024	0.196
Grid Purchases	37.752	35.395	40.911
Grid Sales	-2.686	-3.673	-4.575
TOTAL	**42.494**	**39.781**	**44.963**

4 Discussion and conclusion

The present study has enabled to understand and evaluate the impact of electricity consumption on global warming in a medium-sized microgrid located in Spain. The analysis has provided the carbon footprint of electricity over a three-year period (2020-2022).

In general terms, the electricity in CEDER MG has a lower carbon footprint compared to electricity that comes directly from the grid. While grid electricity has an average carbon footprint of 128 g CO_2eq/kWh, CEDER electricity accounts for 91 g CO_2eq/kWh, resulting in 29% lower total global warming emissions. The primary source of greenhouse gas emissions is attributed to electricity purchases from the grid, as 65% of CEDER MG's load is supplied by the grid. Among the various generation and storage units in the MG, only PV represents a significant impact, being the generation technology with the highest yield. It is important to note that the Diesel generator and all storage systems are used minimally and therefore have a very low, almost negligible, impact on carbon emissions. Finally, the energy surplus injected into the grid has a positive impact on global warming, as this electricity has a lower emission rate than grid electricity.

To sum up, the implementation of this microgrid has resulted in a reduction of carbon emissions compared to a scenario where all electricity is sourced from the grid. In comparing both scenarios, the implementation of CEDER MG has avoided a total of 16.7 t CO_2eq per year.

Furthermore, better operation and optimization of the storage system in the MG could have a significant impact on the carbon footprint of CEDER MG. By storing excess energy and using it later, the dependence on the grid would be reduced, thereby improving the carbon footprint of the electricity.

ISBN 978-9930-617-71-7

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

Funding. This work has been funded by the Spanish Ministry of Education through the National Program FPU (grant number FPU21/04288).

Acknowledgments. This study was supported by University of Valladolid with 2024 grants for attendance at courses, conferences and workshops relevant for the development of doctoral theses.

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ISBN 978-9930-617-71-7

Economic Analysis of a Hybrid Wind-Solar System for Electric Vehicle Supply in Brazil

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Abstract. As climate change concerns and the need to reduce fossil fuel dependence drive the search for sustainable transport solutions, electric vehicles (EVs), including plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs), are emerging as viable alternatives. This study focuses on Brazil, leveraging its abundant renewable resources to explore the integration of hybrid wind-solar systems for EV charging. Despite the potential, challenges arise due to regional climatic variability and the lack of comprehensive economic analyses tailored to Brazil's diverse conditions. To address these issues, we perform a detailed economic analysis of implementing hybrid wind-solar systems to meet the electricity demand of BEVs and PHEVs across different regions. The study calculates the net present value (NPV), levelized cost of electricity (LCOE), and payback period for these systems, considering regional variations in energy availability and climatic conditions. Our findings reveal significant variations in both costs and returns, with NPV values indicating greater profitability in specific locations, while payback periods are shorter where wind energy is more favourable. The LCOE analysis demonstrates that the costs associated with solar and wind energy vary considerably depending on local climatic conditions, emphasising the necessity of region-specific cost evaluations. Additionally, the study highlights that delaying the adaptation of the hybrid system to accommodate future electric vehicle demands could result in substantially higher costs.

Keywords: Hybrid wind-solar system, Electric vehicle charging, Economic analysis.

ISBN 978-9930-617-71-7

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1 Introduction

The increasing concern about climate change and the need to reduce dependence on fossil fuels have driven the search for sustainable alternatives in the transport sector. In this context, electric vehicles (EVs), including hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs), emerge as promising solutions for reducing greenhouse gas emissions and enhancing energy efficiency. In Brazil, a country with vast potential for renewable natural resources, integrating clean energy sources for charging these vehicles presents a significant opportunity to align technological development with environmentally responsible practices.

Despite the abundant potential for solar and wind resources, implementing efficient and economically viable infrastructure for EV charging in Brazil faces several challenges. The country's geographical and climatic variability directly influences the availability and reliability of these renewable energy sources, complicating the standardisation of energy solutions. Furthermore, the lack of comprehensive economic analyses that account for regional specifics and projected EV demand impedes strategic planning and adequate investment in sustainable microgrids.

To address these challenges, implementing hybrid systems combining solar and wind energy emerges as an effective alternative to ensure a consistent energy supply tailored to Brazil's regional conditions. By balancing the inherent fluctuations of each renewable source, these systems can provide greater stability and efficiency in supplying energy for EV charging. A detailed economic evaluation of these systems, considering different scenarios of resource availability and energy demand, is crucial for determining their feasibility and guiding public policies and investments in the sector.

The economic viability analysis of integrating photovoltaic systems and battery storage reveals that decentralized photovoltaic electricity generation, combined with battery storage, can offer significant savings and social benefits, particularly in rural and urban areas with high EV penetration [1]. This integration can reduce grid reinforcement costs and improve energy security.

Furthermore, efficient modelling of integrating photovoltaic technologies with vehicle-to-grid (V2G) technology is essential for enhancing the capacity of electricity distribution systems. Optimised analytical methods have demonstrated improvements in the support capacity of distribution systems, addressing uncertainties and challenges associated with integrating PV and V2G [2].

The efficiency of EV charging systems can be improved through the integration of solar energy and advanced controllers. Using controllers based on optimisation algorithms can enhance the energy efficiency of vehicles and extend battery life, reducing dependence on conventional electricity sources [3]. The adaptation of traditional charging stations to integrated solar energy and storage systems has also shown significant benefits, particularly in urban contexts. Retrofitting these stations can offer substantial economic and environmental advantages, with notable applications in hotels and central residential areas [4].

The integration of photovoltaic and wind systems with EV charging stations, complemented by green hydrogen production, is a promising approach for sustainable mobility. Studies demonstrate that this integration can be economically viable and

ISBN 978-9930-617-71-7

effective in reducing carbon emissions while supporting the demand for both light and heavy vehicles [5].

Optimising solar-battery charging stations, considering network constraints, is crucial for maximising the economic feasibility of these systems. Research highlights the importance of aligning investments in renewable energy with fleet electrification strategies and understanding how network constraints affect system performance [6].

Additionally, the combination of solar, wind, and biogas energy for EV charging and hydrogen refuelling offers a practical and cost-effective solution for meeting the specific energy demands of different locations. This configuration has proven to be more viable than other options in terms of costs and benefits [7].

Finally, modelling and controlling AC microgrids connected to the grid, with the integration of EVs and renewable sources, are essential for ensuring energy quality and system stability. These approaches have demonstrated improvements in efficiency and stability, providing a solid foundation for the future of electric mobility [8].

Although there is a broad range of studies focused on integrating photovoltaic and wind systems with electric vehicles, a significant research gap remains regarding the optimal combination of these technologies across different regional contexts. Most studies focus on individual solutions without extensively exploring how these approaches can be adapted to meet the specific needs of different regions, considering their EV fleet and electricity demand.

This work aims to address this gap by providing a detailed economic analysis of implementing hybrid wind-solar systems in the Brazilian context to meet the electricity demand for BEV and PHEV vehicles. The study seeks to assess the feasibility and economic benefits of combining these renewable energy sources in various regional scenarios, considering electricity demand and specific climatic conditions in different regions of Brazil. In this way, it aims to provide a basis for adapting charging strategies and optimising energy resources in diverse regions of the country.

To achieve the proposed objective, this article is structured into two main sections. The first section focuses on the methodology, detailing the methods and parameters used to calculate the net present value (NPV), levelized cost of electricity (LCOE), and payback period. This section will explain the approaches adopted to assess the economic viability of integrating hybrid wind-solar systems for EV charging. The second section will present and discuss the results of this analysis, examining the economic performance of the proposed systems across various regional scenarios. This structure aims to provide a thorough understanding of both the analytical framework and the practical outcomes, supporting informed decision-making and effective planning for sustainable EV charging infrastructure in Brazil.

2 Methods

The economic analysis for implementing the infrastructure of wind farms and photovoltaic farms, aimed at meeting the electricity demand of PHEVs and BEVs, was conducted. To calculate the electricity demands for both PHEVs and BEVs, various factors were considered, including the electric range, annual distance travelled, battery size,

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and the percentage of capacity to be charged based on the minimum and maximum state-of-charge limits of the battery. For PHEVs, daily charging was assumed, as drivers are likely to utilise the electric range to save on fuel. Equations (1-3) detail how the electricity demand for these vehicles was calculated.

$$E_{demand} = f_{recharge} \cdot (MBC \cdot \%SoC_{MAX} - MBC \cdot \%SoC_{MIN}) \quad (1)$$

$$f_{recharge} = \frac{D_{annual}}{MER} \quad (2)$$

$$MER = Mean_{autonomy} \cdot (MBC \cdot \%SoC_{MAX} - MBC \cdot \%SoC_{MIN}) \quad (3)$$

where, E_{demand} is the electricity demand in kWh/year per vehicle, which will be multiplied by the number of vehicles in the annual fleet; $f_{recharge}$ is the charging frequency, assumed as 365 for PHEVs; D_{annual} is the annual distance travelled, set at 15,000 km; MER is the average electric range in km; $Mean_{autonomy}$ is the average efficiency, in km/kWh, set at 1.91 miles/kWh for PHEVs and 3.52 miles/kWh for BEVs, based on EVStatistics data; MBC is the average battery capacity in kWh, set at 14.9 kWh for PHEVs and 82.8 kWh for BEVs, according to EVStatistics data; $\%SoC_{MAX}$ and $\%SoC_{MIN}$ are the maximum and minimum state-of-charge limits of the battery, assumed as 20% and 90%, respectively [9,10].

For the photovoltaic farms, the required annual capacity, calculated based on the electricity demand and Brazil's specific potential power (SPP), following the methodology described by [11], was used for the calculations of capital cost, operation and maintenance, and replacement.

It is important to note that the average SPP considered for Brazil implies that the location of solar panels would be adapted to the specific climatic conditions of each region in the country. In areas with higher solar incidence, the solar panels would be installed in strategic locations, exposed to sunlight for prolonged periods, aiming to maximise solar energy capture. Conversely, in regions with less favourable climatic conditions for solar energy, measures to optimise the efficiency of energy generation would be adopted, such as adjustments in the positioning and inclination of the panels. This approach allows for an analysis of the utilisation of the photovoltaic energy generation potential across the entire national territory.

Regarding wind farms, the capacities calculated based on the number of turbines were considered. Three distinct approaches were adopted for the calculation: the first utilised the economic parameters in USD/kW outlined by [12], while the second employed the costs presented by [10]. The third alternative considered the lowest available values for wind and solar energy, as extracted from the references consulted.

Three key economic indicators were considered for the economic analysis: Net Present Value (NPV), Levelized Cost of Energy (LCOE), and Payback Period (PBP), as represented by Equations (4-8) [10,11]. Additionally, the following climatic scenarios were considered: most favourable to wind energy (W), more favourable to wind than to solar energy (W+), favourable for both wind and solar energy (WS), more favourable

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to solar than wind energy (S+), and most favourable to solar energy (S). These aspects were integrated into the economic analysis to provide a comprehensive and accurate assessment of the potential for implementing the infrastructure of wind farms and photovoltaic panels. The parameters in Tables 1 and 2 served as the basis for this study. For comparison purposes, the economic indicators were calculated for the years 2023 and 2024.

$$NPV = \sum_{n=0}^{N} \frac{C_n}{(1 + d_{nominal})^n} \tag{4}$$

$$LCOE = \frac{-C_0 + \frac{\sum_{n=1}^{N} C_n}{(1 + d_{nominal})^n}}{\frac{\sum_{n=1}^{N} Q_n}{(1 + d_{real})^n}} \tag{5}$$

$$d_{real} = \frac{d_{nominal} - i}{1 + i} \tag{6}$$

$$PBP = \frac{C_0}{S_{annual}} \tag{7}$$

$$S_{annual} = FiT_{rate} \cdot E_{annual} \tag{8}$$

where, C_n is the cash flow in year n, in USD; $d_{nominal}$ is the nominal discount rate, assumed to be the SELIC rate; N is the project analysis period, in years; C_0 is the initial capital cost of the investment, in USD; Q_n is the energy generated in year n; d_{real} is the real discount rate; i is the annual inflation rate, assumed to be the IPCA index; S_{annual} is the revenue generated by the project, in USD; FiT_{rate} is the electricity rate (feed-in tariff), in USD/kWh; and E_{annual} is the electricity produced in the year, in kWh.

Table 1. Parameters applied in the economic analysis of photovoltaic (PV) and wind systems.

Approaches	Parameters	PV	Wind	References
1	Capital Cost (USD/kW)	400	1,500	[10]
	Replacement Cost (USD/kW)	400	1,250	
	Operation and Maintenance Cost (USD/kW)	10	50	
	Lifespan (years)	25	20	
2	Capital Cost (USD/kW)	950	1,098	[12]
	Replacement Cost (USD/kW)	900	1,098	
	Operation and Maintenance Cost (USD/kW)	10	2	
	Lifespan (years)	25	20	
3	Capital Cost (USD/kW)	400	1,098	[10,12]

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Replacement Cost (USD/kW)	400	1,098
Operation and Maintenance Cost (USD/kW)	10	2
Lifespan (years)	25	20

Table 2. Macroeconomic parameters applied in the economic analysis of photovoltaic and wind systems.

Macroeconomic Parameters	Values	Units	References
Project Analysis Period	25	Years	Tahir et al. (2024); Ullah et al. (2023)
Electricity Cost	0.721	USD/kWh	ANEEL (2024)
Nominal Discount Rate - SELIC	9.13	%	Central Bank of Brazil
Annual Inflation - IPCA	3.71	%	Central Bank of Brazil

3 Results and Discussion

3.1 Net Present Value

The electricity demand for the PHEV and BEV was calculated as 3,807 kWh/year per vehicle and 2,648 kWh/year per vehicle, respectively. These values were then multiplied by the number of PHEVs and BEVs in the 2023 and 2024 fleets, resulting in 176.95 GWh for 2023 and a forecasted 258.21 GWh by the end of 2024.

The NPV values vary considerably across different locations and climatic conditions (Figure 1). Comparing the references by [10] and [12], it is observed that the NPV values tend to be higher in [10], indicating a greater profitability of the investment. This suggests that, according to the costs associated with maintenance, operation, replacement, and capital costs of turbines and photovoltaic panels provided by [10], the financial return on investment in renewable energy is more favourable compared to the values provided by [12].

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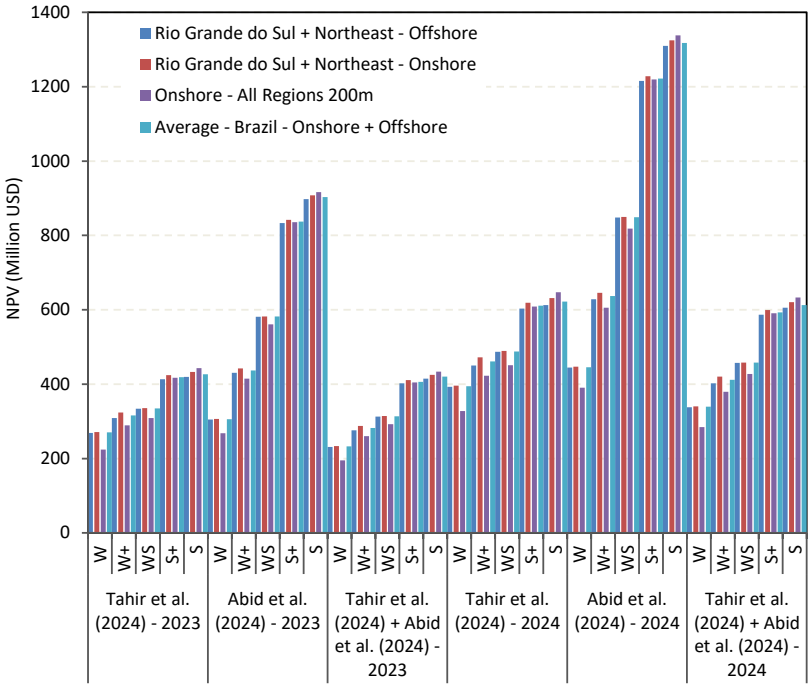


Fig. 1. NPV calculated for the electricity demands of electric vehicles in 2023 and 2024.

In the analysis of the demand for the year 2024, an additional consideration emerges: the need to adapt the electrical system not only to meet the new fleet of electric vehicles but also to support the existing fleet from 2023. This adjustment entails substantial costs, particularly when considering the expansion of wind and photovoltaic systems to handle the increased demand. Delaying this adaptation may result in even higher future costs.

To assess the costs associated with expanding the infrastructure, an approach was adopted to calculate the NPV for adapting the 2023 system to meet the projected demand for 2024. This involves determining the difference between the installed capacity in 2023 and the capacity required for 2024, followed by calculating the costs associated with this additional capacity. When examining the costs associated with expanding the hybrid wind-solar system from 2023 to meet the 2024 demand, as illustrated in Figure 2, it becomes clear that the costs are significantly lower. This underscores the importance of immediate implementation of renewable systems, as addressing adaptations

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year by year allows for more effective cost control and a smoother transition to meet future electricity needs.

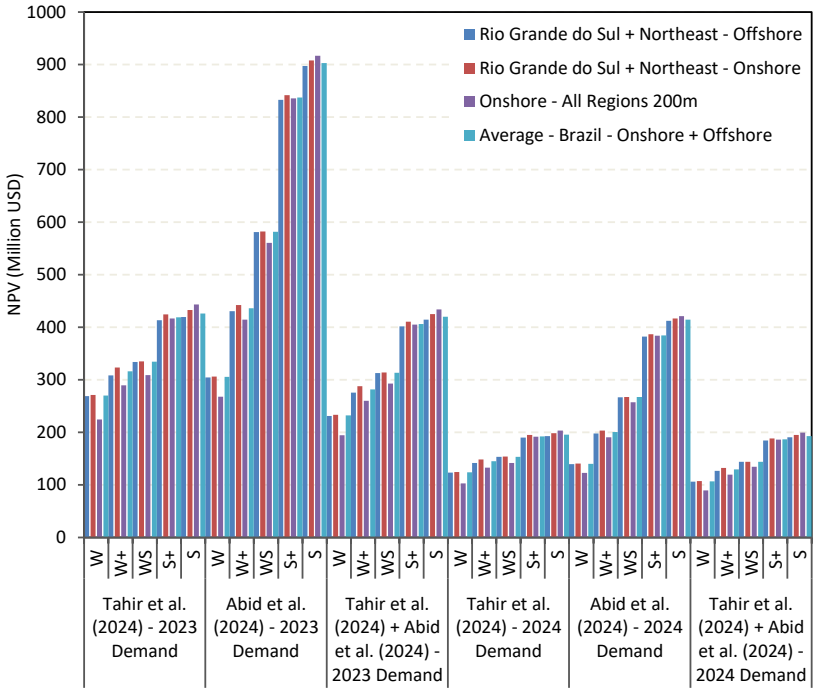


Fig. 2. Comparison of the NPV calculated for the projected hybrid system, adjusted to meet the 2024 demand based on the 2023 demand.

3.2 Levelized Cost of Energy

The comparison of the LCOE results for wind energy between the references [10] and [12] reveals significant variations in the values. Figure 3 presents the LCOE values for the wind and photovoltaic systems calculated from the costs provided by [10] and [12]. Figure 4 shows a comparison of the LCOE values found for the wind-solar system under each climatic condition, considering both sources and different wind farm locations.

When considering the least favourable climatic condition for solar energy (condition W), it is observed that the LCOE values for wind energy are lower when using the reference from [12]. This can be attributed to the fact that the costs used by [10] are lower for solar energy, while the costs associated with wind energy in [12] are lower. This difference in costs directly influences the LCOE values calculated for each energy source in each reference.

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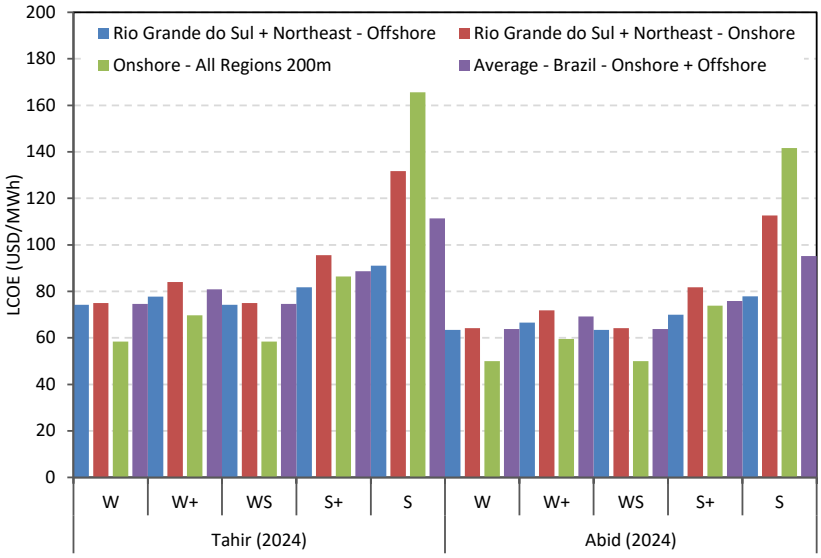


Fig. 3. Comparison of the LCOE values found for wind farms across different locations and climatic conditions, considering different references.

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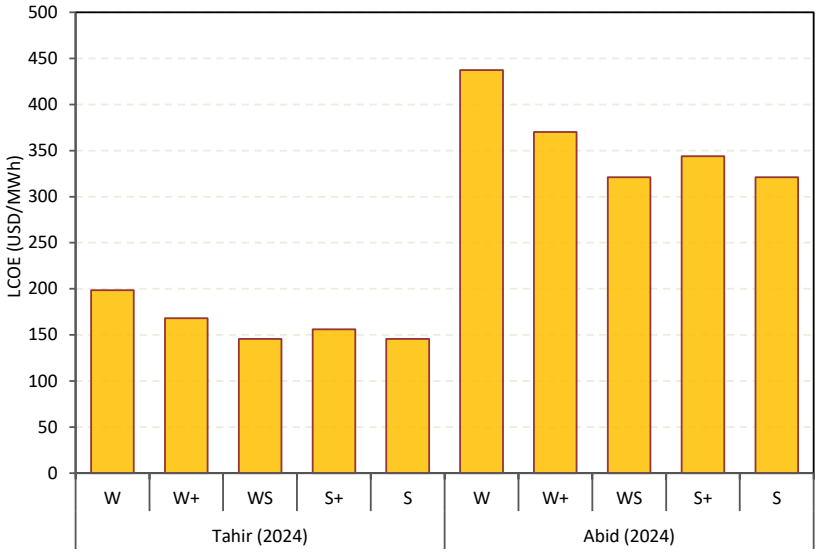


Fig. 4. Comparison of the LCOE values found for the Brazilian photovoltaic system under different climatic conditions, considering various references.

When comparing the LCOE results for solar energy, it is observed that the values are significantly lower in the reference by [10]. This suggests that the costs associated with solar energy are lower according to this reference compared to [12], which directly impacts the calculated LCOE values.

Furthermore, when analysing the LCOE values for wind energy across different locations and climatic conditions, it is notable that the values vary significantly. In more favourable conditions, where wind speeds are higher, such as in conditions W+, W, and WS, the LCOE values are up to 9.22% and 18.4% lower than in conditions where solar energy is more favourable, namely S+ and S, respectively. This highlights the importance of carefully selecting wind farm locations to maximise efficiency and reduce energy generation costs.

Similarly to wind energy, the LCOE values for solar energy also vary according to the climatic condition considered. LCOE values are higher for condition W compared to other more favourable conditions. This comparative analysis underscores the complexity involved in evaluating renewable energy costs and the need for careful and detailed approaches when estimating costs associated with wind and solar energy, considering multiple sources and climatic conditions.

When analysing the LCOE values for the hybrid wind-solar system, as provided by [10] and [12], and combining the datasets from these two sources, it is notable that there are substantial differences in the costs associated with electricity generation from wind and solar sources (Figure 5). The results from [10] tend to show lower LCOE values compared to the corresponding values from [12]. In climatic condition W, the combined

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LCOE values for wind and solar energy are approximately 47% and 46% lower, respectively, in [10] compared to [12]. However, when considering the combined results from both sources, the LCOE values tend to align more closely, indicating a more realistic range of costs associated with renewable energy generation.

When contextualizing these results with previous references, such as the LCOE values found by [13] for solar energy, which range from 10.6 to 23.6 cents/kWh, it is observed that the values found in this study are in line with these references. Specifically, the LCOE values for solar energy in the hybrid system range from 14.6 to 19.9 cents/kWh, suggesting a reasonable consistency with previous estimates.

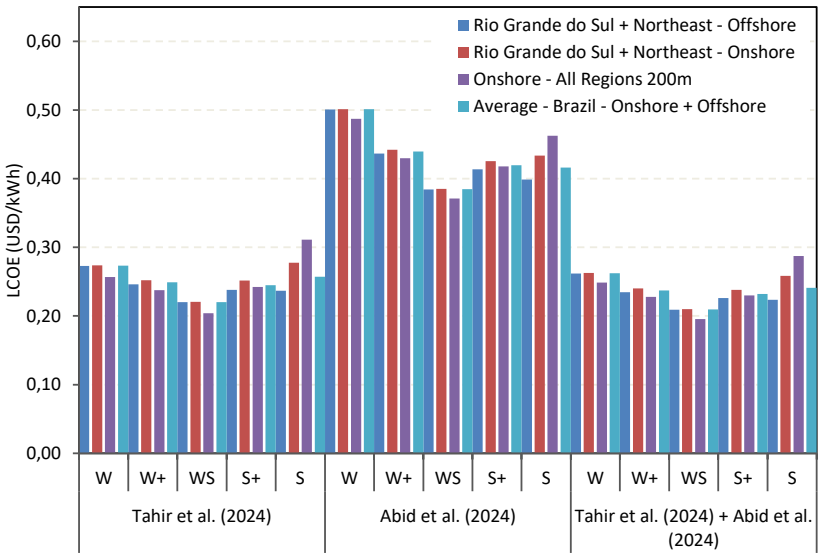


Fig. 5. Comparison of the LCOE values found for the hybrid wind-solar system, considering different wind farm locations.

3.3 Payback Period

When analysing the payback period results for the hybrid wind-solar system, as illustrated in Figure 6, some differences between the studies by [10] and [12] become apparent. Generally, the payback period values tend to be shorter in the data from [10], suggesting a quicker recovery of the initial investment compared to the data from [12]. Additionally, when comparing different locations and climatic conditions, it is observed that locations where wind energy is more favourable have shorter payback periods compared to those where solar energy is more favourable. When combining the results from both studies, considering the lower costs associated with the wind and solar systems, there is a significant reduction in the payback period. Compared to the individual references from [10] and [12], the payback period of the hybrid system is notably shorter, being up to 23% and 56% less, respectively. This disparity underscores the strong

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influence of the costs associated with the photovoltaic system, particularly in conditions more favourable to solar energy (WS, S+, and S). Notably, the costs provided by [12] for solar energy are substantially higher compared to those provided by [10], resulting in a significant difference in the payback period.

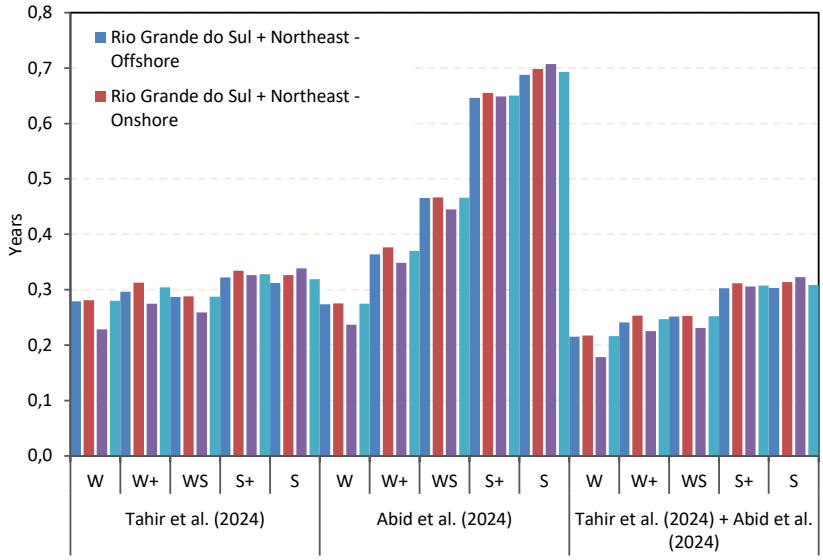


Fig. 6. Comparison of the payback periods for the hybrid wind-solar system across different wind farm locations.

4 Conclusions

When evaluating the net present value (NPV) for different locations and climatic conditions, it is evident that costs and financial returns vary significantly. The NPV values indicate that investments in renewable energy, such as solar and wind power, can be more profitable in certain areas, according to the costs provided by different references, highlighting the importance of a careful analysis of local costs when planning renewable energy investments. Considering the adaptation of the hybrid system to meet future electric vehicle demands, it is observed that delaying this adaptation can result in substantially higher costs in the future. A gradual implementation of renewable systems over time allows for more effective cost control and a smoother transition to meet increasing electricity demands.

The analysis of the levelized cost of energy (LCOE) reveals differences in the costs associated with wind and solar energy, reflecting variable costs under different climatic conditions and locations, and underscores the importance of considering multiple sources and climatic conditions when estimating renewable energy generation costs.

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Comparing the payback periods across the referenced studies shows that the costs associated with the photovoltaic system have a significant influence. The results suggest that investments in renewable energy can be recovered more quickly under certain conditions.

In summary, the results highlight the complexity involved in evaluating the costs and benefits of renewable energy and emphasise the importance of a careful and detailed approach when planning and implementing renewable energy systems to meet electricity needs efficiently and sustainably.

Future research could benefit from incorporating empirical analyses through case studies or pilot projects to validate the theoretical economic projections and identify potential implementation challenges. Additionally, conducting a sensitivity analysis on key parameters, such as discount rates and energy prices, would deepen insights into the stability of the results. Finally, the inclusion of additional financial indicators, such as Internal Rate of Return (IRR) and Return on Investment (ROI), could broaden the economic perspective and provide a richer comparative analysis with studies from other regions.

Funding The authors are very grateful to the financial support, in part, for the scholarship for a Sandwich Doctorate Abroad provided by the National Council for Scientific and Technological Development (CNPq), with the project “Economic Feasibility and Eco-Efficiency of Hybrid Electric Vehicles”, through the process nº [200877/2022-4]; for the Research Productivity Scholarship CNPq Level 2, entitled "Industrial Ecopark with Carbon Sequestration working under the concept of Biorefinery and Economy", through the process nº [306976/2021-8]; for the Jovem Cientista do Nosso Estado – JCNE (in Portuguese) Scholarship FAPERJ, entitled “SUSTENTABILIDADE ECONÔMICA E AMBIENTAL DE VEÍCULOS ELÉTRICOS HÍBRIDOS” (in Portuguese), through the process nº E-26/200.166/2023 (282055); and the Brazilian Coordination for the Improvement of Higher Education Personnel (CAPES), Finance Code: 001.

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ISBN 978-9930-617-71-7

Comparative Analysis of Different Passive Technologies for Improving the Energy Performance of Buildings

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Abstract. The global consumption of electrical energy by buildings has attracted everyone's attention. Attempts have been made to implement buildings with almost low consumption to provide comfort and efficient resource management. A particularly versatile technique for energy efficiency is building energy modeling. This technique can help energy managers choose technologies that could be used to reduce energy use. This research focused on the transformation of an existing building into a more energy efficient building by implementing passive design strategies using EnergyPlus. Significantly optimizing the thermal envelope, solar orientation, and natural ventilation systems reduced the building's energy demand. The results demonstrate the potential of passive architecture as an effective tool for improving energy efficiency and sustainability in the building sector. This study contributes to the existing knowledge on building energy retrofitting, providing practical insights on applying bioclimatic architectural principles in a real-world context.

Keywords: Green roofs, building energy modeling, sustainable building, passive technology, energy efficiency

1 Introduction

Today, in developed countries, much less than 1% of buildings are designed and constructed to the net-zero standard. However, this is changing. The State of California and the European Commission have mandated that buildings comply with these standards, which is expected to add hundreds of thousands of these new and retrofitted buildings in the coming years [1].

The main goal of passive systems in sustainable architecture is to achieve thermal comfort and energy efficiency in a building through proper orientation, efficient materials in the envelope, and knowledge of the conditions of the building's location, among other factors [2]. According to the Intergovernmental Panel on Climate Change,

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residential and commercial buildings contribute approximately 25% of global CO_2 emissions each year [3].

In this context, the challenge arises to transform an existing building into a more energy efficient building by implementing passive design improvements. Passive energy efficiency strategies include using architectural and design elements that optimize natural resources, such as sunlight, natural ventilation, and thermal insulation, without relying on additional mechanical systems. These improvements reduce the building's energy demand and enhance thermal comfort and indoor environmental quality.

Building energy modeling (BEM) techniques and other novel decision-making tools are necessary to optimize building performance [4]. Elbeltagi et al. [5] explain that through virtual technologies, BEM allows us to predict energy demand. Pursuing energy efficiency in buildings is a common goal of BEM research [6]. Applying BEM to existing buildings can support investigating cost-effective retrofit opportunities without intervention [7]. Energy simulations are essential as a support method during the whole life cycle of the building, from design to normal building operations and demolition actions [8]. There are examples of BEM applications in different types of buildings, such as offices [9], residential [10], hospitals [11], offices [12] and offices and education [13].

Passive houses, which use the building's architecture to stay warm in cold months and cool in warm months, can reduce energy consumption by up to 90% [14]. Several techniques adapted to tropical climates, such as the Dominican Republic, can be applied to maintain passive energy consumption in a more energy efficient building.

The implementation of green roofs contributes to urban sustainability and improves the thermal performance of buildings, reduces energy usage, and promotes biodiversity in densely populated urban areas [15], [16]. Implementing green roofs and vegetated facades improves insulation and helps lower the air temperature around the building, mitigating the urban heat island effect. Incorporating passive shading systems, such as blinds and awnings, allows control of direct sunlight entry and minimizes indoor heating. Using natural and nighttime ventilation systems helps cool the building by taking advantage of cooler night temperatures.

Passive architecture, an energy-efficient approach, aims to reduce a building's environmental impact using natural heating and cooling while minimizing mechanical methods. This approach encompasses five basic principles: orientation, insulation, airtightness, ventilation, and passive solar design [17], [18].

2 Case Study: Ercilia Pepin Building

2.1 Building Description

A building situated in the tropical savanna (Aw) climate of the Dominican Republic was selected from the Instituto Tecnológico de Santo Domingo (INTEC) campus for a detailed study of its physical characteristics. The Ercilia Pepín Building (EP) has a total area of 1,180.24 square meters of construction distributed as follows:

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Level 1: Underground

The first level is underground and is dedicated to laboratories specializing in automation and nanotechnology.

Level 2: Student and office spaces

The second level is designed to provide comfort and functionality for students and staff. On this floor, you will find:

- **Bathrooms:** Equipped to meet the needs of all users.
- **Offices:** Administrative and workspaces for teaching and administrative staff.
- **Student Living Room:** Students can relax, socialize, and study between classes.

Level 3: Classrooms and administrative offices

The third level is mainly intended for academic and administrative activities. This floor includes:

- **Two classrooms:** Spacious and equipped to facilitate interactive learning.
- **Restrooms:** Available for students and staff.
- **Various administrative offices:** Spaces for administrative and academic staff designed to facilitate work and daily management.

Each classroom, office, and laboratory are equipped with air conditioning, ensuring a comfortable environment for all users, regardless of outside weather conditions. The materials used for the construction of the building are traditional, reinforced concrete walls, concrete slab roof, hydraulic slab floors, and glass windows, which are essential to provide natural lighting to the building but can be a significant source of heat gain in summer if they are not designed to be energy efficient.

2.2 Methodology

A Building Information Model (BIM) was developed using industry-standard software: AutoCAD, Revit, and OpenStudio. The initial phase involved creating a 2D schematic diagram, detailing precise measurements of the building's geometry. This schematic was subsequently imported into Revit to generate a 3D model, carefully considering the building's orientation to optimize solar exposure and energy efficiency.

Material properties were assigned to the building components: ceramic tiles for flooring, and a combination of concrete and drywall for walls, with drywall predominating in office areas. The unique curvature and material composition of the dome roof necessitated specialized modeling techniques.

To accurately simulate real-world conditions, virtual windows and doors were incorporated into the model, with precise specifications regarding type, material, and dimensions. To approximate the shading effects of trees, digital objects were strategically placed to cast shadows on the building at specific times of day.

The energy performance of the building was analyzed by incorporating active loads, such as lighting and equipment, into the OpenStudio model. These elements were assigned specific energy consumption profiles to accurately simulate real-world energy

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usage. Additionally, a parallel Excel model was created to facilitate rapid design iterations and sensitivity analyses. It is important to note that this project focused on a passive building design approach, prioritizing building envelope optimization and natural lighting strategies to reduce energy consumption.

2.3 Preliminary Measurements

An electric energy audit was carried out to determine the building's active consumption since the building does not currently have a local measurement system to determine energy consumption. The abovementioned items include all mechanical and electronic elements that add load to the building, such as computers, fans, air conditioners, etc.

The audit results show that 89% of the loads come from office equipment. These include computers, air conditioners in specific classrooms, and telephones. So, to solve the problem, these areas must be attacked more rigorously. Table 1 shows the results of the building's energy performance obtained through the energy audit.

Table 1. Current behavior of electricity demand.

Building Name	Power Factor	Demand Factor	Maximum demand (kW)
Ercilia Pepín	0.80	2.68	21.67

Fig. 1 shows the building's average electric energy demand over 24 hours. The building's highest consumption period is from 8 a.m. to 6 p.m. when the demand is between 20 and 21 kW. In the other periods, the demand is less than 2 kW.

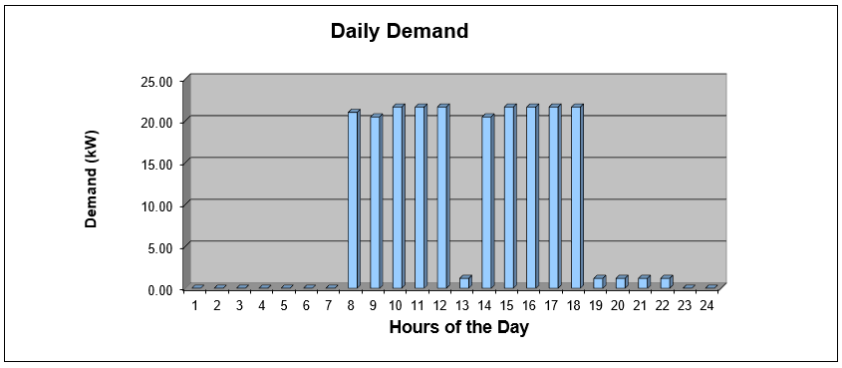


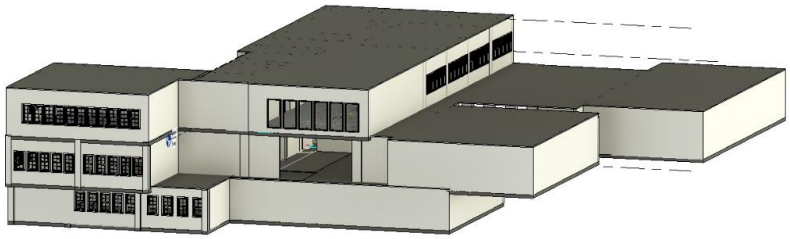
Fig. 1. Average electric energy demand during the day.

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2.4 Building Digital Model

Due to the building's lack of architectural schematics, a laser distance meter was used to collect its measurements. The survey provided a detailed layout of the building. Measurements were collected for the distance between the roof, walls, and window area in contact with the exterior. Fig.2 shows the digital twin of the building in its base form, which includes the elements and materials of the actual building.

(a)



(b)

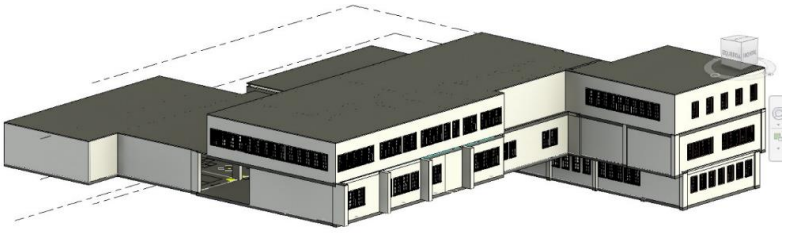


Fig. 2. (a) View of the front of the EP building in REVIT. (b) View of the back of the EP building in REVIT.

3 Building Improvements

3.1 Passive Technologies

Once the digital twin of the building was built, we proceeded to apply different types of passive technologies to see which ones would have the best results in helping to improve the energy efficiency of the building. For this research, the following techniques were analyzed:

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Window Removal and Enhancement

The windows facing east and west of the building receive direct solar radiation for much of the day, which considerably increases the thermal load inside and, therefore, the need for air conditioning; to mitigate this effect, it is proposed that such windows be eliminated when possible. In cases where they cannot be completely removed, it is suggested that existing windows be replaced with double—or triple-glazed windows.

Sun Protection and Reflective Colors

To protect the building from direct solar radiation, it is recommended that awnings or blinds be installed on windows and entrances. Awnings provide shade and allow you to control the amount of sunlight entering the building, which can reduce the cooling load. Another measure is to paint the building's walls and ceilings light colors, preferably white.

Natural Ventilation

The building's design includes a corridor that runs from north to south, facilitating natural cross-ventilation. However, a warehouse or container before the electrical machinery laboratory blocks this ventilation. This obstacle is recommended to be relocated to allow fresh air to enter, improving air circulation in the building.

Natural Lighting

Skylights should be installed in strategic areas of the building, such as bathrooms, corridors, and common areas, to maximize natural light and reduce energy consumption in artificial lighting.

Vegetation and Green Walls

The implementation of green walls both outside and inside the building is proposed. Green walls are greenery covering the building's surfaces, providing natural thermal insulation. These walls help maintain a more stable internal temperature.

3.2 Solar Panels

Since office supplies are extremely necessary and passive consumption can only be reduced without affecting employees' work, it was decided to include the application of solar panels on the building's roof in the digital model.

The selected area at INTEC has a daily energy consumption of 21.67 kWh. Given the abundant average solar radiation of 5.5 kWh/m²/day in the region, a solar panel system with a capacity of approximately 2.87 kW would be sufficient to cover this daily consumption. This system could be comprised of roughly eight solar panels, each rated at 400 W. Considering that each panel occupies about 2 square meters, the total space required for the installation would be only 16 square meters. This is entirely feasible given the availability of a flat roof area of 500 square meters.

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4 Results and Discussion

After considering the passive strategies to be evaluated, different scenarios were carried out in which the energy performance of the building was evaluated to determine the best way to reduce the building's energy consumption. Among the passive technologies that provided the best benefit was the implementation of vegetation and green walls (see Fig.3), which had the following characteristics:

- **Thermal Insulation.** Green walls are a natural barrier against heat, reducing heat transfer into the building.
- **Air Quality.** Plants on green walls help filter pollutants and improve indoor air quality, creating a healthier environment.
- **Acoustic Insulation. R**educe outdoor noise pollution, providing a calmer environment.
- **Aesthetics and Biodiversity.** Improve the appearance of the building and promote urban biodiversity.
- **Ventilation.** Cooler and healthier environment, which improves productivity and well-being.
- **Recreation Areas.** More attractive and pleasant space for recreational activities.

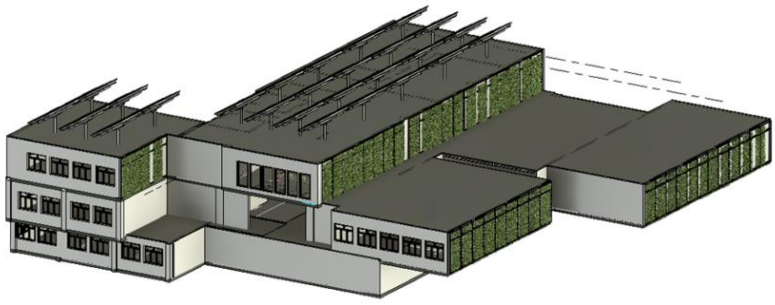


Fig. 3. Improved model with green walls on the east and west facades

Additionally, the installation of triple-glazed windows (see Fig.4) and the application of high-reflectivity paint on walls and ceilings has resulted in a noticeable reduction in heat transmission in winter and summer. This translates into a significant decrease in energy demand for heating and cooling.

A cyclonic mesh system was implemented in the dome area to improve natural ventilation and reduce thermal load, allowing constant and efficient airflow. Furthermore, aluminum windows with outward openings were incorporated, optimizing air circulation and renewing the interior environment.

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Solar panels were installed on the building's roof to increase energy efficiency and reduce dependence on conventional energy sources. In addition to generating clean electricity, these panels help reduce indoor temperatures.

The results show that the interventions carried out have positively impacted the building's energy performance, improving the thermal and acoustic comfort of the occupants. Likewise, a substantial reduction in greenhouse gas emissions has been achieved, contributing to climate change mitigation.

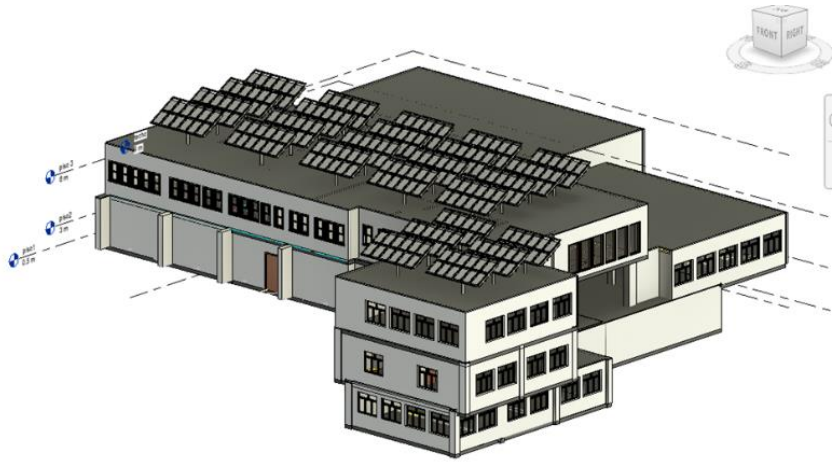


Fig. 4. Triple-glazed windows in common areas.

Likewise, a substantial reduction in greenhouse gas emissions has been achieved, contributing to climate change mitigation. Table 2 shows the building's energy consumption after applying the passive strategies.

Table 2. The behavior of electricity demand after applying the passive technologies.

Building Name	Power Factor	Demand Factor	Maximum demand (kW)
Ercilia Pepín	0.80	2.11	15.79

Fig. 1 shows the building's average energy demand over 24 hours. The building's highest consumption period is from 8 a.m. to 6 p.m. when the demand is between 14 and 16 kW. In the other periods, the demand is less than 2 kW.

ISBN 978-9930-617-71-7

Fig. 5 shows the building's average electric energy demand over 24 hours. The building's highest consumption period is from 8 a.m. to 6 p.m. when the demand is between 14 and 16 kW. In the other periods, the demand is less than 2 kW.

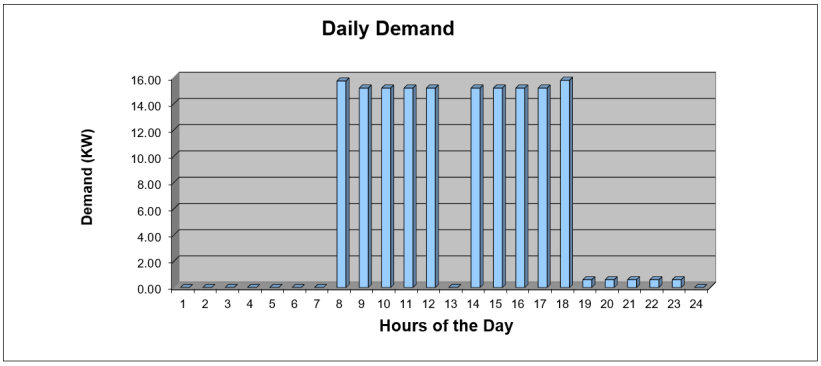


Fig. 5. Average electric energy demand during the day.

5 Conclusion

The transformation of the EP building into a nearly zero-energy building (NZEB) represents a significant step towards sustainability and energy efficiency in the building sector. Implementing passive design strategies and optimizing natural resources has considerably reduced the building's energy demand while improving thermal comfort and indoor environmental quality.

Improvement proposals, such as removing and improving windows, sun protection, using reflective colors, natural ventilation, implementing greenery and walls, and maximizing natural lighting, have proven effective in reducing energy consumption. In addition, integrating solar panels on the roof of the building contributes to generating renewable energy on-site but complements the passive measures adopted, ensuring optimal energy performance.

Tools such as OpenStudio and Revit have been crucial in creating a digital twin of the building. This allows the proposed improvements to be simulated and evaluated without needing to be physically implemented. This has made making informed decisions and validating energy efficiency strategies easier before implementation.

The transformation of the EP building into an NZEB demonstrates the potential of passive design strategies in reducing energy consumption and sets an example for future construction and renovation projects in sustainability and energy efficiency. The experience and results obtained in this project highlight the importance of conscious planning and design in creating more sustainable and environmentally responsible buildings.

ISBN 978-9930-617-71-7

Acknowledgments

The authors acknowledge the support provided by the Thematic Network 723RT0150 "Red para la integración a gran escala de energías renovables en sistemas eléctricos (RIBIERSE-CYTED)". This research was funded by FONDOCyT Grant No. (FONDOCYT-2023-1-3C1-0547) in the Dominican Republic.

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ISBN 978-9930-617-71-7

Modelling and validation of the pine pellet gasification process in a downdraft fluidised bed reactor using the application of free-to-use software.

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Summary.

The need for sustainable energy production, derived from the current climate change crisis, has opened interest in the study of biomass conversion technologies resulting from the industrial sector. The present work focuses on the characterization of bioenergy from the gasification of wood waste in a sawmill. The study was carried out experimentally in a downdraft fluidized bed reactor. The results were used to validate a theoretical model in the free use software Cape Open to Cape Open, from which it was possible to determine that since there is a relationship of more than 80% between the gas composition data obtained experimentally and those obtained with the software, the simulation turns out to be adequate. To further support the model developed, it was compared with the results reported by various authors.

Keywords: bioenergy, gasifiers, syngas, forest residues, simulation,

1.-INTRODUCTION.

Today, concern about the continued use of fossil fuels has increased as a result of visible effects on the environment and daily life in many regions around the world. Therefore, the need to produce energy in a sustainable way has led to growth in research in this field, as is the case of obtaining synthesis gas through biomass gasification.
Establishing a thermoenergetic and economic analysis of energy production alternatives is useful because, in addition to determining their use in the electrical field, it is also possible to establish their application in the thermal field, as is the case of cogeneration systems. The economic evaluation of these alternatives provides a second basis for their development, since a means of sustainable energy production can be achieved and, in turn, have a long-term economic benefit for the sites where they are implemented.
According to data from the Ministry of Environment and Natural Resources, about 60% of the timber production in the state of Veracruz corresponds to pine wood that is worked in sawmills. According to the Food and Agriculture Organization of the United Nations, 5 to 7 percent of a wood log is lost in bark during the sawmilling process and about 30 percent in sawdust, trimmings, and shavings. Therefore, the purpose of this work is to characterize the energy from the gasification of sawmill waste, such as bark, and to propose its subsequent use for the generation of electricity.
In the field of the use of forest residues, and specifically pine bark, China has been the country where the largest number of specific studies have been carried out on the gasification of pine bark and the characterization of the syngas obtained, as is the article by Wang et al. [1]. where it is appreciated that the production of electrical power from synthesis gas is feasible due to the calorific value it contains.

1.1.- Background to gasification and pyrolysis of pine wood bark and residues.

Forest residues, one of the main sources of carbon-neutral lignocellulosic biomass, are abundant to support energy sustainability and reduce carbon emissions into the atmosphere, as mentioned by Wang et al. [1]. Syngas is a promising source of renewable energy generation and green chemicals. The production of syngas provides the opportunity to achieve negative carbon dioxide by implementing carbon capture and storage [2]. Various research has been carried out worldwide involving the gasification process of pine waste. In Brazil, in 2017, the capacity of wood to adsorb lead in aqueous medium at various pH levels was studied, determining the amount adsorbed at equilibrium. To do this, the wood was added to a fixed-bed gasifier with two-stage countercurrent flow, at a working temperature of 900°C to obtain the synthesis gas [3].

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In 2019, in Portugal, a study on the generation of energy and bio-based products from pyrolysis of forest residues was presented. Pyrolysis experiments were carried out with woody biomass consisting of wood and bark, using an auger reactor to better understand the impact of pyrolysis operating parameters on co-product properties [4].
During the same year in China, a co-gasification of waste tires and pine bark was carried out in a CO2 atmosphere, where it was reported in different fractions of waste tire mixture (WT) and pine bark (PB). The syngas characteristics of the gasification of mixtures were realized using a fixed-bed reactor in CO2 atmosphere at 800 and 900°C. The results showed that the increase in the proportion of pine bark increased the maximum flow rate of H2, CO, total syngas, but decreased the maximum flow rate of other hydrocarbons (CmHn) at the two temperatures [5].
Similarly, during the year 2020, a work was carried out in China where the characteristics of the syngas from the gasification of pine bark in a CO2 atmosphere using a fixed-bed reactor at temperatures of 700, 800, 900 and 1000°C are presented. . The results showed that the gas yields of H2, CO and total synthesis gas increased with increasing temperature. However, the yield of total hydrocarbons was maximum at 800°C. Syngas with a calorific value of 21.0 to 23.3 MJ/kg was obtained from CO2 gasification [1].
On the other hand, in Australia during 2020, research was carried out where a kinetic model of biomass gasification with CO2 was presented, where one of the components was pine bark, which mimics the reduction zone of a dry-feed entrained flow reactor. The results indicated that during the high-temperature CO2 gasification condition, the gas phase chemistry is dominated by the reverse homogeneous water-gas exchange reaction (rWGSR). An increase in CO2 concentration served a dual purpose: to increase the rate of devolatilization and to reduce diffusional limitation [6].
On the other hand, in 2022 a review of co-gasification and co-pyrolysis for the production of synthesis gas on different types of biomass, including pine bark, was carried out. Co-conversion, experimental and techno-economic modelling studies, an analysis of the impact of mixing ratio, catalysts and pretreatment on gas performance, the effect of mixing plastic with biomass on efficient utilisation and highlights of challenges, future prospects and policy implications for technology improvement are reviewed [7].

2.-METHODOLOGY.

2.1.- Development of the theoretical model

The software used for the simulation was Cape Open to Cape open (COCO). It is a free CAPE-OPEN compliant steady-state simulation environment that consists of the following components:

- COFE. The CAPE-OPEN flowchart environment is an intuitive graphical user interface for chemical flowcharting. COFE has a sequential solution algorithm that uses automatic tear flows. COFE displays the properties of streams, takes care of unit conversion, and provides tracing functions.
- FIREBRAND. COCO's thermodynamics for engineering applications is based on the code from the ChemSep thermodynamics library and includes a database of more than 430 commonly used chemicals.
- COUSCOUS. It contains a divider, a mixer, heat exchangers, pumps, and reactors, among other unit operations. ChemSep-LITE, a limited version of ChemSep with a maximum of 40 compounds and 300 stages.
- CORN. The CAPE-OPEN Reaction Numerics package that comes with COCO makes it easy to specify any type of kinetic or equilibrium reaction.

The model taken as a basis for the simulation of a gasifier was the one carried out by Biomass Technology Group [8]. It simulates a rapid pyrolysis plant with a fluidized bed reactor. According to the author, the model was developed from experimental data, where what was mainly sought to obtain was bio oil and lean gas that would be used for complete combustion for the generation of steam and later the generation of electricity. This model uses a series of conversion reactors, where the only thing that is considered are the chemical reactions involved in the process (mainly for the pyrolysis of biomass and gas combustion) and their corresponding stoichiometric numbers.
From this proposed model, the parts involved in gas generation were taken, and the missing reactions were added to complete the gasification process in a general way, and thus obtain a gas with a better composition than that obtained by the author of the initial model. The reactions used and the modifications made are described below.
Equation 1, proposed by Biomass Technology Group (2019), describes the reaction used for the decomposition of biomass in the pyrolysis stage in the gasifier.

$$\mathrm{CxHyOz(Biomass)} \rightarrow \mathrm{a(H2O)} + \mathrm{b(O2)} + \mathrm{c(C20H26O8)} + \mathrm{d(C21H26O8)} + \mathrm{e(C8H8O3)} + \mathrm{f(C4H6O2)} + \mathrm{g(C20H28O2)} + \mathrm{h(C10H12O2)} + \mathrm{i(C6H10O5)} + \mathrm{j(C12H22O11)} + \mathrm{k(C6H6O2)} + \mathrm{l(CO)} + \mathrm{m(CO2)} + \mathrm{n(CH4)} + \mathrm{or(C3H6O2)} + p\mathrm{(Char)} + q\mathrm{(C3H6O2)} \quad \text{(Equation 1)}$$

Where $_{x, y}$ and $_{z}$ are the molar ratios of biochar, hydrogen and oxygen in the chemical formula of biomass, and whose values are given by proximal, elemental and ultimate analyses; while the coefficients from "a" to "q" are the stoichiometric numbers of the products produced in the pyrolysis process
The stoichiometric numbers used for the pyrolysis section of the pine pellets are shown in Table 1.

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Table 1. Stoichiometric balance for pyrolysis.
Own elaboration.

ESTEQ NUMBER.	COMPOUND	CHEMICAL FORMULA						BALANCE					
0.4955	WATER	C	-	H	2	O	1	C	0	H	0.99	O	0.49
0.03383	OXYGEN	C	-	H		O	2	C	0	H	0	O	0.06
0.01	LIG A	C	20	H	26	O	8	C	0.20	H	0.26	O	0.08
0.01	LIG B	C	21	H	26	O	8	C	0.21	H	0.26	O	0.08
0.0302	BENZALDEHYDE-3HYDROXY-4METHOXY	C	8	H	8	O	3	C	0.24	H	0.24	O	0.09
0.0428	BUTENOIC ACID	C	4	H	6	O	2	C	0.17	H	0.25	O	0.08
0.0096	DEHYDROABETIC ACID	C	20	H	28	O	2	C	0.19	H	0.26	O	0.02
0.0187	ISOEUGENOL	C	10	H	12	O	2	C	0.18	H	0.22	O	0.03
0.04382	LEVOGLUCOSAN	C	6	H	10	O	5	C	0.26	H	0.43	O	0.21
0.04235	MALTOSE	C	12	H	22	O	11	C	0.50	H	0.93	O	0.46
0.0375	P HYDROQUINONE	C	6	H	6	O	2	C	0.22	H	0.22	O	0.07
0.5341	CARBON MONOXIDE	C	1	H	-	O	1	C	0.53	H	0	O	0.53
0.305	CARBON DIOXIDE	C	1	H	-	O	2	C	0.30	H	0	O	0.61
0.35	METHANE	C	1	H	4	O		C	0.35	H	1.40	O	0
0	METHYL ACETATE	C	3	H	6	O	2	C	0	H	0	O	0
4.802	BIOMASS	C	1	H	1.50	O	0.66	C	4.80	H	7.2030	O	3.16
0.209	CHAR	C	6.275	H	6.30	O	1.15	C	1.31	H	1.3167	O	0.24
0.0345	HYDROXYACETONE	C	3	H	6	O	2	C	0.10	H	0.207	O	0.07
0.0909	HYDROGEN	C	-	H	2	O	-	C	0	H	0.1818	O	0

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The procedure for the preparation of the simulation diagram is described below.
Step 1.From the pyrolysis equation discussed above, and considering the stoichiometric numbers and the compounds involved in the reaction, a file was opened in COFE to establish the flow diagram that would be used for the simulation.
Step 2.- For the case study, the selected elements were the package of TEA properties, which received the name of Pyrolysis SRK VERSION 3. The compounds added were those mentioned in Table 1.
Step 3.- The package for the reactions and compounds must be selected.
Step 4.- A package of CORN reactions was selected, which was named Pyrolysis reaction VERSION 3 and Char Combustion VERSION 3, and the compounds involved in equation 1 and the stoichiometric numbers of the compounds in table 1 were selected. Similarly, compounds related to the respective reactions developed for the oxidation and reduction processes were selected.
Step 5.- With the configuration completed, the flow diagram shown in Figure 1 was developed, based on the flow diagrams for pyrolysis simulation performed by [8], [9], and [10].

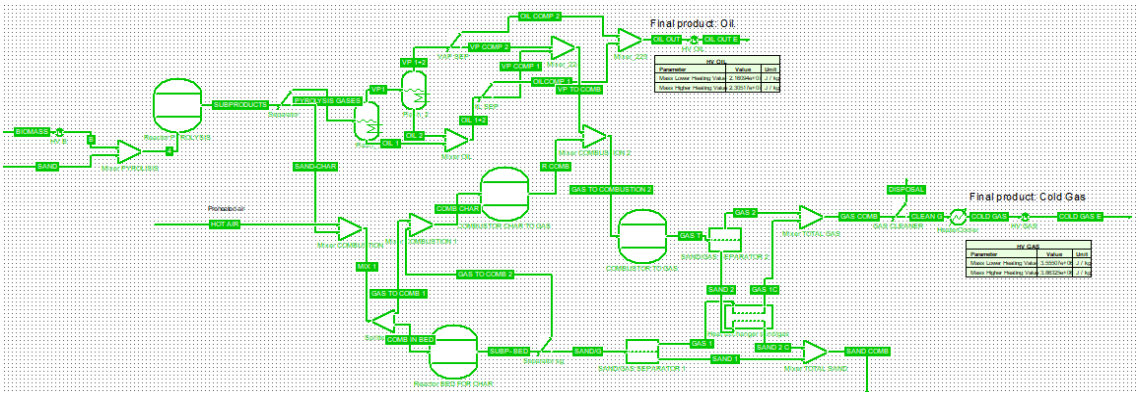


Fig. 1. Flow chart for process simulation.
Own elaboration.

2.2. Experimental development.

On the other hand, the gasifier used for the experimental tests was the ANKUR model PG-45, downdraft type installed at the gasification plant of the Autonomous University of Mexico. In general, it is made up of various filters and cooling systems for the resulting gas, which is divided into two phases: dirty gas and clean gas.
Some of its technical control characteristics are the following:

- Operating temperatures range from 850 to 950 °C.
- Maximum allowable humidity for biomass: <35% (wet basis).
- The biomass load is continuous.
- The flow of syngas to the outlet of the gasifier is around 110 Nm^3/h
- The pressure measurement at each point is carried out by means of U-tube pressure gauges with water.
- The pressure difference range in the Venturi tube for syngas flow should range from 25 to 50 mm of water.
- The pressure difference range in the gasifier should be less than 150mm water column.

For the experimental analysis, the characteristics of syngas production by gasification were evaluated. The ANKUR PG-45 reactor was used. Figure 2 shows the general diagram of the occupied test gasifier and Figure 3 shows the reactor ignition process.

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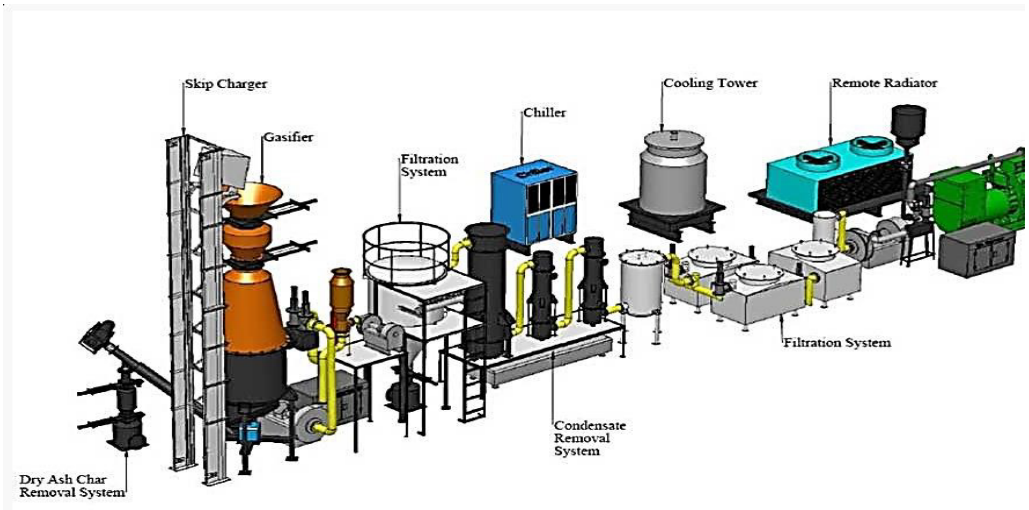


Fig. 2. General diagram of the gasifier and elements for clean gas.
Source: Ankur Scientific [12]



Fig. 3. Biomass ignition process for gasifier operation.
Source: own.

3.- RESULTS AND DISCUSSION

Table 2 shows the averages of the data measured during the period of obtaining clean gas.

Table 2. Measurements taken from the gasifier.
Own elaboration

AVERAGE GASIFIER READINGS						
TIME	**BIOMASS (kg)**	**ΔP REACTOR**	**ΔP VENTURI**	**T Output (°C)**	**T combustion front (zone 1) (°C)**	**REMARKS**
1 hour	72	41.5	26.63	254.79	213.32	The operation of the gasifier began at 9:00 a.m. The change from dirty to clean gas was carried out at 11:00 a.m. Biochar measurements began at 12:00 p.m.

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The results of the outlet currents under the previously mentioned temperature and pressure conditions can be seen in Table 3.

Table 3. Reporting of results by stream.
Own elaboration.

Stream	OIL OUT	DISPOSAL	COLD GAS	SAND COMB	Unit
Temperature	344.89	800	50	800	°C
Flow rate	29.05	31.24	39.70	1470	kg/h

From the separation of fluids in the flash tanks, it could be noted that a greater amount of gaseous product is obtained compared to the liquid product. To verify the above, a biomass flux of 50 kg/h was taken as a basis and the temperatures of Flash 1 were modified, with values of 326.8 °C, 376.85 °C, 426.8 °C and finally 476.85 °C, respectively, as shown in Figure 4. It is notable that near 500°C, oil production is almost zero, so almost all the product of pyrolysis is transformed into gas.

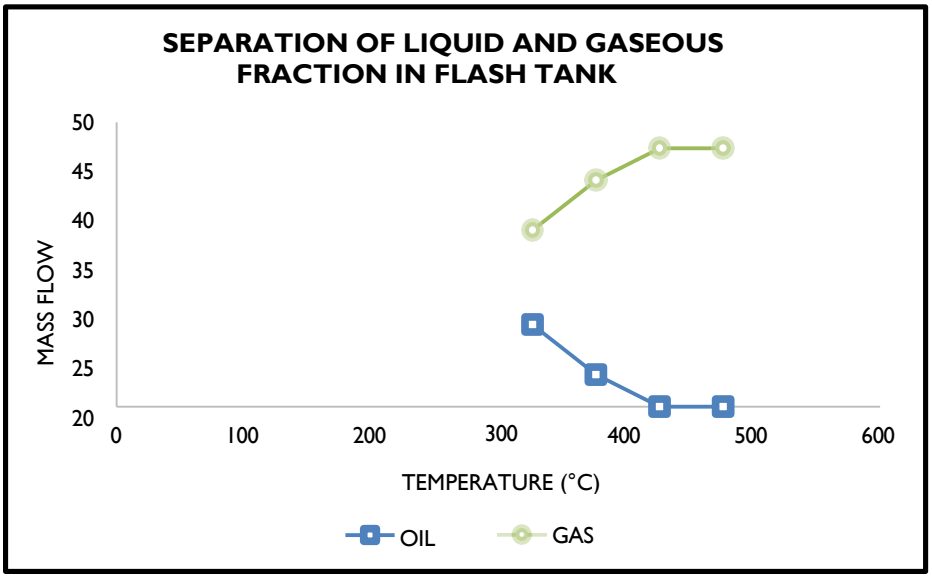


Fig. 4. Expected behavior of gas and oil flows with respect to temperature.
Own elaboration.

The syngas composition is shown in table 4, where a calorific value of 3.56 MJ/kg and a gas flux of 39.7 kg/h can be noted.

Table 4. Composition of pyrolysis syngas.
Own elaboration.

Stream	COLD GAS E	Unit
Temperature	50	°C
Flow rate	39.70	kg/h
Mole frac Oxygen	0.04	
Mole frac Carbon monoxide	0.11	
Mole frac Carbon dioxide	0.12	

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Mole frac Methane	0.05	
Mole frac Nitrogen	0.57	
Mole frac Hydrogen	0.08	
Mass Lower Heating Value	3.56E+06	J/kg
Mass Higher Heating Value	3.86E+06	J/kg

From the measured data, it could be seen that the hourly feed after clean gas begins to be obtained was 72 kg/h. Similarly, it was notable that as time went by, the gas outlet temperature began to gradually decrease, as did the temperature of the combustion front corresponding to zone 1 of the gasifier, as can be seen in Figure 5. This data logging was important for monitoring the performance in the gasifier and gas production.

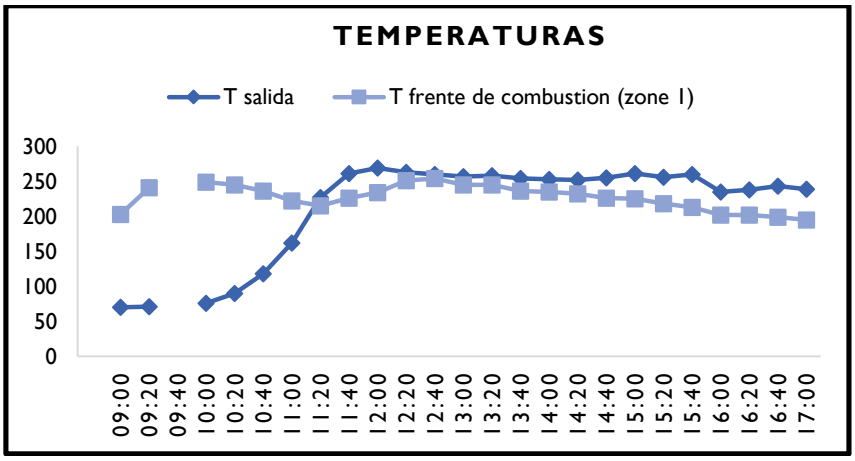


Fig. 5. Gas outlet temperature and combustion front measurements.
Own elaboration.

Syngas composition

Table 5 shows the composition of the syngas, from which an average calorific value of 4 MJ/m3 could be observed; Likewise, it can be seen that the components observed mostly correspond to carbon dioxide and carbon monoxide, although adequate data were also observed in terms of percentages of hydrogen and methane according to what the literature indicates, as can be seen in Figure 6. Similarly, it was observed that the contents of CO and H2 began to decrease when the gas outlet temperature exceeded 240°C. These effects were also related to the entry of oxygen at some points of the gasification system, as an increase in oxygen could be seen almost at the same time.

Table 5. Measurements taken from the gas analyzer.
Own elaboration.

GAS ANALYZER							
HOUR	**%CO**	**%CO2**	**%CH4**	**%H2**	**%O2**	**%CnHm**	**PCI (kcal/m3)**
15:00	11.32	12.12	4.71	7.83	2.98	3.01	999
15:30	10.54	13.72	4.75	6.06	3.85	0.45	927
16:00	10.06	13.48	5.24	6.94	4.17	0.42	983

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16:30	10.22	13.27	5.24	7	4.35	0.47	999
17:00	9.28	12.42	4.86	6.37	4.73	0.47	951

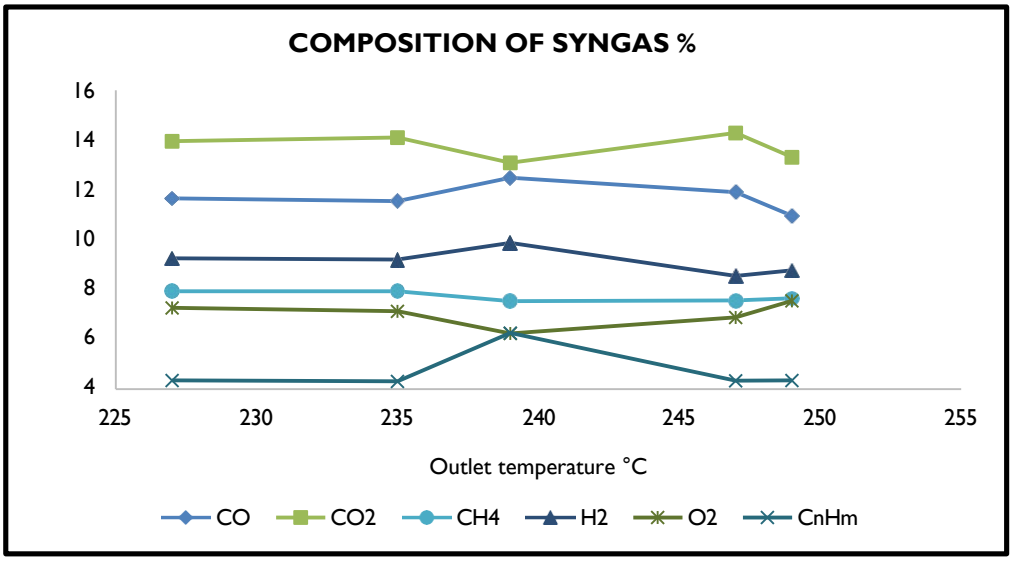


Fig. 6. Composition of the syngas with respect to the change in temperature.
Own elaboration.

Otherwise, to determine the totals of biochar output, the mass of the two containers that were used to collect biochar was determined. Subsequently, both containers were weighed when they had a level of biochar inside them coinciding with the gauging line and the data was summed during the time that the gasifier was expelling the completely black biochar, where the totals are shown in table 6.

Table 6. Total biochar.
Own elaboration.

BIOCHAR FLOW		
FED BIOMASS (kg)	**MEASURED BIOCHAR MASS (kg)**	**% CARBONACEOUS RESIDUE PER BIOMASS FED**
290	93	32.06
355	93	26.19

Table 7 shows a general balance between the mass entering and leaving the gasifier, taking into account the input of biomass at the input and syngas, biochar, and tars at the output.

Table 7. Input-output mass balance.
Own elaboration.

BALANCE TOTAL FLOWS (kg/h)

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18.60	Biochar Flow
68.60	Biochar + Gas Flow
71	Biomass flow

In order to visualize a complete overview of the theoretical and experimental study, in table 8 you can see a comparison between the composition and energy content of the resulting gas obtained both theoretically and practically and in the simulation carried out, where a gas with a calorific value of 4 MJ/m3 can be seen

Table 8. Characteristics of pine waste synthesis gas.
Prepared by the author with data from [11].

CONCEPT	**DATA THEORETICAL (Gasification of splinters of pine)**	**DATA OF SIMULATION (Gasification pellets pine)**	**EXPERIMENTAL DATA (Pine pellet gasification)**	**% SIMULATION-EXPERIMENTATION DIFFERENCE**
Mole frac Carbon monoxide	24.78	11.77	10.28	87.31
Mole frac Carbon dioxide	11.10	12.80	13	98.46
Mole frac Methane	2.10	5.56	4.96	89.09
Mole frac Hydrogen	18.72	8.10	6.84	84.44
Mass Lower Heating Value	5.51 MJ/kg	4.02 MJ/m3	4.06 MJ/m3	-

4. CONCLUSIONS:

With the implementation of a simulation for the gasification process developed experimentally, it was possible to analyze the main factors that can affect the calorific value of the resulting gas, such as the stoichiometry of the reactions. With the experimental part, it was possible to verify that the composition of the synthesis gas from the experimental tests is similar to that expressed by other authors.

Subsequently, it was observed that there is similarity between the data obtained experimentally and those obtained from the simulation. It can be seen that there is a correlation between both data of more than 80%, which verifies that the simulation is adequate according to what was obtained in experimental tests with the advantage of using software that is freely accessible and used for research.

The development of this study was useful to verify that the residual biomass that is produced in sawmills has sufficient energy potential to be used in electricity and thermal generation. Likewise, the creation of a tool that allows modifying variables within the process, such as a theoretical model, facilitates the possibility of maximizing the efficiency of the process and improving the characteristics of the syngas. In addition to this, as it is considered an emissions-neutral technology, gasification is a viable method for the use of biomass that reduces the amount of waste that could be disposed of in open-air landfills and that, in turn, allows the energy transition in industries.

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ISBN 978-9930-617-71-7

Facade Construction Technologies and Their Impact on the Urban Microclimate: A Comparative Study between the Cities of Madrid and Mendoza

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Abstract. The choice of facade technology has a significant impact on the urban microclimate and pedestrian comfort. The thermal and optical properties of materials, along with the climatic context, influence the mean radiant temperature (MRT) within street canyons. To assess the impact of different facade technologies on microclimatic energy performance during the summer period for the cities of Mendoza and Madrid, 8 scenarios of 10-story buildings were constructed using ENVImet v. 5.6 software. The construction technology (traditional and lightweight) and optical properties (albedo: 0.30 and 0.80) were modified according to the climatic contexts (BWk and Csa). The results indicated that traditional technology, with higher thermal mass, better dampens temperature fluctuations, providing a more stable urban environment. In contrast, lightweight technology, with lower heat capacity, presents greater temperature variations. Scenarios with lightweight technology recorded a maximum mean radiant temperature up to 4.5°C higher than scenarios with traditional technologies. On the other hand, increasing the albedo level of facade surfaces raised MRTs by up to 5.3°C, with a greater impact on traditional technology. To improve thermal comfort in outdoor spaces, it is necessary to consider a combination of strategies, including the appropriate selection of materials and the optimization of urban design.

Keywords: Urban Microclimate, Traditional and Lightweight Technology, Thermal and Optical Properties.

1 Introduction

Urban agglomerations are undergoing profound transformation, characterized by accelerated urbanization, densification, and territorial expansion, along with a demographic shift towards an aging population and an intensification of thermal stress associated with global warming [1]. These trends can be observed in both developed and developing countries and may potentially lead, due to the combined effects of increased heat exposure and greater vulnerability to heat, to increased thermal stress in future cities [2]. The growth of urban populations has generated a greater demand for

ISBN 978-9930-617-71-7

land and an intensification of urban land use. These processes, by increasing built-up areas and reducing soil permeability, contribute to the rise in urban surface temperatures and, therefore, to the intensification of the urban heat island (UHI) effect [3]. The growing urbanization and climate change have highlighted the need to develop strategies to mitigate these effects and improve the quality of life in cities both in the European Union and the Southern Cone [4].

The thermal and optical properties of the materials that make up building envelopes determine the radiative behavior of a surface in response to solar radiation and other environmental stimuli. Specifically, thermal properties (thermal conductivity, thermal diffusivity, heat capacity, etc.) influence heat transfer due to a temperature difference with the environment, while optical properties (solar reflectance or albedo and emissivity) determine the radiative behavior (in the solar and infrared range) of the surface layer of materials according to the portion of solar radiation absorbed by the component and reflected towards urban areas [5], [6]. The amount of energy re-emitted towards urban areas is one of the main causes of the urban heat island effect [7].

In this context, the mean radiant temperature (MRT) is a climatic parameter that quantifies the average temperature of the surfaces surrounding a person and is, therefore, key to assessing pedestrians' outdoor thermal comfort [8, 9, 10]. This measure includes both air temperature and thermal radiation exchanged with surrounding objects [11]. MRT is affected by factors such as the thermal and optical properties of building materials [12, 13], urban geometry, and vegetation [14]. Accurate calculation of radiation, especially long-wave radiation, is essential to assess the thermal stress pedestrians are exposed to [15]. On the other hand, the albedo of urban surfaces, by determining the amount of reflected solar radiation, significantly influences urban thermal comfort. High albedo reduces heat absorption, keeping surfaces cooler and decreasing the emitted long-wave radiation [16]. However, reflected radiation increases the radiant load for pedestrians.

Consequently, while this strategy may be effective in reducing surface temperatures, its impact on lowering MRT is limited. Studies by Alchapar et al. [17] in Latin American cities showed that every 10% increase in albedo levels of pavement and roof surfaces reduces air temperature by 0.5°C in Mendoza, Argentina, and by 0.9°C in Campinas, Brazil. However, cool materials applied to vertical envelopes (facades) can cause overheating, as the mitigation potential is not only determined by surface optical properties but also by the geometry of the urban profile [18]. An example of this is the studies by Pisello et al. [19, 20], which demonstrated that high solar reflectivity facade coatings within deep street canyons increase mutual reflections between buildings, as solar radiation becomes trapped at street level a phenomenon known as the "Inter-Building Effect–IBE"-.Therefore, proper management of MRT is essential to design more comfortable and climate-resilient urban environments [21].

A growing global trend in the construction field is the adoption of new construction technologies, such as lightweight (dry) and modular technologies for housing solutions. Globally, lightweight construction has experienced steady growth over the past decade, driven by factors such as faster construction times, design flexibility, and cost-effectiveness due to reduced construction time. It is estimated that the global dry construction market will reach a value of USD 231.4 billion by 2028, with a compound annual growth rate (CAGR) of 5.7% during the forecast period from 2023 to 2028 [22]. This growth is also observed in Latin America, particularly in countries like Argentina,

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Chile, Mexico, and Colombia. The region is estimated to account for 14% of the global dry construction market by 2028 [23]. This type of technology is marketed as a more efficient and sustainable solution than traditional systems, offering high levels of thermal resistance due to the presence of polystyrene or polyurethane as the main material in its technological composition. However, these dry systems are characterized by low thermal inertia, which leads to higher energy consumption for heating and cooling in buildings [13]. This alteration of the energy balance of lightweight/dry envelopes changes the speed and manner in which building envelopes absorb and release energy to the external environment (street canyon). In fact, various studies review the trends and challenges of dry construction technology, highlighting the need to address low thermal inertia as a key challenge to ensure thermal comfort and energy efficiency in buildings [24].

This research aims to contribute to the sustainable development of building envelopes by efficiently managing solar resources in urban areas. The study is motivated by the need to understand the effect that the low thermal inertia of lightweight construction technologies has on urban overheating and on the outdoor thermal comfort of residents in various climatic contexts. Given the pressing need to mitigate urban overheating, this research zeroes in on the critical summer period, when solar exposure, energy consumption, and thermal demand are at their peak. This seasonal focus provides a sharper lens to evaluate how modifications in the thermal and optical properties of façade materials can impact urban microclimates. By examining these variables under the most demanding conditions, this study aims to reveal the tangible benefits and effectiveness of façade technology adjustments in reducing urban overheating and improving energy efficiency. Therefore, the objective of this work is to evaluate the impact of lightweight construction systems applied massively to facades on mean radiant temperature at pedestrian level (1.5 m) during the summer period in two climatic contexts: Mendoza and Madrid, through the construction of a theoretical model developed in ENVImet V.5.6.

Among microclimatic models, ENVI-met is the software with the most applications in research on pedestrians' outdoor thermal comfort [4]. However, previous studies have observed deficiencies in predicting MRT. In the latest version of ENVImet (version 5), the calculation approach has optimized modelling accuracy by introducing six radiative flux calculation directions and three short-wave radiation projection factors. Sinsel et al. [25] conducted a study to determine the software's accuracy through field tests in Hong Kong. The results showed significant improvements in model accuracy (R^2: 0.9, d: 0.95), with errors (RMSE: 3 K, MBE: 1.2 K). While the previous version of ENVI-met (prior to V5) relied on averaged sky view factors (AVF), the new version uses a more sophisticated radiation scheme (IVS) that accounts for long-wave and short-wave radiation reflected by each environmental element. This approach allows for more accurate MRT results, especially in complex environments like urban areas [26, 27].

The goal is to find the most effective combination of surface and mass properties during the summer period. This includes considering the optical properties (albedo and emissivity) of external surfaces, as well as the thermal properties of materials beneath the surface to account for the effects of thermal insulation or thermal mass of a component. These properties are defined in the calculation of the Solar Transmittance Index (STI), which combines in a single parameter the performance of the radiative

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properties of the external surface and the thermophysical properties of the materials beneath it [28]. The hypothesis proposed is that strategies using technologies with universal materials that do not consider the thermal and radiative requirements of urban environments and the locally available natural resources conditions the habitability of outdoor urban spaces and limits the possibilities for efficient thermal and environmental responses. If the regional climatic resources and the morphological characteristics of the urban environment are not considered may even exacerbate the problem they seek to mitigate [29].

2 METHODOLOGY

2.1 Study Cities as case studies

The cities of Mendoza (Argentina) and Madrid (Spain) were selected for the analysis. These cities share similar environmental characteristics during the summer but differ in latitude—32º in Mendoza and 40º in Madrid. This difference in proximity to the equator (resulting in a 12º variation in solar altitude) offers an opportunity to explore how the angle of solar incidence affects the urban energy balance. By comparing these two settings, the study can more thoroughly examine the impact of solar angle on energy dynamics and microclimate responses in urban areas. Fig. 1 describes the location of the cities analyzed in this study, while Table 1 describes the main characteristics of each city, obtained from the Climate.OneBuilding. Org[1].

Table 1. Geographic and Climatic Conditions of the Evaluated Cities

Characteristics	Mendoza, Argentina	Madrid, Spain
Location	(-32.86° S; -68.86°) 750m s/nm	(40.42°; -3.7°) 680m s/nm
Population	2.043.540 hab.	3.460.491 hab.
Climate according to Köppen classification [24]	Desert with cold steppe, BWk	Typical Mediterranean, Csa
Maximum daily horizontal global radiation	1117 W/m^2	1011 W/m^2
Solar height in summer	78.9º (February)	66.5º (August)
Mean wind speed (height: 10 m)	2.18 m/s (south)	2.61 m/s (south)
Annual mean temperature	16.79 °C	14.72 °C
Average minimum temperatures	-5 °C	-7.6 °C
Average maximum temperatures	39 °C	40.4 °C
Annual average relative humidity	60.32 %	52.16 %
Annual average precipitation	220 mm	435 mm

The steppe climate (BSk) and the Mediterranean climate (Csa) are two types of semi-arid climates with distinctive characteristics. The steppe climate, typical of steppes, is

[1] https://climate.onebuilding.org/

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characterized by cold winters and warm summers, with scarce and irregularly distributed precipitation throughout the year. On the other hand, the Mediterranean climate is distinguished by dry, hot summers and mild, rainy winters, showing a clear seasonality in precipitation. Both Köppen climate classifications reflect these differences: BSk encompasses climates with annual mean temperatures below 18°C, while Csa corresponds to climates with warm, dry summers. Although both experience water scarcity, their thermal and precipitation patterns are markedly different. It is important to note that local factors, such as altitude or urban conditions, can influence the specific characteristics of these climates in each region [29].



Fig. 1. Location of the study cities—Mendoza, Argentina, and Madrid, Spain—according to the Köppen climate classification [30].

2.2 Study Area and Theoretical Model

For this study, a single area was selected, consisting of a peripheral social neighborhood in the city of Mendoza (32° 54′ 48″ S, 68° 50′ 46″ W). The area is characterized by a regular urban layout and homogeneous building typology. The residential buildings, typically single-family homes of one or two stories, form a low-density urban fabric with rectangular blocks and street widths ranging from 16 to 20 meters. The built-up area represents approximately 80% of the total neighborhood area, while the remaining 13% is covered by urban vegetation. The average building height is 3.2 meters, resulting in a height-to-width (H/W) ratio between 0.15 and 0.19. Given the building's residential function, the envelope primarily consists of opaque materials, with glazed surfaces making up less than 10% of the façade. Regarding construction technology for the opaque envelopes, the roofs are lightweight, with a wooden structure, ceramic tile covering, and expanded polystyrene insulation (U-value: 0.625 W/m²K). The walls are traditional construction without thermal insulation, consisting of solid brick plastered on both sides (U-value: 1.07 W/m²K). The vehicular pavements are made of asphalt.

The microclimatic model was designed in ENVI-met version 5.6, forming a grid of 100(x); 80(y); 30(z) with a resolution of 3.0 (dx); 3.0 (dy); 5.0 (dz) meters, as the reference surface is 300 x 240 m. Microclimatic variables used to validate the theoretical model were collected through fixed measurement stations (Po) located within the study area (Fig. 2), positioned at pedestrian height (1.5 m). The data

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collection was conducted using HOBO® H08-003-02 devices, which offer a temperature accuracy of ±0.7 °C and a humidity accuracy of ±5%. All equipment was installed following the standards set by the World Meteorological Organization (WMO, 2006) [31]. The simulation utilized actual meteorological data collected during the summer months for both cities—February 2023 for Mendoza and August 2023 for Madrid.

Fig. 2 shows the morphological configuration of the entire urban neighborhood, with the highlighted area representing the section modeled and simulated using ENVI-met software. This specific section was chosen for analysis due to its homogeneous morphological characteristics, which make it representative of the broader area, as well as its proximity to the monitoring point.



Fig. 2. Study area in the ENVImet v.5.6 model space.

For the simulations, 2 days (2 cycles), totaling 48 h, were considered. The results presented in Fig. 3, obtained through numerical modeling with ENVImet, show a high correspondence between the simulated and the observed air temperature and relative humidity curves at the Po. The fit statistics (R^2 = 96.9% and 89.9% for temperature and relative humidity, respectively) suggest that the model effectively captures the physical processes involved.

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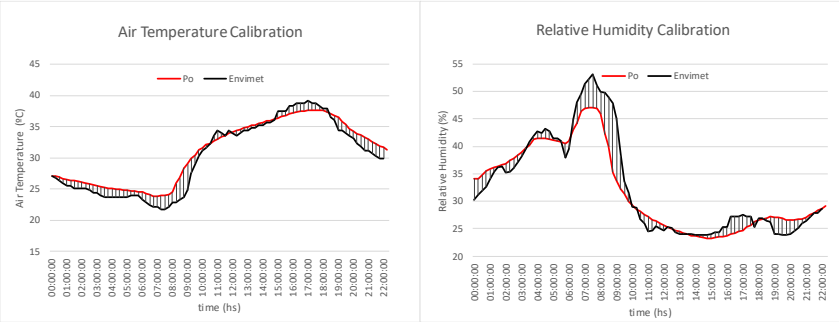


Fig. 3. Calibration curves for air temperature and relative humidity of the ENVImet model compared to the monitoring point (Po). High 1.5m.

2.3 Scenarios

Based on the adjusted area, a simplified model scenario was designed, based on a typical area of 30 meters in height (10 stories) and without vegetation. This scenario allowed for isolating the construction variable and achieving a greater presence of the facade relative to the total envelope area, with a sky view factor of 31%.

To evaluate the impact of different facade technologies on microclimatic energy performance for the cities of Mendoza and Madrid, 8 scenarios were analyzed, varying their construction technology (traditional and lightweight) and optical properties according to the BWk and Csa climatic contexts (Table 2).

Table 2. Proposed Scenarios

ID	Technology	
	Lightweight	Traditional
Low Albedo	L_0.3	T_0.3
High Albedo	L_0.8	T_0.8

The input climatic parameters correspond to the summer period of both cities. The analysis day for Mendoza is February 8, 2023, and for Madrid is August 23, 2023 (Table 3).

Table 3. Input Data for the ENVImet v.5.6 Model

Parameters	MENDOZA (February, 2023)	MADRID (August, 2023)
Average air temperature; °C	30.7°	29.8°
Maximum air temperature; °C	40.1°	38.8°
Minimum air temperature; °C	22.9	23.0°
Relative humidity; %	29.0	32.3
Wind speed; m/seg	5.0	3.6
Maximum global solar radiation; W/m^2	1017	1011

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The selected days exhibit representative characteristics of summer in each city, as shown in Table 1, featuring high solar radiation, low cloud cover, and reduced humidity.

Table 4 describes the construction resolutions for the facades and the levels of albedo and emissivity.

Table 4. Thermal and optical properties according to construction technology

Traditional Technology (T) - Thickness: 0.18 m		
Properties	Stucco	Solid Brick
* Thickness (m)	0.04	0.14
* Specific Heat (J/kgK)	669	650
* Thermal Conductivity (W/mK)	0.09	0.44
* Density (Kg/m^3)	1920	1500
Albedo	0.30 / 0.80	
* Emissivity	0.90	
Thermal Transmittance of the Component (W/m^{2}K)		1.07
Lightweight Technology (L) -Thickness: 0.12 m		
Properties	Cementitious board	Polyestirene insulation
* Thickness (m)	0.03	0.09
* Specific Heat (J/kgK)	840	1500
* Thermal Conductivity (W/mK)	0.2	0.07
* Density (Kg/m^3)	620	400
Albedo	0.3 / 0.8	
* Emissivity	0.94	
Thermal Transmittance of the Component (W/m^2. K)		0.623

** Default values. ENVImet v.5 material library*

Thermal transmittance (W/m²·K) was calculated using the thermal conductivity and thickness of the materials for each technology. Albedo values were established for facade materials based on the extreme values reported by Alchapar et al. [32]

3 RESULTS

To evaluate the microclimatic impact of the thermal and optical properties of different facade technologies in the cities of Mendoza and Madrid, a comparative analysis was conducted. This analysis first assessed the thermal performance of each technology in

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isolation, and secondly, its implications for the mean radiant temperature (MRT) within the study area.

3.1 Thermal Capacity of the Analyzed Technologies

The thermal capacity of a material is a physical property that indicates the amount of thermal energy required to raise the temperature of a given quantity of that material by one degree Celsius (or Kelvin). In other words, it is a measure of a material's ability to store heat. This concept is closely related to the thermal inertia of materials, which requires more complex calculation models that consider the geometry of each component and boundary conditions, as the ENVImet model does. Thermal capacity is calculated using the following formula:

$$C = Q / \Delta T \text{ (eq. 1)}$$

Where: C: Thermal capacity (J/°C); Q: Amount of heat absorbed or released (Joules, J); ΔT: Temperature change (°C).

The bar chart in Fig. 4 describes the thermal capacity of each component by technology and its total value assuming an area of 10 m² as calculated by ec. 1. These data show that the traditional technology, consisting of plaster and brick, has a thermal capacity 2.6 times greater than that of the lightweight technology. This implies that traditional technology can store a much larger amount of heat compared to lightweight technology. This significant difference indicates that traditional materials possess a greater capacity to store thermal energy. As a result, buildings constructed with these materials will experience reduced thermal amplitude, meaning their internal temperatures will fluctuate less throughout the day and across seasons. The implications of these findings on the outdoor microclimate will be discussed in the next section.

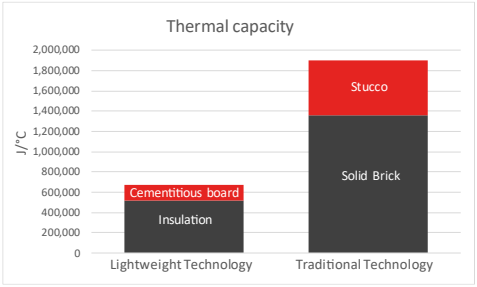


Fig. 4. Total thermal capacity (J/°C)

3.2 Impact of Facade Technologies on Urban Mean Radiant Temperatures.

Using the ENVI-met software, various thermal and optical facade configurations were simulated and their influence on the urban environment was quantified. Fig. 5 and 6 describe the MRT curves for the 8 analyzed scenarios.

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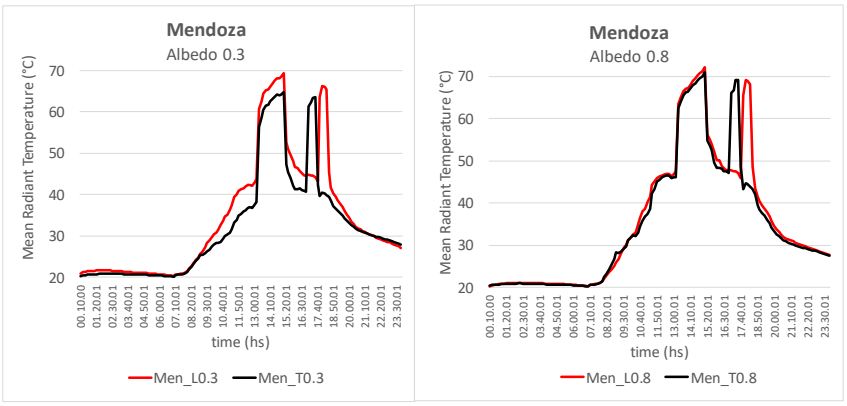


Fig. 5. Mendoza, Argentina. Mean radiant temperature curves for traditional (T) and lightweight (L) technology, according to optical property: 5.a. albedo: 0.30 and 5.b. albedo: 0.80. High 1.5m.

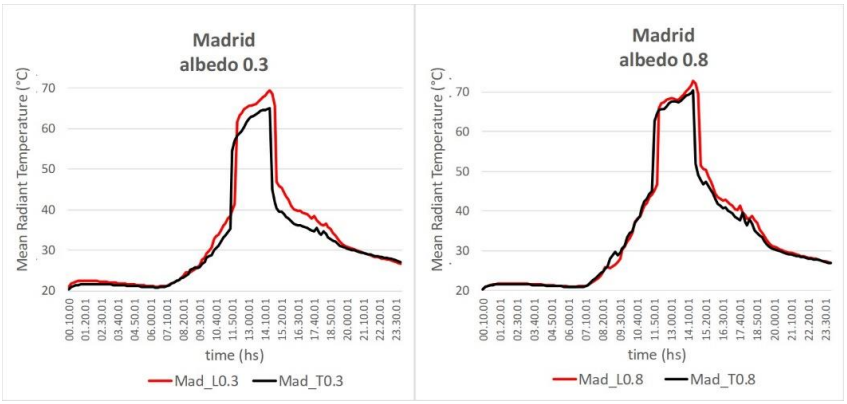
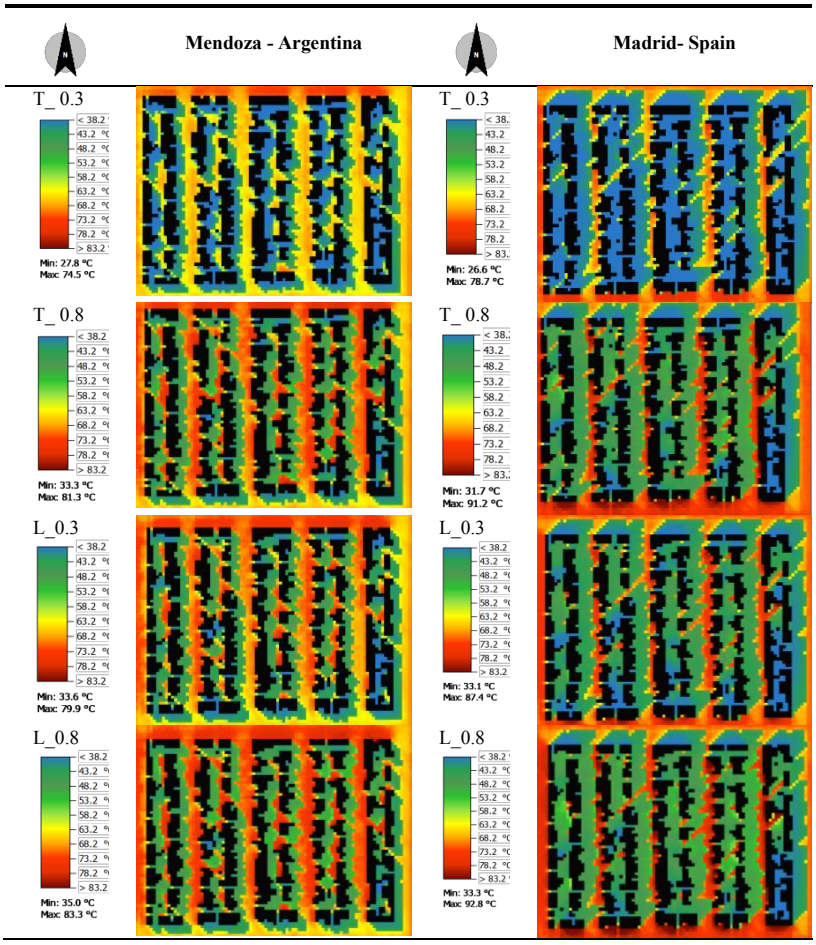


Fig. 6 Madrid, Spain. Mean radiant temperature curves for traditional (T) and lightweight (L) technology, according to optical property: 6.a. albedo: 0.30 and 6.b. albedo: 0. 80. High 1.5m.

Analysis by Albedo Level (0.3 vs. 0.8). A higher albedo value on facades at 30 meters height results in an increase in both maximum and average MRT for both technologies and cities. For example, in Mendoza, increasing the albedo of the facades to 0.8 raises the maximum MRT by 4.64°C for traditional technology and 2.85°C for lightweight technology. A similar pattern is observed in Madrid, with increases of 5.33°C and 3.25°C, respectively (Fig. 5 and 6 and Table 5).

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Table 5. Mean radiant temperature outputs rendered Leonardo´s of 8 scenarios analyzed, at 15:00 hs. (solar hours) and at pedestrian's heigh (1.5m).



Tables 6 and 7 provide the maximum mean radiant temperature (MRT) data for the cities of Mendoza and Madrid, considering different facade technologies (lightweight and traditional) and albedo values (0.3 and 0.8). The behaviors of facades are analyzed as follows:

Analysis by Technology (Traditional vs. Lightweight). Lightweight technology, being a system with a lower mass, responds more quickly to climatic variations, which can result in higher MRT compared to traditional technology. In Mendoza and Madrid, the maximum MRT differences observed were 4.46°C and 4.53°C, respectively. On the

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other hand, traditional technology, due to its greater mass, stores more heat and acts as a thermal buffer. However, this characteristic can lead to overheating, especially during the central hours of the day and under low albedo conditions (Fig. 5a and 6a and Table 5).

Analysis by Climatic Context (BWk vs. Csa). Both Mendoza and Madrid show similar trends regarding the influence of albedo level and technology on MRT. This is due to their similar climatic characteristics on the days of analysis (solar radiation intensity, temperature, and air humidity). Maximum MRT differences were recorded for traditional technology with albedo 0.8 (Diff = 0.8°C) (Fig. 5 and 6 and Table 5). However, the difference in solar altitude significantly affects shadow projections at the same solar hour (Table 5). With a solar altitude that is 12.5° lower than in Mendoza, Madrid experiences a larger shadow cone, which contributes to enhanced thermal comfort during peak hours.

Table 6. Maximum Mean Radiant Temperature (MRT) for Mendoza, Argentina. High 1.5m.

Max MRT	Lightweight Tech.	Traditional Tech.	**Technology Dif.**
â 0.3	69.3	64.9	**4.46**
â 0.8	72.2	69.5	**2.67**
Albedo Dif.	**2.85**	**4.64**	**-1.79**

Table 7. Maximum Mean Radiant Temperature (MRT) for Madrid, Spain. High 1.5m.

Max MRT	Lightweight Tech.	Traditional Tech.	**Technology Dif.**
â 0.3	69.5	65.0	**4.53**
â 0.8	72.8	70.3	**2.45**
Albedo Dif.	**3.25**	**5.33**	**-2.08**

4 CONCLUSIONS

This study delves into the effects on the microclimate associated not only with optical properties (albedo) but also with the mass and thermal properties of the materials that make up facade surfaces. Two facade technologies were compared: a lightweight one with a thickness of 12 cm and a traditional one with a thickness of 18 cm. Despite its smaller thickness, the lightweight technology exhibited lower thermal conductivity due to the presence of expanded polystyrene insulation. The traditional technology, on the other hand, showed higher conductivity, with a thermal capacity 2.6 times greater than the lightweight one. To analyze the simultaneous effect of thermal and optical properties, two levels of surface albedo (0.30 and 0.80) were included for each technology. This analysis allowed for the comparison of radiative performance within an urban setting in two climatic contexts (BWk and Csa).

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Differences were observed in the radiative behavior of each technology, highlighting their contribution to the generation of specific urban microclimates according to the following facade characteristics:

The materials comprising the traditional technology are characterized by higher thermal inertia, which better mitigates fluctuations in external temperature, providing a more stable environment for pedestrians. This is especially advantageous in cities with extreme climates like Mendoza and Madrid, where temperatures can vary significantly throughout the day. The difference in MRT between the lightweight and traditional technologies is considerable, indicating that the choice of technology has a significant impact on the radiative behavior of the street canyon. Maximum MRT differences of around 4.5°C were recorded in both cities.

On the other hand, the albedo level of facade surfaces plays a decisive role in the microclimate. The impact of albedo is conditioned by the morphological and climatic context. Although a higher albedo reduces solar heat absorption, its effect on MRT can be counterproductive in 10-level height scenarios, especially for traditional construction technologies. In this case, increases of around 5°C in MRT were observed in both studied cities when albedo was raised to 0.80.

Therefore, to improve thermal comfort in outdoor spaces, it is essential to consider the specific urban context and combine the use of albedo with other strategies such as shading, vegetation, and optimizing building orientation.

Although the trends are similar in both cities, there are slight differences in the magnitude of temperature variations. This suggests that other local local geographic (as latitude) and climatic factors may influence the thermal performance of facades. Future work will expand to an annual period, including different climatic contexts and scenarios with varying building configurations and heights.

Acknowledgments. The Authors wish to thank financial support from URBAN-TherCOM Project (Grant PID2020–114873RA-C33 funded by MCIN/AEI/10.13039/501100011033). The authors gratefully acknowledge the support of the National Agency for Scientific and Technological Promotion (ANPCyT) of Argentina in collaboration with CIEMAT (Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas) and CSIC (Consejo Superior de Investigación Centifica).

Conflict of Interest Statement. The authors declare that they have no competing interests relevant to the content of this article.

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ISBN 978-9930-617-71-7

Reliability, Availability, and Maintainability Analysis for Grid-Connected Solar Photovoltaic Systems

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Abstract. Photovoltaic solar technology is today economically competitive, modular, and with a low environmental impact. Solar power generation has contributed significantly to the growth of renewable sources of electricity worldwide. It is a priority to understand that the performance, control, and safety of this renewable energy source depends on technical disciplines such as reliability, availability, and maintainability, generating a trinomial of related variables that characterize the performance of Solar Photovoltaic Systems and have generated interest for researchers, manufacturers, installation providers, maintenance-calibration services, financial entities and government policies of environmental impact. Reliability, availability, and maintainability (RAM) are fields of engineering knowledge that are used to address operational and safety problems of systems. Its objective is to identify the weakest areas of a system where they will improve the overall reliability of the system and, consequently, availability and maintainability as complementary control activities in the maximum use of resources. In this document, a review of the original article on the RAM Analysis of a grid-connected solar photovoltaic system is presented. A data analysis approach is developed with Reliability Engineering tools that allow an adequate and reflective point of view for the operation, control, and improvement of the Solar Photovoltaic System.

Keywords: Availability; maintainability; reliability; photovoltaic system.

1 Introduction

Solar-photovoltaic (PV) systems have become one of the most significant contributors to global renewable electricity. In 2023, renewable electricity capacity additions reached an estimated 507 GW, a nearly 50% increase from 2022. This rapid growth was largely driven by China's expanding solar PV (+116%) and wind (+66%) markets. Solar PV and wind will account for 96% of renewable power capacity additions over the next five years, primarily due to their lower generation costs and supportive policies [2]. To ensure accurate photovoltaic energy production, a RAM (reliability, availability, and maintainability) assessment is critical for grid-connected solar PV system planning [3]. RAM analysis helps estimate system production effectiveness, identifying critical components that significantly impact overall system reliability. By predicting system behavior over time, it facilitates the development of well-timed maintenance plans. As such, RAM analysis plays a crucial role in the global development and economic viability of renewable energy systems [4].

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RAM analysis is critical for PV system planning and long-term operation but is limited by the lack of robust data and the complexity of these systems. Most existing studies focus only on the reliability of vulnerable subsystems like the inverter [5], PV module (PVM) [6-10], and balance of systems (BOS) [6], considering only failure information. As a repairable system, the repair interval, including fault detection and part replacement, must be considered in the solar PV system's operation. Few studies evaluate the reliability of the entire system, often using oversimplified assumptions, which can lead to discrepancies between simulated and real results [7]. Reliability modeling assumptions are established based on conditions and factors that affect performance and quality. They can be multivariate according to geographic location, environmental conditions such as temperature and relative humidity, photochemical reactions, stress, and strain levels of the same components due to their design and manufacturing nature. Mechanism-by-mechanism level comparison is required to build an effective overall reliability model to understand the operation of the PV system in terms of the actual performance and safety of each component. This remains of interest to researchers and stakeholders (manufacturers, suppliers, and stakeholders) requiring a significant amount of additional research.

This paper presents an analysis of performance indicators for solar photovoltaic (PV) systems, with a focus on metrics that ensure system longevity and prevent early failures. Solar PV systems, which convert sunlight into electricity, are composed of essential components such as solar panels, inverters, and supporting infrastructure, including cables, mounting structures, and sometimes batteries for energy storage. Recent studies, including prior analyses on reliability, availability, and maintainability, as in [7] have laid the groundwork for assessing these performance indicators. This paper builds on that foundation by examining the performance indicators used over the past five years, providing insights into their role in extending PV system lifespan and mitigating the risks of early failures.

1.1 Reliability-Availability-Maintainability Relationship approach

According to [11-14], RAM analysis focuses on large-scale grid-connected solar PV systems and is carried out using design reliability methods, conceptualization of system configuration, and event and failure analysis. For an adequate development of reliability work, a reliability block diagram (RBD) and fault tree analysis (FTA) must be considered in the system understanding stage. In FTA, the physical layout is interpreted into a logical diagram whereby each block represents a system component. Each block is described only by the failure rate. The reliability of the overall system is determined using the failure rates of each sub-assembly and thus every failure is very important. Commonly, failure rates are assumed constant. More recent work has introduced dynamic FTAs with failure rates described by time-dependent probability density functions. [8]. However, this approach does not rely on actual field values or the best probability density functions of each sub-assembly. It´s important to incorporate the metrics of Mean Time To Repair (MTTR) and Mean Time Between Failures (MTBF) to understand how the useful life cycle of the PV system behaves.

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Within the context of the failure data, it is essential to know its probabilistic behavior and treat it that way for RAM estimation [1]. [3] and [13]. The required input data are obtained from literature-based failure rates (see Table 2). Data quality is achieved through proper planning and implementation of measurement and traceability controls. The data in this paper were collected from several reliable research papers [1] and [10], the largest amounts of reliable data, failure, and repair rates as the J. Power Sources database [19].

The rest of the paper is organized as follows. Section 2 presents the configuration of the Solar PV system at the level of component details per subsystem and sub-assemblies. Section 3 presents the concepts and statistical tools foundations of reliability, availability, and maintainability, and the experiment planning and data collection plan for the BOS subsystems, photovoltaic modules, and inverters. Section 4 proposes a section of results and discussion, and Section 5 presents the conclusions that respond to the research question and objective posed.

2 Configuration of Solar-PV System

2.1 Grid-Connected Systems

In areas with extensive public grids, the energy storage costs for medium- to large-sized PV systems can be reduced by directly connecting such systems to the electricity grid using compatible inverters. The components available today allow for grid connection of installations with output amounting to upwards of 100 Wp [9].
The proposed model to be studied is presented in Figure 1 and shows the configuration design of the solar photovoltaic system connected to the grid. The grid connection is integrated for a photovoltaic module, an inverter, the BOS, and the utility grid.
In addition, the BOS (Balance of System), is part of the structures on which the modules are mounted and oriented as well as other elements necessary to build a photovoltaic (PV) system.

2.2 Detail of subassemblies by subsystem

Figure 1 shows the diagram of the photovoltaic system to be studied in this article, made up of three main components (subsystems) that are explained below.

- Balance of System (BOS): are all the subassemblies such as cables and peripheral components that make the connection of the subsystems possible, such as bypass diodes, DC and AC switches, differential, mains power outlet, connectors, and DC combiner.
- A Photovoltaic module, also known as a solar panel or solar plate, is a device that captures solar energy to start the sustainable energy process. The subsystem is composed of individual photovoltaic cells connected to each other. The subassemblies that make up this subsystem are solar cell, front glass, encapsulation, interconnection, solar junction, and junction box.
- Inverter: an electrical device that plays a fundamental role in renewable energy systems. Its main function is to convert direct current (DC) electricity, generated by the photovoltaic modules, into alternating current (AC) electricity. Its components are the IGPT module, DC link capacity, microcontroller, AC and DC contactors, cooling fans, and PCB.

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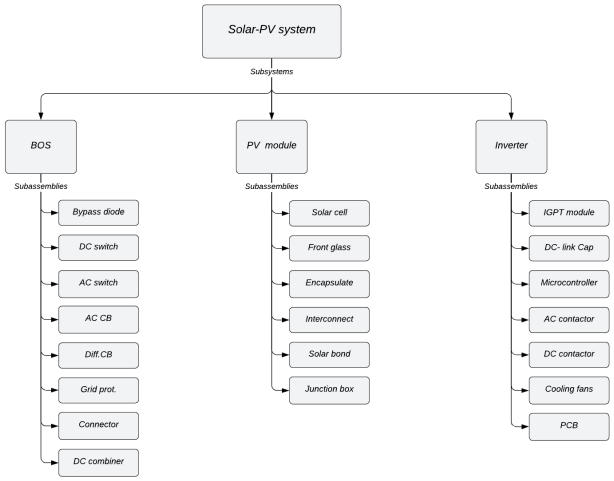


Figure 1. Detail of subassemblies by subsystem of Solar FV System.

This paper will focus only on the large-scale grid-connected solar-PV system with a grid that has low reliability.

3 Reliability-Availability-Maintainability Analysis

This section presents the concepts and statistical foundations of reliability, availability, and maintainability, which is the approach applied to this review article as an opportunity for improvement when conducting a study taking into consideration the RAM Analysis of a photovoltaic system in general. Figure 2 shows a diagram with the probability functions, metrics, and percentiles in reliability and the metrics related to availability and maintainability.

3.1 Reliability concepts, functions, and metrics

Reliability

In context, the Reliability R(t) of solar PV system components is the probability it will adequately perform its specified purpose for a period of time under specified environmental conditions. The probability of solar PV system components is the function of the configuration, subsystem, or even sub-assemblies is the proportion of times that system is expected to occur when the system is conducted repeatedly under identical conditions. Because it is a probability, reliability must always take on a value between 0 and 1.

Table 1 presents the reliability, availability, and maintainability statistics applied in this study and the analysis of the results obtained. The table is constructed by the statistic, description, mathematical equation, and equation number.

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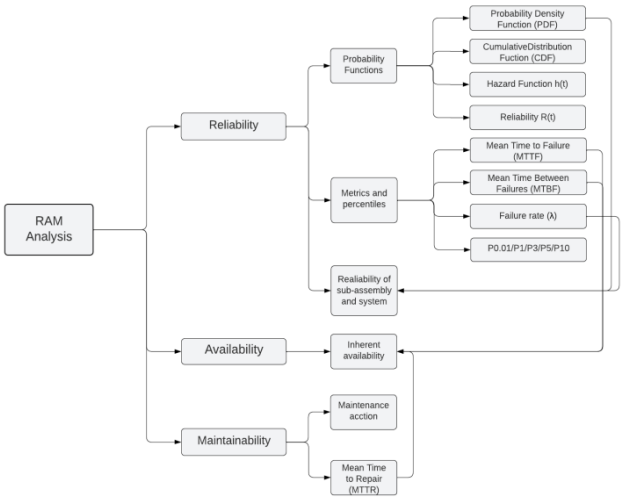


Figure 2. Fundamental components of RAM Analysis Diagram.

3.2 Availability

Availability is the probability that a system is operating satisfactorily at any moment in time when used under stated conditions. This measure considers an item´s reliability and maintainability. Another way to express this is the proportion of time a system is in a functioning condition. [10]. Table 1 shows the mathematical equation that allows its calculation.

3.3 Maintainability

Maintainability is the probability that a failed item will be repaired within a given amount of time once it has failed. Thus, maintainability is a function of time. It is necessary to have a confidence level, for example, 95%. In defining maintainability it is necessary to describe exactly what is included in the maintenance action. The following items are typical: diagnosis time, part procurement times, teardown time, rebuild time, and verification time. To understand the performance of maintainability about of metric the mean time to repair (MTTR) [10]. Table 1 shows the mathematical equation that allows its calculation.

3.4 Multivariate control charts

The multivariate control chart is a type of variable control chart that shows how correlated or dependent variables together influence a process or outcome. They are especially useful for understanding interactions. Minitab draws multivariate charts for up to four factors and displays the means for each factor at each of its levels. [11].

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3.5 Experiment planning and data collection plan

This section presents the scheme of the experiment proposed at the level of integrating elements by system-subsystem-subassemblies and the test method of 7 power systems in a range of 100 kW to 2500 kW, which we will define as test levels to which the system is subjected to estimate reliability based on its performance and behavior in two periods of 1 and 20 years. Figure 3 is the design for the development of RAM analysis.

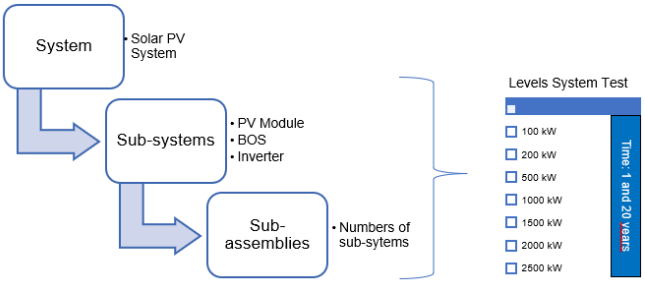


Figure 3. Design of Experiment for solar PV system.

Data collection plan

The data collection plan outlines the primary sources for statistical treatment, detailing information based on sub-assembly numbers, failure causes, and repairs for each PV system. Obtaining accurate failure and repair rates is a critical challenge in RAM analysis. To address this, large amounts of reliability data, including failure and repair rates, were collected from various literature sources, covering different technologies and layouts. The data were collected over varying scan times, and median values were calculated for each sub-assembly to reduce uncertainties, as noted in Table 2. To evaluate RAM results, seven large-scale grid-connected solar PV systems, with power outputs ranging from 100 kW to 2500 kW, were designed. The number of sub-assemblies increased with the system's power output, as listed in Table 3. More details on sub-assemblies and design methods are provided in [1]. Using the data from Tables 2 and 3, along with the RBD method, the failure and repair rates for each sub-assembly of the seven systems are shown in Tables 4 and 5.

3.6 Reliability Modelling

Reliability modeling is the second stage in RAM analysis. Several reliability methods have been discussed for RAM evaluations, with one of the most effective being the Reliability Block Diagram (RBD) for grid-connected solar-PV systems. In RBD, system components are represented by sequential or parallel blocks, linked based on their impact on the system. Each block is defined by the component's failure and repair rates. Figure 4 shows a grid-connected solar-PV system consisting of three subsystems arranged in series, meaning the system functions only when all subsystems are operational. The failure rate (λ_i) and repair rate (μ_i) of this system, as a whole, can be calculated by Equations (16) and (17).

$$\lambda_{Tot} = \sum_{i=1}^{n} \lambda_i. \quad (16)$$

$$\mu_{Tot} = \sum_{i=1}^{n} \lambda_i \; / \sum_{i=1}^{n} \frac{\lambda_i}{\mu_i} \quad (17)$$

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Table 1. Statistical techniques for the study of Solar PV systems.

Statistical	Description	Mathematical equation	Equation number
Probability Functions Reliability			
Probability density function f(t) or PDF	The probability density function (PDF), denoted f(t), is one of several functions that you can use to define a distribution. It indicates when a new item is likely to fail and, therefore, indicates the distribution of the failure over the entire time range.	$f(t)= \lambda * e^{-\lambda t}(t)$ where: f(t) is the Probability density function λ is the failure rate e is the exponential function	(1)
Cumulative distribution function F(t) or (CDF)	The cumulative distribution function (CDF), denoted F(t), is the probability that a unit fails at time t. It is interpreted as the called failure probability or unreliability and it is understood as the probability of the system's success, which can be given as shown in a mathematical equation. The estimation F(t) is the sum of all pdf * time intervals.	$F(t)= 1 - R(t)$ where: F(t) is the cumulative failure function. R(t) in the reliability in time t	(2)
Survival function S(t) or R(t)	The Survival function also known as the reliability function, or R(t) is the probability that an item survives beyond a particular time t. It is the area curve, f(t), to the right of t. Another way to denote reliability is:	$R(t)= 1 - \int_0^t f(t)dt$ $R(t)= 1 - F(T)$	(3) (4)
	Furthermore, the reliability and cumulative distribution function (CDF) can be expressed with the density function f(t) as shown in the mathematical equation.	$R(t)= \int_t^{\infty} f(t)dt$ $F(t)= \int_{-\infty}^t f(t)dt$	(5) (6)
Hazard Function h(t)	The hazard function, denoted h(t): is the probability of failure in the next small time interval given that it survived at time t. Also known as failure rate (instantaneous). The hazard function is a measure of the likelihood of failure as a function of age. It is unique for each distribution and the importance it is to understand the behavior of the failure reason to identify if the system is in a decreasing, increasing, or constant state.	$h(t)= \frac{f(t)}{1- \int_0^t f(t)\,dt}= \frac{f(t)}{R(t)}$ where: h(t) is hazard function	(7)
Metrics			
Mean time to failure (MTTF)	Mean time to failure, denoted (MTTF) is the average useful life of a subsystem or sub-assemblies in a system. It is a common metric used to evaluate different items in a system. The mean time to failure (MTTF) for the sub-assembly, which expresses the expected life for the sub-assembly, represents the most common method for specifying the reliability of non-repairable items. Another way to calculate is the following:	$MTTF = \int_0^{\infty} t * f(t)dt = \int_0^{\infty} R(t)dt.$ $MTTF = \frac{\sum t}{n}$ where: t´s are failure times n is the total of failure times	(8) (9)
Mean Time Between Failures (MTBF)	Mean Time Between Failures (MTBF) is used to describe the performance of a system and measure the mean time between failures for repairable items. The general formula for the situation where a number of reparable items are tested for a given amount of time, with failed items being promptly replaced. Another way to calculate is the following:	$MTBF = \frac{nm}{r}$ where: n = number the items m = number of times in the test r = number of failures $MTBF= \frac{1}{\lambda}$	(10) (11)
Failure rate (λ)	The failure rate, denoted (λ) is the reciprocal of the mean life. Failure rate is usually denoted by the letter for the Greek letter lambda (λ), so, it can be calculated as shown in a mathematical equation.	$\lambda = \frac{1}{MTBF}$	(12) (13)

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		or $\lambda = \frac{1}{MTTF}$	
Availability			
Availability (A)	Availability, denoted (A) is the probability that a system is operating satisfactorily at any moment in time when used under stated conditions. $A = \frac{Total\ time\ a\ functional\ unit\ is\ capable\ of\ being\ used\ during\ a\ given\ interval}{The\ length\ of\ the\ interval}$ If the item is reparable and needs no preventive maintenance, and if the repair can begin immediately then failure occurs, availability can be defined as shown in a mathematical equation.	$A = \frac{MTBF}{MTBF + MTTR}$ This availability type is known as inherent availability.	(14)
Maintainability			
Maintainability (M)	Maintainability denoted (A) is the probability that a failed item will be repaired within a given amount of time once it has failed.	$MTTR = \frac{\sum tr}{n}$	(15)

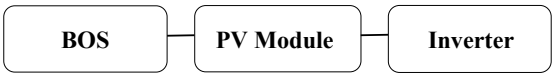


Figure 4. Simple Reliability Block Diagram of Grid-Connected solar PV system.

Sub-assembly and System Reliability

The Solar-PV Systems are complex and contain a large number of sub-assemblies that may be connected in series, in parallel, or even a combination of series and parallel. When the sub-assemblies are connected in series, the overall system will be interrupted in case of failure of one sub-assembly. On the other hand, all subassemblies must fail in order to interrupt the overall system in the parallel system.

According to equations 18 and 19 show the Boolean techniques, the reliability performance for a repairable system containing an independent series n subassembly can be calculated by:

$$R_{System} = \prod_{i=1}^{n} R_{i}, \quad (18)$$

Where Ri is the reliability of the sub-assembly i.

For an exponential distribution, the total sub-assembly reliability becomes:

$$R_{SubAssembly,Tot} = e^{(-\sum_{i=1}^{n} m_i \lambda_I t)} \quad (19)$$

Where, m_i is the total number of the sub-assembly i, and λ_i is the failure rate of sub-assembly i.

If the system contains x series units with M parallel subassemblies, as you can see the equation 20, the system reliability can be obtained using:

$$R_{System} = 1 - (1-R^x)^M \quad (20)$$

Overview analysis

The Weibull distribution is the most commonly used distribution for analyzing reliability data. It is an extremely flexible distribution that can model many situations. For the general analysis of the Weibull distribution, its estimation, and parameters, the following equations 20 and 21 are used. Where beta parameter is the shape parameter, η is the scale parameter, α is the significant level and t is the estimate time.

Beta parameter:

$$\beta = \frac{\ln[-\ln(1-F(t))]}{\ln(t/\alpha)} \quad (20)$$

Eta parameter:

$$\eta = \frac{t}{[-\ln(1-F(t))]^{1/\beta}} \quad (21)$$

Data Sources: failure and repair rates for various sub-assemblies of Solar-PV Systems

This section presents the main data sources for statistical treatment, where the details of the documented information collected are based on the criteria of sub-assembly numbers, failure, and repair rates for each solar PV system.

Table 2. Failure and repair rates for various subassemblies of solar-PV systems [1].

Subassembly	Failure rate, λ, (10-6 failures yr^-1)	Repair rate, μ, (yr^-1)
PV modules	26,000	NA
	3,2000	0,0667
	4,6000	0,0057
	0,0150	0,0037
	0,0150	0,0037
	1,4000	NA
	0,0046	0,025
	24,000	0,0039
	NA	0,0083
Converter	5,9000	NA
	8,1000	0,13
	27,000	0,1
	0,4600	0,025
Bypass diode	5,4000	0,1667
	0,3100	0,0208
	0,3100	0,0208
	3,5000	NA
	0,6800	NA
	0,3100	0,0208
DC switch	0,2000	0,0208
	0,2000	0,0207
	0,7000	NA
	0,2000	0,0208
AC switch	0,0340	0,0208
	0,0340	0,0207
	0,7000	NA
	0,0340	0,0208

Table 3. Number of subassemblies for each PV system [12].

Power (kW)	100	200	500	1000	1500	2000	2500
PV modules	437	874	2166	4351	6517	8702	10868
Converter	3	6	15	27	42	57	72
Bypass diode	23	46	114	229	343	458	572
DC Switch	3	6	15	27	42	57	72
AC Switch	1	1	1	1	1	1	1
AC circuit breaker	1	2	5	9	14	19	24
Differencial circuit breaker	1	1	1	1	1	1	1
Grid protection	1	1	1	1	1	1	1
Connector (Coupler)	874	1748	4332	8702	13034	17404	21736
Inverter	1	2	5	9	14	19	24

Table 4. Subsystem failure rate (yr^{-1}). [13]

Subsystem/ Power (KW)	100	200	500	1000	1500	2000	2500
BOS	0,07812	0,12069	0,24739	0,44065	0,65250	0,86534	1,07718
PV modules	0,02061	0,04122	0,10214	0,20518	0,30733	0,41037	0,51251
Inverter	0,12500	0,25000	0,62500	1,12500	1,75000	2,37499	2,99999

Table 5. Subsystem repair rate (yr^{-1}). [13]

Subsystem/Power (kW)	100	200	500	1000	1500	2000	2500
BOS	64,5320	64,5320	64,5320	64,5320	64,5320	64,5320	64,5320
PV modules	11,6964	11,6964	11,6964	11,6964	11,6964	11,6964	11,6964
Inverter	12,6547	12,6547	12,6547	12,6547	12,6547	12,6547	12,6547

4 RAM results and discussions

4.1 Failure rate analysis

This section presents the details of the failure reason analysis with the purpose of understanding how frequently and at what time the subsystem and system in general fail. The event chart of failure rate is a graphical tool that shows the time intervals and frequencies of failures. Figure 5

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presents an event chart that visually compares failure reasons across subsystems. The PV Modules subsystem has the lowest failure frequency, with failures closely grouped between 0.02061 and 0.51251 years. The Inverter subsystem shows the largest amplitude, with failure frequencies spaced out between 0.125 and 2.9999 years. The BOS subsystem has a more uniform failure frequency between 0.07812 and 1.07718 years. This analysis helps identify which subsystem has the longest intervals and failure frequencies.

4.2 Reliability Overall Analysis

As shown in Figure 2, the overall reliability analysis is based on the estimation of the four functions of the probability density function (PDF), cumulative failure function (CDF), survival function (R(t)), and hazard function (h(t)). Table 6 presents the reliability results for the BOS, PV Modules, and Inverter subsystems for 1 and 20 years of comparison periods. The reliability analysis compares two periods (1 and 20 years) for systems ranging from 100 kW to 2500 kW. The 100 kW BOS subsystem has a reliability of 92.48% in the first year, which drops to 20.96% by year 20. Similarly, PV Modules show a decline from 97.96% to 66.22%, while the Inverter drops from 88.85% to 8.20%. All three subsystems show a decrease in reliability over time, and as the power system's capacity (kW) increases, reliability further decreases. Notably, the inverter has the lowest reliability and is likely to fail first. Figure 6 shows the behavior of reliability in the first year, with the PV Modules subsystem having the highest reliability at 97.96% and the Inverter subsystem having the lowest reliability at 88.85%. Over the 20-year period, reliability remains the same for the PV Modules and Inverter with 66.22% and 8.21% respectively. Likewise, for the other test systems, reliability decreases as the power level increases. Figure 6, which shows the 20-year period, shows how reliability decreases more rapidly as the power level of the systems increases from 100 kW to 2500 kW.

Table 6. Summary of Subsystems and System Reliability for the Solar PV System about power levels and time conditions (in %).

Conditions	Power Levels (kW)	100		200		500		1000		1500		2000		2500	
	Time (years)	1	20	1	20	1	20	1	20	1	20	1	20	1	20
Subsystem	BOS	92,48560	20,96440	88,63120	8,94822	78,08340	0,70987	64,36160	0,01488	52,07440	0,00022	42,09080	0,00000	34,05530	0,00000
	PV modules	97,96030	66,22180	95,96220	43,85320	90,28990	12,96540	81,44970	1,65116	73,54090	0,21408	66,34050	0,02726	59,89880	0,00353
	Inverter	88,84970	8,20855	77,88010	0,67380	53,52620	0,00037	32,46530	0,00000	17,37750	0,00000	9,30150	0,00000	4,97874	0,00000
System	Total Reliability	80,49709	1,13959	66,23893	0,02644	37,73673	0,00000	17,01907	0,00000	6,65488	0,00000	2,59728	0,00000	1,01560	0,00000

A relevant analysis compares subsystems using multivariate analysis, showing how each subsystem behaves relative to power levels (kW), as illustrated in Figure 7. The multivariate chart for 1-year reliability shows that the inverter subsystem has the lowest performance compared to the BOS and PV Modules, with an interaction average of 40.62%. In the 20-year period, the inverter again shows the lowest interaction average, with only 1.27% reliability, confirming that the inverter subsystem is the one most likely to fail first. Some studies classify the PV inverter as just another sub-assembly within the BOS [14], while most current research focuses on inverter reliability estimates and improvements [22-26].

This study, however, separates the BOS and inverter subsystems. The inverter's reliability decreases to 0.7858 after 2 years and 0.2996 after 10 years. The BOS subsystem has a reliability of 0.5942 after 10 years and 0.2098 after 30 years. The MTTF (Mean Time to Failure) for the inverter and BOS are 8.3 and 19.21 years, respectively. The lower MTTF for the inverter is mainly due to its complexity and the electronic components that are more affected by stress factors. As a result, the inverter's lifespan is much shorter than the typical solar PV system's predicted lifetime of 20–25 years.

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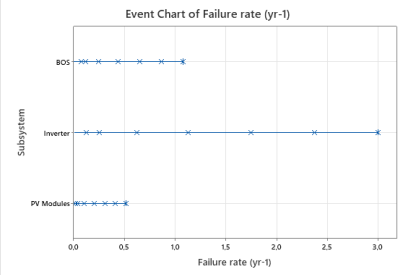


Figure 5. Event chart of failure rate.

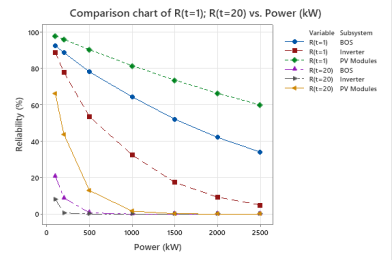
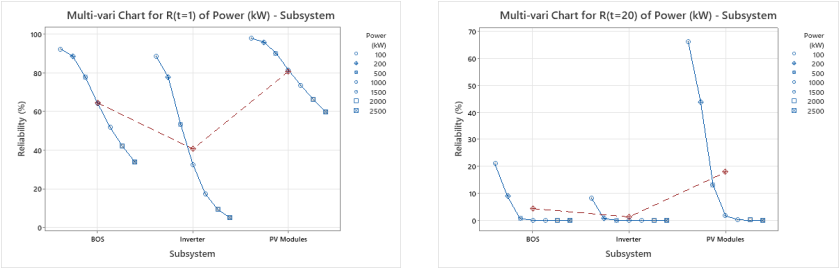


Figure 6. Impact of operational failure of a subsystem for a period of one and twenty years of operations.



(a) (b)

Figure 7. Multi-variable chart of comparison reliability performance subsystems of Solar PV Systems (a) for a period of one year and (b) for a period of 20 years.

Total reliability

An important contribution of the analysis is estimating the total reliability of each test system over time, which helps identify practical reliability performance and propose preventive measures to maintain solar PV system operation. The total reliability was estimated using equation (18) and is presented in Table 6. Figure 9 illustrates the total reliability behavior of each test system from 100 kW to 2500 kW. The results from the 1-year and 20-year test periods confirm that reliability decreases as power increases, with 1-year reliability dropping from 80.50% to 1%. For the 20-year period, reliability ranges from 1.13% (at 100 kW) to 0% (at 500 kW), with the inverter subsystem reaching 0% reliability, indicating system failure. A preliminary conclusion is that by the end of the 20-year period, the photovoltaic system will almost certainly have failed, as shown in the dotted line graph of this period.

4.3 Availability

Availability is a fundamental characteristic of understanding the operation of a system. Table 7 presents the availability results by subsystem according to the power level (kW) of the test system. The availability of the BOS, PV modules, and Inverter subsystems decreases as the PV power increases, this is better visualized in Figure 10 where the decreasing trend is evident. The above is consistent with the reliability analysis presented in the previous section. Another important aspect is that the inverter subsystem

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is the one that decreases most rapidly in availability with respect to the other two subsystems.

Table 7. Availability of Subsystems vs. Power (kW) Systems Test (in %).

Subsystem/Power (kW)	100	200	500	1000	1500	2000	2500
BOS	99,8791	99,8133	99,6181	99,3218	98,999	98,6768	98,3582
PV modules	99,8241	99,6489	99,1343	98,2760	97,4397	96,6104	95,8021
Inverter	99,0219	98,0627	95,2936	91,8359	87,8512	84,198	80,8365

Availability as an integrating variable of performance as a key success indicator of a Solar PV System is, according to equation (17), a function of the failure (λi) and repair rates (μi), where this relationship has a linear dependence between the failure and repair reasons that directly affects the condition that the subsystems and the system, in general, are in adequate operating and control conditions at the time "t" and that maintainability management is effective. The maintainability is discussed in greater detail in the following section.

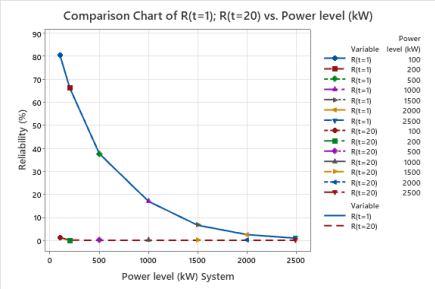


Figure 9. Comparison Chart of Reliability per 1 and 20 years vs power level system test.

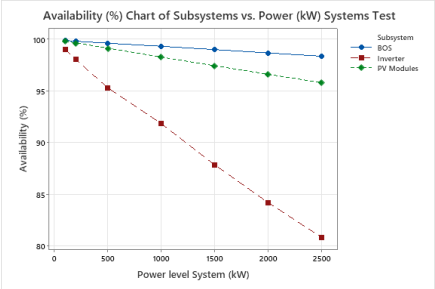


Figure 10. Availability Chart of Subsystems vs. Power (kW) Systems Test (in %).

4.4 Maintainability

Maintainability is the third fundamental variable in the performance of a system in general. In our context, together with reliability and availability, they create the perfect trinomial to understand the solar FV system. The challenge of this article is to get the message across. As mentioned in section 3.1, maintainability is the probability of repair in a specific period of time. Table 5 presents the repair rates of the BOS, PV Modules, and Inverter subsystems across different test power levels. It shows that repair times remain constant from 100 kW to 2500 kW, helping to predict subsystem behavior over time and improve maintenance management. Figure 13 illustrates subsystem behavior, with PV Modules having the lowest repair rate (11.6964 years) and BOS the highest (64.532 years), while the Inverter repair rate is 12.6547 years, just 1 year longer than PV Modules. Figure 12 illustrates the relationship between maintainability, reliability, and availability.

Mean Time Between Failures (MTBF) is calculated using equation (11), where the failure rate determines the maintenance interval. Table 8 and Figure 14 show that the MTBF decreases as power levels increase. The Inverter subsystem requires the earliest maintenance, from 8 years at 100 kW to 0.3333 years at 2500 kW. The BOS

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subsystem follows with 12.80 years at 100 kW to 0.9283 years at 2500 kW, and PV Modules last the longest, from 48.52 years at 100 kW to 1.9512 years at 2500 kW. The MTBF results highlight trends over time, showing how successive failures behave inconsistently across power systems. The MTBF metric is crucial for planning and scheduling maintenance actions to prevent failures and ensure system availability, as illustrated in Figure 14. It also aids in estimating replacement times for subsystems.

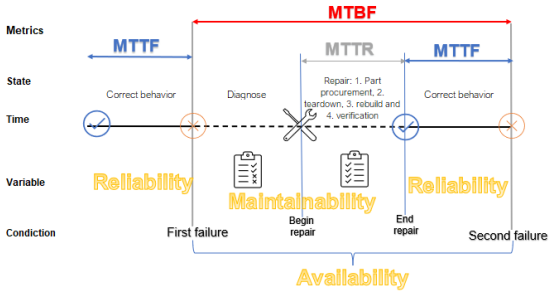


Figure 12. Relational Diagram of RAM vs Metrics.

Table 8. MTBF Subsytem vs. Power level Systems (yr-1).

Subsystem/Power (kW)	100	200	500	1000	1500	2000	2500
BOS	12,80082	8,28569	4,04220	2,26937	1,53257	1,15562	0,92835
PV modules	48,52014	24,26007	9,79048	4,87377	3,25383	2,43683	1,95118
Inverter	8,00000	4,00000	1,60000	0,88889	0,57143	0,42105	0,33333

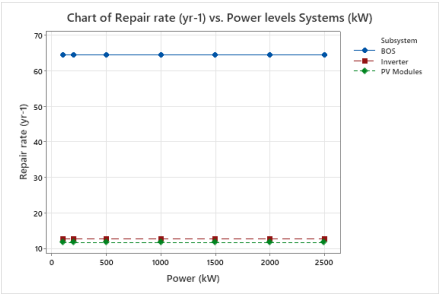


Figure 13. Chart of subsystem´s repair rate of Solar FV System.

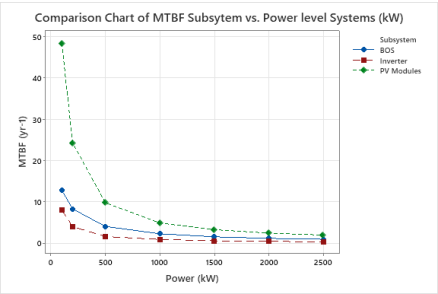


Figure 14. Comparison Chart of MTBF Subsytem vs. Power Level Systems (kW).

5 Conclusions

The RAM Analysis study of seven practical designs for a grid-connected Solar PV System is developed. The failure and repair rates databases are taken from the literature. Each stage of reliability, availability, and maintainability analysis is structured and delimited, emphasizing its estimation and relationship based on the performance of three subsystems that make up the general system. In the reliability analysis through the comparative approach of the cluster by subsystem and the power level (kW) system

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of test in relation to the periods of 1 and 20 years, it is evident that the three subsystems BOS, PV module, and Inverter are the most reliable and available in both time scenarios of comparison and the inverter subsystem has the lowest reliability both in 1 year and in 20 years, therefore the inverter subsystem is the component that will fail first. In maintainability, the MTTR remains constant, however, the MTBF of BOS, PV Module, and Inverter subsystems decreases as the test power level increases.

Acknowledgments. All authors for supervising and approving the paper for publication. This article is part of a research strengthening activity project on Reliability in Solar PV Systems, CF#1351030.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

Nomenclature

AC	Alternating current electricity	PVM	PV module
BOS	Balance of systems	RAM	Reliability, availability, and maintaina-
CDF	Cumulative distribution function	bility	
DC	Convert direct current electricity	RBD	Reliability block diagram
FTA	Fault Tree Analysis	R(t)	reliability function
MTTF	Mean time to fail	λ	failure rate
MTTR	Mean time to repair	μ	repair rate
MTBF	Mean Time Between Failures	β	shape parameter
PDF	Probability density function	η	scale parameter

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ISBN 978-9930-617-71-7

STRATEGY AGAINST ENERGY POVERTY: ANALYSIS OF THE VENTILATION POTENTIAL OF A GROUND-AIR HEAT EXCHANGER

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Abstract. Using passive systems is a viable strategy to condition living spaces and contribute to improving air quality. In this study, CFD methodology was used to conduct a numerical analysis of the thermal performance of the ground-air heat exchanger (EAHE). A numerical model was developed, which consists of a two-dimensional system in a permanent state, whose dominant mechanisms are convection inside the fluid transport tube and conduction in the ground. The variation of the velocities was considered in terms of a critical Reynolds number, that is, in transition from a laminar to turbulent flow (Re = 4000). A warm climate representative of the Mexican Republic was chosen. The analysis consisted of varying the depth of the EAHE from 5 m to 10 m with increases of 5 m until reaching 50 m. The numerical results of the heat exchanger showed that the best performance for both heating and cooling occurred after a tube length of 35 m, since the subsequent changes were not considerable. On the other hand, after a depth of 4 m, the changes are also insignificant.

Keywords: Ground-air heat exchanger, Thermal comfort, Ventilation, CFD, Energy Poverty.

1. Introduction

The international scientific community has developed alternative strategies to achieve thermal comfort in buildings, as part of environmental well-being. These strategies reduce energy consumption and the high generation of pollutants. These alternatives encompass a range of topics, from substituting traditional construction materials, to bioclimatic design and passive design in buildings.

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There is a critical issue with the current methods of conditioning the interior of buildings, which often require mechanical heating and cooling systems (air conditioning). This reliance is the main contributor to the energy crisis in the residential sector. Therefore, it is imperative to propose and implement viable alternatives to ensure comfortable living conditions in homes.

Passive design is an alternative for reducing residential energy demand, because it includes methods used in architecture to achieve environmental conditioning, through renewable natural resources. The elements considered to achieve this goal are: the sun, breezes, winds and the properties of construction materials, and their orientation. In this sense, passive design seeks to minimize mechanical air conditioning systems use, through procedures such as thermal inertia.

In passive systems, there is the Canadian tube or earth-air heat exchanger. The function of this system is to cool or heat a flow of air supplied to a building through the thermal inertia of the earth. Thermal inertia is the property that indicates the amount of heat that a body can store and the speed with which it gives it off or absorbs it. Due to its properties, the soil has a lower temperature than the environment at a certain depth in warm seasons. In the same way, it has a higher temperature in cold seasons.

Various studies have been carried out on the thermal behavior of ground-air heat exchangers, which can be classified as: experimental studies, theoretical studies, analytical studies and numerical studies. In the latter, the studies are carried out by developing mathematical models or by developing commercial programming code or software. Below are some studies in the literature that use a passive system similar to the one used in this research.

[1] A study on an air-to-ground heat exchanger with a continuous operation has been performed during the hottest month in Yaoundé. It identifies cooling and heating periods according to the local range of thermal comfort and calculates duct lengths for 70% efficiency for various speeds of the air inlet. The ground temperature readings utilized in the analytical model range from 20.8 °C to 23.4 °C at 5 meters depth; therefore, duct lengths should be kept between 44.3 and 48.7m to achieve 70% efficiency depending on the air speed (0.5–1.5m/s). [2] This research, proposed a renewable energy system that combines a solar chimney, photovoltaic panels, and an earth-air heat exchanger (SC-PV-EAHE). An analytical and numerical methods was used to ensure natural ventilation, thermal comfort and electricity production. The system's effectiveness was assessed under hot and cold temperate climate conditions with calculations based on summer weather data for Baghdad and Tehran. The results indicated that this system could meet cooling requirements between 116 W and 1500 W. [3] Earth Air Tunnel Heat Exchanger (EATHE) systems are relatively unknown in India due to limited ground space. This study compared the thermal performance of a newly designed helical EATHE system with a conventional U-shaped one for summer and winter. The validation model using similar configurations was developed and validated. The study showed that the helical system performs better with less ground space. [4] This explored

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numerically an integrated cooling arrangement comprising of an earth-to-air heat exchanger (EAHE) and a domed roof implemented to satisfy a building's cooling needs. The system can deliver thermal comfort in a test room with 1000 W cooling demand employing three 35 m pipes effectively without utilizing any electricity when simulated using ANSYS FLUENT and MATLAB, with experimental validation performed. [5] This research examines the changing thermal behavior of inner room air using an Earth Air Heat Exchanger (EAHE) under the influence of sunspot movement during the heating season. A numerical model for simulating time dependent temperature distribution and position of sun spots was developed in Fluent (CFD).

Numerical simulations indicated that sunspots increased floor surface temperatures by 6.85 °C, thus implying that their energy contribution outweighed that made by EAHE on sunny days. [6] This research aims to analyze the thermal performance of an Earth-Air Heat Exchanger (EAHE) to reduce ventilation energy consumption and achieve thermal comfort. Simulations showed that the optimal depth is 6 meters, while effective pipe length increases along with an increase in air velocity and diameter. If pipe-to-pipe spacing exceeds 3 meters, multi-pipe EAHE behaves like a single-pipe EAHE. [7] This study showed that when the duct lengthens from 0 to 100 meters, the temperature of the outgoing air reduces from 34 .5 ºC to 24 .0 ºC while performing in cooling mode. Hence a minimum tube length of 40 meters should be used in this area. Though some factors like drops in air pressure, humidity, and geometry were not taken into account, this method remains capable of optimizing the thermal efficiency of the system. [8] This research examines two passive technologies for obtaining thermal comfort in a room subject to extreme desert conditions. CA rectangular earth-air heat exchanger supplies cooled air with phase change material (REAHE + PCM), while PCM in the ceiling (room + PCM) reduces thermal load and delays the peak in temperature. The results showed that adding PCM toin the roof could reduce the peak heat fluxes up to 33%, with the best configuration keeping the indoor temperature 0.6 K below comfortable levels. [9] This review addresses latest trends in EATHE design, the role of surface modifications and numerous designing factors. EATHE systems have achieved great energy savings and can operate alone or even hybridize with traditional HVAC systems, leading to possible reductions in greenhouse gas emissions. [10] This numerical study optimizes geometric parameters for better Ground_ to_ Air Tunnel Heat Exchanger (GATHE) performance using ANSYS Fluent, validated with experimental and analytical data. Three soil types with thermal conductivities of 0.65, 1.25, and 3.50 W/mK were analyzed, finding a critical soil thickness ten times the pipe diameter. The lowest outlet temperature, 300.1 K, was achieved with a 60 m pipe and the highest conductivity soil. [11] The coupled solar chimney with an earth-to-air heat exchanger system passively improves indoor air quality and temperature without electricity or carbon emissions. Results showed that pipe diameter and length are more crucial for airflow and thermal regulation than chimney height or solar collector length. The system maintained stable indoor temperatures, reducing average summer temperatures by 4.4°C and increasing winter temperatures by 6.4°C, with the buried pipe outlet temperature ranging from 12.8 ºC–26.5 °C. [12] This paper introduces an inverse approach to optimize EAHE parameters for achieving year-round indoor thermal comfort. Computational

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Fluid Dynamics simulations confirmed that this approach effectively ensures year-round thermal comfort. [13] This study explores an innovative integrated solar-geothermal system combining a photovoltaic-thermal system, ground heat exchanger, and liquid desiccant system to meet the electricity, hot water, and heating/cooling needs of a residential building in a hot, humid urban area. The system provides around 2500 hours of passive cooling via the ground heat exchanger and reduces building energy consumption by 32%, with an overall efficiency of 45%. [14] This research addresses the impact of backfilling on heat and mass transfer in an Earth-Air Heat Exchanger (EAHE) system for deep underground emergency ventilation.

An advanced numerical model, validated with field data, shows that backfilling can significantly improve the thermal performance of EAHE systems, potentially doubling efficiency. [15] The simulation of earth-air exchangers (EAHE) showed that they could be used as a heat exchange medium with a volume of 12 m^3 and a heat transfer surface area of 24.4 m^2 at best. The EAHE cooling capacity ranged between 1,002 and 1,282 watts depending on soil condition. [16] The climate hot periods in dry areas were used in combination with earth air heat exchangers (EAHE). The effective heating and cooling capacities of EAHE were calculated using the current model from which optimum operating hours for different months were derived. Results indicated that on the coldest day, EAHE increased temperature inside greenhouses by eight °C while on hottest days, it lowered their temperatures by around 21 °C. [17] This study described an experimental study of an EAHE in a warm, humid climate of Mexico. The EAHE used a horizontal configuration consisting of horizontal 6m long pipe, and two 3m long vertical segments for outlet and inlet sections. Monitoring for 6 months for the temperature of the soil at depths from 0 to 2.5 m in intervals of 0.25 m, as well as air temperature at the inlet and outlet, was recorded. The maximum energy extracted by EAHE as a cooling effect was about 4.438 kWh for August month only.

The bibliographic review, establishes the ground air ventilation system as a functional system to regulate temperatures inside the building. Each study is unique due to the operating conditions, which is why this study will shed more light on this topic.

2. Physical Model and Mathematical Model

For the study, the design parameters implemented by Rodriguez-Vazquez [18] were taken into consideration, which consists of a system whose dimensions are a depth of 2 m [19-20], a pipe length of 5 m, a PVC pipe with a diameter of 0.15 m and a speed with a Reynolds number value of 1500. The study also considers that the soil surrounding the pipe is mainly made up of limestone (caliza), since it is the predominant type of soil in Xalapa, Veracruz, and has a thickness on the east, west, and south borders of 1 m. This design was named the base design, presented in Figure 1, and its data in Table 1.

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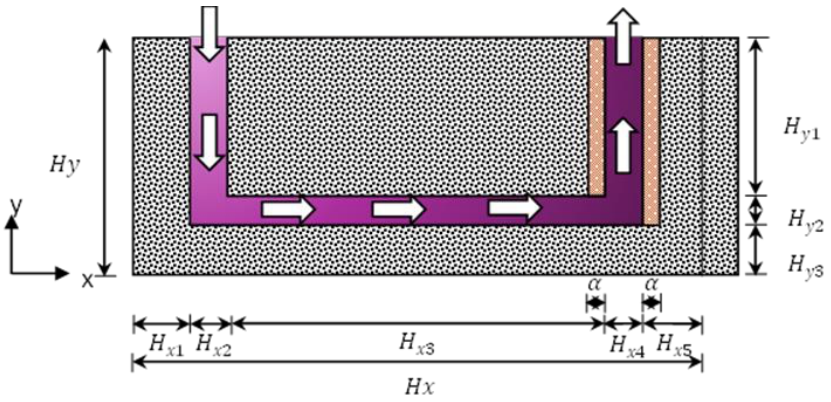


Figure 1. Physics Model of the EAHE.

Table 1. Dimensions of the any section of the EAHE.

Section	Symbol	Dimension
Pipe diameter	Hy_2, Hx_2, Hx_4	0.15 m
Depth from the ground surface to the pipe.	Hy_3	2 m
Thickness of soil after horizontal pipe	Hy_1	1 m
Depth	Hy	3.15 m
Thickness of soil around vertical pipe	Hx_1, Hx_5	0.5 m
Tube length	Hx_3	5 m
Thickness of insulating material	α	0.05 m
Length	Hx	6.30 m

The mathematical model considers a two-dimensional heat transfer model where the conduction phenomenon with constant properties dominates the heat transfer from the ground surface to the pipe wall. In contrast, convection predominates inside the pipe in a laminar regime. The thermo-physical properties are constant and independent of temperature. The model neglects the thickness of the pipe between the ground surrounding the pipe and the air inside the pipe because the thickness is too small to generate a significant impact. The model also neglects the evaporation and condensation inside. In the case of the pipe surface, the model considers evaporation from the ground, convection-conduction of heat through the ground, and radiation emitted and absorbed from the ground. Figure 2 shows the occurring phenomena.

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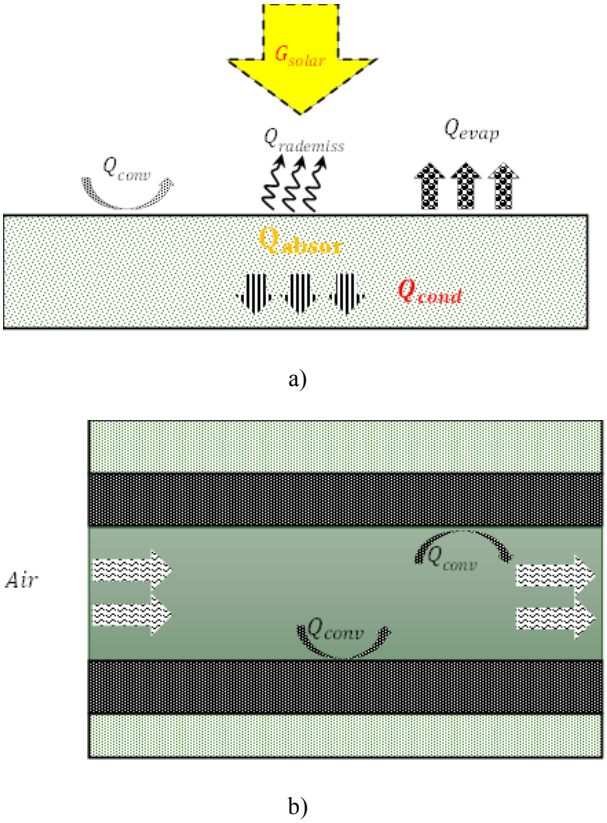


Figure 2. Thermal Effects: a) Surface of the pipe e b) Inside the pipe.

Three conservation governing equations govern the mathematical model of the system, which are adapted based on the considerations raised in the physical model. Table 2 presents the governing equations. Table 3 shows various formulations implemented for the study, which were used for the boundary conditions on the soil surface in modeling the EAHE.

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Table 2. EAHE Governing Equations.

Name	Equations
Mass	$\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}=0$
Momentum in x	$\frac{\partial(\rho u.u)}{\partial x}+\frac{\partial(\rho u.v)}{\partial y}=\frac{\partial}{\partial x}\left(\mu\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}\right)-\frac{\partial P}{\partial x}$
Momentum in y	$\frac{\partial(\rho v.u)}{\partial x}+\frac{\partial(\rho v.v)}{\partial y}=\frac{\partial}{\partial x}\left(\mu\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial v}{\partial y}\right)-\frac{\partial P}{\partial y}$
Energy	$\frac{\partial(\rho vT)}{\partial x}+\frac{\partial(\rho vT)}{\partial y}=\frac{\partial}{\partial x}\left(\Gamma\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\Gamma\frac{\partial T}{\partial y}\right)$

Table 3. EAHE Governing Equations.

Name	**Equations**
East	$\frac{\partial T}{\partial y}=0 \quad in \quad x=0 \qquad to \quad 0\le y\le Hy$
West	$\frac{\partial T}{\partial y}=0 \quad in \quad x=Hx \quad to \quad 0\le y\le Hy$
South	$\frac{\partial T}{\partial x}=0 \quad in \quad y=0 \qquad to \quad 0\le x\le Hx$
North	$-q_{cond}=-q_{conv}(CE)+q_{rad}(LR)-\alpha G(SR)+q_{evap}(LE)$ $q_{conv}=h_{sur}(T_{amb}-T_{Sur})$ $h_{Sur}=5.678\left[0.775+0.35\left(\frac{vel_{wind}}{0.304}\right)\right]$ para $vel_{wind}<4.88$ $h_{Sur}=5.678\left[0.775+0.35\left(\frac{vel_{wind}}{0.304}\right)^{0.78}\right]$ para $vel_{wind}\ge 4.88$ $SR=\alpha G$ $LR=\varepsilon\Delta R$ $E=0.0168fh_{Sur}[(aT_{Sur}+b)-HR(aT_{amb}+b)]$

The study considers the air entering the EAHE and the ambient air to have the same temperature and supplied at a constant speed, its mathematical models are as follows.:

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$v = f(Re)u = 0$ supplied air flow

$\frac{\partial T}{\partial y} = 0, \frac{\partial u}{\partial y} = 0$ y $\frac{\partial v}{\partial y} = 0$ Outgoing airflow

Another consideration makes the system a fluid-filled cavity, where the properties are assigned according to the node positions with respect to the physical model. Also, a blocking technique is implemented for the nodes corresponding to the soil zone to cancel the hydrodynamic effect, leaving only the heat transfer by conduction.

3.- Solution Methodology

The Finite Volume Method was implemented to discretize the partial differential equation governing the phenomena and solve the mathematical model. The method's first step is developing a computational domain that contains control volumes to solve the discretized equations.

In this sense, the discretization allows the integration of the partial differential equation in the control volume to obtain a system of algebraic equations called the grouped coefficient equation. After the discretization, an interpolation scheme must be applied to treat the convective terms. A coupling method for the velocity and pressure variables is necessary in the final process. In this study, the Simplec algorithm was employed. The Line Gauss-Seidel- Alternating Direction Implicit method for solving algebraic equations was used for the solution of the algebraic equations system.

4.- Results of the Thermal performance of EAHE

The EAHE performance was analyzed by modifying five design parameters separately: tube length, depth, and airspeed, considering the meteorological data of the city of Xalapa, Veracruz. After finding the optimal value for each parameter, these values were implemented in the proposed system of this study, and its thermal performance was compared against the reference system. The parametric study was considered when the highest and lowest temperatures occur on the hottest and coldest days of the year, respectively. The following section shows the results of this analysis considering wind speed based on a Reynolds number of Re=4000.

The temperature at the outlet of the EAHE was analysed when the tube was at different depths, with intervals of 0.2 m between them, up to a depth of 5 m. The results of the study results showed that, in both cases, there was a beneficial effect on the air outlet compared to the inlet, with an increase in temperature in the cold season and a decrease in the warm season. However, the effect ceased to be insignificant after 4 m.

For the analysis of the pipe length, the separation distance between the system's inlet and outlet was increased in 5 m increments until it reached 50 m.

Figure 3 describes the study results, showing that the increase in the pipe length has a benefit in the cold season, with an increase of 10% compared to the original design.

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However, this increase is no longer significant after 35 m. On the other hand, the increase in the pipe length in the warm season is beneficial only between 10 and 15 m in length, obtaining a temperature 3% lower than that of the base design, since after this distance, the temperature increases again until reaching a more significant increase compared to the original design. Therefore, a distance of 35 m was selected as the ideal length since the benefit is more significant in the cold than the harm in the warm season.

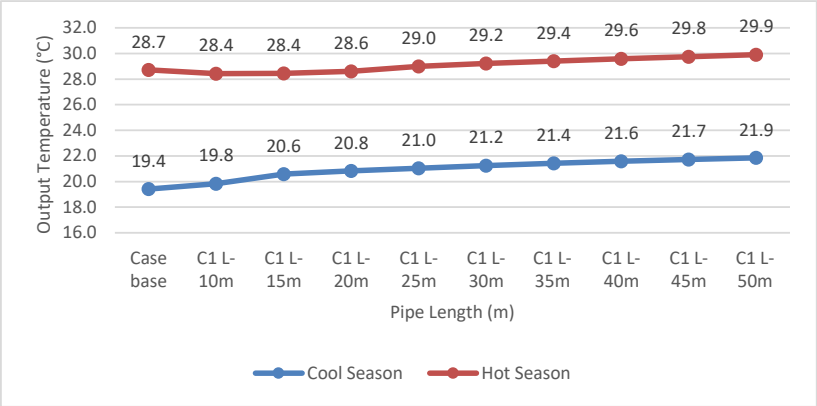


Figure 3. EAHE air outlet temperature at different tube lengths for the climatic conditions of Xalapa, Veracruz.

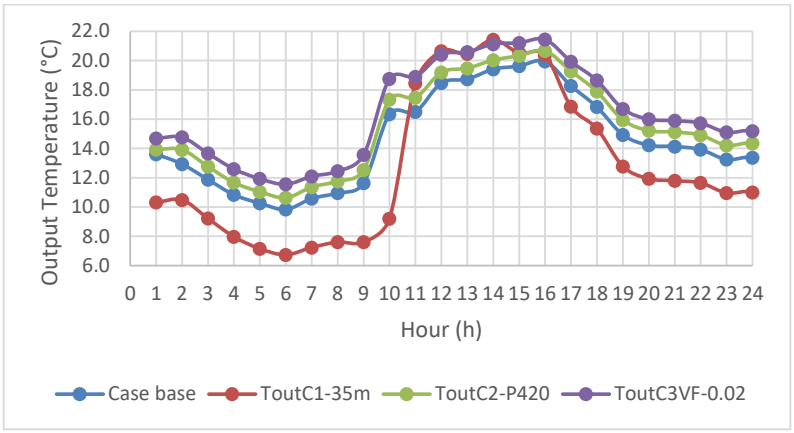
4.1 Thermal performance analysis with respect to tube length

Once the design parameters that best benefit the temperature difference at the EAHE outlet were established using a critical hour, a complete evaluation of the warmest and coldest day of the year was carried out for the three models. The modeling results showed that, during the first and last hours of the cold day, the greatest temperature increase above the base design was obtained with a Reynolds number value of 4000 (ToutC3-VF0.02), with a temperature increase of up to 17% at 5 am. In contrast, the model with a pipe length of 35 m (ToutC1-35m) presents thermal performance similar to the base design between 11:00 and 14:00 hours.

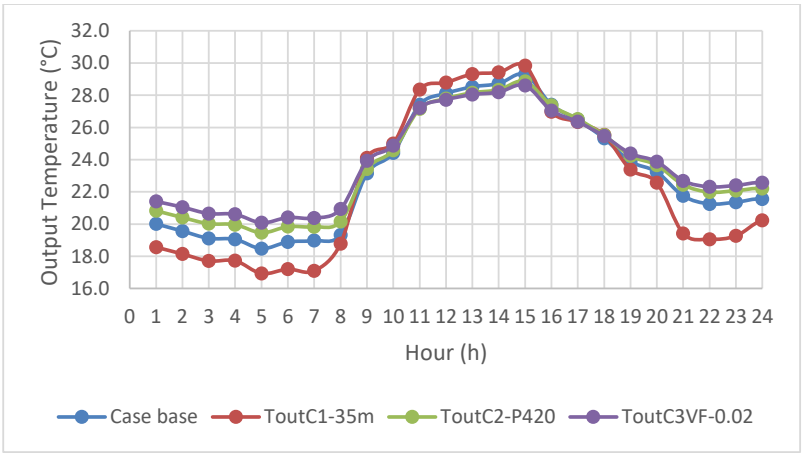
Figure 4 presents the thermal performance on the hottest day. The graph shows that the ToutC1-35m model shows a decrease in temperature of up to 11% concerning the base design during the first and last hours of the day, while the ToutC2-P420 and ToutC3-VF0.02 models showed a better cooling capacity for the base design between 11:00 and 15:00 h, with an increase in cooling capacity of more than 2%.

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a)



b)

Figure 4. Thermal performance of the EAHE over the course of the day for each optimal parameter found: a) Coldest day and b) Warmest day.

Based on the above results, the best parameter to increase the air temperature at the EAHE outlet is low air velocities through the pipe, while the best parameter to decrease the temperature at the EAHE outlet is to increase the pipe length. With these results, it is possible to achieve an automatic control that allows the air velocity to be modified depending on the air temperature and take advantage of the additional pipe path to

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improve heat transfer between the soil and the pipe. Table 4 presents the geometric data of the new design.

Table 4. Geometric data of the new design.

Section	Symbol	Base design	New design
Diameter of the pipe	H_{x2}, H_{x4}, H_{y2}	0.15 m	0.15 m
Depth of burial	H_{y1}	2 m	4.2 m
Thickness of the soil after the horizontal pipe	H_{y3}	1 m	1 m
Thickness of the soil surrounding the vertical pipes	H_{x1}, H_{x5}	0.5 m	0.5 m
Length of the horizontal pipe	H_{x3}	5 m	35 m
Thickness of the thermal insulation	α	0.05 m	0.05 m
Total length	$\boldsymbol{Hx}$	**6.30 m**	**40.3 m**
Total depth	$\boldsymbol{Hy}$	**3.15 m**	**5.35 m**

5.- Conclusions

In a parametric study, there is a wide variety of parameters to consider, each affecting the performance of the EAHE in a different way, where, for certain conditions, they can improve the system's efficiency without significantly harming the performance under the opposite meteorological conditions. In the case of the parameters studied in this work, a better performance was obtained for cold seasons, presenting the following conclusions:

- By increasing the pipe length and air speed, an increase of about 12 and 17% respectively is obtained compared to the base design in the heating capacity of the air leaving the system.
- After two meters depth, significant changes in air temperature are low compared to those obtained with the length and air speed, about 8%

Despite the good performance obtained by the new design parameters, future will need to analyze the effect of a change in the soil substrate surrounding the tube with different thermophysical properties, as well as the effect of different humidity levels on the air entering the system and the benefit of the air leaving the system in a room.

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ISBN 978-9930-617-71-7

Sustainable management of urban solid waste in smart cities for energy generation and carbon credits

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Abstract. The accelerated urban growth in Latin America poses significant challenges in managing municipal solid waste (MSW), affecting environmental sustainability and the quality of life of communities. This work explores the intersection between smart cities and the circular economy as a transformative approach to address these challenges. The amount of MSW disposed in a landfill is calculated by taking the population of the metropolitan area of Cuernavaca, Mexico, as a reference. It is considered the landfill has the capacity to capture and reuse landfill gas (LFG) to generate electric power and obtain carbon credits. The LandGEM software, developed by the US EPA, is used to estimate the annual amount of LFG in the landfill. This work proposes two approaches to manage the LFG generated in the landfill: simply flaring it in an industrial flare and using it to produce electric power in a gas engine. These approaches result in a significant reduction in greenhouse gas emissions, with the first approach observing a 76% reduction, and the second approach achieving an 89% reduction. The financial benefits are also substantial, with the first approach reaching a total of US$ 26 400 000 in carbon credits, and the second approach increasing this amount to US$ 32 000 000. Finally, an analysis of the impact of sustainable management of landfills in smart cities is made concerning the Sustainable Development Goals of the United Nations 2030 Agenda.

Keywords: Circular economy, landfill, greenhouse gases emissions, renewable energy, carbon certificates, Sustainable Development Goals.

1 Introduction

As urban populations grow, integrating smart cities and circular economy principles represents a transformative approach to urban sustainability, addressing challenges such as resource scarcity, waste management, and environmental conservation. In particular, the collection, management, and disposal of municipal solid waste (MSW)

ISBN 978-9930-617-71-7

represents an economic, social, and environmental challenge for Latin American populations and an opportunity to apply smart cities and circular economy principles to achieve a sustainable society.

Cities face significant challenges in waste management, including limited collection capacity, diversity of waste types, and insufficient disposal points. That is why, to optimize the collection and disposal of urban solid waste, various applications of Internet of Things (IoT) technology have been proposed, such as sensors to monitor the level of filling and degree of toxicity of waste so that, through this information, collection routes are established every day and significant environmental problems can be avoided [1-2]. By optimizing garbage truck routes, the number of unnecessary trips is reduced, which decreases fuel consumption and carbon emissions since a reduction of up to 32% in the distance traveled by garbage trucks has been reported. This approach not only improves operational efficiency but also contributes to environmental sustainability.

It is also important to establish the relationship between landfills and waste management in the context of smart cities since a large proportion of MSW is destined for open-air dumps and gradually for landfills. However, their use poses severe environmental challenges, such as soil, water, and air contamination. In soil and water, this is mainly caused by poor design and lack of care of leachates that originate naturally from waste degradation and in the air by methane and carbon dioxide emissions originating from the decomposition of organic matter contained in waste. In this context, the circular economy is presented as an approach that seeks to close the life cycle of products, promoting reuse, recycling, and resource recovery [3]. Currently, landfills face criticism in various places due to their environmental impact, so the relationship between landfills and smart cities becomes relevant since the latter seek to integrate advanced technologies to improve the efficiency and sustainability of urban services. However, the transition towards more sustainable waste management faces several challenges, including the lack of adequate infrastructure, the shortage of financing, and the need for training in waste management, so other scopes of the smart cities concept can offer innovative solutions, such as the use of waste treatment technologies that convert waste into energy [4-5]. Thus, an area of great interest in the context of sustainability and circular economy is the capture and use of landfill gas (LFG) generated in landfills for the reduction of greenhouse gases (GHG's) and the possibility of generating electric energy, which aligns with one of the goals of smart cities, which seek to improve the quality of life of citizens through sustainability and technological innovation, as documented in Italy in the Regional Energy Plan of Emilia-Romagna [6]. This activity is part of the European Union's objectives of reaching 32% of energy from renewable sources by 2030 as part of its strategy to mitigate climate change and promote the energy transition by using waste from industrial activities for the generation of goods and services as established by the circular economy [7].

This manuscript analyses the reduction of GHG emissions that would be achieved in the metropolitan area of Cuernavaca, Mexico, by the proper disposal of MSW in landfills that can capture and use LFG for the generation of electricity for own use and/or shared with industries or communities established in the surroundings of the landfill. A life time of the landfill of 10 years is considered, and the project's duration for generating carbon credits is 21 years, as conventionally stipulated in this type of

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project. The installation of this project would contribute to economic, social, environmental, and energy sustainability, which is part of the principles of smart cities and the circular economy. Also, it contributes substantially to meeting various Sustainable Development Goals (SDG) of the United Nations 2030 Agenda for Sustainable Development, which seeks to eradicate poverty, protect the planet, and guarantee peace and prosperity for all.

2 Methodology

The estimation of GHG emissions was carried out using the Landfill Gas Emissions Model (LandGEM), developed by the United States Environmental Protection Agency (US EPA), which is basically an Excel spreadsheet that, based on established parameters (for example, quantity of urban solid waste, years of operation of the landfill, environmental conditions, etc.), calculates the GHG emissions produced in a landfill in a specific time [8].

LandGEM is based on the following first-order equation to quantify emissions from waste decomposition in landfills:

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k \cdot L_0 \left(\frac{M_i}{10}\right) e^{-kt_{ij}} \quad (1)$$

Where:

Q_{CH4}: Annual methane generation in the calculation year (m^3/year)

I: First year of increase

n = (year of calculation) – (initial year where MSW is received)

j = 0.1: increase in year

k: methane generation rate (year)

L_0 = Potential methane generating capacity (m^3/Mg)

M_j = MSW mass accepted in one year (Mg)

t_{ij} = Age of the MSW that was accepted in the year x

The methane generation rate (k) determines the quantity of methane generated per unit mass of MSW deposited in the landfill. Its value depends on the waste's moisture content, the nutrients available to the microorganisms that convert it into methane, the waste's pH, and the average ambient temperature. The default value assigned by the US EPA for conventional landfills is 0.05.

The potential methane generation capacity, L_0, depends only on the type and composition of the MSW placed in the landfill; for example, a high cellulose content in the waste increases its value. The default value assigned by the US EPA for conventional landfills is 170.

Once methane has been generated in the landfill, two alternatives exist for reducing emissions. In the first, methane is simply burned in a conventional flare and converted

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into CO_2, which reduces global GHG emissions because the global warming potential of CO_2 is 27 times lower than that of methane.

In a second alternative, methane is used as fuel in an internal combustion engine; in this way, methane is transformed into CO_2 and generates electrical energy. Due to this, the reduction in emissions increases for each MJ of electrical energy produced since, according to the emission factor of the National Electric System, 121.667 g of CO_2 is emitted for each MJ of electrical energy produced.

3 Results and Discussion

3.1 Analysis of MSW generation over the life time of the landfill

For the calculations of GHG emission reductions, the MSW generated by the Cuernavaca, Morelos metropolitan area population is taken as a reference. However, to perform the calculation, it is necessary to know the number of inhabitants that will exist during the life time of the landfill and the amount of MSW generated per capita. According to the information shown in Fig. 1, it is observed that in 2024, there will be 1 140 000 inhabitants, and the trend shown since the year 2000 indicates an average growth rate of 1.47% [9]. With this, it is possible to predict the number of inhabitants during the years of life time of the landfill.

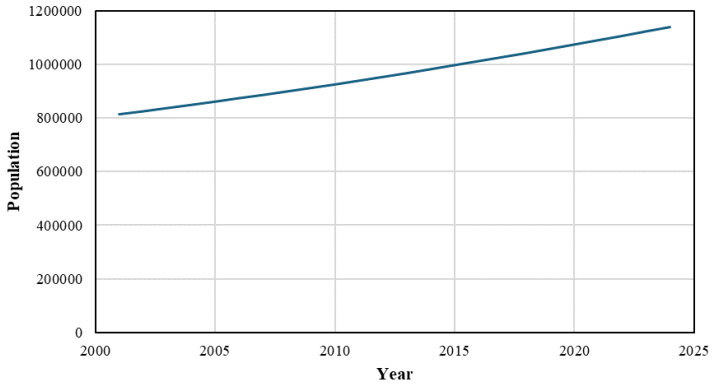


Fig. 1. Inhabitants in the metropolitan area of Cuernavaca, Mexico in the period (2001-2024). **Source:** Authors with information in [9].

On the other hand, it is necessary to know the per capita generation of MSW by the inhabitants of the Cuernavaca, Morelos metropolitan area, which is 0.8832 kg/inhabitant per day [10].

Considering a life time of the landfill of 10 years, which is the time it will be receiving MSW, the projected accumulated amount of waste due to population growth is shown in Table 1.

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Table 1. MSW generated during the life time of the landfill. **Source:** Authors.

Year	Population	MSW (Mg/year)
2024	1 140 000	362 465
2025	1 156 758	367 793
2026	1 173 762	373 200
2027	1 191 017	378 686
2028	1 208 525	384 252
2029	1 226 290	389 901
2030	1 244 316	395 632
2031	1 262 608	401 448
2032	1 281 168	407 349
2033	1 300 001	413 338

3.2 Estimation of methane generated in the landfill during the life of the project

Annual MSW quantities are entered into LandGEM software to estimate the LFG generated by its natural decomposition. This LFG is composed of approximately 50% methane, the remainder mainly CO_2, and minor gases. Considering a project lifetime of 21 years, with MSW deposited during the 10 years of its life time, the amount of methane generated is shown in Fig. 2.

3.3 Estimation of project baseline emissions

The GHG emissions produced in the landfill without any corrective action are estimated considering the methane annually generated and its global warming potential, which, according to IPCC Sixth Assessment Report, 2020 (AR6), is 27.0 when its origin is not fossil [11]. In this way, the annual GHG emissions in the landfill due to methane in the project's life are calculated using the following equation:

$$E_{GHG,baseline} = \dot{W}_{methane} \cdot WGP_{methane} \quad (2)$$

Where:

$E_{methane,baseline}$: Annual GHG emissions due to methane (Mg_{CO2eq})

$\dot{W}_{methane}$: methane generated annually in the landfill (Mg/year)

$WGP_{methane}$: global warming potential of methane (27.0 Mg_{CO2eq}/Mg_{CH4})

The baseline annual emissions over the life of the project are shown in Figure 3a.

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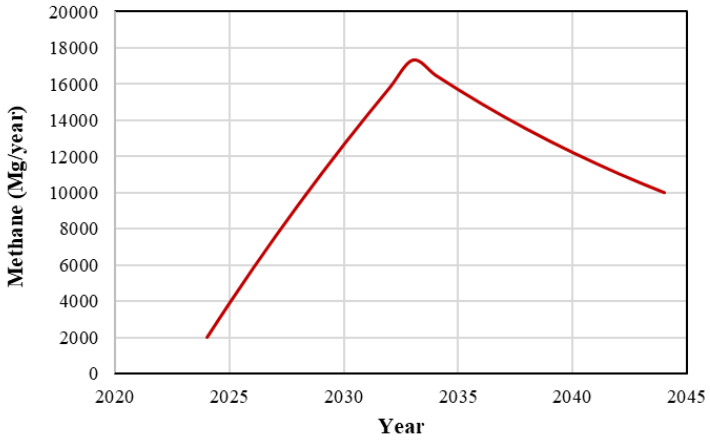


Fig. 2. Methane generated in the landfill in the period (2024-2044). **Source:** Authors

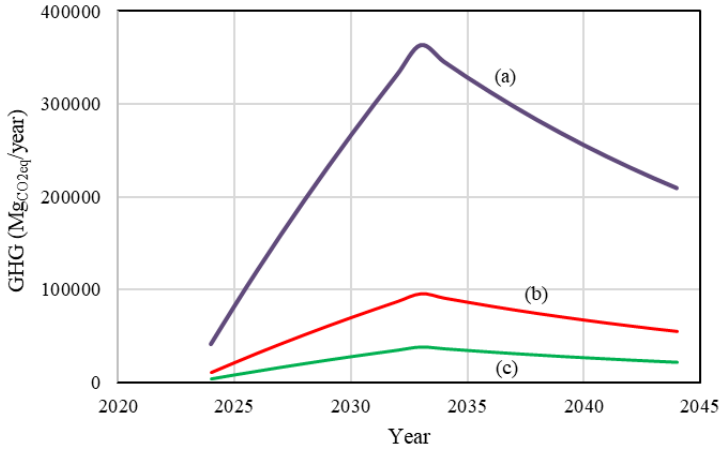


Fig. 3. GHG emissions from project activities. (a) Baseline without any action at the landfill. (b) Methane capture and flaring in industrial flares. (b) Methane capture and power generation in a Gas Engine. **Source:** Authors

3.4 Calculation of GHG's emission reductions from methane flaring in industrial flares

In the first approach to reduce GHG's emissions, methane is captured and flared in a conventional flare, such as the one designed and widely used by the German company

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Aqualimpia Engineering, shown in Fig. 4. Conventionally, this flare has a flaring efficiency of 85% [12].

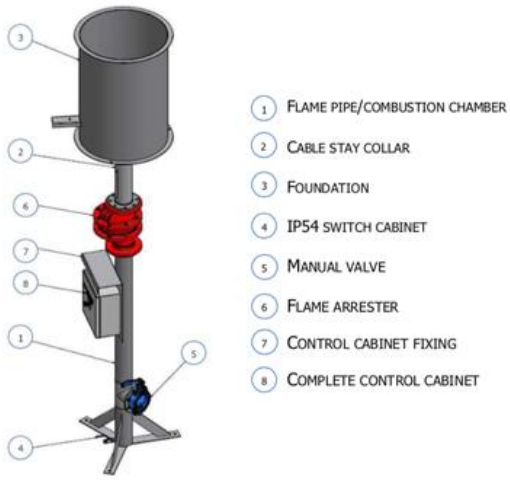


Fig. 4. Biogas flare from Aqualimpia Engineering e.K. **Source:** [12]

Thus, the methane flow is divided into 2 parts: flared methane and unflared methane, which are obtained from the following equations:

$$\dot{W}_{flared\ methane} = \eta \cdot \dot{W}_{methane} \tag{3}$$

$$\dot{W}_{unflared\ methane} = (1 - \eta_{flare})\dot{W}_{methane} \tag{4}$$

The GHG's emissions due to each of the above quantities, and the total of this approach are calculated as:

$$E_{flared\ methane} = \dot{W}_{flared\ methane} \times \frac{M_{CO_2}}{M_{CH_4}} \tag{5}$$

$$E_{unflared\ methane} = (\dot{W}_{unflared\ methane})(WGP_{methane}) \tag{6}$$

$$E_{GHG,total} = E_{flared\ methane} + E_{unflared\ methane} \tag{7}$$

Where M_{CO_2} is the carbon dioxide molar mass (44), y M_{CH_4} the methane molar mass (16).

The annual emissions of the project with methane capture and flaring are shown in Figure 6b. It can be observed that there is a reduction of GHG's emissions of 76%.

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3.5 Estimation of GHG's emission reductions from electricity generation

The methane captured in the landfill can be used to generate electricity through various devices such as internal combustion engines, microturbines, gas turbines, and fuel cells. Each has its advantages over the others, and the choice depends mainly on the quantity and quality of the biogas generated in the landfill. The electricity generated with biogas can be for personal consumption and partially cover the needs of nearby industries and/or populations in a kind of industrial symbiosis under the principles of the circular economy.

In the present study, the Gas Engine TCG 2020 from Caterpillar Energy Solutions GmbH, shown in Fig. 5, is taken as a reference for the generation of electrical energy, which can reach an average electrical efficiency of 42% with a methane burning efficiency of 87% according to its technical specification [13].

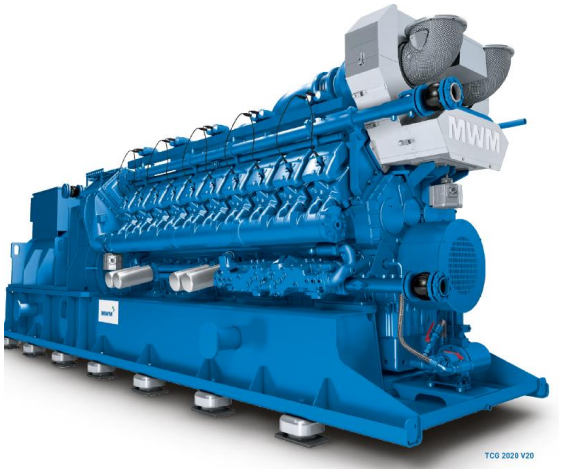


Fig. 5. Caterpillar Energy Solutions GmbH, "Gas Engine TCG 2020," MWM. **Source:** [13]

To calculate GHG emissions using this approach, the methane burned in the gas engine and the methane that is not burned are calculated according to the following equations:

$$\dot{W}_{burn\ methane} = \eta_{GE} \cdot \dot{W}_{methane} \tag{8}$$

$$\dot{W}_{unburn\ methane} = (1 - \eta_{GE})\dot{W}_{methane} \tag{9}$$

$$E_{burn\ methane} = \dot{W}_{burn\ methane} \times \frac{M_{CO_2}}{M_{CH_4}} \tag{10}$$

$$E_{unburn\ methane} = \dot{W}_{unburn\ methane} \cdot WGP_{methane} \tag{11}$$

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The electrical energy generated in the gas engine is calculated with the methane produced in the landfill, the electrical efficiency of the gas engine, and the heating power of the methane (55 500 MJ/Mg):

$$EE = \dot{W}_{methane} \cdot HP_{methane} \cdot \eta_{electrical} \quad (12)$$

The electrical energy generated by the landfill's LFG is no longer produced somewhere in the National Electric System, thereby achieving a reduction in emissions in said system, which is calculated considering its emission factor. According to the Mexican Ministry of Energy, the emission factor of the National Electric System in 2024 is 0.438 tCO_2e / MWh (0.000121667 $MgCO_2$/MJ). Thus, the emissions reduced in the National Electric System are:

$$RE = EE \cdot 0.000121667\ Mg_{CO_2}/MJ \quad (13)$$

Finally, the emissions generated under this approach are:

$$E_{GHG,total,EE} = E_{burn\ methane} + E_{unburn\ methane} - RE \quad (14)$$

The annual emissions of the project with methane capture and electricity generation are shown in Figure 3c. It can be observed that there is a reduction in GHG emissions of 89%.

3.6 Estimation of Carbon Credits generated over the life of the project

The execution of the project can generate carbon certificates; however, the price of these certificates is variable and depends on various factors such as geographic location and type of project. One carbon certificate is equivalent to the reduction of 1 $MgCO_{2eq}$. This range of values is between US$ 3 – 167, and a substantial increase is expected in the coming years [14].

Projects related to the capture and use of LFG, as well as projects established in Mexico range between US$ 4 – 10, so for the purposes of this work an average of US 7 can be taken [15].

The carbon certificates that would be obtained by the execution of the 2 scopes are presented in Table 2.

Table 2. Carbon certificates generated during the life time of the landfill. **Source:** Authors.

Year	Flared methane	Electrical energy generation
2024	US$ 217 005	US$ 263 064
2025	US$ 426 616	US$ 517 165
2026	US$ 629 242	US$ 762 797
2027	US$ 825 270	US$ 1 000 432
2028	US$ 1 015 070	US$ 1 230 517
2029	US$ 1 198 995	US$ 1 453 480
2030	US$ 1 377 382	US$ 1 669 729
2031	US$ 1 550 550	US$ 1 879 652
2032	US$ 1 718 806	US$ 2 083 620

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2033	US$ 1 882 441	US$ 2 281 986
2034	US$ 1 790 633	US$ 2 170 692
2035	US$ 1 703 303	US$ 2 064 826
2036	US$ 1 620 232	US$ 1 964 123
2037	US$ 1 541 212	US$ 1 868 332
2038	US$ 1 466 046	US$ 1 777 212
2039	US$ 1 394 546	US$ 1 690 537
2040	US$ 1 326 534	US$ 1 608 088
2041	US$ 1 261 838	US$ 1 529 661
2042	US$ 1 200 297	US$ 1 455 058
2043	US$ 1 141 758	US$ 1 384 094
2044	US$ 1 086 074	US$ 1 316 591
Total	US$ 26 373 859	US$ 31 971 663

3.7 Impact of sustainable management and use of landfill resources on the Sustainable Development Goals of the United Nations 2030 Agenda

The role of smart city and circular economy principles in achieving the United Nations 2030 Agenda is significant, particularly in the sustainable management of landfills. These principles have been identified as having a profound impact on various Goals of the United Nations 2030 Agenda, as listed below:

SDG 3: Good Health and Well-being. The public health of nearby communities is directly impacted by the inadequate management of MSW, leading to air and water pollution. Therefore, the installation of landfills that operate under strict regulations, controlled by IoT and sustainable practices, is not just important, but essential to guarantee the well-being of the population.

SDG 6: Clean Water and Sanitation. The installation and operation of sanitary landfills must consider protecting water resources. Poorly managed landfills contaminate nearby water sources, affecting public health and access to clean water. Therefore, the design must include waterproofing and leachate treatment systems to protect water resources and guarantee access to clean water.

SDG 7: Affordable and Clean Energy. Energy generation from LFG is a significant contributor to a renewable and affordable source of energy. This approach helps to diversify energy sources and contributes to energy security by reducing dependence on fossil fuels.

SDG 8: Decent Work and Economic Growth. The transition to a circular economy and improved MSW management generates employment opportunities in recycling, energy recovery, and waste management sectors.

SDG 11: Sustainable Cities and Communities. Proper solid waste management and the installation of efficient landfills are essential to create sustainable, clean, and healthy cities. Energy recovery from LFG improves air quality by mitigating GHG emissions from landfills and the National Electricity Sector.

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SDG 12: Responsible Consumption and Production. This goal focuses on ensuring sustainable consumption and production patterns. Landfill installations must be accompanied by policies that promote waste reduction, reuse, and recycling. Energy recovery from landfills promotes the circular economy by converting waste into resources, encouraging more efficient use of materials, and reducing waste generation.
SDG 13: Climate Action. Waste management has a direct impact on greenhouse gas emissions. Implementing technologies that convert waste into biogas and capture and utilize it helps reduce emissions of methane, a potent greenhouse gas.
SDG 15: Life on Land. Waste management is also related to ecosystem conservation. If not managed properly, landfills can impact local biodiversity and surrounding ecosystems. Implementing waste management practices that prioritize recovery, and recycling helps protect ecosystems and promote the restoration of degraded land.

4 Conclusions

Adopting a waste management model that integrates the circular economy and smart city technologies is necessary to build a more sustainable and resilient future in urban communities. The integration of circular economy principles and the development of smart cities represents a key strategy to address the environmental, economic, and social challenges associated with managing urban solid waste (MSW). The capture and use of landfill gas (LFG) generated in landfills is presented as a significant opportunity for the generation of renewable energy, aligning with the Sustainable Development Goals of the United Nations 2030 Agenda, contributing to energy sustainability and improving the quality of life of nearby communities by reducing air and water pollution. Taking as a reference the population of the metropolitan area of Cuernavaca, Mexico, an estimate of GHG emissions was made due to the organic decomposition of MSW that would be disposed of in landfills with the capacity to capture and reuse LFG. Calculations show a 76% reduction in GHG's emissions if this gas is captured and flared in an industrial flare. On the other hand, if this gas is used for power generation in a gas engine, the reduction in emissions increases to 89%. With this last approximation, a total of around US$ 32 00 000 would be achieved for the duration of the project activities, which would be great economic support for the sustainable operation of waste management and handling of the landfill.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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ISBN 978-9930-617-71-7

Modelado de la Red Eléctrica de Mallorca y Evaluación del Impacto de las Fuentes Renovables en el 2030

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Abstract. Este estudio analiza el impacto de la integración de energías renovables (RES) en la red de transporte de 66 kV de la isla de Mallorca. El trabajo se centra en dos escenarios: el estado actual de la red y una proyección con una capacidad de 1.1 GW_p de energía fotovoltaica instalada, que es el objetivo gubernamental previsto para 2030. Para llevar a cabo este análisis, se recopilaron datos sobre las ubicaciones de subestaciones, datos de generación fotovoltaica utilizando una herramienta de despliegue de escenarios de fuentes de energía renovables y se realizaron estimaciones de la demanda segregada por nodos a partir de la radiación nocturna captada por satélite. Una vez tratados los datos, se creó un modelo de la red de transporte y se realizaron simulaciones mediante flujos de potencia utilizando la librería Pandapower, evaluando el porcentaje de carga en las líneas y el voltaje en los nodos. Los resultados para el escenario actual muestran que algunas líneas ya operan cerca de su capacidad límite, además de coincidir con las planificaciones de ampliación previstas por el operador del sistema de transmisión. En el escenario con 1.1 GW_p de RES, se identifican sobrecargas en varias líneas y nodos fuera de los rangos de voltaje permitidos, en las horas de mayor producción solar. El estudio concluye que será necesario reforzar la red o implementar soluciones de almacenamiento de energía para gestionar los excedentes y evitar problemas de saturación.

Keywords: Fotovoltaica, Simulación dinámica, energías renovables, diagnóstico.

1 Introducción

Las actividades relacionadas con los combustibles fósiles, como su extracción, transporte, procesamiento y combustión, tienen importantes consecuencias negativas para el medio ambiente, impactando directamente en las economías y sociedades a nivel mundial. Estas acciones, junto con otras intervenciones humanas, son las principales responsables de las emisiones de Gases de Efecto Invernadero (GEI) [1], [2], que impulsan tanto el calentamiento global como el Cambio Climático (CC). La creciente crisis climática se refleja en fenómenos como el aumento de olas de calor, incendios forestales

ISBN 978-9930-617-71-7

y el derretimiento de glaciares y polos. En respuesta, el Acuerdo de París de 2015 [3], fijó como objetivo principal limitar el aumento de la temperatura global a menos de 2°C respecto a los niveles preindustriales.

La Unión Europea se ha posicionado como líder en la transición energética mediante la implementación de políticas que buscan la descarbonización de diversos sectores, como el transporte, que representa un 25% de las emisiones totales en Europa, así como la industria y los edificios. Estas políticas están diseñadas para promover el uso de tecnologías bajas en carbono, fortalecer la economía y preparar el sistema eléctrico para gestionar un aumento significativo en la participación de las energías renovables [4]. Para asegurar una transición energética efectiva, se está llevando a cabo un despliegue masivo de fuentes de energía renovables (RES). Esta integración de RES en el sistema eléctrico se considera esencial, no solo para disminuir las emisiones de GEI, sino también para aumentar la seguridad energética en Europa [5].

En este contexto, resulta de gran importancia realizar un análisis no solo de la producción futura sino de cómo va a integrarse ésta en la red eléctrica. Este análisis permitirá prever si es posible alcanzar los objetivos propuestos y tener en cuenta que el transporte de la energía es una de las principales limitaciones, así como cuantificar, prever y localizar las mejoras necesarias en las infraestructuras debido al augmento de la penetración de las renovables. Así mismo, la simulación de diversos escenarios y que examinen el efecto de integrar mecanismos que proporcionen flexibilidad, como sistemas de almacenamiento de energía o centrales de producción de hidrógeno, es fundamental, para poder estudiar el desarrollo energético.

En este trabajo se aborda el estudio sobre la capacidad de la red de transporte (66 kV) actual de Mallorca y cómo afectará el aumento de las RES a la misma. Este estudio se ha desarrollado mediante el análisis de distintas penetraciones de RES, utilizando un conjunto de datos de entrada predefinidos, con el objetivo de poder analizar las líneas del sistema de transporte de la red eléctrica más afectadas y el voltaje en cada nodo que no supere el umbral deseado. Se ha desarrollado mediante el lenguaje de programación Python.

Los datos con los que se fundamenta este estudio son los datos de generación fotovoltaica y sus localizaciones, creadas a partir de la herramienta numérica para realizar el estudio de despliegue de RES [6]. A cada nodo de transporte se le asignan una generación fotovoltaica. Además, se ha recopilado información sobre la demanda eléctrica de la isla de Mallorca, la cual ha sido segregada por nodos de transporte.

Una vez que cada nodo de transporte cuenta con su respectiva generación fotovoltaica y demanda energética, se procede a modelar la red de transporte eléctrica de Mallorca. Utilizando la librería Pandapower [7], se realiza un análisis de flujos de potencia en la red de transporte. Este análisis permite evaluar la carga de la línea y el voltaje en cada

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nodo. Posteriormente se realiza un análisis para un escenario de 1.1 GW_p de RES, evaluando así el impacto de la integración de energías renovables en la red de distribución eléctrica.

El presente trabajo está organizado en cuatro secciones además de la introducción. En la primera sección se detalla la metodología propuesta para recopilar, simular y analizar los resultados. En la segunda sección aborda el caso de estudio con la presentación de datos de inicio. En la tercera sección se presentan y analizan los resultaos obtenidos. En la última sección se presentan las conclusiones de este trabajo.

2 Metodología

La metodología en la que se fundamenta el desarrollo de este estudio se basa en el uso de un conjunto de datos de entrada, obtenidos de fuentes abiertas y del programa para generar escenarios RES, y consiste en la secuenciación de un conjunto de pasos. Primeramente, es necesario obtener los datos que permitan modelar la red de transporte, concretamente sus nodos, sus líneas y las capacidades de cada línea. Una vez se conocen los elementos de la red de transporte (subestaciones, nodos, centrales de generación…), para su modelado deben definirse las generaciones renovables, las generaciones procedentes del mix energético y sus cargas en los nodos. Las generaciones renovables son proporcionadas por una herramienta numérica que indica la generación procedente de las RES en función de la potencia instalada en cada nodo de la línea de transporte, usando un modelo de Montecarlo. Cabe mencionar que este trabajo se ha centrado en los datos de generación fotovoltaica. Por otra parte, el sistema de generación se simula como una red independiente. Las cargas son estimadas a partir de los datos de generación obtenidos del Operador del Sistema de Transmisión (TSO). Sin embargo, dado que el TSO no ofrece datos de consumo segregados por nodos de transporte, aquí se estiman utilizando la radiación captada durante la noche por el satélite "Suomi National Polar-orbiting Partnership" (Suomi NPP) [8]. Para ello, se crea un factor de ponderación basado en el mapa de radiación, que permite estimar las cargas en cada nodo. Posteriormente, se simula la red de transporte utilizando la metodología de flujos de potencia, usando la librería Pandapower [7]. Esta simulación proporciona los resultados del voltaje en cada nodo y el porcentaje de carga en cada línea. Finalmente, la herramienta procesa los datos, generará un mapa de las líneas más cargadas y elabora una lista con los nodos que excedan el rango de voltajes deseados.

2.1 Recopilación de datos, filtrado y acondicionamiento

En este primer paso, ocurre la recopilación, filtrado y acondicionamiento de todos los datos de entrada que describen de manera precisa la red de transporte que se pretende modelar. A continuación, se detalla el conjunto de parámetros de entrada:

- **Elementos de la red de transporte**. Con el objetivo de simular la red de transporte, es necesario reconocer sus elementos, esencialmente sus nodos, líneas, capacidades,

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distancias y el número de circuitos. A partir de la documentación extraída de la Red Eléctrica de España (REE) [9], complementado por "Google maps" [10] se han extraído las localizaciones de cada subestación y se ha podido elaborar un esquema de la red de transporte de Mallorca.

- **Generación RES.** Para la definición de la generación producida por las RES, se ha recurrido a una herramienta numérica desarrollada con anterioridad [11], capaz de procesar datos meteorológicos, ficheros de información geográfica (GIS) y patrones de crecimiento. De forma estocástica se estima la generación de renovables de un territorio y de cada nodo de la red de transporte. Cabe destacar que la generación de energía renovable (RES) de cada nodo se estima en función de la ubicación de la instalación, asignándola al nodo más cercano. El procedimiento seguido se presenta en la **Fig. 1**.

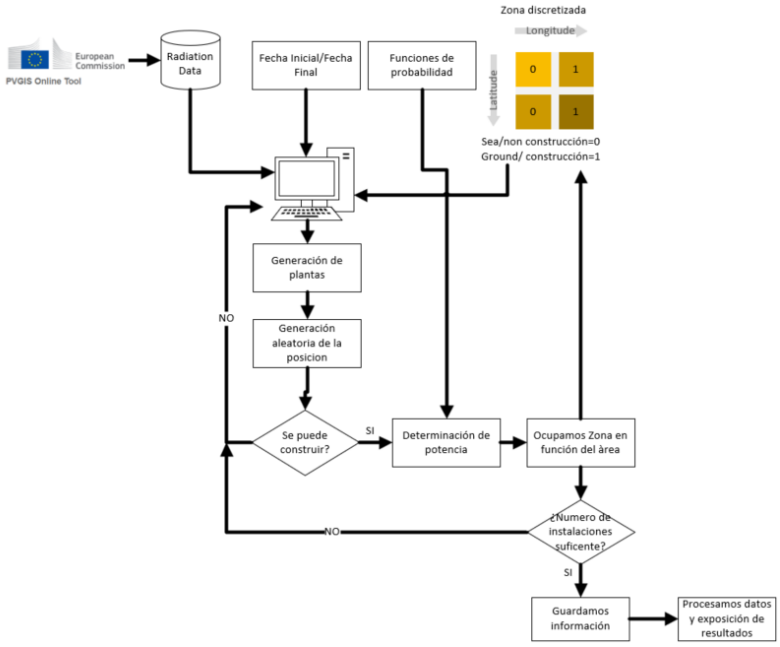


Fig. 1. Diagrama de bloques del funcionamiento de la herramienta.

- **Generación no renovable.** En este caso, puesto que se pretende simular una red de transporte de 66 kV existiendo una red de generación de 220 kV, ésta se modela como si fuese una red externa. Es decir, los nodos donde la red de generación pase de 220 kV a 66 kV son consideradas como parte de una red independiente.

- **Estimación de la demanda eléctrica segregada por nodo.** Otro parámetro para poder modelar la red de transporte son las cargas en cada nodo. El TSO, encargado de

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gestionar la red de transporte, no facilita los datos en cada subestación, pero si facilita el total de la demanda. Por este motivo se ha elaborado una técnica que permite segregar la demanda eléctrica en cada nodo y así estimar el consumo. La técnica desarrollada se basa en el análisis de la radiación nocturna emitida por el territorio a estudiar. Esta es captada por el instrumento "Visible Infrared Imaging Radiometer Suite" (VIIRS) acoplado al satélite Suomi NPP [12]. Una vez descargado el producto VNP46A1 con una resolución de 15º arco segundo se hace uso de los valores del sensor de radiancia ($nW \cdot cm^{-2}sr^{-1}$). Los valores se muestran en la **Fig. 2**

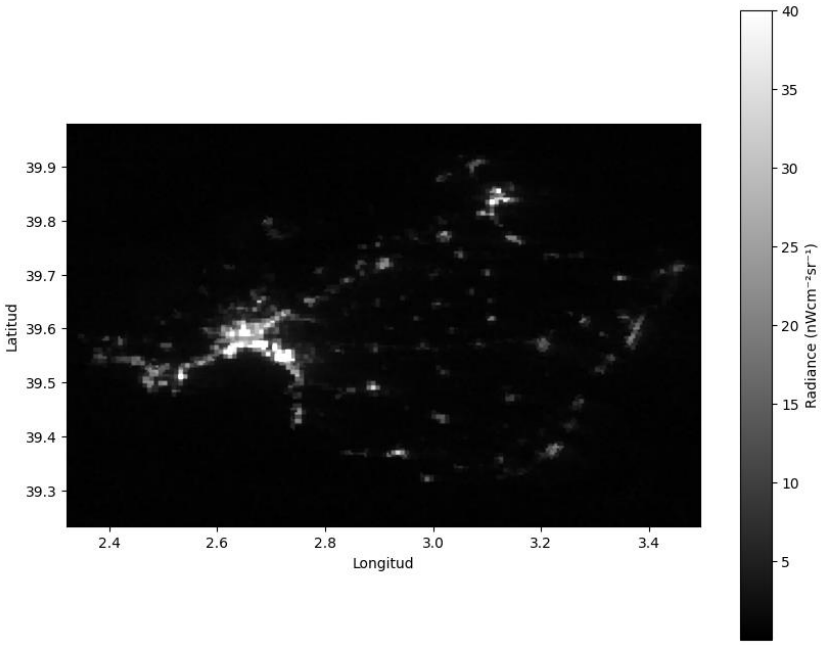


Fig. 2. Mapa de radiancia, saturado a $40nWcm^{-2}sr^{-1}$

A continuación, se filtran todos los pixeles que se encuentran delimitados dentro de la superficie de estudio y se suma su contenido (r_t). Mediante la clasificación de todos los pixeles al nodo más cercano se procede a sumar la radiación perteneciente a cada nodo (r_n). Posteriormente, se divide la radiación de cada nodo por r_t, obteniendo así, un peso que luego se multiplica por la demanda total (E_t), para así estimar la carga por nodo (E_n), como se puede visualizar en la **Eq. 1**.

$$E_n = \frac{r_n}{r_t} \cdot E_t \quad (1)$$

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2.2 Simulación y validación

Una vez se han introducido el conjunto de datos presentados anteriormente, se crea el modelo mediante la librería Python de "PowerPandas". Creando una red donde cada nodo representa una subestación, cada nodo tiene una carga y una generación fotovoltaica. Finalmente, los nodos que tengan transformación de 220 kV a 66 kV son los nodos que inyecten la corriente y se consideran como una red independiente. Al terminar el modelo, se procede a simular los flujos de potencia para una hora dada con la librería "Power-grid-model" [13], donde se asume que es un sistema compensado y se usa el algoritmo de Newton-Raphson como solucionador.

El resultado consiste en representar en el mapa las líneas con el porcentaje de carga y comprobar que los nodos estén dentro del $\pm 5\%$ del voltaje nominal. Al no poder contrastar con datos reales y verificar la aproximación, se verifica que las líneas y los nodos más cargadas actualmente relacionándolos con las próximas intervenciones que tiene previstas realizar el TSO en la red de transporte.

3 Caso Práctico

Para evaluar le eficacia del modelo desarrollado, se ha decidido aplicarlo a un escenario real, específicamente a la isla de Mallorca, España. Es necesario mencionar que en Mallorca no hay un gran potencial eólico, salvo en zonas protegidas, no existiendo ningún parque eólico en la isla. Por su parte, el despliegue de aerogeneradores de menor potencia es residual. Por este motivo, toda la metodología únicamente se centra en la energía fotovoltaica como fuente principal de RES.

A fin de poder evaluar el estado de la red de transporte en esta región en diferentes potencias de despliegue de RES, se ha optado por analizar dos casos: uno correspondiente al estado actual en el momento de más consumo; otro correspondiente al escenario con una capacidad de RES de 1.1 GWp (objetivo regional en 2030) en el momento de más producción, con el fin de poder evaluar, las líneas y nodos más conflictivos ayudando así al despliegue de nuevas infraestructuras (parques solares, producción de hidrogeno, subestaciones, etc.).

Actualmente, la red de transporte de Mallorca esta definida en dos redes de transporte, una a 220 kV y otra a 66 kV. Cabe destacar que para este estudio únicamente se ha contemplado la red de transporte de 66 kV, ya que es la que potencialmente se verá más afectada. Adicionalmente, existe una conexión a la red peninsular mediante dos cables de corriente continua de alta tensión (HVDC), con una capacidad de transmisión de 400 MW (2x200 MW) donde se transporta el 11.6% de la demanda de energía eléctrica de las Islas Baleares. El resto de la demanda eléctrica es cubierta gracias a plantas de carbón y ciclo combinado como son las del Murterar (carbón y Diesel, 335 MW), Cas Tresorer (gas natural, 477 MW), Son Reus (gas natural, 611 MW) y aproximadamente el 12% (en 2023) en RES, principalmente fotovoltaica. Los detalles de la red y los diferentes puntos de generación se muestran en la **Fig. 3**.

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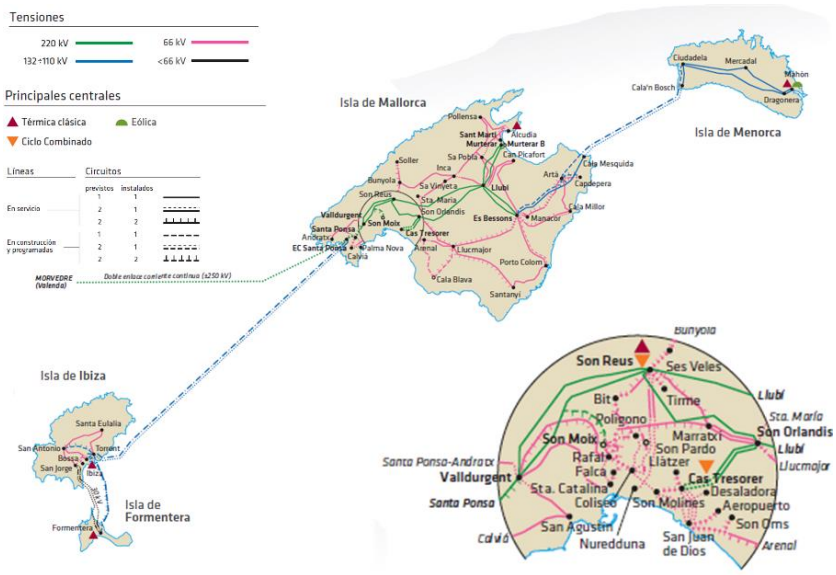


Fig. 3. Esquema de la red de distribución de las Islas Baleares. Fuente: Red Eléctrica [9].

El caso de estudio propuesto, al centrarse únicamente en la red de transporte de 66 kV de Mallorca (líneas rosas en **Fig. 3**), se ha modelado de la siguiente manera. Los nodos que contengan la red de transporte de (220 kV), serán los nodos que alimentan el resto incluyendo el consumo de la zona más próxima, modelándose como una red que aporta energía. En cambio, los nodos que no contiene la red de transporte de 220 kV son nodos que consumen energía. Cabe destacar que la generación RES está presente en todos los nodos. El esquema del modelo creado se muestra en la **Fig. 4**

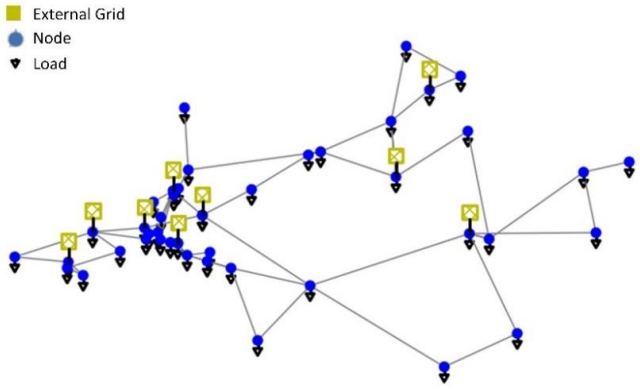


Fig. 4. Modelo red de transporte de 66 kV de la isla de Mallorca.

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3.1 Planificación de la red de transporte 2021-2026

Según REE, las Islas Baleares recibirán la mayor inversión de todo el territorio nacional en cuanto a futuras planificaciones de la red de transporte. Ello es debido, principalmente, a que se debe poder asegurar el suministro eléctrico y el proceso de transición ecológica para que las renovables supongan un 67 % del mix de generación. Se planifican las siguientes actuaciones que afectarán a la red de transporte 66 kV [14], como son:

- Nueva subestación Son Noguera 66 kV con entrada-salida en la línea Arenal-Llucmajor (>2026).
- Repotenciación, cambios de conductor, renovaciones y monitorización dinámica en la capacidad de Llucmajor-Orlandis a 66 kV.
- Ampliaciones en subestaciones de transporte de Bunyola 66 kV y Cala Millor 66 kV.

4 Análisis de los resultados

En esta sección se presentan los resultados obtenidos con la metodología descrita en la sección 2. El análisis de los resultados se ha realizado primeramente para el estado actual de la red transporte para poder validar el modelo a partir de las ampliaciones que prevé el TSO. Seguidamente se analiza otro escenario con una potencia de RES instalada de 1.1 GWp.

4.1 Análisis de los resultados de la red de transporte actual

En este análisis se simula el estado actual de la red de transporte, no solo para caracterizar el mismo sino también para poder validar el funcionamiento del modelo. Además, el análisis de flujos es realizado en el momento de mayor demanda eléctrica, el 13 de agosto del 2022 a las 22h. Los resultados muestran que ninguna línea supera el 100% de su capacidad, como se muestra en la **Fig. 5**. No obstante, hay tres líneas cercanas a la sobrecarga. La línea 1 está cargada al 94.9% de su capacidad, la línea 2 al 92.3%, con uno de sus extremos situado en la central de ciclo combinado de 477 MW (Cas Tresorer). La línea 3 presenta una carga del 78.2%, atribuida a la demanda de polígonos industriales. Referente a los voltajes de los nodos, todos se encuentran dentro del rango $\pm 5\%$. El nodo con menor voltaje se encuentra en Santanyí con un 0.97% del voltaje nominal y el de mayor voltaje en Alcudia con 1.03%.

Los resultados obtenidos son compatibles con las planificaciones del TSO. Por ejemplo, la alta carga de la línea 1 de la **Fig. 5** (la línea de Llucmajor- Son Orlandis a 66kV) explica el plan de intervención de REE de equiparla con un sistema de monitorización dinámica de la capacidad (DLR).

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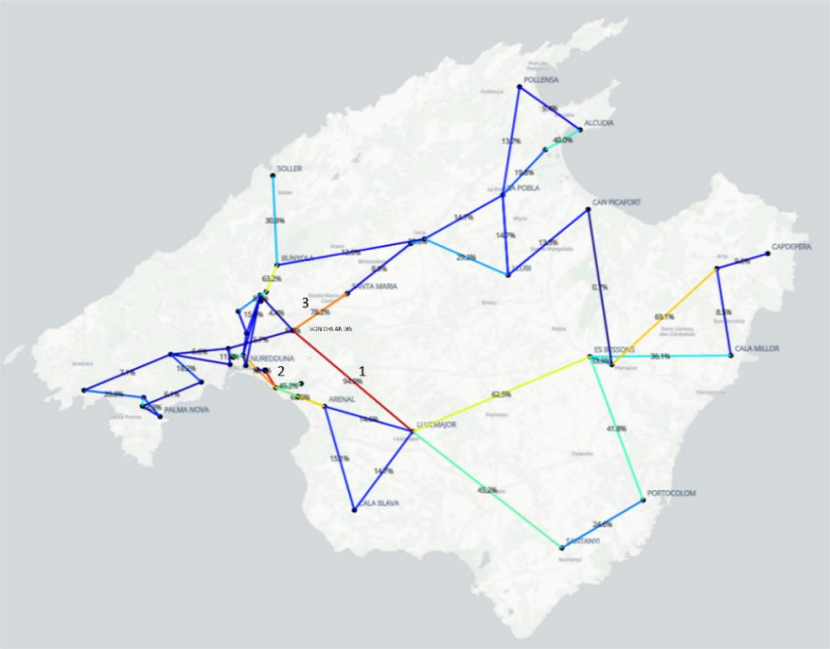


Fig. 5. Simulación del porcentaje carga actual de las líneas de la red de transporte (66kV) de la isla de Mallorca, en base al consumo y las generaciones a las 22h del 13 de agosto del 2022.

4.2 Análisis de los resultados de la red de transporte con un escenario RES de 1.1 GWp

En esta subsección se analiza el impacto de las RES en la red de transporte de 66 kW manteniendo las cargas, pero añadiendo 1.1 GWp de renovables. Los resultados generados por la herramienta de despliegue RES por un 1.1 GWp aparecen en la **Tabla 1**. Los resultados globales son: una generación anual de 1,678 GWh, con una penetración renovable del 33.84% de renovables y la aparición de los primeros excedentes. Esto implica que en las horas de mayor producción habrá excedentes. En este caso se analiza el momento de mayor producción, concretamente el 13 de agosto a las 12h.

Tabla 1. Resultados aportados por la herramienta de despliegue RES.

Escenario de despliegue de 1.1GWp de RES	
Potencia Instalada [GWp]:	1.1
Generación anual fotovoltaica agregada [GWh]:	1,678
Energía consumida [GWh]:	1,578

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Penetración Renovable [%]:	33.84
Excedentes Producidos [GWh]:	100

Si bien pueden darse excedentes, ello no implica que la red de transporte pueda transportar tal cantidad de energía. Por ello, es necesario realizar un análisis de flujos. Al analizar la red de transporte con la metodología expuesta en la sección 2 los resultados obtenidos del porcentaje de carga durante la hora de mayor producción fotovoltaica. En la **Fig. 6** se presentan los resultados obtenidos de los porcentajes de carga de las líneas de la red de transporte. Las líneas 1,4 y 6 indicadas en la **Fig. 6** sobrepasan el 100%. Mientras que las 3,4 y 5 no llegan a sobrepasar, pero están al límite de su capacidad.

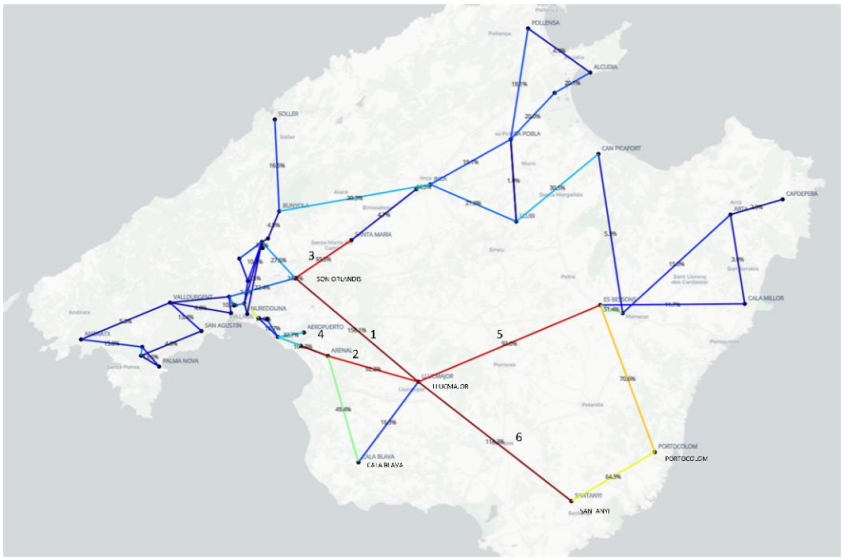


Fig. 6. Simulación de la red eléctrica de transporte (66kV) para el escenario del despliegue 1.1 GW_p de RES en la isla de Mallorca, evaluado en el momento de mayor producción mayor producción que se corresponde con el 13 de agosto a las 12h.

Respecto a los voltajes, los nodos que superan el rango permitido del $\pm 5\%$ son los nodos de Cala Blava en un 7%, Santanyí un 13%, Llucmajor en un 8% y Porto Colom en un 8.6%.

4.3 Discusión de los resultados

Los resultados obtenidos para la simulación del escenario actual muestran que el modelo predice la línea más cargada, coincidiendo con las modificaciones de línea del TSO. Por lo tanto, se puede inferir que el modelo captura con cierto grado de confianza

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el comportamiento real del sistema. El nivel de carga actual de las líneas de la simulación muestra como ya existen líneas críticas, y que en un futuro deberán ejecutarse planes de mejora. El segundo escenario muestra que al incrementar la aportación de las RES en 1.1 GW_p, algunas líneas no son capaces de evacuar la energía. Los resultados coinciden con las zonas actuales donde hay mayor capacidad de generación fotovoltaica [15], lo que representa un desafío significativo para la red eléctrica de la isla de Mallorca.

Los resultados destacan la necesidad de gestionar adecuadamente los excedentes y de expandir la capacidad de la red, especialmente para evacuar la generación durante las horas de mayor producción solar. Sin una gestión efectiva de estos excedentes, la red de transporte podría convertirse en un factor limitante para la transición energética.

Para solventar este problema deberán desarrollarse nuevas estrategias de gestión del binomio generación-demanda consumo, un refuerzo de la red de transporte (concretamente en las zonas de mayor producción fotovoltaica), un despliegue masivo de sistemas de acumulación de energía para minimizar los flujos de energía, como pueden ser los sistemas de baterías eléctricas ($LiFePO_4$...) o la producción de hidrogeno verde. De lo contrario, y si el problema de la gestión de excedentes no se solventa, se desarrollarán varios problemas que afectarán de manera severa al sistema eléctrico

5 Conclusiones

En este trabajo se ha presentado un estudio con la capacidad de simular la red de transporte de un territorio en un conjunto de escenarios. Se puede comprobar la eficacia del modelo pues es capaz de identificar la línea más cargada actualmente con la línea donde el TSO prevé realizar actuaciones inmediatas. Además, el estudio permite prever el problema sobre los flujos de energía debido a las RES durante sus horas de mayor producción y localizar las líneas y nodos más susceptibles. Este enfoque puede ser útil para desarrollar un plan estratégico para el crecimiento de la red de transporte, además de poder realizar futuros estudios sobre las localizaciones de nuevas subestaciones, infraestructura, como centrales de producción de hidrogeno o nuevas líneas marítimas HVDC. De este modo, se podrá incluir en los análisis un factor limitante adicional: la red de transporte.

Finalmente, este estudio se ha aplicado a la red de transporte de la isla de Mallorca en un escenario donde hay instalados 1.1 GW_p, que se corresponde con el objetivo marcado por el gobierno regional en el 2030. Los resultados obtenidos indican una saturación en las líneas y sobrecarga en los nodos en las zonas de mayor producción solar. Para afrontar este problema, se deberá reforzar la red de transporte o disminuir los flujos de energía a partir de un despliegue masivo de sistemas de almacenamiento en la red distribución y/o transporte.

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ISBN 978-9930-617-71-7

Life Cycle Assessment of Photovoltaic Glass in Greenhouse Systems: Environmental Trade-offs Between Energy Generation and Material Production

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Abstract. This study presents a life cycle assessment (LCA) comparing the environmental performance during the use phase of two greenhouse systems: one utilizing conventional glass (C-GH) and the other employing photovoltaic glass (PV-GH). The analysis was performed on experimental data. The results reveal significant environmental benefits of PV-GH across various impact categories. Specifically, PV-GH reduces greenhouse gas emissions by 36% (4.69 kg CO_2 eq) compared to C-GH (7.33 kg CO_2 eq), supporting findings that highlight solar energy's role in reducing agricultural emissions. Additionally, PV-GH demonstrates a 30% reduction in ozone and a net positive impact in ionizing radiation due to decreased reliance on conventional energy sources. In particulate formation and terrestrial acidification, PV-GH shows decreases of 30% and 28%, respectively, indicating how renewable energy use helps mitigate emissions from fossil fuel combustion. PV-GH further reduces water consumption by 52% and fossil resource use by 35%, which significantly alleviates resource strain. These findings support existing literature on the environmental advantages of renewable energy in agriculture.

Keywords: Life cycle assessment, photovoltaic greenhouse, environmental impacts, PV energy generation.

1 Introduction

Greenhouses play a critical role in enhancing food security by offering a controlled environment for agricultural production, which is particularly advantageous in arid regions. By providing protection against extreme weather conditions, greenhouses enable the year-round cultivation of crops that would otherwise be seasonal or susceptible to climate variations (Goddek et al., 2023; Kurgat, 2013). The ability to control environmental factors allows the efficient optimization of resources such as water and

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fertilizers, leading to increased productivity and greater efficiency in food production processes (Aznar-Sánchez et al., 2020).

In addition to improving resource use, greenhouses support the cultivation of a diverse range of crops, thereby contributing to dietary diversity and stability in food supply (Kurgat, 2013). Through their capacity to mitigate the impacts of climate change and reduce dependency on external food imports, greenhouses play a critical role in ensuring the stability and resilience of food systems (Aznar-Sánchez et al., 2020; Goddek et al., 2023). Furthermore, greenhouses promote sustainable agricultural practices by minimizing resource wastage and enhancing both the quality and safety of the food produced (Goddek et al., 2023).

The incorporation of photovoltaic (PV) panels into greenhouse systems presents multiple benefits, as evidenced by recent academic studies. This dual-use approach enables both energy generation and crop cultivation, enhancing land-use efficiency. PV panels can be engineered to provide variable shading, which not only regulates the internal greenhouse climate but also shields crops from excessive solar radiation, particularly advantageous in hot climates. This controlled environment contributes to improved crop yields and enhanced produce quality (Chalkias & Stathatos, 2024).

The electricity generated by PV panels can be utilized to power essential greenhouse operations, reducing reliance on external energy sources, and lowering operational costs. In some instances, excess energy produced can be fed back into the electrical grid, creating an additional revenue stream for farmers (Chalkias & Stathatos, 2024; Peng et al., 2023). Advanced PV greenhouse systems have the capacity to integrate with smart management technologies, enabling the optimization of both energy production and crop growth conditions (Goddek et al., 2023). Furthermore, the adoption of PV panels in greenhouse systems aligns with sustainable agricultural practices by reducing the carbon footprint of operations and promoting the use of renewable energy in food production. This integration of renewable energy into agriculture supports broader efforts to reduce greenhouse gas emissions and transition toward more sustainable food production systems (Chalkias & Stathatos, 2024; Goddek et al., 2023; Luqman et al., 2023).

Transparent photovoltaic (PV) glass for greenhouses has emerged as a promising technology that integrates energy generation with agricultural production, as demonstrated by recent academic research. These systems incorporate semi-transparent PV materials—such as amorphous silicon, perovskites, or organic PV cells into the structural components of greenhouses. Studies indicate that well-designed PV greenhouse systems can generate substantial amounts of electricity while preserving appropriate light conditions for plant growth. This technology offers customizable light transmission, allowing for optimization tailored to specific crop species and climatic conditions (Aira et al., 2021; Peng et al., 2023).

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Research has highlighted the potential of PV greenhouses to achieve energy self-sufficiency, reduce operational costs, and potentially enhance crop yields through improved climate control mechanisms. However, the impact of such systems on plant growth varies depending on crop type and the degree of shading. Recent studies have concentrated on optimizing the balance between energy production and crop yield, as well as examining the effects on plant physiology and morphology (Moreno et al., 2023). Despite these advancements, challenges remain, particularly in terms of cost-effectiveness and the long-term durability of the PV materials. Nonetheless, transparent PV glass in greenhouses presents a promising approach to integrating sustainable agriculture with renewable energy generation, contributing to a reduction in the carbon footprint of food production systems (Moretti & Marucci, 2019; Yano et al., 2014).

The integration of photovoltaic (PV) glass in greenhouse systems offers a promising solution to reduce energy consumption and improve the sustainability of agricultural crops. To analyze the environmental impact of these systems, a full life cycle analysis (LCA) is essential. The LCA provides a holistic view of the energy amortization time, greenhouse gas emissions through the life cycle of the photovoltaic modules. This assessment helps quantify the net environmental benefits of using renewable energy in greenhouses, highlighting the reduction in carbon footprint and resource consumption compared to conventional energy sources. In addition, the LCA contributes to decision-making processes for selecting materials and designs that conform to sustainable agricultural practices, ensuring compliance with environmental standards and certifications.

The goal of this study is to provide information related to the analysis of the environmental sustainability of the implementation of photovoltaic glass in greenhouses for plant production using the LCA tool. This information will be useful for stakeholders when making decisions on the adoption of this type of application in greenhouses.

2 Material and methods

2.1 System Description

The systems analyzed were a greenhouse whose enclosure consisted of a wooden structure supporting a conventional glass (C-GH), i.e., not photovoltaically active, with dimensions, mechanical and thermal properties like photovoltaic glass, compared to a greenhouse whose enclosure consisted of amorphous silicon (a-Si) photovoltaic glass (PV-GH). The greenhouses were part of the same construction and were located next to each other, separated by an intermediate partition that isolated them.

The internal characteristics of the spaces were the same, each was equipped with the same monitoring systems and control elements, so the electrical consumption for these systems was considered. Therefore, the production of electrical energy with the panels and the consumption requirements for the operation of the system were considered. The influence of glass types on crop yield and production are not considered in this analysis

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since their variation is not significant. Fig 1 shows the configuration of the greenhouse that was analyzed with the two spaces compared. Each greenhouse section had a rectangular structure 6 m long and 2.5 m wide, physically separated by a transparent inner partition. The one-water roof, oriented to the southwest and with a slope of 35°.

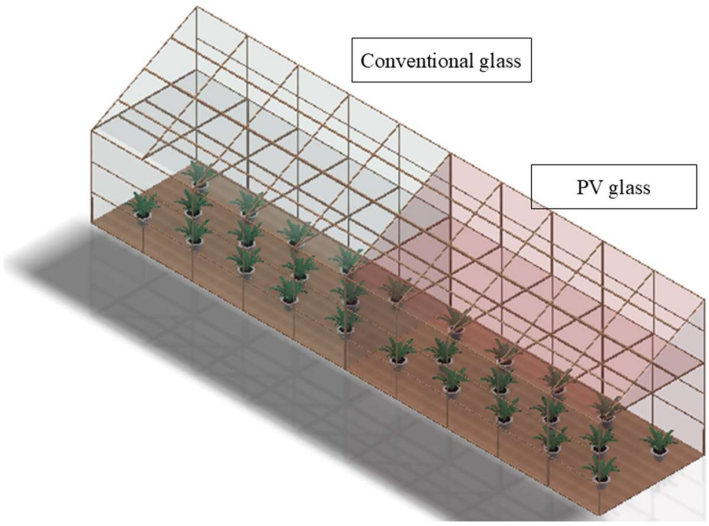


Fig. 1. Schematic view of greenhouse analyzed.

2.2 Methodology

Life cycle assessment (LCA)

In this study, the LCA methodology was used to quantify the impacts of a greenhouse with a conventional glass enclosure and a greenhouse with a PV glass enclosure. The LCA was conducted in accordance with International Organization for Standardization (ISO) standards 14040 and 14044 (14040, 2006; 14044, 2006). The LCA methodology followed ISO guidelines, including identification of system boundaries, collection of data on greenhouse inputs and outputs, assessment of impacts, and interpretation of the results. The environmental impacts were quantified using the ReCiPe method.

Life cycle inventory (LCI)

Inventory data for conventional and PV glass enclosure greenhouses are presented in Table 1. The LCA model was built with SimaPro® 9.1.1.1 Ph.D. (PRé Consultants, Amersfoort, The Netherlands) software by entering mass and energy values.

The functional unit is a reference unit used to compare the environmental impacts of different products or systems, to ensure that the LCA results are meaningful and relevant an appropriate unit must be defined. For the present study, the functional unit was

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defined as 1 cubic meter (m^3) of the volume of the controlled greenhouse for the period of analysis, which was the vegetative cycle of a lettuce crop (42 days). This functional unit was chosen because it represents a common unit of measurement for greenhouse size and allows the environmental impact of different greenhouse structures to be compared, considering that the energy produced is used to supply the equipment that controls the environment inside the installation, similar to Sajid et al. (2023).

Table 1. Inventory table of greenhouses for a functional unit of 1 m^3.

System	Inputs	Unit	Quantity
Conventional System	Wood structure	kg	5.8
	Nuts and bolts	kg	0.018
	Conventional glass	kg	36.6
	Electricity requirement for greenhouse equipment	kWh	1.9215
Photovoltaic System	Wood structure	kg	5.8
	Nuts and bolts	kg	0.018
	Photovoltaic glass a-Si	kg	21.3
	Electricity requirement for greenhouse equipment	kWh	1.4052
	Electricity production	kWh	2.2537

System boundaries

System boundaries were defined to determine which inputs and outputs were included in the analysis. The system boundaries for the present analysis include the operation phase of each of the spaces (greenhouse options PV-GH and C-GH), during a period in which the vegetative cycle of a lettuce crop is developed. The base materials were considered, which are the glass for the greenhouse enclosure, as well as the basic support materials for the structure. On the other hand, the energy requirements for the operation of the monitoring and control equipment inside the greenhouse were considered; in the case of the photovoltaic system, the production of electricity for the energy balance was also considered.

The following figures show the boundaries of the systems analyzed and the processes considered:

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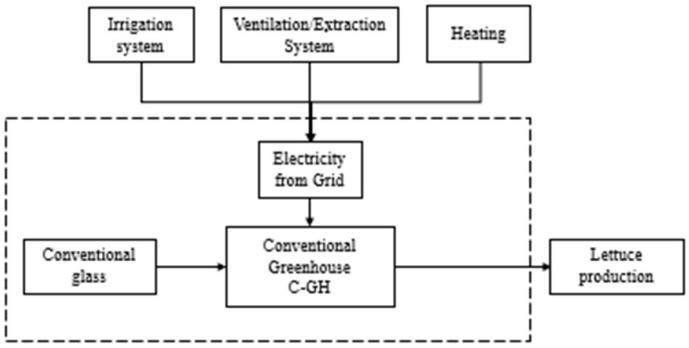


Fig. 2. System boundary diagram for LCA of conventional greenhouse

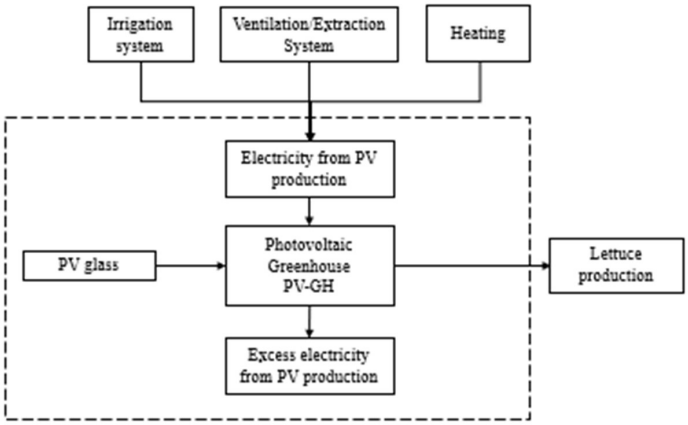


Fig. 3. System boundary diagram for LCA of PV greenhouse

The system boundaries did not consider the glass disposal.

The analysis of the characteristics of lettuce production is not included because the study focused on the energy sustainability of the facility.

3 Results and discussion

The following figure (Fig 4) shows the impact categories that were selected for the interpretation of results, the PV system presents better results in relation to the conventional system.

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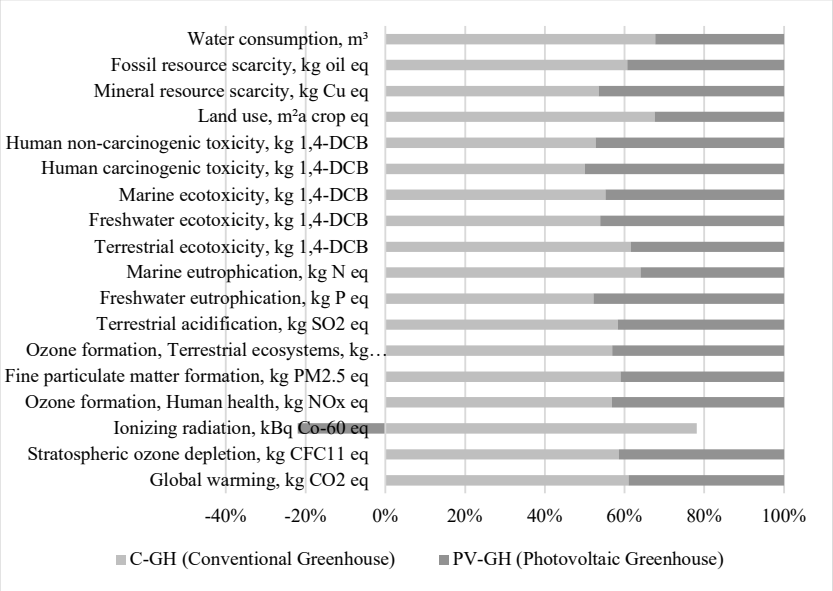


Fig. 4. Midpoint category scores for the comparative between the use phase of the greenhouse systems

In the environmental impact results of the comparison between conventional greenhouse (C-GH) and a photovoltaic greenhouse (PV-GH) using the ReCiPe Midpoint H method, it is observed that the photovoltaic greenhouse (PV-GH) offers substantial improvements across most categories compared to the conventional greenhouse (C-GH).

For the global warming potential, the PV-GH produces 4.69 kg of CO_2 equivalent, while the C-GH generates 7.33 kg CO_2 eq. This reduction in greenhouse gas emissions in the PV-GH is significant and consistent with previous studies that demonstrate how solar energy systems help reduce carbon emissions in agricultural applications (Hassanien & Ming, 2017). In a context where climate change is intensifying, this reduction is important, as agriculture is responsible for a considerable fraction of global emissions. This reduction is largely attributable to the energy generated by the photovoltaic system, which offsets the need for electricity from external sources, thus reducing emissions associated with electricity production from the grid (Fthenakis & Kim, 2011).

Regarding stratospheric ozone depletion, the PV-GH emits 1.43E-06 kg CFC-11 eq, compared to 2.03E-06 kg CFC-11 eq for the C-GH. Although the difference is small, the result suggests that the use of photovoltaic technologies can help minimize gases that affect the ozone layer, which has been demonstrated in other studies

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evaluating the benefits of reducing refrigerants in agriculture (Rodríguez-Mas et al., 2023; Tawalbeh et al., 2021).

In the case of ionizing radiation, a negative value is observed for the PV-GH (-0.0101 kBq Co-60 eq) compared to the C-GH (0.0358 kBq Co-60 eq). This suggests that the PV-GH has a net positive impact in this category, likely due to its ability to reduce reliance on conventional energy sources that produce radioactive by-products. By generating clean energy, the PV system offsets the demand for energy from sources such as nuclear power and fossil fuels, which are associated with ionizing radiation emissions. As a result, the PV-GH not only minimizes its own contribution to ionizing radiation but also contributes to a broader reduction in radiation levels across the energy system (Upreti & van der Horst, 2004).

In terms of fine particulate matter formation and terrestrial acidification, the PV-GH also shows lower values, with 0.0090 kg PM2.5 eq and 0.0284 kg SO_2 eq, respectively, compared to 0.0129 kg PM2.5 eq and 0.0397 kg SO_2 eq from the C-GH. The lower emission of particles and acid compounds is associated with the use of renewable energy, which reduces emissions related to fossil fuel combustion, consistent with the findings of Sanz-Cobena et al. (2017). The reduction in fossil fuel-based energy consumption, which is a major contributor to acidifying emissions such as sulfur dioxide (SO_2) and nitrogen oxides (NO_x) (Pehnt, 2006).

For eutrophication and ecotoxicity (terrestrial and aquatic), the PV-GH shows lower impacts in all subcategories. For example, freshwater eutrophication in the PV-GH is 0.000387 kg P eq, while in the C-GH it is 0.000423 kg P eq. Additionally, terrestrial ecotoxicity is 2.97 kg 1,4-DCB in the PV-GH, compared to 4.76 kg 1,4-DCB in the C-GH. This aligns with the research of Lal (2004), who argues that intensive agricultural practices tend to increase eutrophication and ecotoxicity, problems that can be mitigated with sustainable technology.

In the categories of resource use and water consumption, the results also reflect an advantage for the PV-GH. It uses only 0.0134 m^3 of water and 1.35 kg of petroleum equivalent, compared to 0.0281 m^3 of water and 2.08 kg of petroleum eq for the C-GH. The reduction in water and fossil fuel consumption in the PV-GH suggests a saving of key resources, which is particularly important in areas with water scarcity or high energy costs. This finding aligns with the study by Upreti and van der Horst (2004), which demonstrates that renewable energy in the agricultural sector can alleviate pressure on critical natural resources.

Despite the results indicating that the implementation and use phases of photovoltaic glass in greenhouses offer an efficient alternative regarding energy consumption and impacts related to electricity production, the system boundaries could be expanded to include earlier stages. This would enable a more comprehensive evaluation in which a key factor is determining the payback period for processes such as the manufacturing of photovoltaic glass, its useful life, and its end-of-life disposal in relation to its

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utilization in greenhouses. While the operational phase of PV-GH is less carbon-intensive due to its renewable energy generation, the environmental burden associated with the production of photovoltaic glass is a critical aspect. The energy and materials required for manufacturing PV glass, particularly in terms of silicon processing and cell encapsulation, are substantial when compared to the production of conventional glass (Frischknecht et al., 2020). Therefore, while PV-GH offers long-term reductions in GW through energy savings, the manufacturing phase must be carefully considered, as it represents a large portion of the environmental load in the total life cycle.

The manufacturing process of photovoltaic glass contributes a notable portion of the overall score in the categories. Emissions during the production phase, particularly those related to raw material extraction and glass fabrication, are more intensive compared to the processes used for conventional glass. While the operational benefits of PV-GH outweigh the initial manufacturing impacts, reducing emissions during production would further improve its performance in this category. Like the GW and TA categories, the PV-GH demonstrated a lower fossil resource scarcity (FRS) impact compared to C-GH. This reduction is primarily driven by the decreased reliance on fossil fuels for electricity generation due to the integration of photovoltaic glass. However, it is crucial to highlight that the photovoltaic glass production process is resource intensive. The extraction and processing of rare metals and other materials for photovoltaic cells contribute significantly to fossil resource depletion, particularly when compared to the simpler production processes for conventional glass (Peng et al., 2013; Valero et al., 2014).

Although photovoltaic technology offers operational advantages in terms of reducing total energy consumption, the greatest emissions of ozone precursors and particulate matter are from the industrial processes involved in the production of photovoltaic technology, so it is necessary to analyze how and at what point the benefits obtained during the use phase are offset.

The results of this LCA highlight the environmental performance duality between the two greenhouse designs. The PV-GH demonstrates clear advantages in terms of reducing global warming potential, land acidification and fossil resource scarcity due to its ability to generate renewable energy. These advantages are most pronounced during the operational phase, where the energy self-sufficiency of the PV-GH greenhouse reduces dependence on fossil fuels and decreases associated emissions.

It is necessary to consider that the influence of PV glass production is significant, especially in terms of ozone and particulate formation and energy use. The manufacturing process of PV materials is much more resource and energy intensive than that of conventional glass, resulting in higher emissions for certain impact categories. This suggests that while the operational phase of PV-GH is more environmentally friendly, the production phase requires optimization to minimize its environmental footprint and should be considered in determining a more comprehensive analysis.

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4 Conclusions

This life cycle assessment (LCA) study provides a comparison between a use phase of a conventional greenhouse (C-GH) utilizing standard glass and a photovoltaic greenhouse (PV-GH) employing photovoltaic glass as a cladding material. The findings reveal that PV-GH offers considerable environmental advantages in key impact categories, particularly in global warming GW, Terrestrial acidification TA, and Fossil resource scarcity FRS. These benefits are predominantly attributed to the generation of renewable energy within the PV-GH, which reduces reliance on grid electricity, consequently lowering emissions associated with fossil fuel combustion.

However, the environmental impacts associated with PV glass production are significant and must be considered. The PV glass manufacturing process, which involves energy-intensive steps such as silicon processing and cell encapsulation, contributes substantially to the environmental load in categories such as ozone formation and particulate formation.

The results of this study underscore the importance of addressing the environmental impacts of photovoltaic glass production to fully realize the ecological advantages of PV-GH systems. Efforts to reduce the environmental footprint of photovoltaic glass manufacturing (through material innovations, process optimization, and improved energy efficiency) are essential to enhancing the overall sustainability of these technologies.

Although high-efficiency PV has a clear potential to reduce greenhouse gas emissions and dependence on non-renewable energy sources, the advantages and disadvantages of the manufacturing phase need to be carefully considered. This study highlights the need for a holistic approach, encompassing both the operational and production phases, to optimize the environmental performance of PV systems in building applications. Future research should focus on refining production technologies, improving material efficiency, and advancing recycling processes to further reduce the life cycle impacts of PV technologies. Addressing these areas will be critical to maximizing the ecological benefits of photovoltaic glass in both agricultural and architectural contexts.

The overall environmental performance of PV-GH is superior in categories related to energy consumption and greenhouse gas emissions; this advantage should offset to some extent the environmental burdens associated with PV glass production.

Acknowledgments. Diana Alexandra Murcia Velasco was financed on the grounds of University of Valladolid predoctoral contracts and co-financed by Banco Santander.

Disclosure of Interests. The authors declare no conflict of interest.

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ISBN 978-9930-617-71-7

Alternatives to reduce the carbon footprint of port operations in LNG terminals

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Abstract: This study focuses on comparing different alternatives to reduce the carbon footprint in port operations of LNG terminals in the Port of Sines in Portugal, during the period 2018-2022. Through the described methodology, several options were identified, including transition to alternative fuels, process optimization, carbon capture and storage, development of new technologies and, finally, offsetting their carbon footprint by recovering the cold lost by unloading LNG from the ship to shore.

Keywords: Liquefied natural gas, Carbon Footprint, Liquefied Natural Gas Terminal.

1 Introduction

Natural gas is a crucial energy source in the global energy mix [1]. It is currently promoted to meet the energy demand for fossil fuels with lower contribution to greenhouse gas (GHG) emissions and low sulphur content [2]. Global offshore liquefied natural gas (LNG) trade continues to expand, with Europe and Asia becoming the main markets, especially. These account for 90% of the global share and only during the period from 2011 to 2022 the number of LNG transport ports has grown significantly [4].

Portugal, being a net importer of energy, relies on LNG to meet its growing demand and reduce its dependence on other fossil sources [3]. The Port of Sines, strategically located on the Atlantic coast, plays a pivotal role in this energy transition, serving as the main entry point for LNG into the country [5].

Despite the economic and energy benefits associated with LNG, its production and transport, like all human activity, leaves a carbon footprint [6, 7]. GHG emissions throughout the entire value chain, from extraction to combustion, contribute to climate change and other environmental problems. In this context, it is imperative to assess and mitigate GHG emissions associated with LNG port operations [8].

Scientific literature has extensively explored the carbon footprint associated with offshore shipping [9] and ports [10], including LNG [7, 8]. However, studies focusing

ISBN 978-9930-617-71-7

specifically on emissions generated by LNG port operations are still limited [4]. Previous studies have identified various sources of emissions at LNG terminals (LNGT), including methane leaks during loading and unloading operations [7, 11], energy consumption at port facilities [12], and emissions from transport vehicles [13, 14]. In addition, various strategies have been proposed for the energy transition of different port terminals to reduce emissions. These include improving energy efficiency, carbon capture and storage, and the adoption of renewable energy generation technologies [15, 16].

This paper purpose to estimate the carbon footprint associated with LNG port operations in Sines, Portugal, for the period 2018-2022 and to explore opportunities to reduce them. That is, the main factors contributing to the carbon footprint are identified and, in this context, measures to reduce them are proposed. The results of this research provide valuable information for decision-making in the energy sector and contribute to the development of sustainable strategies for LNG management in seaports.

2 Methodology

2.1 Carbon footprint calculation model for seaports

There are different international methodologies for calculating the carbon footprint, including those established in ISO 14064 [17] or the GHG Protocol [18]. These seek to provide a standardized framework for the measurement, reporting and verification of emissions, based on the scope defined in each one. Although this study is carried out considering only CO_2eq, the 4th Report of the International Maritime Organization (IMO) [19] and its guidelines [20, 21]. They recommend including other emissions. These include volatile organic compounds (VOC), particulate matter (PM), black carbon (BC) and others, which are specific to the type of fuel used by the maritime industry [19-23].

GHG Protocol [18] provides a detailed methodology for estimating emissions, which has been used by the IMO [20, 21] for transport on the high seas and in port operations [19-23]. This Protocol classifies emissions into three scopes:

- Scope 1: Direct Emissions. These are GHG emissions produced by sources that are under the direct operational control of an organization, at a site that the organization owns or controls.
- Scope 2: Indirect Emissions from Purchased Energy. These are the indirect GHG emissions associated with the generation of electrical energy consumed by the organization.
- Scope 3: Other Indirect Emissions. These include all other GHG emissions that are not included in Scopes 1 and 2. These are the indirect emissions throughout an organization's value chain.

Scope 3 typically accounts for most emissions in maritime ports [24] and in those organizations that have complex supply chains or products with long life cycles. Therefore, understanding and managing these emissions is essential to achieve a significant reduction in the carbon footprint. On the other hand, in recent decades, there has been a growing trend for port activities and terminals to be granted under concession [25], so their emissions are included in this scope.

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Table Table 1the sources of emissions according to the scopes defined in the GHG Protocol [18], considering the concession made to port terminals [19, 20].

Table 1. Sources of emissions from port activity considered by the IMO [19, 20].

Scope	Emissions	Sources	
1	Direct (emission sources within the Port's jurisdiction area)	Fixed	• Operation of power plants. • Use of boilers. • Fugitive emissions of refrigerants. • Others
		Mobiles	• Mobility of ships, pilot boats or tugboats. • Mobility of port cargo. • Mobility of employees within the area of jurisdiction of port activity.
2	Indirect	Power supply to the facility by the port authority.	
3	Indirect (emissions caused by concessions given to operate within the port's jurisdiction area)	Fixed	• Power supply. • Equipment for loading and unloading cargo from ships. • Operation power plants. • Use of boilers. • Fugitive emissions of refrigerants. • Others
		Mobiles	• Mobility of ships or tugboats. • Mobility of port cargo. • Mobility of employees.

2.2 Methods

Calculating the carbon footprint is methodologically complex and requires more information as the rigors of the exercise increases. The fact that it involves agents outside the organization itself considerably increases this complexity, due to the demand for the necessary information and the difficulty of providing it. However, at an organizational level, the greater detail and completeness with which this calculation is carried out makes it a suitable tool for making decisions on environmental issues throughout the process chain and/or activities, for designing environmental strategies and reducing emissions, and for obtaining carbon neutrality certifications, among others.

Emissions from port activities due to Scope 1 and 2 are less than 1% [24], in this sense it has been decided to calculate emissions considering Scope 3. Emissions due to:

- Fixed sources: emissions due to energy consumption of land-based facilities that guarantee the unloading of LNG and, in addition, of technical-administrative buildings.
- Mobile sources: emissions due to the operation of ships and, in addition, land transport, both of cargo and employees.

LNG is transported in specialized ships called LNG tankers. These have double-walled insulated tanks to keep the gas at a temperature of -162°C in liquid state [29]. In general terms, the LNG unloading process at the port terminal can be described as follows [7]:

- Mooring the ship and connecting to the cryogenic hoses.

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- Pumping LNG using high-power pumps to extract it from the ship's tank.
- Partial vaporization in heat exchangers to reduce pressure and facilitate storage.
- Storage in cryogenic tanks.
- Distribution: LNG can be regasified and distributed through pipelines or transported by land to end consumers.

2.3 Materials

The calculation of the carbon footprint (in tCO_2eq) is carried out for the period 2018-2022 and within the maritime and land limits of the jurisdiction area of the port of Sines for the LNG terminal. For this calculation, emissions have been grouped according to their source:

a) Electricity consumption, which includes operations related to pumping, distribution and others of LNG during its unloading. In this case, the electric energy consumption record and the emission factor published by APA have been used [30].
b) Land transport, which includes the commuting of employees and the proportion of LNG leaving the terminal in cryogenic tanker trucks [29]. For this calculation, data on the number of employees (considering that 5% are transported in public vehicles and the rest in private vehicles) and the number of tanker trucks according to statistics kept by the terminal operator are used.
c) To maritime transport within the port's jurisdiction area, including ship operations, for which the statistics recorded in the JUL have been used [31].

Within these emissions, those due to maritime transport are the most complex, since they depend on the energy consumed by the ship's main and auxiliary engines during its manoeuvres, the type of fuel and their respective emission factors [32]. For this calculation, the model established by the European Environment Agency (EEA) was used, which includes the relationship of the auxiliary engines based on the main ones and emission factors according to the type of fuel used [33]. The times for operations within the ships are found in the JUL records [31].

JUL records [31] include the times of the PLF-Entry, anchoring, suspending, berthing and living. Finally, there are applications or programs that have specialized in the calculation of emissions [34-36]. However, for reasons of database customization and flexibility, a spreadsheet is automated, which includes the collected data, the mathematical expressions of the model and the factors used. [34] [35] [36].

3 Results

Below are the results obtained from emissions calculations:

a) Electrical energy consumption:

The TGN is fed directly through two 60 kV lines of the public distribution network. On average, this terminal consumed 62,053.12 MWh per year in the 2018-2022 period. Additionally, this terminal produced average emissions of 12,269.49 tCO_2eq, considering the APA emission factors for each year.

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b) Land Transport

The calculations for the land transport emissions were based on information given by the concessionaire regarding the number of tanker lorries and then modal distribution considered. Approximately, only 7% of the LNG distributed is transported via terrestrial A standard capacity of 44 t per lorry was used. This terminal emits 36.03 tCO_2eq. The emissions calculations are considered for the mobility of its workers. This terminal emits 30.81 tCO2eq in this case.

c) Maritime transport

In the case of this LNG terminal, 1,411 ship calls were analysed for the period 2018-2022. The calculation model estimates an average annual emission of 19,142.65 tCO_2eq, shown in Table 2 and 3. The largest proportion of energy and emissions is due to the use of electricity.

Table 2. Average operating time and emissions per manoeuvre for the period 2018-2022

Step	2018	2019	2020	2021	2022
Time (h)					
PLF-Entry	2.56	2.55	2.49	--	2.74
Anchoring	61.83	10.77	46.37	--	51.37
Suspending	2.08	1.76	2.90	--	2.65
Berthing	23.52	23.28	23.61	--	22.33
Leaving	0.80	0.80	0.72	--	0.77
PLF-Exit	0.00	0.00	0.00	--	0.00
Total	90.79	39.15	76.10	--	79.86
Emissions ($kgCO_2eq$)					
PLF-Entry	18.32	19.37	17.08	--	18.37
Anchoring	288.17	60.44	163.99	--	202.41
Suspending	9.68	9.69	10.26	--	9.97
Berthing	93.27	98.52	89.46	--	84.29
Leaving	5.71	5.99	4.98	--	5.26
PLF-Exit	0.00	0.00	0.00	--	0.00
Total	415.16	194.02	285.77	--	320.30

Table 3. Average source energy and emissions for the period 2018-2022

Variable	Electrical energy	Land transport	Maritime transport	Total
Energy (MWh)	62,053.12	228.95	19,142.65	81,214.72
Energy (%)	76.41	0.02	23.57	100
Emission (tCO_2eq)	12,269.49	30.81	5,087.54	17,387.84
Emission (%)	70.68	0.01	29.31	100

Figure 1 shows the distribution of LNGT emissions by type of manoeuvre for the period 2018-2022, considering all ship calls. Approximately 90% of the emissions are due to anchoring and berthing manoeuvres.

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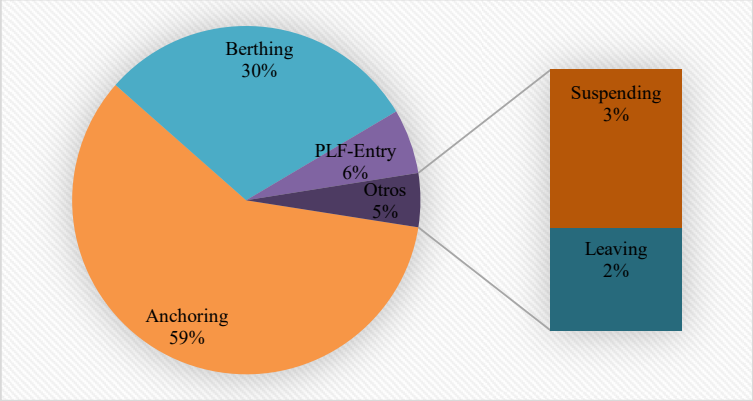


Fig. 1. Distribution of CO_2eq emissions by type of ship manoeuvre at the terminal

Reducing the carbon footprint in LNGT is a highly relevant and complex issue. Considering:

- That LNG is a fossil-based energy source with greater calorific value and lower emissions than traditional fuels.
- There are combustion risks due to the handling and storage of LNG, due to its high flammability.

Alternatives to reduce the carbon footprint in LNG ports:

Transition to alternative fuels:

- Hydrogen: It is an energy vector with great potential for decarbonisation.
- Biofuels: Their use can reduce GHG emissions if produced sustainably.
- Ammonia: Although still in the development phase, ammonia can be used as a fuel in marine engines.
- Electricity: Electrification of ports can significantly reduce emissions, especially if it comes from renewable generation sources. In the case of LNGT, this type of alternative is viable for powering its onshore processes.

Process optimization:

- Improving energy efficiency: Implementing technologies that reduce energy consumption during port operations.
- Waste management: Reduce waste generation and improve its management, avoiding methane emissions in landfills.
- Digitalization: Using digital tools to optimize logistics and reduce ship waiting times.

Carbon Capture and Storage (CCS):

- Capture CO_2 emissions generated by the combustion of LNG and store it safely underground.

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Development of new technologies:

- Fuel cells: Converting hydrogen into electricity efficiently.
- High-density batteries: Storing large amounts of energy to propel ships.

Finally, unlike other ports, this one has the possibility of offsetting its carbon footprint by recovering the cold that is lost in the heat transfer process and using it to:

- Refrigeration: In cold rooms, warehouses or nearby industrial processes.
- Conditioning of buildings: In buildings port or communities nearby.

Conclusions

This study focuses on evaluating and comparing different alternatives to reduce the carbon footprint of the port operations of the LNG terminal of the Port of Sines in Portugal, during the period 2018-2022. Through the described methodology, various options were identified and analysed, including transition to alternative fuels, process optimisation, carbon capture and storage, development of new technologies and, finally, offsetting its carbon footprint by recovering the cold lost by unloading LNG from the ship to shore.

Acknowledgments

Content produced within the scope of the Agenda "*NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade*", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project no. º 53).

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ISBN 978-9930-617-71-7

Smart industry solutions: finite element solver comparison for FEM vehicle cabin analysis

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Abstract. Smart manufacturing requires acceleration of the designing processes like the analysis of the mechanical structure and other needs through advanced techniques like the finite element method. This article compares the computational performance of the finite element method's algorithm applying direct solvers (inverse matrix and LU decomposition method), iterative solvers (Jacobi and Gauss-Seidel method), and precondition iterative methods (preconditioning Jacobi and Gauss-Seidel. A pickup truck cab structure's design, taken from the literature, was used as a study case. The entire structure comprises longitudinal steel tube sections joined by 28 nodes. The FEM algorithm was programmed in Octave's environment and verified with the book's software results and LISA's FEM software as witnesses. The behavior of implement methods showed that preconditioning Jacobi and Gauss-Seidel were the most suitable methods because of their convergence ratio and time machine performance (19.865 s and 20.394 s, respectively). The reaction percentage difference between the present results and the software is around 0.001%. Therefore, the current methodology is suitable for efficiently finding solutions for similar structures in smart manufacturing applications.

Keywords: FEM · preconditioning solvers · performance evaluation· smart industry solutions

1 Introduction

In the context of smart industry, the finite element method (FEM) modeling has become an essential tool for the analysis and design the complex structures. The capacity to simulate and predict the material behavior and components under different conditions is crucial to improve efficiency and reduce costs in the factory and maintenance of structures. However, the increasingly complex industry system demand accelerates the modeling processes to maintain competitiveness and innovation.

ISBN 978-9930-617-71-7

A benefit of FEM is its capacity to reduce the number of physical testings of prototypes, which reduces the time and the developer project cost. Also, the integration of FEM with emergent technologies can accelerate the modeling processes [14]. The FEM provides suitable tools to guarantee the resilience and sustainability of structures.

The classification of structures is usually divided into two large families [1]: discrete and continuous. The first is formed by assembling easily recognizable elements and joined together through nodes [18], as in buildings and bridges. Continuous structures, such as machine elements (connecting rods, pulleys, housings, etc.), are common in engineering. However, it is not possible to discretize these structures because the joining points between the different elements are not present here.

In the past, continuous systems were solved using analytical methods, which limited the study only to simple geometries and simple boundary conditions to know the relationship between the displacements of the elements that make up a structure. The displacements of the elements were generated by subjecting the system to external forces at any point, as well as the nodes that make up each element. Therefore, it is necessary to solve an equation that involves all the nodal displacements $\boldsymbol{U}$, the loads to which the structure is subjected $\boldsymbol{F}$, the stiffness of each element $\boldsymbol{K^e}$, and store them in a square matrix $\boldsymbol{K}$; the dimensions of the square matrix is as large as the elements the structure contains. Different methodologies allow us to reach the above conclusion, two of them already becoming classics due to the time they have been in use [18]: finite differences and FEM. Both have their advantages and disadvantages. Still, FEM is usually the most widely used technique mainly because, unlike finite differences, it does not typically present problems when the geometry has complex contours.

The solution of $\boldsymbol{KU} = \boldsymbol{F}$ has been approached by different proposals of solution methods such as LU factorization, for the linear case, iterative methods, such as Gauss-Seidel, and Jacobi [7,11]; the iterative methods modify the components of the approximation one by one, or several at the same time, using relaxation in a certain order until reaching convergence. In addition, in more recent times, the use of preconditioners to improve computation times using iterative methods has become very popular. Wathen [15] makes a detailed explanation of this technique, and GUO [5] applies it successfully in solving the diffusion equation. In applied engineering, the need to evaluate systems with non-linear properties, boundary conditions dependent on space and time, and complex geometry are the main reasons for obtaining non-linear sparse equation systems.

Therefore, the smart manufacturing demand for analyzing large, complex structures with irregular geometries. It is required the use of specialized software based on the FEM due to its low computational cost and easy handling in the post-processing and results evaluation process. The present work aims to compare different solvers (inverse matrix, LU factorization, Jacobi and Gauss-Seidel

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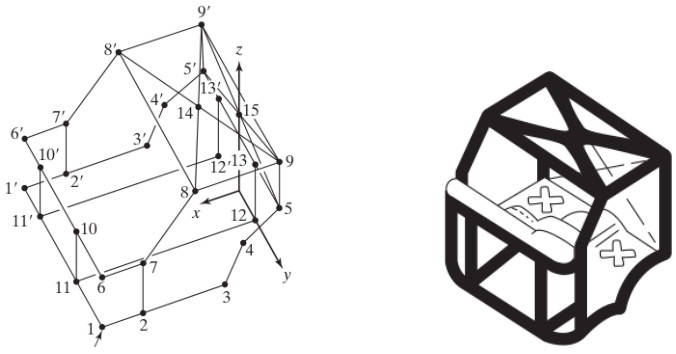
with successive over-relaxation and preconditioning solvers) for the numerical solution of a case study: the design of a pickup truck cabin.

2 Methodology

This section describes the physical and mathematical model, solvers, and methodology for solving the equation system. Finally, the general conditions of the study are included.

2.1 Problem of study and formulation of the mathematical model

The study case consists on designing a pickup truck cab; the problem statement was addressed by **Chandrupatla & Belegundu** [2]. Figure 1 shows the physical model and the finite element model of a pickup truck cab. The FEM model is composed by 28 nodes. Nodal coordinates (in inches) appear in Table 1.



(a) Simplified model **(b)** Pickup truck cab

Figure 1. Study case

Figure 1 shows that X-Z is a plane of symmetry. Each Ω_i in Figure 2 is made of steel with $Ae = 0.2$ in^2, $Iy = Iz = 0.003$ in^4 and $J = 0.006$ in^4. A load is applied in node 1, its components are $Fx = -3194.0$ lb y $Fy = -856.0$ lb with nodes 2,3,20 and 21 treated as fixed nodes. The main problem of this model design is finding the reactions for fixed nodes.

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Table 1: Nodal numbering for the study case

Nodo	x	y	z	Nodo	x	y	z
1	58.0	38.0	0	9	0	38.0	75.0
2	48.0	38.0	0	10	58.0	17.0	42.0
3	31.0	38.0	0	11	58.0	17.0	0
4	17.0	38.0	22.0	12	0	17.0	0
5	0	38.0	24.0	13	0	17.0	24.0
6	58.0	38.0	42.0	14	18.0	0	72.0
7	48.0	38.0	42.0	15	0	0	37.5
8	36.0	38.0	70				

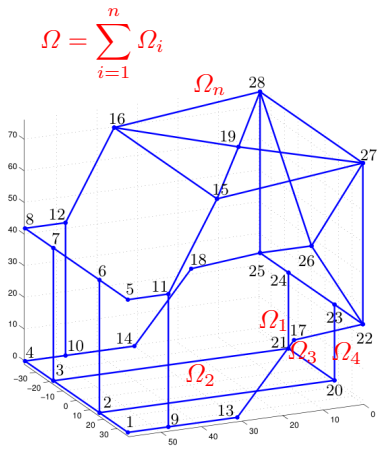


Figure 2. Finite element model for a pickup truck cab. Here Ω denotes the entire structure, composed of longitudinal sections $\Omega_1, \Omega_2, \ldots, \Omega_n$ such that $\Omega = \sum_{i=1}^{n} \Omega_i$.

The structure with the node numbering presented in Fig. 2 was proposed to solve the problem posed. The structure is a bounded $\Omega \subset \mathbb{R}^3$, with boundary $\Gamma = \Gamma_D \cup \Gamma_N$ and $\Gamma = \Gamma_D \cap \Gamma_N = \emptyset$. Γ_D is a positive measure surface. Under the action of a force $\boldsymbol{f}$ in Ω, and a tensile force $\boldsymbol{h}$, which acts on Γ_N the body is deformed, and each point moves from position $\boldsymbol{x}$ to position $\boldsymbol{x} + \boldsymbol{x}(\boldsymbol{u})$. Therefore, the problem can be summarized as follows: given $\boldsymbol{f}$ and $\boldsymbol{h}$, determine the displacement $\boldsymbol{u}$, under elastic equilibrium conditions affecting Ω [12]. Equation (1) describe the mathematical model of the system.

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$$\left.\begin{array}{rl} -\nabla \cdot \sigma = \boldsymbol{f} \text{ en } & \Omega \\ \boldsymbol{u} \quad = \boldsymbol{0} \text{ en } & \Gamma_D \\ \boldsymbol{\sigma} \cdot \boldsymbol{n} \ = \boldsymbol{h} \text{ en } & \Gamma_N. \end{array}\right\} \tag{1}$$

Where $\boldsymbol{n}$ is the normal vector to Γ_N y $-\nabla \cdot \sigma = \boldsymbol{f}$ en (1) can be viewed as $-\mu \Delta \boldsymbol{u} - (\mu + \lambda) \nabla (\nabla \cdot \boldsymbol{u}) = \boldsymbol{f}$, which is known as Navier equation [3, 12].[1]

3 Solvers

This section describes the direct and iterative methods to solve the stiffness matrix equation system.

3.1 Direct solvers

The direct solvers provide exact solutions, although they can be sensitive to rounding errors. Also, the number of arithmetic operations is a known variable. However, the direct solvers can demand an extensive memory resource and intensive computational efforts to find the solution [9]. The inverse matrix and decomposition LU were the direct solvers employed to solve the stiffness matrix and evaluate the computational effort.

Inverse matrix method: The inverse matrix is a linear algebra technique used to find the inverse of a square matrix. The procedure consists of calculating the matrix determinant; if the determinant is zero, the matrix has no inverse. Afterward, the adjunct or co-factor matrix is found, which must be transposed. Finally, each element of the transpose matrix is factored by the determinant matrix original. Equation 2.

$$A^{-1} \cdot x = A^{-1} \cdot b \tag{2}$$

$$A^{-1} = \frac{1}{det\,(A)} \cdot adj\,(A)^T \tag{3}$$

The solution of the equation system is limited for linear systems. The computational effort is low for a small equation system; however, the inverse matrix method requires more effort for systems with several variables, like the physical model discretized by the FEM method.

[1] μ and λ are called Lamé coefficients. Under the assumption that the body is homogeneous and isotropic with respect to deformations, they are considered constant and verify the conditions $\mu > 0$ and $2\mu + 3\lambda > 0$.

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LU decomposition method: The LU decomposition method can be based on Gauss elimination, a widely employed direct method that can help solve big linear equation systems. One drawback of the LU decomposition algorithm is the computation storage resources since this method requires n^2 elements [4]. Equation 4 expresses the general LU decomposition algorithm.

$$L\left(Ux - c\right) = LUx - Lc = Ax - b \tag{4}$$

Therefore, based on matrix properties:

$$LU = A \tag{5}$$

$$Lc = b \tag{6}$$

3.2 Iterative solvers

The iterative methods solve linear and non-linear equation systems through successive approximations [17]. The iterative solvers start with an initial estimation and gradually improve the solution along the iterations. The flexibility to evaluate several variables is a vital feature of iterative solvers. However, the solution convergence is not guaranteed for all scenarios due to the case conditions. This study evaluated the Jacobi and Gauss-Seidel methods to solve the stiffness matrix. The relaxation technique was incorporated into the iterative solvers.

Jacobi: This method decomposes the matrix into a diagonal matrix and two triangular matrices. The main idea is to solve the equation for every specific variable using the information of other variables of the previous iteration. The iterative process is repeated until the residual or difference value between the current and the previous iteration is lower than a convergence criterion. The Jacobi method is easy to implement and appropriate to parallelize since the variable updating can be achieved independently. However, the numerical convergence is not always guaranteed since the coefficient matrix must be dominant diagonally. Equation 7 expresses the general Jacobi method. k indicates the actual iteration, and $k-1$ indicates the previous iteration.

$$x_i^k = \frac{1}{a_{ii}} \left(b_i - \sum_i a_{ij} x_j^{(k-1)} \right) \tag{7}$$

Gauss-Seidel: This method is an improvement of the Jacobi method and is based on the same idea of decomposing the coefficient matrix, with the difference of the variable updating. The Gauss-Seidel method updates each variable as soon as it is calculated, using the recently available information; this feature makes the Gauss-Seidel an accelerated solver compared to the Jacobi method. The convergence of this method depends on the dominant diagonally matrix and its symmetry. Due to the information dependency, the parallelization approach

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is unavailable for the Gauss-Seidel method without modifying the original approach. Equation 8 expresses the Gauss-Seidel method.

$$x_i^k = \frac{1}{a_{ii}} \left(b_i - \sum_{j<i} a_{ij} x_j^{(k)} - \sum_{j>i} a_{ij} x_j^{(k-1)} \right) \tag{8}$$

Successive Over-Relaxation (SOR): The main idea behind SOR is to accelerate the convergence of the Gauss-Seidel method using a relaxation factor α. However, this technique is also used in the Jacobi method. It can be used as an under-relaxation method to reduce the acceleration when the convergence is compromised due to the non-linear equation system. Equation 9 expresses the SOR technique for Jacobi and Gauss-Seidel.

$$x_i^\alpha = x_i^* + \alpha \left(x_i - x_i^* \right) \tag{9}$$

3.3 Preconditioning solvers

The preconditioning solvers are improved iterative methods to solve sparse and extensive equation systems. The preconditioner matrix transforms the original system $Ax = b$ into an equivalent and improved system to solve. The preconditioning accelerates the numerical convergence of the iterative method treated [11]. The preconditioned solvers reduce the iterations required to achieve the solution and the computational effort.

For this study, the Jacobi and Gauss-Seidel were preconditioned to compare the computation performance for the stiffness solution and its applicability to cases with linear or non-linear properties. Equation 10 shows a preconditioning matrix P.

$$P^{-1}Ax = P^{-1}b \tag{10}$$

Equation 10 has the same solution of $Ax = b$, however, the coefficient matrix $P^{-1}Ax$ is more suitable. The difficulty is to find a matrix A^{-1} or approximate and easy to invert at a reasonable computational cost. The preconditioning matrix for the Jacobi and Gauss-Seidel are $P_J = D$ and $P_{GS} = D + L$. D and L are the diagonal and lower triangular parts of matrix A. The preconditioning matrix was obtained using the incomplete factorization of the original A matrix. The technique used for the present study is the Incomplete LU decomposition, which considers that the L and U matrices obtained from factorized A have the same nonzero structure as the lower and upper components of A. Equation 11 described the components of A matrix obtained from Incomplete LU decomposition. R is the residual of the factorization.

$$A = LU + R \tag{11}$$

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3.4 Study case solution using FEM

It was decided to work with one-dimensional elements for modeling the structure of Figure 2, such as the one seen in Figure 3, which generates the matrix $\boldsymbol{k}^{\boldsymbol{\Omega}}_{prim}$, whose form can be seen in (12) [2,6,8,10,16]. Where A, E and l_{Ω} are the area, the modulus of elasticity of the material, and the length of the element, respectively.

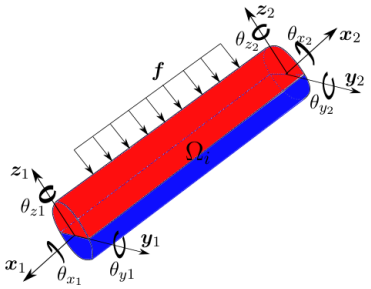


Figure 3. Representation of a longitudinal element Ω_i.

$$
\begin{bmatrix}
\frac{EA}{l_e} & 0 & 0 & 0 & 0 & 0 & \frac{EA}{l_e} & 0 & 0 & 0 & 0 & 0 \\
0 & \frac{12EI_z}{l_e^3} & 0 & 0 & 0 & \frac{6EI_z}{le^2} & 0 & -\frac{12EI_z}{l_e^3} & 0 & 0 & 0 & \frac{6EI_z}{l_e^2} \\
0 & 0 & \frac{12EI_y}{l_e^3} & 0 & -\frac{6EI_y}{le^3} & 0 & 0 & 0 & -\frac{12EI_y}{le^3} & 0 & -\frac{6EI_y}{l_e^3} & 0 \\
0 & 0 & 0 & \frac{GJ}{l_e} & 0 & 0 & 0 & 0 & 0 & -\frac{GJ}{l_e} & 0 & 0 \\
0 & 0 & -\frac{6EI_y}{l_e^2} & 0 & \frac{4EI_y}{l_e} & 0 & 0 & 0 & \frac{6EI_y}{l_e^2} & 0 & \frac{2EI_y}{l_e} & 0 \\
0 & \frac{6EI_z}{l_e^2} & 0 & 0 & 0 & \frac{4EI_z}{l_e} & 0 & -\frac{6EI_z}{le^2} & 0 & 0 & 0 & \frac{2EI_z}{l_e} \\
-\frac{EA}{l_e} & 0 & 0 & 0 & 0 & 0 & \frac{EA}{l_e} & 0 & 0 & 0 & 0 & 0 \\
0 & -\frac{12EI_z}{l_e^3} & 0 & 0 & 0 & -\frac{6EI_z}{l_e^2} & 0 & \frac{12EI_z}{le^3} & 0 & 0 & 0 & -\frac{6EI_z}{l_e^2} \\
0 & 0 & -\frac{12EI_y}{l_e^3} & 0 & \frac{6EI_y}{le^3} & 0 & 0 & 0 & \frac{12EI_y}{l_e^3} & 0 & \frac{6EI_y}{le^3} & 0 \\
0 & 0 & 0 & -\frac{GJ}{l_e} & 0 & 0 & 0 & 0 & 0 & \frac{GJ}{l_e} & 0 & 0 \\
0 & 0 & -\frac{6EI_y}{l_e^2} & 0 & \frac{2EI_y}{l_e} & 0 & 0 & 0 & \frac{6EI_y}{l_e^2} & 0 & \frac{4EI_y}{l_e} & 0 \\
0 & \frac{6EI_z}{l_e^2} & 0 & 0 & 0 & \frac{2EI_z}{l_e} & 0 & \frac{-6EI_z}{le^2} & 0 & 0 & 0 & \frac{4EI_z}{l_e}
\end{bmatrix} \tag{12}
$$

In order to integrate $\boldsymbol{k}^{\boldsymbol{\Omega}}_{prim}$ into the global matrix $\boldsymbol{K}$, which contains all the information that the individual elements of the structure provide, it is necessary to use (13)

$$
\boldsymbol{k}_{\Omega} = \boldsymbol{L}^T \boldsymbol{k}^{\boldsymbol{\Omega}}_{prim} \boldsymbol{L}. \tag{13}
$$

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Where $\boldsymbol{L}$ is a direction cosine matrix $\boldsymbol{D}$, which is commonly known as spin matrix, and its form [2, 6, 8, 13] can be seen in (15)

$$\boldsymbol{L} = \begin{bmatrix} D & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & D & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & D & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & D \end{bmatrix}, \tag{14}$$

with

$$D = \begin{bmatrix} l_1 & m_1 & n_1 \\ l_2 & m_2 & n_2 \\ l_3 & m_3 & n_3 \end{bmatrix}. \tag{15}$$

Now, the forces related to the structure can be punctual, $\boldsymbol{f}_p$, or uniformly distributed [2, 8]. If the forces are the first ones, they are taken into account by introducing nodes at the points of application. If they are the second ones, they are introduced into the global load vector $\boldsymbol{F}$ using the relation (16) [2].

$$\boldsymbol{f}^{\Omega} = \boldsymbol{L}^T \boldsymbol{f}_{prim}, \tag{16}$$

with

$$\boldsymbol{f}^{\Omega}_{prim} = \begin{bmatrix} 0 & \frac{f_y l_\Omega}{2} & \frac{f_z l_\Omega}{2} & 0 & -\frac{f_z l_\Omega^2}{12} & \frac{f_y l_\Omega^2}{12} & 0 & \frac{f_y l_\Omega}{2} & \frac{f_z l_\Omega}{2} & 0 & \frac{f_z l_\Omega^2}{12} & \frac{f_y l_\Omega^2}{12} \end{bmatrix}^T. \tag{17}$$

We then obtain the vector $\boldsymbol{U}$ constructed from the individual displacements of each node. This information must be understood as seen in (18) [8].

$$\boldsymbol{U} = \begin{bmatrix} x_1 \\ y_2 \\ z_1 \\ \Theta_{x1} \\ \Theta_{y1} \\ \Theta_{z1} \\ \vdots \\ x_n \\ y_n \\ z_n \\ \Theta_{xn} \\ \Theta_{yn} \\ \Theta_{zn} \end{bmatrix} \begin{matrix} \left.\begin{matrix} \\ \\ \\ \end{matrix}\right\} \text{Translations node 1} \\ \left.\begin{matrix} \\ \\ \\ \end{matrix}\right\} \text{Node 1 rotations} \\ \\ \left.\begin{matrix} \\ \\ \\ \end{matrix}\right\} \text{Translations node n} \\ \left.\begin{matrix} \\ \\ \\ \end{matrix}\right\} \text{Node n rotations} \end{matrix} \tag{18}$$

Finally, since $\boldsymbol{K}$ s a singular matrix, Dirichlet-type conditions of the form $u_i = 0$, are considered, where i corresponds to the i-ťh displacement (translational and rotational) of the i-ťh node whose value is considered fixed.

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3.5 Solution's Algorithms

With the theory exposed on sección 3.4, Algorithm 1 solves $\boldsymbol{KU} = \boldsymbol{F}$, which is a result of aplying FEM tecniques to (1) [8, 18]. Algorithm 1 considers the number of nodes N_n, its numeration n, the number of nodal displacements N_u, as well as its restring nodes n_{res} and coordinates ϕ_n to find $\boldsymbol{U}$. Inertia is also consider in the form of I_y, I_z, and J. Steps 6 through 12 compound the whole iterative process, and step 11 is important for applying boundary conditions. Steps 13 through 18 assigns $\boldsymbol{f}^{\Omega}$ and $\boldsymbol{f}_p$ to $\boldsymbol{F}$, which is important to choosing any given solver. Finally, $\boldsymbol{R}$ and $\boldsymbol{M}$ are calculate in base of $\boldsymbol{U}$. A computer code was developed in OCTAVE ®programming environment, it call **3DES**. Also, a free and more developed software, named LISA ®, is used to validate results. The computational runs were executed on a computing platform with an Intel Core i5-10300H processor with 2.5 GHz and 16 GB of RAM on a Windows operating system (windows 10 64-bits).

Algorithm 1 Build of stiffness matrix $\boldsymbol{K}$ and load's vector $\boldsymbol{F}$ and node's displacements $\boldsymbol{U}$

Require: Ω, N_n, N_u, n, n_{res}, ϕ_n, A_Ω, E, G, I_y, I_z, J, $\boldsymbol{f}^{\Omega}$, $\boldsymbol{f}_p$
1: $\boldsymbol{K} \leftarrow [\boldsymbol{0}]_{N_u \times N_u}$
2: $\boldsymbol{U} \leftarrow [\boldsymbol{0}]_{N_u \times 1}$
3: **for** $i \leftarrow 1$ **to** N_Ω **do**
4: Compute $\boldsymbol{L}(\Omega_i)$
5: Compute $\boldsymbol{k}^{\boldsymbol{\Omega}}_{prim}(\Omega_i)$
6: $\boldsymbol{k}_\Omega = \boldsymbol{L}^T \boldsymbol{k}^{\boldsymbol{\Omega}}_{prim} \boldsymbol{L}$
7: $\boldsymbol{K}(\Omega_i) \leftarrow \boldsymbol{k}_\Omega$
8: $\boldsymbol{K}(n_{res}(i)) \leftarrow 0$
9: **end for**
10: **if** $\boldsymbol{f}^{\Omega} \neq \emptyset$ **then**
11: $\boldsymbol{F} \leftarrow \boldsymbol{f}^{\Omega}$
12: $\boldsymbol{F} \leftarrow \boldsymbol{f}_p$
13: **else if** $\boldsymbol{f}_p \neq \emptyset$ **then**
14: $\boldsymbol{F} \leftarrow \boldsymbol{f}_p$
15: $\boldsymbol{F} \leftarrow \boldsymbol{f}^{\Omega}$
16: **end if**
17: **print** $\boldsymbol{K}$ and $\boldsymbol{F}$
18: Declare selction solver
19: **if** selection solver = direct **then**
20: Perform inverse matrix and LU decomposition
21: **else if** selection solver = iterative **then**
22: Perform Gauss-Seidel and Jacobi
23: **else if** selection solver = preconditioning **then**
24: Perform preconditioning Jacobi and preconditioning GS
25: **end if**
26: **print** Results for $\boldsymbol{U}$

4 Numerical solution and verification of results

Table 2 shows the error between reactions of Chandrupatla & Belegundu and the reaction's results from the algorithm proposed in section 3.5. The first column of the table expresses the fixed nodes of the study's problem. Each node has

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six degrees of freedom (dof), as seen in the second column. For example, dof 7 through 9 correspond to x, y, z displacements and dof 10 through 12 correspond to Θ_1, Θ_2, Θ_3 rotation's displacements. It is the same for nodes 2, 20, and 21. Columns 3 and 4 exhibit the reaction's results in klb units, and the comparison between them indicates that the estimation error is around 0.001%. LISA's software generates a similar result. Fig. 4 shows that the highest deformation rate occurs in nodes 1,5,9,11 and 13, similar to **3DES**. If the structure is divided in half, it can be seen that the first half is deformed by the action of the impact's load applied in node 1, and the second half is barely moved by it.

Table 2: A briefly comparison of reactions

Nodes	DOF	Reactions [2][klb]	3DES [klb]
1	7	26.000	25.980
	8	-2.235	-2.239
	9	4.151	4.145
	10	56130	56.060
	11	41.560	51.560
	12	391.000	390.400
2	13	0.162	0.152
	14	-1.067	-1.064
	15	-1.260	-1.258
	16	19.780	19.670
	17	9.342	9.363
	18	-9.995	-9.993
20	115	5.951	5.968
	116	1.550	1.552
	117	-4.528	-4.517
	118	-27.320	27.320
	119	104.900	104.600
	120	-23.280	-23.990
21	121	0.150	0.147
	122	2.608	2.607
	123	1.637	1.630
	124	-35.780	-37.750
	125	-11.900	11.880
	126	-4.857	-5.001

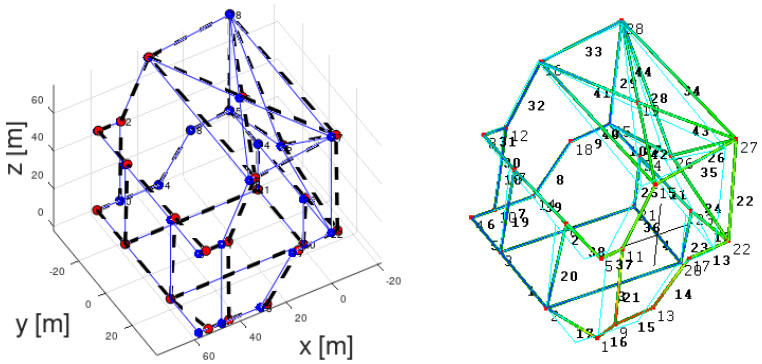
According to Table 3, a performance problem occurs when Jacobi and Gauss-Seidel's methods are applied to searching $\boldsymbol{U}$. Those methods diverge even when applied under relaxation. However, it is fixed with suitable preconditioning criteria. The behavior of those methods is interesting; by themselves, they diverge

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as iteration increases, but when preconditioning is applied, the solution achieves the convergence, with a low rate of iterations and less machine time expended, 19.865 s and 20.394 s respectively. Fig.5 shows the iterative behavior.

Table 3: Comparison of iterative and direct methods.

Method	No. of iter [-]	Time [s]	Residual [-]
Inverse Matrix	N/A	3.620	N/A
LU decomposition	N/A	3.293	N/A
Jacobi's method	-	-	no convergence
Gauss-Seidel method	-	-	no convergence
Preconditioning Jacobi	53	19.865	7.48E-04
Preconditioning Gauss-Seidel	53	20.394	7.48E-04



(a) 3DES **(b)** LISA software

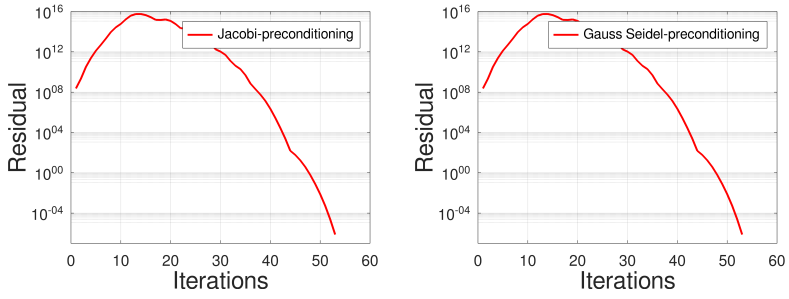
Figure 4. A comparison between LISA and **3DES** results

Fig.5 shows that the iterative solution presented a similar behavior, an effect of the ILU decomposition. The preconditioning strategy generates a superior matrix that only uses the information of the previous iteration. Therefore, the approach preconditioning Gauss-Seidel presented a similar numerical convergence. The sparse stiffness matrix was an obstacle that conventional Jacobi and Gauss-Seidel methods could not solve; an alternative that must be explored in future works is the rearrangement of the equations to reduce the divergence solution using the under-relaxation iterative methods. Another scenario to examine is combining the SOR and preconditioning techniques to reduce the iterations.

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The present study case considered linear properties and boundary conditions. However, the sparse matrix was the main difficulty for the iterative solvers. Although the direct solvers obtained the best computational performances, these methods are limited for the non-linear boundary conditions. Therefore, iterative solvers are reliable for general scenarios.

The effect of preconditioning methods must be analyzed to explore the potential of iterative solvers in the search for the best computational performance in the numerical solution of the structure and coupled phenomena analyzed in the smart industry area.



(a) Jacobi performance **(b)** Gauss-Seidel performance

Figure 5. A comparison between Preconditioning Jacobi and Gauss-Seidel method

5 Conclusions

This article presented a comparison of the computational performance of the finite element method's algorithm applying direct solvers, iterative solvers, and preconditioned iterative solvers to accelerate the numerical solution in the application of smart industry.

A pickup truck cab structure's design was used as a study case. The FEM algorithm was programmed in Octave's environment, and the numerical solution was compared with the reported data in the literature and the LISA's FEM software.

The results indicate that the algorithm proposed is suitable and trustworthy. The direct solvers presented the best computational time but were limited to linear problems. The preconditioning Jacobi and Gauss-Seidel were the most suitable methods because of their convergence ratio and computational performance. However, other preconditioner strategies must be evaluated to reduce the iterations with complex geometries and non-linear boundary conditions.

ISBN 978-9930-617-71-7

The main lines of future work are oriented toward extending the proposed solution methodology to triangular elements and coupled phenomena like vibration, temperature, and time effects, and considering the variation of the dimensions and materials to provide new solutions for smart industry problems.

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ISBN 978-9930-617-71-7

Inactivation of *E. coli* using ZnO and UV-LED technology: A promising approach for water treatment

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Abstract.

This study aims to evaluate the efficacy of advanced oxidation processes, in particular photocatalysis combined with ultraviolet light from light-emitting diodes (UV-LEDs), to inactivate *Escherichia coli* bacteria (strain *ATCC 8739*). The innovation of this research lies in the use of zinc oxide (ZnO) obtained from the recycling of zinc-carbon batteries, a sustainable alternative that has been little explored in bacterial disinfection applications. In addition, a log-linear kinetic model with tail effect is used to describe the inactivation process, evaluating the effectiveness of different ZnO concentrations (0%, 0.1%, 0.2% and 0.6%) under UV irradiation at 365 nm in a collimated system, with an exposure time of 15 minutes in all cases. The results show that recycled ZnO in combination with UV-LED light is effective in disinfection, achieving an inactivation of 3 log in 15 minutes with a concentration of 0.6% ZnO. This approach represents an important contribution to the field of photocatalysis for water treatment, proposing a sustainable technology that can have a relevant impact in the context of smart and sustainable cities.

Keywords: *E. coli*, batteries Zn-C, zinc oxide, water management, SDG 6

1 Introduction

Batteries are electronic devices used in a wide variety of applications, from wristwatches to toys, remote controls to flashlights. Two types of batteries commonly used

ISBN 978-9930-617-71-7

are alkaline batteries and zinc-carbon (Zn-C) batteries. Both types have their own advantages and disadvantages, as well as environmental impacts. Alkaline batteries are commonly used because of their long-life, high-energy density and availability in a wide variety of sizes [1]. On the other hand, zinc-carbon batteries are cheaper and easier to produce, which makes them widely used in low-power applications. However, they also have a significant environmental impact. The production of these batteries requires the extraction of zinc and the emission of greenhouse gases in the manufacturing process. In addition, zinc-carbon batteries have a shorter lifespan than alkaline batteries, resulting in a larger amount of waste that must be properly disposed of to avoid environmental pollution. As these batteries are discharged, the zinc anode decomposes and forms a layer of zinc oxide, which is deposited on the surface of the anode. This zinc oxide layer is a valuable material that can be used to produce catalysts [4].

Catalysts are substances that increase the rate of a chemical reaction without being consumed in the process, playing a crucial role in various industrial and scientific applications [5]. Catalysts produced from recycled Zn-C batteries, for instance, have a wide range of uses, including the production of methanol from carbon dioxide and the synthesis of various organic compounds. They are also essential in facilitating oxidation and reduction reactions, making them highly valuable in chemical processing. To obtain catalysts from Zn-C batteries, the zinc anode is initially extracted, followed by decomposition of the zinc oxide layer in the presence of a reducing agent, such as hydrogen, to produce metallic zinc particles. These particles are then treated with an oxidizing agent to create a highly active form of zinc oxide that serves as an efficient catalyst [6].

Advanced oxidation is a process that uses strong oxidants to degrade organic contaminants present in water [8]. Catalysts act as accelerators in this process, increasing the reaction rate and reducing the treatment time required. In advanced oxidation processes using zinc oxide as a catalyst, a wide range of contaminants can be treated, including organic compounds, pesticides, pharmaceuticals and hormones. In addition, UV disinfection with zinc oxide can also eliminate the formation of disinfection byproducts, such as trihalomethanes and haloacetic acids, which are toxic and can be carcinogenic [9].

One of the most frequently used advanced oxidation processes are photocatalysis processes. Titanium dioxide (TiO_2) is one of the most widely used photocatalysts over the years; however, as an alternative to this compound, other metal oxide nanoparticles, such as zinc oxide (ZnO), have also been studied due to their potential to improve disinfection, especially against bacteria and parasites [10], [11], [12]. Both TiO_2 and ZnO are semiconducting metal oxides that facilitate the absorption of UV light, a characteristic that makes them ideal for use as catalysts in the photocatalysis process. Both materials are broad bandgap n-type semiconductors and can interact with lipopolysaccharide molecules present in the outer membrane of *E. coli* as well as produce reactive oxygen species (ROS) under ultraviolet illumination [10]. The radicals generated in the photocatalysis process cause additional damage to those produced by UV light in the structures of organisms, such as cell walls, membranes, genetic material, and proteins, with particular importance on enzymes involved in the repair of cell damage [11], [13]. Previous studies have found improved disinfection of organisms by photocatalytic

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treatment relative to the application of UV light alone [12], [14]. Therefore, the application of photocatalytic treatment can increase disinfection and decrease the doses of UV light required to achieve a certain degree of inactivation, especially in the inactivation of organisms more resistant to UV light [15]. Reducing the doses of UV light needed in the treatment allows, on the one hand, to save energy by requiring fewer lamps and, on the other hand, to increase efficiency by shortening the exposure time in the reactor. Furthermore, as explained in [16], another advantage of these photocatalytic materials is that they can come from recycling processes, unlike chemical methods that rely on the consumption of chemical disinfectants to achieve the expected results.

On the other hand, the use of LEDs for UV disinfection represents a significant advance in water treatment technology, offering higher efficiency and longer life compared to conventional UV lamps [18]. In addition, LEDs allow precise wavelength control, which optimizes zinc oxide activation and maximizes disinfection efficiency. The use of zinc oxide as a catalyst in UV LED disinfection promises to become a highly effective and safe approach for water treatment, capable of eliminating pathogenic microorganisms and degrading organic contaminants. This technology is envisioned as an ideal solution for both wastewater and drinking water treatment systems, making a significant contribution to Sustainable Development Goal 6 (SDG 6) by promoting universal access to safe drinking water and sanitation. In this context, the present study aims to analyze the effectiveness of advanced oxidation processes, specifically photocatalysis combined with UV LED irradiation, in the inactivation of *E. coli* ATCC 8739.

The research question is posed on how to take advantage of recycled materials, specifically Zinc-Carbon batteries, to develop an efficient and sustainable water disinfection technology by applying advanced oxidation processes with ZnO and UV-LED. This approach not only contributes to sustainability by reusing materials and reducing toxic waste, but also responds to the urgent need for water treatment solutions that minimise energy consumption and are adaptable in urban environments. Smart Cities, as a model of smart cities, seek to implement innovative technologies that optimise resources and improve the quality of life of citizens. In this context, the proposed methodology could be integrated into decentralised water treatment systems within smart cities, enabling an environmentally friendly and low-energy approach to drinking water disinfection and wastewater treatment. In this way, the research contributes to the principles of sustainability and resilience, essential in the development of safer and more efficient cities to meet the challenges of climate change and resource scarcity.

2 Materials and Methods

2.1 Preparation and characterization of zinc oxide

Zn-C batteries provided by the company ETAPA EP from the city of Cuenca-Ecuador were used. First, batteries in good condition, i.e., without rust or spills, were selected and disassembled to obtain the zinc case, which was leached to obtain zinc oxide using a pyrometallurgical method proposed by Garcia y Ochoa [19]. Briefly, 115.6 g of the Zn box was leached in 300 mL of 37% hydrochloric acid in an Erlenmeyer at

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100°C for 60 min, obtaining zinc chloride. Subsequently, 250 mL of 50% sulfuric acid was added. The solution was heated at 100 ºC for one hour. To eliminate the impurities of the zinc sulfate obtained, 500 mL of distilled water were added to the solution and the mixture was heated to boiling point. After that, it was filtered through Whatman Nº40 paper, the filtered solution was cooled at room temperature for 24 hours, obtaining zinc sulfate crystals. Sodium hydroxide (Fisher scientific., assay ≥ 98.9 %) at 30 % was used on the crystals until a pH of 6.5 was reached. The new solution was again filtered through Whatman No. 40 paper and after that, the paper with the solute was dried at 100 °C for 1 hour. Finally, the dried paper was placed in a crucible and incinerated at 900 ºC in a muffle for 6 hours (Fig. 1).



Fig. 1. Preparation process of ZnO from zinc carbon batteries

2.2 Preparation and characterization of zinc oxide

- **Purity**: The zinc content was determined using a Perkin Elmer 3300 AA atomic absorption spectrometer, equipped with a graphite furnace (HGA 600).
- **Color**: The color of the obtained zinc oxide was assessed through direct observation, recording the visual characteristics of the synthesized sample.
- **Yield**: The yield of the zinc oxide production process was calculated using the following formula (Eq. 1):

$$Y = \frac{w_o - w_f}{w_o} * 100 \qquad (1)$$

Where W_0 = initial weight of the Zn and W_f = weight of the oxide obtained

- **Particle Size**: The particle size was determined by measuring absorbance using the THERMO SCIENTIFIC GENESYS 50 spectrophotometer (model 840-298000). The absorbance values allowed estimation of the average particle size in the zinc oxide sample.

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2.3 Obtaining *E. coli* strain ATCC 8739

The bacterial strains *E. coli* ATCC 8739 were supplied by the Spanish Type Culture Collection (University of Valencia, Spain) in lyophilized format, with this they were firstly arranged in suspension format in glycerol-water to be preserved. In each test, these lyophiles were reactivated in 50 mL of Tryptic Soy Broth (TSB) culture medium (Sigma-Aldrich), for 24 h at 37ºC. Subsequently, a subculture was performed by depositing 1 mL of the culture in 50 mL of TSB medium. After another 24 h, the subculture was centrifuged at 3000 rpm for 10 min; after discarding the supernatant, the sediment obtained was washed with peptone solution (10%) and added to 50 mL of distilled water with phosphate buffer at pH 7.20, obtaining the bacterial inoculum in exponential growth phase [20].

To determine the bacterial concentration after the treatments, the membrane filtration method and subsequent incubation on chromogenic selective agar was applied. Sterile 0.45 µm grid membrane filters (Pall Corporation, NY, USA) were used to obtain the appropriate number of CFU (colony-forming units); decimal serial dilutions of each sample were seeded in triplicate. Merck Coliform Agar Acc. Chromocult® was used as selective medium, deposited in Petri dishes. The samples were incubated at 37 °C for 24 h; after this time, the CFU developed were counted and those corresponding to the plates with a number of CFU between 20 and 150 were considered as valid dilutions. Sterile conditions were controlled by means of blank sample plates during the microbiological analysis process (see Fig. 2).

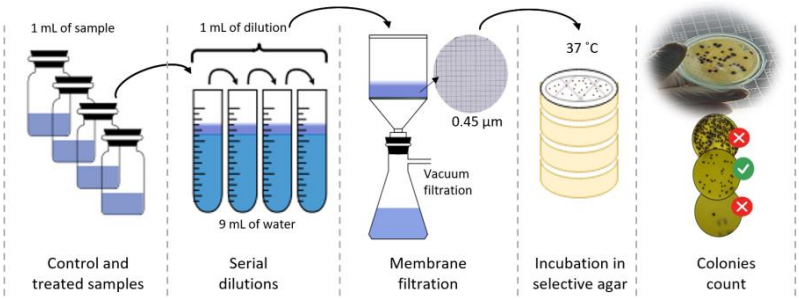


Fig. 2. Analysis of bacterial samples after treatment using the membrane filtration method: the use of sterile 0.45 µm membrane filters to retain bacteria, followed by incubation on chromogenic selective agar, allows accurate quantification of colony forming units (CFU) in treated samples.

2.4 LED reactor description

UV treatment was applied using a triple wavelength collimated beam LED reactor (AquiSense Technologies, USA) containing a triple wavelength UVinaire™, a control box, a UV homogenization tube and an AC-DC adapter (12 V 90 W). The applied wavelength was 365 nm (provided by a set of 3 LEDs) with an average intensity

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measured at 6 cm (the same height used to perform the experiments) of 388.26 µW cm^{-2} at 365 nm determined with an ILT 950 UV spectroradiometer (Massachusetts, USA).

2.5 Inactivation experiments

For the experiment, 10 mL aliquots were meticulously prepared, consisting of 9 mL of autoclave-sterilized distilled water and 1 mL of bacterial strain stock suspension, to which specific ZnO concentrations (0%, 0.1%, 0.2%, and 0.6%) were added. Each prepared solution was placed in 10 cm Petri dishes and exposed to a 365 nm wavelength using the collimated device described in the previous section, with exposure times extending up to 40 minutes.

The Petri dishes were strategically positioned so that the center of each dish aligned precisely with the irradiation point of the device, ensuring an even distribution of UV light across the sample. During exposure, each sample was kept under constant agitation with a pre-sterilized magnetic stirrer and rod, promoting uniform treatment. At regular intervals, approximately every 10 minutes, 1 mL samples were carefully withdrawn and immediately subjected to serial dilutions based on the initial concentration to assess post-treatment bacterial levels. Valid samples were considered those with countable colony numbers. Following this, the diluted samples were plated onto Petri dishes in accordance with the protocol detailed in section 2.3.

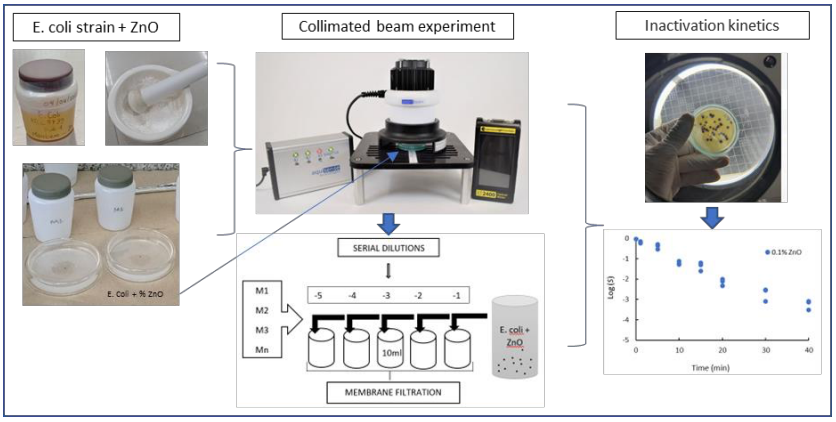


Fig. 3 Scheme of the experimental procedure: aliquots of bacterial sample are prepared, to which zinc oxide (ZnO) is added in different concentrations. These samples are then placed in Petri dishes and exposed to UV light at 365 nm in a collimated irradiation device, keeping the solution under constant agitation. After the exposure time, an aliquot is extracted and bacterial counts are performed by serial dilutions and seeding on selective agar.

2.6 Analysis of results

The effectiveness of disinfection was assessed by calculating the logarithmic reduction in the survival of microorganisms, using the formula $\log(N/N_0)$, where N_0 and N

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represent the number of colonies (CFU/mL) before and after UV irradiation, respectively. To describe the inactivation processes of *E. coli*, the inactivation model fitting tool of Geeraerd and Van Impe, known as GInaFiT (Geeraerd et al., 2005), was used. GInaFiT is a software widely used in microbiology to fit microbial survival curves, allowing researchers to model various patterns of bacterial inactivation as a function of kinetic parameters. The R^2 values obtained from the regression between the experimental data and the values fitted by the model indicated the accuracy of the fit. From the inactivation kinetic parameters, the dose (D_3) required to reduce the initial concentration by two to three orders of magnitude was determined and used as an estimator of treatment efficacy.

3 Results

3.1 Preparation and characterization of zinc oxide

The catalyst was characterized and the results are shown in Table 1. The purity showed a percentage of 98.49%, higher than that of García y Ochoa [19] who used the same principle (hydrometallurgical). The color was white as seen in the sample in Fig. 2. The yield is 56.20%, this percentage is similar to that obtained by by these authors of 54.7% but is lower when using alkaline batteries being the percentage of 66.42%. Finally, 20.92% of the sample is in the nanometer scale, which implies that the size reduction was not homogeneous.

Table 1. Characteristics of obtained zin oxide

Characteristic	Value
Color	White
Yield	56.20 %
Particle size (1-10nm)	20.92 %

3.2 Inactivation of *E. coli* ATCC 8739 following UVLED irradiation at various doses of ZnO

The experiments performed to demonstrate an effective inhibition of bacterial growth in all cases evaluated. Fig. 4, shows the survival of *E. coli* ATCC 8739 cells against the four concentrations of ZnO used as catalyst. In all cases, a significant decrease in survival is observed as the ZnO concentration increases, initially showing a linear behavior in inactivation until a specific exposure time is reached, after which an asymptotic trend is observed. This result highlights the effect of ZnO in reducing bacterial viability, especially at higher concentrations, suggesting a maximum impact achieved in the disinfection process (Fig. 4).

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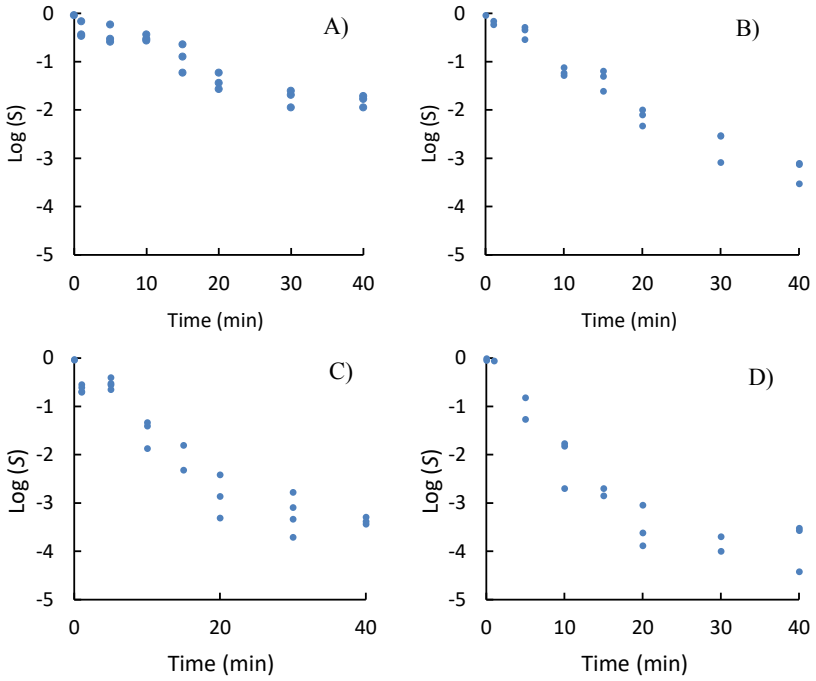


Fig. 4. *E. coli* inactivation curves for different catalyst concentrations (% ZnO): A) 0 %, B) 0.1 %, C) 0.2 % and D) 0.6 % ZnO.

Regarding the concentration of ZnO; if take the same time of exposure to radiation, 20 minutes, for example; the strains exposed only under the UV system are the least affected (Fig. 4-A) and have a higher survival since they do not reach an elimination beyond 1 log of inactivation, this means that the growth inhibition has been less than 90%. As the catalyst dose is increased, greater inactivation is achieved, in the case of 0.6% ZnO up to 4 log inactivation (Fig. 4-D), thus proving that the ZnO nanoparticles do have a positive effect on the inactivation of the *E. coli* ATCC 8739 strain. coli ATCC 8739, this can be explained because under the UV illumination process, ZnO is activated to generate a conduction electron and a hole (ZnO-h+), which behaves as an oxidizing agent. The creation of the electron-hole pair has been shown to be important for the oxidation process [17], [22]. The higher the concentration of ZnO the greater the contribution of oxygen molecules that are transformed into superoxide radical anion (+ O-), which in turn reacts with H+ to generate a hydrogen peroxide radical (+ HO-) and produce hydrogen peroxide anions (HO-) that finally end up forming H2O2, responsible for affecting the cell membrane and subsequent lysis of the microorganism (put author) . This oxygen uptake mechanism and its bactericidal capacity is therefore

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influenced by the amount of ZnO added, being directly proportional to this bactericidal capacity.

3.3 Kinetics of response to ZnO treatment and UV radiation.

The data were fitted to a kinetic model, in all cases showing inactivation kinetics according to a log-linear model with tails (Eq. 2), where S: survival; S_0: survival in the absence of irradiation; S_{res}: residual survival; k: inactivation rate; D: UV dose) [23]. The R^2 values show good prediction results for the model with values above 0.9 in most cases (Table 1).

$$S = (S_0 - S_{res})\, e^{-k \cdot D} + S_{res} \qquad (2)$$

The inactivation kinetic parameters obtained by the model allow quantifying the effect of the treatment on the variants studied (Fig. 3). The inactivation rate (k) decreases with increasing ZnO concentration, with values from 0.15 to 0.45 min-1 for catalyst doses from 0 to 0.6% ZnO, respectively, when 0.6% ZnO was used, being 3 times higher than without catalyst. Therefore, the photocatalyst does play an important role in determining the inactivation rate, since a higher initial concentration of photocatalyst (0.6%) produces a more effective bactericidal effect.

The Log (S_0) values of the incubated samples represent the effect of incubation on the survival of the organisms, without taking into account the effect of UV treatment and UV treatment with ZnO, thus quantifying the impact of incubation on bacterial survival. The values in all cases are close to 0 indicating that incubation by itself has no effect on survival in general.

By using the Log-linear with tail model, it allows estimation of the logarithm of residual survival ($logS_{res}$) that characterizes the inactivation tail kinetics and is useful if minimum counts are desired, since it will not be necessary to prolong a treatment beyond the indicated fluences because additional inactivation would not be achieved [24]. It is observed that the values are close to 0 in all cases.

Table 2. Kinetic parameters of the statistical adjustment of the assays.

% ZnO	k (min^{-1}) ± SE	Log (S_0)± SE	Log (S_{res}) ± SE	R^2	RMSE	D_3 (min) ± SE
0	0.15±0.02	-0.07±0.07	-1.93±0.14	0.92	0.20	-----
0.10	0.23±0.02	-0.04±0.08	-3.29±0.16	0.97	0.21	32.7±7.0
0.20	0.31±0.03	-0.14±0.1	-3.34±0.13	0.95	0.31	23.2±0.9
0.60	0.45±0.04	-0.02±0.13	-3.82±0.14	0.96	0.32	15.6±0.6

Since in a log-linear model with a tail, the efficacy results from the combination S_{res} and k, a new parameter including the effect of both is needed, D_3 being normally used for this purpose [25] (Fig. 4). Therefore to compare the effect on bacterial survival as a

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function of the ZnO concentration tested; they were examined according to the UV dose required to achieve three logarithmic reductions of the initial concentration (D_3). This was calculated using the three inactivation kinetics parameters obtained in the log-linear model fit with tailing. According to the D_3 values, this decreases as the concentration of ZnO applied increases, for 0.1% ZnO a dose of 32.7 ± 7.0 min is needed, while with a concentration of 0.6% ZnO a dose of 15.6 ± 0.6 min is needed to obtain a reduction of 3 orders of magnitude, i.e. the dose needed for growth inhibition to be less than or equal to 99.9% with respect to the initial population of the *E. coli* ATCC 8739 strain.

4 Discussion

In the present study, ZnO recycled from Zn-C batteries was experimented with and used in the photocatalytic degradation of *E. coli* strain ATCC 8739, at concentrations of 0%, 0.1%, 0.2% and 0.6% at different inactivation times of up to 40 min exposure and under the same wavelength (365 nm) in a collimated UV-LED reactor. It was found that with a concentration of 0.6% ZnO an exposure time of 15.6±0.6 min is needed to obtain a reduction of 3 orders of magnitude (99.9% reduction of the initial concentration of the bacterial population).

Previous studies have explored different aspects of *E. coli* inactivation and UV disinfection using ZnO catalysts, including the efficiency of the process, the influence of factors such as bacterial morphology and sunlight intensity, as well as the effectiveness of disinfection on different ZnO surfaces. Overall, ZnO-assisted photocatalysis has been found to be highly effective in inactivating *E. coli*, suggesting that this method could be an effective alternative for water disinfection.

In particular, the study by Karunakaran et al. (2010) demonstrated that ZnO nanorods have an efficiency in photocatalytic inactivation of *E. coli*, reaching an inactivation rate of 99% after 120 min of exposure to UV light. Leung, et.al (2016), study examined the ability of ZnO to inactivate *E. coli* by photocatalysis and they found that the inactivation rate of *E. coli* was 98% in 120 minutes of UV irradiation. Furthermore, they found that the photocatalytic activity of ZnO increased with decreasing particle size [27]. Finally, Liu y Yang (2003)[17], investigated the inactivation of *E. coli* on the surface of ZnO by UV irradiation, finding that the inactivation increased with ZnO concentration. Furthermore, they found that the inactivation of *E. coli* was not only due to photocatalysis, but also due to adsorption and degradation of *E. coli* on the ZnO surface. Overall, these studies suggest that ZnO-assisted photocatalysis may be an effective alternative for water disinfection and that the efficiency of *E. coli* inactivation by ZnO may depend on factors such as bacterial morphology, buffer chemistry, and ZnO concentration.

Regarding the inactivation k, the maximum value found in the study is similar to that reported in another study, where they found a value of 0.45 min-1 for *E. coli* treated with 2 g/l of ZnO in 60 minutes of exposure to UV light, through a collimated UV-Hg reactor [17], the experimental time to obtain this inactivation rate in our case was 40 min.

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Comparing the results obtained, in terms of exposure time, it appears that UV-LED diodes may require less exposure time compared to traditional mercury UV systems, suggesting that this technology could have applications in different areas of disinfection and water treatment. However, further research is required to optimize the inactivation conditions and to evaluate its feasibility and applicability in different situations and environments.

5 Conclusions

In general, an exposure time of approximately 15 min, a ZnO concentration of 0.6%, is needed to achieve an inactivation of 3 log inactivation. Irradiation with ultraviolet light using LEDs can improve the inactivation efficiency and in conjunction with ZnO can also improve its photocatalytic activity. Furthermore, the combination of ZnO and UV may be useful in the disinfection of water and surfaces contaminated with bacteria, which may have important implications for public health and the environment. Despite the promising results, further research is needed to optimize the experimental conditions and determine the feasibility of these techniques for large-scale application.

Declaration of Competing Interest

The authors declare that they have no conflicts of interest regarding the publication of this article. They have no financial or personal relationships with any individuals or organizations that could inappropriately influence or bias the content of this work. The funding sources that supported this research have been disclosed in the acknowledgments section.

Acknowledgements

We would like to express our gratitude to the laboratory personnel who contributed to the success of this research. To the company ETAPA (Empresa de Telecomunicaciones, Agua Potable, Alcantarillado y Saneamiento), to the Battery Recycling Program of the Department of Environmental Management, for providing the batteries used in this study and the facilities for their dismantling.

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ISBN 978-9930-617-71-7

Artificial Intelligence for smart cities

Cricket Score Prediction using Machine Learning Techniques

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Abstract. Cricket's captivating nature, especially in the One Day International (ODI) format, has long fascinated a global audience. However, the sport's unpredictability has posed challenges to reliable match outcome predictions. This research paper presents a machine learning-based model for predicting the total first-inning score of ODI cricket matches. To analyze the data, we use various data preprocessing techniques to clean and organize the data collected from 1188 ODI matches. The selected features for the prediction task include runs, wickets, overs, runs_last_5, wickets_last_5, striker, and non-striker. Using various metrics, we evaluate the performance of different machine learning models, such as Random Forest, Gradient Boosting, XGB, LGBM, CatBoost, AdaBoost, ANN, and MLP. Our results show that Random Forest has the highest accuracy in predicting the final score of an ODI cricket match. By segmented modeling on the Random Forest, we improve the results to 87%. The study concludes by highlighting the potential applications of the developed model in predicting the outcome of future cricket matches and providing insights into the performance of teams and players.

ISBN 978-9930-617-71-7

Keywords: Machine Learning · Cricket · Hyperparameter Tuning · Segmented Modeling · Winning Prediction.

1 Introduction

Cricket is a trendy sport worldwide, with ODI cricket being a stimulating format [6, 11]. Its unpredictable nature poses a challenge even for experts to predict match outcomes. Nevertheless, with the emergence of machine learning and data analytics, it has become feasible to develop more accurate models for predicting the result of cricket matches [4].

Previous studies have focused on developing prediction models and algorithms to forecast various aspects of T20 cricket, particularly in the Indian Premier League (IPL). These include scores [4, 1], win percentages [10], outcomes, player performance [7], and team strengths. These research papers emphasize the importance of accurate predictions in cricket and discuss the challenges associated with game variability and player capabilities. These previous studies use a variety of machine learning algorithms such as linear regression, logistic regression, random forest, support vector machine, and decision trees to analyze data and develop prediction models [1]. Furthermore, such studies have explored prediction models and algorithms for accurately forecasting scores [4, 1], win percentages [10], outcomes, player performance [7], and team strengths in T20 cricket, specifically in the Indian Premier League (IPL). These research papers highlight the importance of accurate predictions in cricket and discuss the challenges associated with game variability and player capabilities. The results demonstrate the potential of machine learning in improving cricket predictions and making significant contributions to the sports industry.

This study presents a machine learning model that can predict the total score of the first innings in ODI cricket matches. We use the data from 1188 ODI matches and apply preprocessing techniques to clean and organize the data. We select seven features for the prediction task, including runs, wickets, overs, runs_last_5, wickets_last_5, striker, and non-striker. Next, we employ eight machine learning algorithms, including Random Forest, Gradient Boosting, XGB, LGBM, CatBoost, AdaBoost, ANN, and MLP, with segmented modeling to forecast the final score. The performance of the algorithms is evaluated using metrics such as R-squared value, mean squared error (MSE), mean absolute error (MAE), and accuracy. The study's findings reveal that Random Forest exhibited superior accuracy, achieving an R-squared value of 80.7% and accuracy of 85.7%. Its segmented version shows further performance improvements, achieving an accuracy of 87%. Furthermore, the research offers insights into team and player performances and highlights potential applications of the model in predicting future cricket match outcomes.

The paper is organized as follows: Section II briefly summarizes the previous research in the field and highlights the research gap. Section III outlines the steps taken in this research, including data collection, preprocessing, feature selection, model selection, evaluation, hyperparameter tuning, and deployment.

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Section IV presents the outcomes derived from this research, and finally, Section V concludes the study.

2 Literature Review

This section presents the most relevant previous studies that have used machine learning models to predict the various aspects of cricket matches. Kamble et al. [4] developed a machine learning system that accurately predicts a cricket team's score and win percentage after 50 overs. The system consists of two models, one for predicting the score and another for predicting the win percentage. The regression toward the mean classifier outperforms a naive mathematician in predicting match outcomes. The system can also predict scores and win percentages before the match, calculate the current run rate, and forecast the final score based on wickets and the game's location [1]. The authors also used machine learning algorithms to predict innings scores in IPL cricket matches.

Predicting cricket match winners is challenging, but machine learning models can improve prediction capabilities [10]. Random Forest outperformed other algorithms, achieving 74% accuracy using the IPL dataset. The paper reviews cricket formats and methodologies for predicting winners and suggests future research directions. In [9], a model was developed for predicting scores and outcomes of Twenty20 cricket matches using XGBoost Regression and Logistic Regression Classifier, predicting first-inning scores based on parameters like run rate, wickets lost, match venue, and batting team. The study also used data mining, machine learning, and data featuring techniques to predict match outcomes in non-curtailed matches between 2002 and 2014. Despite the challenges of predicting cricket's variability due to factors like pitch and weather, the authors developed a highly accurate model for predicting scores and outcomes using these techniques.

Machine learning was used to predict cricket scores and player performance [3]. Recently, the authors of [2] proposed the use of a Random Forest Classifier to accurately forecast the winning team in Indian Premier League (IPL) matches. This tool could be beneficial for team management in player auctions and decision-making. It can also automate the prediction process, benefiting cricket fans and upcoming players. The study uses various algorithms, including random forest, support vector machine, linear regression, and logistic regression, to analyze cricket data and predict IPL match winners.

Nasim et al. [7] introduced a data-driven system using a Hidden Markov model to predict cricket batters' performance. The system accurately predicted runs scored in a ball, aiding in selecting the right batsman and making strategic decisions, overcoming prediction challenges using a data-driven approach for more accurate results.

The authors of [8] has developed a result prediction system for T20 cricket matches, specifically IPL matches, using linear regression, logistic regression, and random forest algorithms. The system predicts the first innings score based on run rate, wickets fallen, venue, and toss. It uses supervised learning algorithms

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Table 1. A Comparison of state-of-the-art-work for Cricket Score Prediction

Ref.	Purpose of Study	Methodology	Dataset	Results	Limitations
[4]	Score and Win Percentage Prediction for Cricket Teams	Linear Regression	Cricinfo	68% to 91% accuracy in predicting match outcomes	Limited discussion on dataset and model interpretability
[1]	First Innings' Score Prediction in IPL Matches	Linear and Ridge Regressions	IPL Dataset	Accurate prediction model	No discussion on validation or model limitations
[10]	Cricket Match Winner Prediction with Machine Learning	Supervised Classification, Random Forest	IPL Dataset	74% accuracy with Random Forest	Limited exploration of different prediction methodologies
[9]	Score and Outcome Prediction in Twenty20 Cricket	XGBoost and Logistic Regressions	Cricket Data (2002-2014)	From 70% to 91% accuracy	External factors not extensively addressed
[2]	IPL Match Winner Prediction using ML	Random Forest, SVM, Linear Regression, Logistic Regression	IPL matches	Accuracy of 88.2% based on toss and venue and 75.1% based on target	No details on model performance, generalization, or ethical considerations
[7]	Performance Prediction of Cricket Batsmen	Hidden Markov Model	Batsmen's Performance Data	72.84% accurate prediction of runs scored	Limited discussion on model's generalization and validation
[8]	Result Prediction for T20 Cricket Matches	Linear and Logistic Regressions, Random Forest	T20 cricket matches	75% accuracy in predicting score and match winner	No details on model's performance on unseen data or biases

to estimate player potentials and match the winner with 75% accuracy, making it an effective tool for T20 cricket match outcomes.

In summary, the key findings from the literature survey are as follows:

1. **Emphasis on T20 dataset**: Most research studies primarily utilize the T20 dataset, mainly focusing on the IPL, for their prediction models[12].
2. **Limited focus on ODI cricket**: There is a noticeable lack of emphasis on ODI cricket in the research papers, indicating a gap in the literature regarding prediction models for this format.
3. **Insufficient feature selection**: Many of the research papers do not adequately address the selection of relevant features for the prediction task, potentially impacting the accuracy of the models.

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4. **Relatively low accuracy**: The accuracy of the prediction models discussed in the papers is reported to be relatively low [5], suggesting the need for further improvement and refinement.
5. **Lack of second innings prediction**: The literature survey highlights a scarcity of research on incorporating score prediction to forecast match results specifically in the second innings, indicating a potential area for future investigation and improvement.
6. **Lack of focus on applying segmented modeling to improve results**: The literature lacks emphasis on employing segmented modeling to enhance cricket match prediction, missing an opportunity to capture dynamic game phases and potentially improve accuracy.

These observations highlight the importance of conducting further research in predicting cricket matches, explicitly focusing on ODI cricket. It is necessary to develop robust feature selection methods, improve model accuracy, and explore score prediction in the context of the second innings to enhance match result predictions.

3 Methodology

In our contribution, we aim to address the research gaps in cricket match prediction. Specifically, we focus on the T20 dataset and conduct a comprehensive ODI cricket analysis to fill the gap in the existing literature. We identify and incorporate relevant features for accurate predictions, thereby addressing the issue of insufficient feature selection. Additionally, we improve the relatively low accuracy of prediction models by implementing innovative techniques and refining existing models through segmented modeling. Lastly, our research focuses on developing methodologies to forecast match results in the second innings, which is a significant gap in current prediction models. The details of these steps are depicted in Figure 1 and covered in subsequent sections.

3.1 Data Collection

For the study on Cricket Match Prediction, data was sourced from 1188 One Day International (ODI) matches. Each dataset included various columns such as mid, date, venue, bat_team, bowl_team, batsman, bowler, runs, wickets, overs, runs_last_5, wickets_last_5, striker, non-striker, and total. All these features were recorded to create a comprehensive dataset that could be used to predict the final score of an ODI match.

The data collection process involved sourcing reliable and verified information to ensure the accuracy of the dataset. The collected data was compiled and organized into a structured format for analysis. This process provided a valuable resource for predicting the outcome of ODI matches in the past. It also helped identify trends and patterns in the performance of teams and players.

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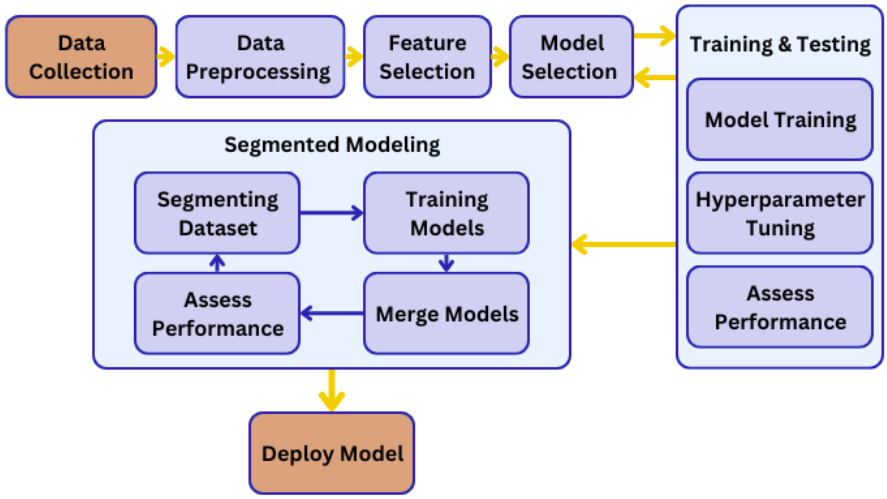


Fig. 1. Our proposed methodology for segmented modeling of cricket score prediction

3.2 Data Preprocessing

After collecting the dataset, the next step was to preprocess the data. We performed the following steps to preprocess the data:

1. **Removing irrelevant columns:** We removed the columns that were not necessary for our prediction tasks, such as mid, date, venue, batsman, and bowler.
2. **Handling missing values:** We checked if any columns had missing values and filled them using mean, median, or mode techniques.
3. **Handling categorical features:** Using label encoding, we converted categorical features such as bat_team and bowl_team to numerical values.
4. **Splitting the dataset:** We split the dataset into training and testing sets to train and evaluate our models.

3.3 Feature Selection

The next step was to select the relevant features for our prediction task. We used the following features for predicting the cricket match score:

1. **runs**: Total runs scored by the team at that instance.
2. **wickets**: Total wickets fallen at that instance.
3. **overs**: Total overs bowled at that instance.
4. **runs_last_5**: Total runs scored in the last five overs.
5. **wickets_last_5**: Total wickets that fell in the last five overs.
6. **striker**: The maximum of runs scored by striker and runs scored by non-striker.

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7. **non-striker**: The minimum of runs scored by striker and runs scored by non-striker.

3.4 Model Selection

After selecting the features, the next step is to choose the appropriate models for our prediction task. We have used Random Forest, Gradient Boosting, XGB, LGBM, CatBoost, AdaBoost, ANN, and MLP models.

Random Forest (RF) is an ensemble learning method that combines predictions from a forest of decision trees. Each tree is built using a random subset of training data by denoting the set of decision trees as $\{T_1, T_2, ..., T_n\}$. The final prediction, y_{RF}, is obtained through majority voting:

$$y_{\text{RF}} = \text{argmax}_i \sum [y_i = k], \text{ for } k = 1 \text{ to } K, \quad (1)$$

Gradient Boosting (GB) is a boosting method that combines weak models. The ensemble $\{h_1, h_2, ..., h_n\}$ is built sequentially, correcting the mistakes of previous models. The final prediction, y_{GB}, is obtained by adding up the predictions from all weak models:

$$y_{\text{GB}} = \sum_{i=1}^{n} \lambda h_i(x), \quad (2)$$

XGBoost (XGB) and LightGBM (LGBM) are efficient gradient-boosting libraries. CatBoost is a gradient-boosting library that enhances the handling of categorical features.

AdaBoost is a boosting method where weak models' predictions are weighted and combined. The final prediction, y_{AdaBoost}, is obtained by weighted voting:

$$y_{\text{AdaBoost}} = \text{sign}\left(\sum_{i=1}^{n} \alpha_i h_i(x)\right), \quad (3)$$

Artificial Neural Networks (ANN) use interconnected neurons. For a neuron j in layer l, the weighted sum of inputs, z_j^l, is computed as:

$$z_j^l = \sum_{i=1}^{n} w_{ji}^l x_i + b_j^l, \quad (4)$$

The output of the neuron, a_j^l, is obtained by applying an activation function:

$$a_j^l = \sigma(z_j^l), \quad (5)$$

Multi-layer perceptron (MLP) is a type of feedforward neural network. Neurons are connected across layers. For a neuron j in layer l, the weighted sum of inputs, z_j^l, is computed as:

$$z_j^l = \sum_{i=1}^{n} w_{ji}^l a_i^{l-1} + b_j^l, \quad (6)$$

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The output of the neuron, a_j^l, is obtained using an activation function:

$$a_j^l = \text{ReLU}(z_j^l), \quad (7)$$

The final predictions, y_{ANN} and y_{MLP}, are obtained by passing the input through the network and receiving the output from the output layer.

3.5 Model Evaluation and Hyperparameter Tuning

After training a machine learning model, the next step is to evaluate its performance. It uses various evaluation metrics such as R-squared value, mean squared error (MSE), mean absolute error (MAE), and accuracy. The R-squared value measures how well the model fits the data, while MSE and MAE measure the average difference between predicted and actual values. Accuracy, on the other hand, measures how accurately the model predicts the actual score of an ODI cricket match.

Once the evaluation is complete, we improve the model's performance by tuning its hyperparameters. Hyperparameters are the parameters that define the model's architecture and are set before training. We use techniques such as Grid Search and Randomized Search to explore the hyperparameter space and select the optimal hyperparameters. We found n_estimators = 100 and max_features = None as the optimal hyperparameters for the Random Forest algorithm.

3.6 Segmented Modeling

The prediction model chosen for the task is trained on different segments of the cricket match dataset. This division enables the model to differentiate between the various stages of the match effectively. Afterward, multiple versions of the chosen model are generated, each trained on different data segments. These models are merged to create a comprehensive prediction system with accurate results. The ensemble's performance is rigorously evaluated to ensure its predictive capabilities. The dataset is further divided into distinct segments, and the training, merging, and evaluation process is repeated iteratively. This approach continues until the best-performing merged model is obtained, which offers superior predictive accuracy and optimal results for forecasting cricket match outcomes.

4 Results and Discussion

We used seven features, including the total runs scored by the team at that instance, total wickets fell at that instance, total overs bowled at that instance, total runs scored in the last five overs, total wickets that fell in the last five overs, max(runs scored by striker, runs scored by non-striker), and min(runs scored by striker, runs scored by non-striker), to predict the total runs scored by the batting team after the first innings.

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We trained and tested our model using several machine-learning algorithms, including Random Forest, Gradient Boosting, XGB, LGBM, CatBoost, AdaBoost, ANN, and MLP. The accuracy of each algorithm was measured in terms of R squared value and accuracy. Our results showed that the Random Forest algorithm had the highest accuracy of 85%, while all other algorithms had an accuracy of about 50% to 65%, as shown in Figure 2.

	Random Forest	Gradient Boosting	XGB	LGBM	Cat Boost	Ada Boost	MLP	ANN
Accuracy	85.70	60.85	60.9	61.0	60.0	50.3	63.7	64.2
R Squared	80.74	54.58	54.6	54.6	53.4	40.3	-	-

Fig. 2. Comparison of the machine learning models

The Random Forest algorithm outperformed other algorithms due to its ability to handle large datasets and take many features. Moreover, the algorithm has fewer hyperparameters to tune, making it easy to use for the given dataset. We achieved a high accuracy rate by optimizing the hyperparameters of the Random Forest algorithm using GridSearchCV. The best hyperparameters for the Random Forest algorithm were n_estimators = 100 and max_features = None.

Implementing the segmented modeling approach with the Random Forest model, we partitioned the dataset into five distinct segments, each representing ten overs of cricket gameplay. Let S_i represent segment i and M_i denote the Random Forest model trained on segment S_i. So, M_1 was trained on over 1 to 10, M_2 on overs 11 to 20, and so forth up to M_5 for over 41 to 50.

We selected the appropriate model M_i during the prediction phase based on the input data's corresponding overs. Let O represent the overs of the match at prediction time. The ensemble prediction system E was designed to choose the correct model M_i based on the following condition:

The expected outcome $E(O)$ is defined as follows:

$$E(O) = \begin{cases} M_1, & \text{if } O \leq 10 \\ M_2, & \text{if } 11 \leq O \leq 20 \\ M_3, & \text{if } 21 \leq O \leq 30 \\ M_4, & \text{if } 31 \leq O \leq 40 \\ M_5, & \text{if } O \geq 41 \end{cases} \quad (8)$$

After rigorous evaluation, the ensemble model E demonstrated an impressive predictive accuracy of 87%, effectively capturing the nuances of each cricket match phase. This approach capitalized on crucial information that would have been overlooked in traditional aggregate models by selecting the appropriate model based on the input's specific overrange. The iterative process of training, merging, and evaluating models based on different segments contributed

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to optimizing predictive capabilities and achieving remarkable results for the final ensemble model E. The segmentation strategy proved to be a valuable tool in refining the Random Forest model's performance and enhancing the overall accuracy of the prediction system.

Figure 3 shows the predictions of the Segmented Random Forest model when the total score was 347.

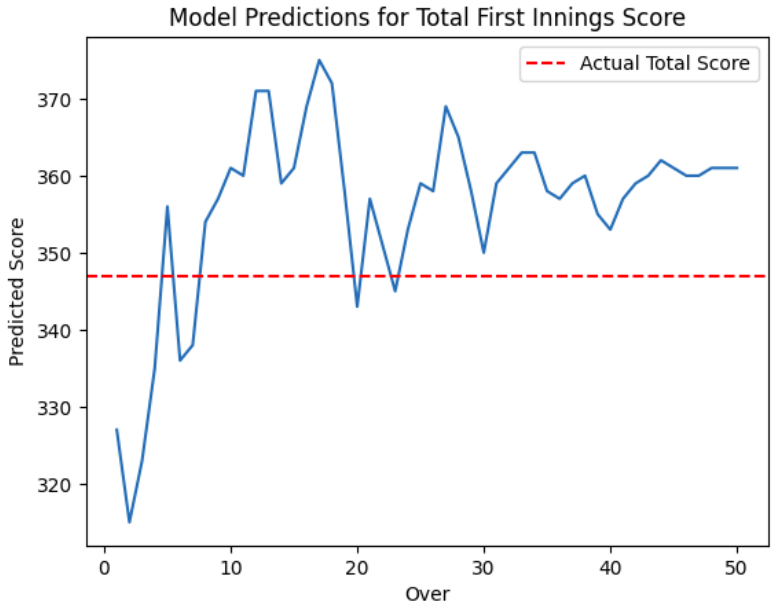


Fig. 3. Segmented Random Forest Predication

Based on the prediction of innings score using the given data, it is possible to determine the winning percentage of the batting team. It can be achieved by comparing the predicted score with the average score of the particular venue and determining whether the predicted score is above or below the average. Additionally, the predicted score can be compared with the highest and lowest scores achieved by a team at that venue to get a better understanding of the team's performance.

It is possible to use the same method to predict the score and winning chances in other formats of cricket, such as T20 and Test matches. However, the accuracy of the predictions may differ due to the distinct dynamics of these formats. T20 matches are shorter, and teams have to play aggressively, resulting in a higher number of wickets falling and a lower score being achieved. In contrast, Test matches are played over a more extended period, and teams have to be more patient in their approach, resulting in fewer wickets falling and a higher score

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being achieved. We can use the same model to predict the second-inning score and winning percentage by following a similar method.

To predict the winning percentage of a team in a cricket match's second innings based on the predicted score and the first innings scores, you can use the following formula:

The winning percentage is calculated using the logistic function:

$$\text{Winning Percentage} = \frac{1}{1 + e^{-x}}, \quad (9)$$

where x is calculated as:

$$x = \frac{\text{Predicted Score} - \text{First Innings Score}}{K}, \quad (10)$$

In this formula, K is a scaling factor that determines the sensitivity of the winning percentage to the difference in scores. You can adjust its value based on your preferences or historical data analysis.

The predicted score for the second inning is Ps, and the first inning score is Fi. Using the formula above, the winning percentage would be:

$$x = \frac{Ps - Fi}{K}, \quad (11)$$

$$\text{Winning Percentage} = \frac{1}{1 + e^{-x}}, \quad (12)$$

Please note that the logistic function $\frac{1}{1+e^{-x}}$ is used to map the calculated value x to a range between 0 and 1, representing the winning percentage.

By plugging in the values of Ps and Fi into the equations, we can calculate the winning percentage for a given predicted and first innings scores.

Let's calculate the winning percentage for a first-innings score of 311 and a predicted score of 320 after 45 overs of the second innings:

1. Given information:
   - 45 overs have been completed in the second innings.
   - Predicted Score (P_s): 320
   - First Innings Score (F_i): 311

2. Calculate K: $K = 50 - \text{Current Overs}$, $K = 50 - 45$

3. Calculate x using the formula: $x = \frac{P_s - F_i}{K}$, $K = 5$, $x = \frac{320-311}{5}$, $x = \frac{9}{5}$, $x = 1.8$

4. Calculate the winning percentage using the logistic function formula: Winning Percentage $= \frac{1}{1+e^{-x}}$
   Now, calculate the value of $e^{-1.8}$ using a calculator: $e^{-1.8} \approx 0.16529888822$

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5. Calculate the winning percentage: Winning Percentage $= \frac{1}{1+0.16529888822}$, Winning Percentage $\approx \frac{1}{1.16529888822}$, Winning Percentage ≈ 0.857143

Based on the given sample data and the formula with $K = 5$, we can predict that the team's winning percentage in the second innings, with a predicted score of 320 and a first innings score of 311, is approximately 85.71%.

In conclusion, predicting innings scores and winning percentages can be a valuable tool for cricket teams and analysts, aiding them in making better decisions about team selection, strategy, and tactics. Moreover, this approach can be further developed by incorporating advanced statistical and machine learning techniques to enhance the accuracy of predictions.

5 Conclusion

The objective of this research paper was to predict the final score of ODI cricket matches using machine learning models. The study used data from 1188 ODI matches, which were preprocessed by removing irrelevant columns, handling missing values, and converting categorical features to numerical values using label encoding. The selected features for the prediction task were runs, wickets, overs, runs_last_5, wickets_last_5, striker, and non-striker. We evaluated several machine-learning models, including Random Forest, Gradient Boosting, XGB, LGBM, CatBoost, AdaBoost, ANN, and MLP. After evaluation, it was found that Random Forest had the highest accuracy in predicting the actual score of an ODI cricket match. Furthermore, segmented modeling with Random Forest achieved an impressive 87% accuracy by capturing cricket match phase nuances. It shows the potential of machine learning models in predicting the outcome of cricket matches and identifying trends and patterns in the performance of teams and players.

Acknowledgment

This work was supported by FCT - Fundação para a Ciência e Tecnologia, I.P. by project reference UIDB/50008/2020, and DOI identifier https://doi.org/10.54499/UIDB/50008/2020. This work is also funded by FCT/MEC through national funds and co-funded by FEDER–PT2020 partnership agreement under the project UIDB/00308/2020 (DOI 10.54499/UIDB/00308/2020).

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ISBN 978-9930-617-71-7

Machine Learning-Based Flood Vulnerability Assessment in Urban Areas: A Case Study of Santo Domingo

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Abstract. Flooding events analysis has drawn the attention of researchers because of the impacts on socioeconomic scale. To ensure broader studies and identify the effects of flooding, satellite imagery with cloud processing of calculated models and machine learning models are applications that ensure rapid response and effective information. Specifically, machine learning methods, such as random forest, allow the identification of required parameters of certain events and the interaction of these parameters to recognize affected areas. Considering this, this article aims to present a methodology to study seasonal flooding events that affected Santo Domingo city in mid-November 2023, using machine learning and cloud processing. To conduct this analysis, the Google Earth Engine platform was used for cloud processing of the Random Forest algorithm trained on specific features for the flooding event. Additionally, the digital elevation model was used on the same platform to compare the results of the trained model. The results showed that the machine learning model helps study these events with sufficient accuracy.

Keywords: Flood vulnerability, machine learning, satellite image, smart cities, artificial intelligence.

1 Introduction

Santo Domingo (SD) suffered severe flooding in mid-November 2023. According to the report published by the Centro de Operaciones de Emergencia (COE), on Nov. 19, the city of SD was placed on red alert with an estimated direct effect on 149,835 households and 480,000 people [1], and it was reported 431 mm of rain in 24 hours [2]. The abovementioned is an expected behavior as per [3], which demonstrates that rainfall increases in the late rainfall season (LRS) (August – November) due to climate change.

To study these flooding events, [4] proposes using Synthetic Aperture Radar (SAR) satellite images in conjunction with machine learning algorithms. SAR images are suitable for detecting floods because they can operate in almost all-weather environments, and day or night conditions [5], [6]. Modern applications use the European Space Agency (ESA) satellite Sentinel-1's SAR sensor [7], [8].

These images are processed using machine learning (ML) techniques. Supervised ML combines feature data to predict dependent variables, such as random forests [9].

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This technique was demonstated to have best results when compared to support vector machine and boosted regression tree [10]. Additionally, Random Forest has the ability of reducing the training and test error rate by increasing the number of sample size and traning trees [11]. For this research, the training methodology included incremental increase of the traning trees on the Random Forest model implemented.

In addition to ML, other information, such as digital elevation models (DEM), has been used mainly in boundary areas with gentle slopes but shows less accuracy where the water is obscured by vegetation [12].

A combination of satellite SAR images, ML, and DEM has been used in India [13], [14], Mexico [15], and the United States [16]. The results of these case studies quantified flooding in agricultural and silt-soil areas and demonstrated the effectiveness of ML algorithms with limited training data sets. They also proved the use of inundation mapping for potential use in emergency response.The case study

Previous studies have addressed the impact of flooding in the Dominican Republic by analyzing the behavior of products on quantitative precipitation forecast [17] and by studying the socioeconomical point of view [18]. Considering the above, this paper shows the application of satellite SAR images, ML, and DEM techniques to study the impact of severe flooding in Santo Domingo on Nov. 17, 2023.

2 Methodology

2.1 Case Study

For this research, the selected study area was delimited to the North, West, and South, with the exclusion of the East due to the satellite's temporality, which did not produce images of the excluded sector in the desired time frame. The delimitator uses a simple polygon as a geofence totaling 285 square kilometers with urban areas, riverbanks, sea surface, and low vegetation.

The polygon points were transferred to the Google Earth Engine (GEE) platform for further geospatial processing. Potential tropical cyclone #22 impacted this region on Nov. 17, resulting in 431 mm of rain in 24 hours, which was the root cause of flooding.

2.2 Google Earth Engine Platform

The GEE platform has been demonstrated to be an efficient web-based service that allows processing, analyzing, and visualizing data [19], [20] showcases the platform's scalability and usefulness when studying water maps and behavior, feature selection, and artificial intelligence (AI) usage. In the same document, the features used by GEE to automatically identify key input parameters for the models are highlighted.

The initial stage in this research was to determine the model features and classify them as urban, low vegetation, and permanent water; these as the baseline for the model cataloged as normal conditions; later, the variables flooding and vegetation flooding, cataloged as after flood conditions, with an average of 6 polygons for each feature,

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hence creating feature collections. All feature collections were assigned a property class as identification for further use in the programming code as follows:

- The feature collection for urban aims to group manmade structures such as buildings, roads, residential areas, and/or spaces with similar characteristics where human settlement can be identified.
- The feature collection for low vegetation aims to group sections of natural vegetation in the surrounding areas or within the city, such as natural parks, recreational parks, and river basin vegetation.
- The feature collection for permanent water aims to group all-natural permanent water sources in the surrounding areas or the city, such as lakes (natural or artificial), rivers, and marine fronts.
- The feature collection for flooding aims to group all urban areas where stagnated water, which is not permanent water, has been identified.
- The feature collection for vegetation flooding aims to group all areas where stagnated water that is not permanent has been identified in the vegetation areas.

After, two mosaics were created from images previous to the flood (date range 6th – 16th Nov.) and post-flood (date range 17th – 24th Nov.), which were treated and concatenated. Concatenation creates a single image with all bands of the mosaic images. Available bands are based on sensor polarization vertical–vertical (VV) and vertical–horizontal (VH). The feature collections previously programmed were used directly over the mosaics, manually wrapping the desired areas with polygons. Fig. 1 shows the concatenated images with feature collection polygons. The red color indicates permanent water, the purple color indicates urban, the green color indicates low vegetation, the blue color indicates flood, and the yellow color indicates vegetation flooding.

All satellite images and mosaics generated will use Google maps services on the background.

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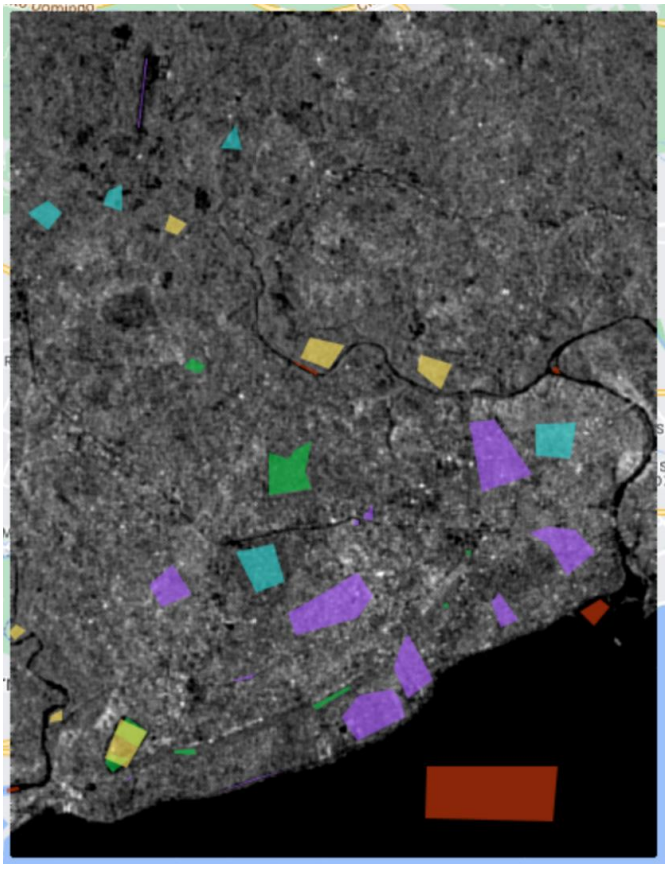


Fig. 1. Study area as a concatenated SAR image from mosaic with feature collections used to identify intended variables.

2.3 Machine Learning Model

A training model was developed using concatenated images, the merged features, and the satellite sensor's bands VV and VH. A supervised classification model using Random Forest with three different aleatory tree models (25,40, and 65), a mean leaf population of one, and a bag fraction of 0.5 was implemented; all other parameters remained as default. For this scenario, the properties of the feature collection are used as predictors for the model using the methodology taught in the Serve-Amazon program.

The coverage area per class in km^2 was calculated to calculate the model output. Additionally, a confusion matrix and an overall training accuracy were generated and calculated to estimate the model precision.

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2.4 Comparison Model

A DEM algorithm was used to determine water settling after heavy rains to verify the validity of the ML model implemented. The DEM calculates where water has been identified in the past ten months from the selected study dates and compares newly identified stagnated water to places with stagnation probability. This is based on where the slopes of the topography are. An experiment was conducted to gather data for when the slope is less than 3%, 5%, 10%, 40% and 50%. A visual comparison of the DEM flood estimates was performed with the generated information using the random forest model—the amount of covered area classified as flood was estimated to calculate the model output.

3 Results and Discussions

The results will be presented in scenarios: scenario one is the Random Forest model with twenty-five trees, scenario two is the Random Forest model with forty trees, scenario three is the Random Forest model with sixty-five trees, and scenario four is the DEM results. The three first scenarios focus the results on flood information based on the feature collection parameters on flooding and vegetation flooding.

3.1 Scenario One

After implementing the Random Forest model, it identified a coverage area of 25.59 km^2 for flood and 44.44 km^2 for vegetation flood. The general accuracy of the system was estimated to be 96.68%. A confusion matrix for the trained and evaluated model, illustrated in Table 1, shows how the model has the weakest performance when trying to predict vegetation flood versus all other features. The second weakest performance is shown when predicting urban vs flood, vegetation flood, and low vegetation. The third weakest performance is when predicting low vegetation versus all other features. The fourth weakest performance is predicting flood versus vegetation flood, urban, and low vegetation features. It can be noted that urban prediction has worse performance than low vegetation and flood predictions, even though urban prediction has no errors when predicting permanent water.

Table 1. Confusion matrix results for scenario one.

	Permanent Water	Flood	Vegetation Flood	Urban	Low Vegetation
Permanent Water	4625	0	1	0	2
Flood	0	2279	10	93	13
Vegetation Flood	0	5	1830	27	61
Urban	0	27	5	7331	1
Low Vegetation	0	2	341	11	1399

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3.2 Scenario Two

After implementing the Random Forest model, it identified a coverage area of 23.71 km^2 for flood and 44.82 km^2 for vegetation flood. The general accuracy of the system was estimated to be 97.33%. A confusion matrix for the trained and evaluated model, illustrated in Table 2, shows how the model has the weakest performance when trying to predict vegetation flood versus all other features. The second weakest performance is shown when predicting urban vs flood, vegetation flood, and low vegetation. The third weakest performance is predicting low vegetation versus flood and vegetation flood features. The fourth weakest performance is when predicting flood versus urban features.

Table 2. Confusion matrix results for scenario two.

	Permanent Water	Flood	Vegetation Flood	Urban	Low Vegetation
Permanent Water	4627	0	1	0	0
Flood	0	2323	2	64	6
Vegetation Flood	0	0	1880	17	26
Urban	0	11	1	7352	0
Low Vegetation	0	0	347	7	1399

3.3 Scenario Three

After implementing the random forest model, it identified a coverage area of 23.71 km^2 for flood and 44.82 km^2 for vegetation flood. The general accuracy of the system was estimated to be 97.33%, showing the same results as the previous scenario. Fig. 2 shows the results obtained in the three previous scenarios for the total area covered.

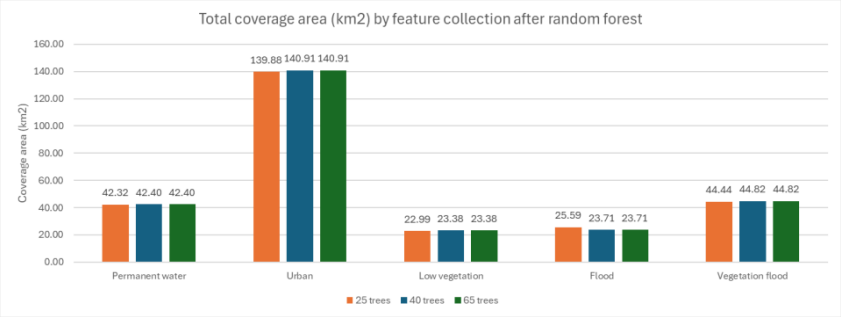


Fig. 2. Total coverage area by class after implementing a Random Forest model with different trees.

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It can be noted that in Fig. 3 a model with sixty-five trees is overfitting the results. Hence, the optimal model will be the one with the performance of forty trees. As the results for case c are identical to case b, case c will not be discussed further.

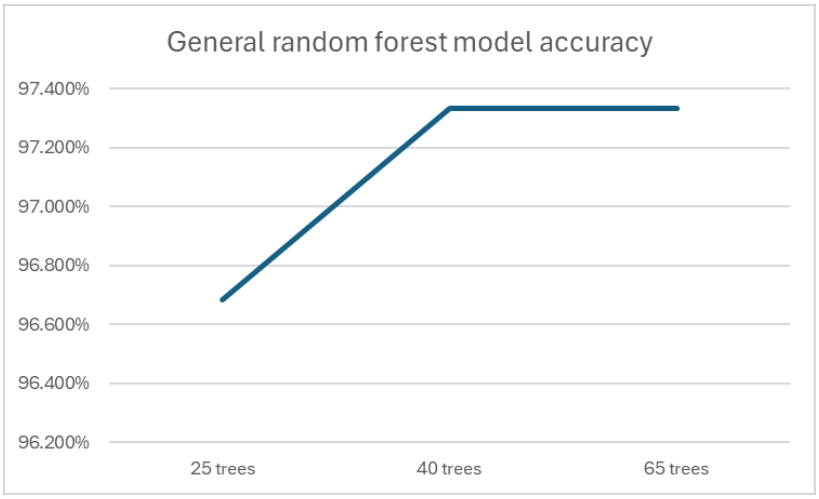


Fig. 3. General model performance after implementing the Random Forest model with different trees.

3.4 Scenario Four

After implementing the DEM, a range of covered areas was identified depending on the program's slope setting. Fig. 4 illustrates the system's performance. It can be noted that increasing the slope parameters also increases the coverage area up to a point where the slope parameter is no longer a significant value due to the area's general topography.

A 3% slope shows a coverage area of 10.50 km^2, a 5% slope shows a coverage area of 12.64 km^2, a 10% slope shows a coverage area of 14.26 km^2, a 40% slope shows a coverage area of 14.72 km^2, and a 50% slope shows a coverage area of 14.72 km^2. DEM after 40% does not show a significant improvement. Therefore, 5% and 40% slope values will be used for visual comparisons.

The coverage area of a 5% slope is approximately 35% of the detected area using the random forest algorithm, and the coverage area of a 40% slope is approximately 38% of the detected area using the random forest algorithm. The abovementioned means that for the selected area of study, the change in slope is not necessarily significant.

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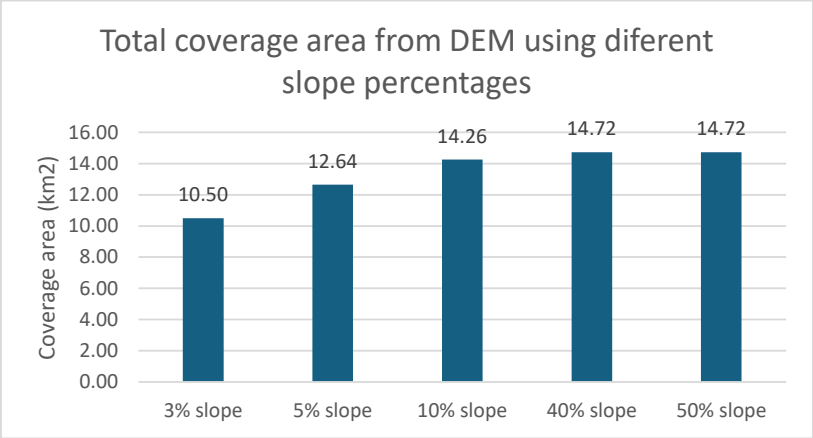


Fig. 4. Total coverage is calculated using DEM for different slope percentages on the elevation model.

A general visual inspection of a projection of pixels over the study area displays the covered area by class, illustrated in Fig. 5. The resultant image reflects the aftermath of the heavy rains on selected dates.

In light blue color, the floods (stagnated water) are identified. Some pixels show very localized flooding points, whereas others show a general flooding area. According to the results, major flooding can occur on the north-west side of the study area (in the north zone), south-southwest and south of the study area (both in the south zone), and to the East of the study area, surrounding the Ozama riverbank (in the frontier south and east zone, to the west and East of the river, respectively).

In pink color, the vegetation flood is identified. This result is of places where vegetation retains water parameters. According to the results, the vegetation flood occurs alongside the Isabela riverbank's natural vegetation (center of the image, in the frontier south zone and north zone), to the south-east of the image (on a recreational private golf course and the Haina riverbank on the west zone), and to the north of the image where natural vegetation is prominent (north zone).

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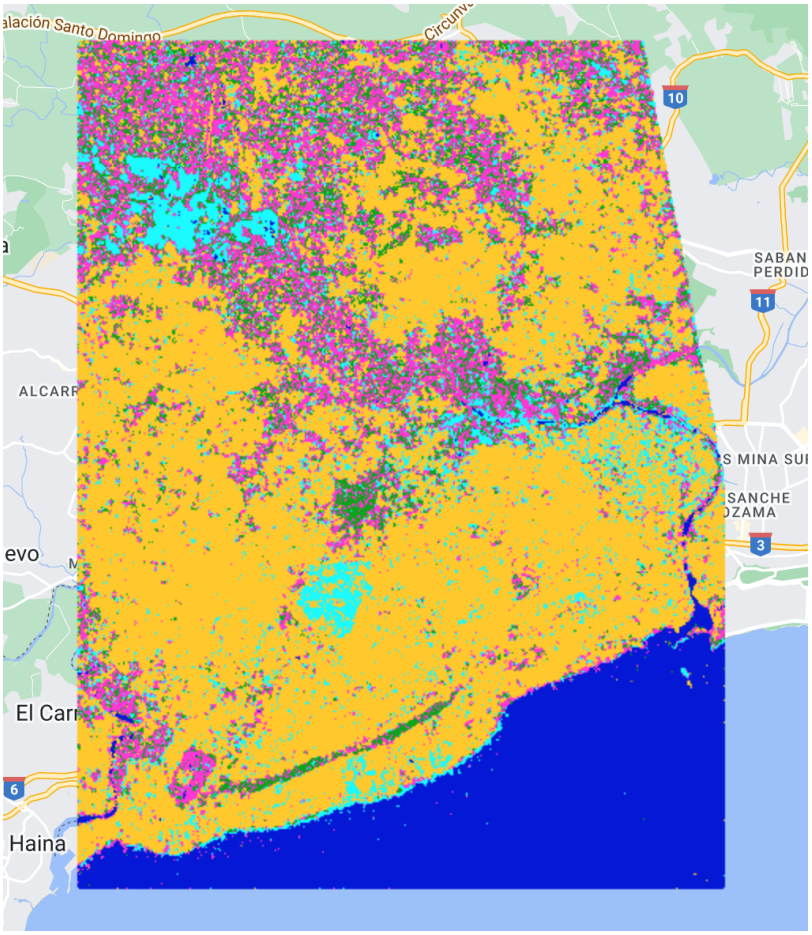
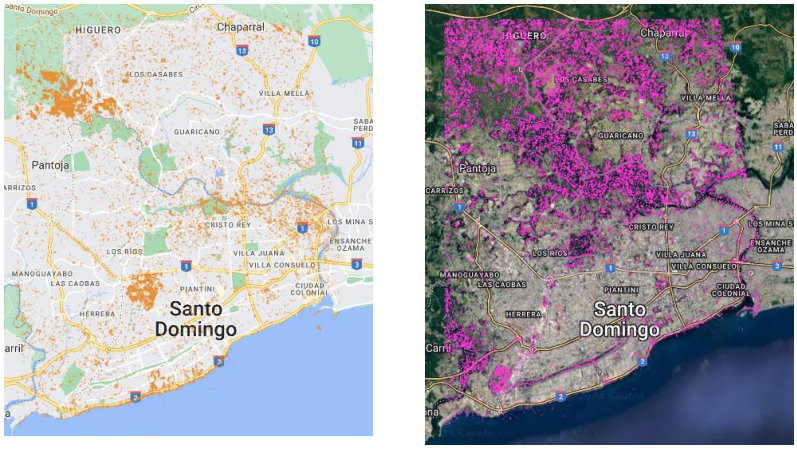


Fig. 5. Resultant image after applying random forest to feature collections. Light blue is used for flooding (stagnated water), and pink is used for vegetation flooding. Green is the color for low vegetation, blue is the color for permanent water, and yellow is the color for urban areas.

Fig. 6 provides a more detailed projection, comparing only flood and vegetation flood. Punctual flooding is identified as spreading all over the study area in Fig. 6(a), and vegetation flooding is better identified around areas with naturally low vegetation in Fig. 6(b).

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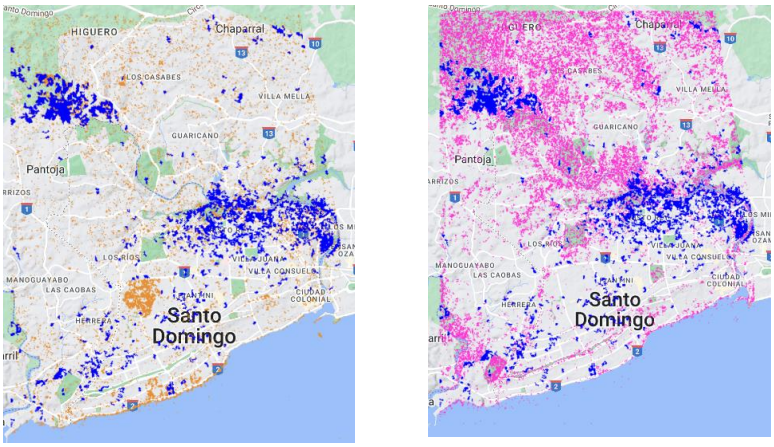
10



(a) (b)

Fig. 6. Coverage comparison between general flood (a) and vegetation flood (b) over the study area.

The DEM comparison with the generated information from the ML code coincides with the flooded areas. Using the DEM with 40% slope information, most of the stagnated water occurs alongside or near the riverbanks, whereas the rest can be found sparse along the city. Two specific zones merge the three types of information: identified flood via ML model, identified vegetation flood via ML model, and identified flood via DEM. Fig. 7 compares these events.



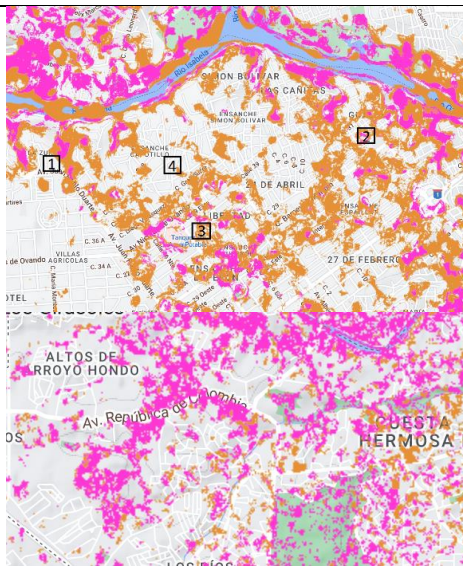
(a) (b)

Fig. 7. Comparison of coverage area between flood from ML model and DEM (a), and vegetation flood and DEM (b)

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After applying the random forest model with the feature collections, the resulting projection aligns with the expected results. By [21], the affected reported areas, with emergencies, are well projected to have been affected by flood or vegetation flood. Table 4 illustrates a combination of the reported areas and the flood type.

Table 4. Coverage area versus reported affected areas with emergencies.

ID	Reported Zone	Flood Type	Image
1	La Zurza	Combined	
2	Gualey	Combined	
3	Ensanche Luperón	Mostly flood	
	Capotillo	Flood	
4	Arroyo Hondo	Mostly vegetation flood	

After inspection and performance calculations, both models seem to fit within the permissible limits. The ML model accuracy is deemed acceptable at 97.3% as it only considers satellite data and certain default values without optimization. The DEM is deemed acceptable as it uses a data set available from the year 2000.

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4 Conclusion

The case study presented in this research highlights the opportunity created by using available satellite SAR data, ML models, and digital elevation model calculations to verify the impact on the city of Santo Domingo after heavy rainfall. The online tool used to perform the calculations allows for quick computation time, efficiency, and resource management results.

The results satisfy the research objective of analyzing the flooding impacts and evaluating the mechanisms to achieve sufficient performance. The created maps comply with the information published by local authorities and international organizations, which validates the presented work.

It was observed how the resources were optimized, resulting in an average performance of 97% for the supervised machine learning model, and after positive visual confirmation by calculating and comparing the digital elevation model results.

It should be considered that the parameters and information obtained would require validation with fieldwork to ascertain the results.

Flooding events have a direct impact on the socioeconomical, human settlement and future planning decision making processes. The use of machine learning techniques can aid in verifying and predicting the flooding effects.

Future work could include updating the elevation models, installing markers in the areas identified as vulnerable, using the model on different flooding scenarios to validate the prediction performance, and using additional ML techniques to verify the truthfulness of the results.

Acknowledgments

The authors acknowledge the support provided by the Thematic Network 723RT0150 "Red para la integración a gran escala de energías renovables en sistemas eléctricos (RIBIERSE-CYTED)". This research was funded by FONDOCyT Grant No. (FONDOCYT-2023-1-3C1-0547) and (FONDOCYT-2018-1H1-IN-001) in the Dominican Republic.

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ISBN 978-9930-617-71-7

Smart public services and other developments for smart cities

Modeling of a water saving and heating system to meet urban and rural needs in Colombia

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Abstract. The research work that is currently underway is aimed at generating a pilot plant for saving water and heating it in a housing complex that requires autonomy in the service for at least 4 days with a total consumption of 800 liters. The proposed saving is the collection of rainwater and grey water in spaces provided for this purpose, where a control and automation point will be created with the aim of regulating consumption and heating the water when required. The heating of the water will be carried out through solar collectors using natural convection and forced pumping using the energy obtained from photovoltaic panels. It is expected that the pilot project will allow an adequate recirculation of water and that its heating will be optimal from the use of non-conventional renewable energies so that it can be replicated in different rural and urban areas to improve the quality of life of the inhabitants of these areas.

Keywords: Water saving, rainwater, grey water, alternative energy sources, solar collector, photovoltaic panels.

1 Introduction

Colombia is undergoing a transition process in energy generation, which highlights the need to diversify the country's energy matrix to ensure greater coverage and quality in supply. At the same time, it is crucial to ensure the supply of water and meet the heating needs of urban and rural areas that do not have easy access to public services. The right to water is one of the sustainable development goals (Messina & Contreras, 2019), and must be guaranteed by governments for communities in the urban and rural sectors.

UNESCO reports indicate that nearly 3 billion people in the world have suffered from water shortages at least once in the last year, which puts at risk both food security and the attention to other health and energy access needs. By 2050, it is estimated that nearly 2.4 billion people will suffer from complete water shortages (UNESCO, 2023).

Despite Colombia's water potential and abundant rainfall for almost half the year, there are regions where the possibility of drought paradoxically alternates with periods of intense rainfall. Figure 1 shows the municipalities in Colombia that reported water rationing and total water shortages at the beginning of 2024.

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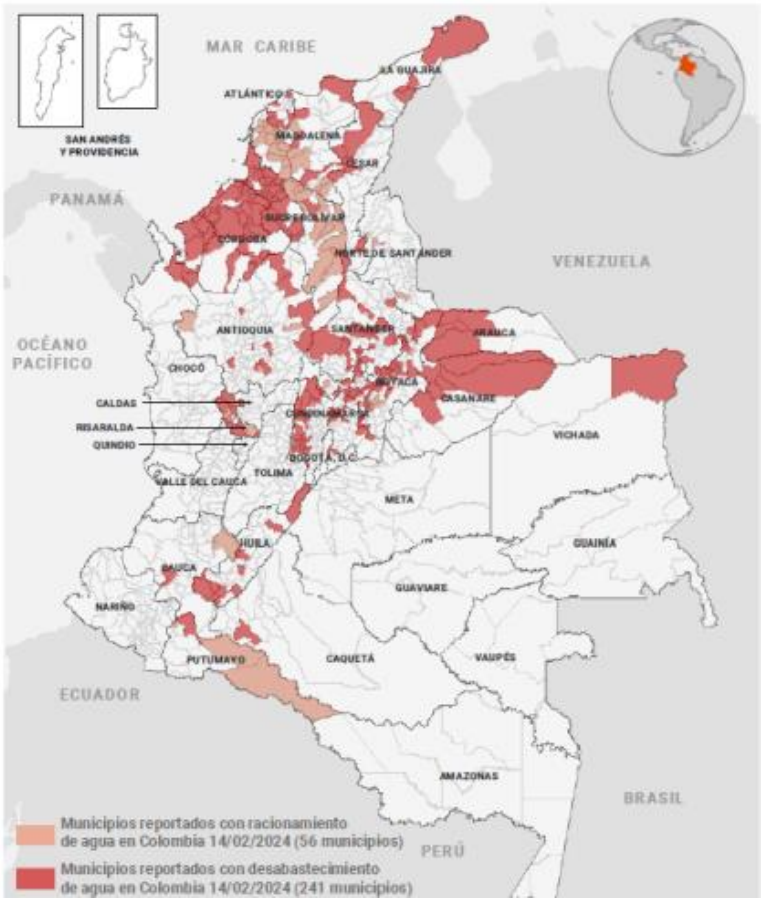


Figure 1. Overview of Colombian municipalities at risk from drought by 2024.

As can be seen in Figure 1, there is a significant number of municipalities at risk of water rationing and shortages. This could affect some 1.7 million people in the event of a moderate El Niño phenomenon and up to 3 million in the event of a strong El Niño phenomenon, according to reports from the National Unit for Disaster Risk Management of Colombia (UNGRD).

In Colombia, the review of official documents shows a crisis in the comprehensive management of water resources that aggravates problems associated with their use, exploitation and availability (quality and quantity) as detailed in the technical report of the National Water Governance Program (Félix, 2017). This crisis generates conflicts between the actors involved in water management, due to the lack of appropriation of responsibilities that allow for its adequate administration and pertinent planning.

The need to ensure comprehensive management of water resources is a primary objective for the Colombian state, and is directly aligned with global policies such as the Sustainable Development Goals (SDG), particularly Goal 6: “Ensure availability and sustainable management of water and sanitation for all” (United Nations Educational, Scientific and Cultural Organization, 2018).

This article is structured as follows: Initially, an introduction is presented on the topic of the lack of effective water resource management in Colombia and the municipalities that are at risk due to the lack of water supply. In section 2, the topic of rainwater and greywater saving systems proposed by authors at an international level is addressed. In section 3, the proposed model of the automated water saving and heating system is presented along with the design phases carried out. In section 4, the operation of the water saving model and the programming carried out for coupling to a superheated steam generation plant are described. Finally, the conclusions of the work carried out and the references used are presented.

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2 Rainwater and greywater saving systems

The review of specialized literature shows our works related to the topic of rainwater collection as a sustainable option for water management, analyzing its viability and benefits. Along with the use of rainwater, the use of water from kitchens, bathrooms (except for toilets), dishwashers and the last rinses of automatic washing machines and showers, known as gray water, is seen as a highly viable option (Suárez et al., 2012).

The work of Monteiro and Lima (2020) proposes a system for the storage of rainwater and the use of gray water from an urban building, where the energy for the supply is taken from the network and only the water collection function is reviewed.

Other references indicate the need to evaluate the collection points, the method of collection, the evaluation of characteristic parameters of eventual water potability if it is to be used for human consumption (Ávila et al., 2023).

Grey water obtained from residential blocks constitutes 50% to 80% of the total waste water, although its levels of potability are often not acceptable for consumption, it can, with simple treatments such as decantation and gravity filtration, be used for irrigation needs of small crops in urban and rural areas with difficult access to water resources (Albalawneh & Chang, 2016).

The review of the different specialized works shows projects on the collection of rainwater and its viability as a sustainable option for water management, highlighting its benefits (Suárez et al., 2012). In addition to the use of rainwater, the use of grey water is considered viable, which comes from kitchens, bathrooms (except toilets), dishwashers, final rinses of automatic washing machines and showers. For example, Monteiro and Lima (2020) propose a system for storing rainwater and using grey water in an urban building, where the energy for supply comes from the grid and only the water collection function is examined. However, other studies underline the need to evaluate the collection points, the method of collection and the potability parameters of the water if it is intended to be used for human consumption (Ávila et al., 2023).

Greywater generated in residential blocks accounts for between 50% and 80% of total wastewater. Although its potability levels are usually not suitable for consumption, it can be used to irrigate small crops in urban and rural areas with difficult access to water resources, through simple treatments such as decantation and gravity filtration (Albalawneh & Chang, 2016). This practice not only improves the sustainability of the water resource, but also contributes to alleviating pressure on drinking water sources, promoting more efficient and responsible water management.

3. Proposed model

The project proposes a model for the use of water resources and its improvement in the efficiency of thermal processes. Use will be made of water from grey water taken from nearby buildings, whether in rural or urban areas. It is clarified that this grey water corresponds to the last rinses of washing machines or collected from some sinks with adequate filtration (Suárez et al., 2012) (Monteiro & Lima, 2020). Likewise, rainwater will be partially used, the use of which is conditioned by the winter seasons that occur in Colombia (Urrea et al., 2016).

The following stages were followed for the initial design:

Stage 1. An assessment of water requirements was carried out based on the number of buildings, people and the time of autonomy needed for the supply. For example, a calculation was made for a single-family housing block with 4 adults who must have up to 4 days of autonomy in the water supply. The required water temperature was determined at 55ºC, in accordance with the recommendations of (Félix, 2017)(Salas-Salvadó et al., 2020). Thus, the calculation of the total amount of water needed is as follows:

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$$(4 \text{ people} * 50 \text{ liters/day} * 4 \text{ days})^{3} = 800 \text{ liters}$$

Stage 2. The estimated calculation of the pipes and fittings (elbows, branches and other connectors) for the water collection system was carried out. The estimated data at a general level taken into account are shown in table 1.

Table 1. Estimated calculation of pipes and fittings for the water collection system

Height (geometric) (suction height + discharge height)	22 m
Total pipe run	50 m
Linner pipe diameter	25 mm
Suction characteristics	
Averange suction height	2 m
Averange pipe length	5 m
Number of foot valves	1
Number of 90º elbows	1
Discharge characteristics	
Average discharge height	20 m
Pipe length	45 m
Number of check valvels	2
Number of 90º elbows	2

A velocity of 3 m/s has been selected for the fluid inside the pipes to be used at the site, which corresponds to the maximum velocity for a pump output.

The additional calculation data for the installation were taken as shown in table 2.

Table 2. Additional data for water saving installation

Equivalent head loss in sution due to pipe length	5 m
Singular Losses	10 m (foot valve) and 5 m (90º elbow) and an equivalent pipe length of 20m
Discharge head loss	
Pipe length	45 m
Singular losses	10 m (gate valve) + 10 m (check valve) + 10 m (2 90º elbows)
Equivalent pipe length	75 m

In the final phase, a ZOONDA 130S M 02 surface pump was selected, the characteristics of which are shown in table 3.

Table 3. Technical characteristics of the ZOONDA 130S M 02 pump

Weight (kg)	10.8
Power (W)	1300
Single-phase voltage (V)	230
Height (m)	50
Maximum flow rate (l/h)	4800

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Stage 3. A flat plate solar collector was selected to heat the collected water. The characteristics of the selected collector are shown in Table 4.

Table 4. Characteristics of the selected solar collector

Capacity	125 litres
Weight with water	37 kg
Installation area	2000 mm x 1000 mm
Maximum pressure	100 PSI
Working pressure	40 a 60 PSI
Thermal insulation	Mineral wool
Inlet and outlet connection	¾ inch smooth copper
Inclination	30º
Daily efficiency	➢ 80%
Daily hot water temperature	50ºC a 70 ºC

Stage 4. Selection of the photovoltaic system comprising the panels, charge regulator, storage battery in inverter for 1500 W, intended to power the pump that carries the water to the solar collector, when the climatic conditions of the region are suitable and there is sufficient energy stored in the batteries. It should be noted that when energy is not required for the pump, it can be used for other needs such as lighting inside rural buildings. The selected photovoltaic system has the following characteristics in table 5.

Table 5. Characteristics of the selected photovoltaic system

Number of Solar Panels in the Solar kit	4
Power of the solar Panels	500 W
Amperes of the charge Controller	80 A
Operating voltage of the battery	24 V
Operating Voltage of the inverter	24 V
Maximum starting surge accepted by the inverter	9000 W
Power generated per day	6400 Wh
Voltage of the solar kit	24 V
Maximum power of the inverter	3000 W
Battery Capacity	600 Ah
Stored Energy	3000 Wh
Panel lifespan	10 años

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Finally, the works to adapt the facility were carried out. Figure 2 shows the diagram of the activities carried out within the framework of the project.

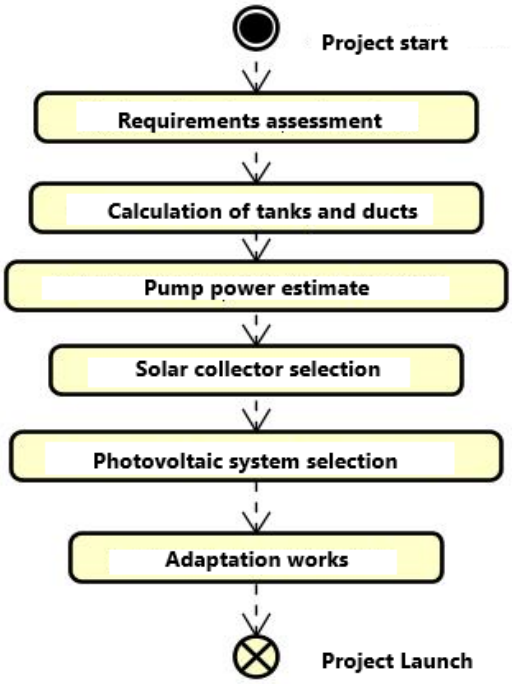


Figure 2. Diagram of activities carried out for the Project

In Figure 3. shows the schematic diagram of the proposed solution.

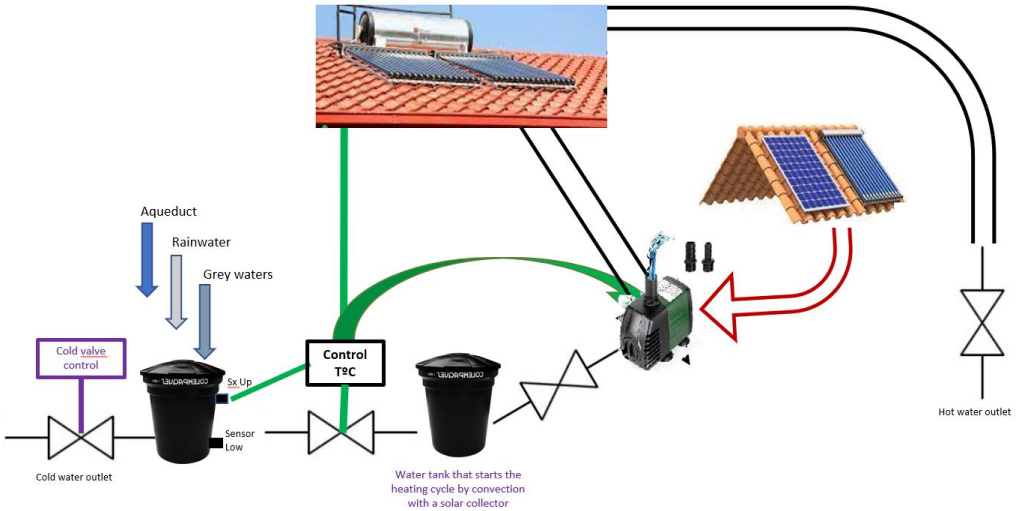


Figure 3. General schematic diagram of the water saving and heating solution.

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The system has two operating phases:

The **first phase** is for collecting cold water that can be taken from three different sources:
a. Water from the aqueduct (for urban areas) or groundwater (for rural areas)
b. Water obtained from rainwater
c. Grey water
In this phase, the primary tank is responsible for collecting water as a reserve. For its operation, it has two level sensors that indicate the minimum and maximum filling value. The tank begins to fill thanks to the water that comes from any of the sources or from all at the same time, activating the lower sensor that sends a control signal to a LATCH – D electronic transfer circuit; the signal is entered through the DATA input. The LATCH-D electronic circuit remains in STANDBY mode, because its activation is only achieved when a clock pulse arrives (CLOCK).
The storage system continues to fill and when it reaches the upper level, an activation pulse is produced that goes to an AND logic gate to which a clock pulse from a NE-555 type oscillator arrives. The output of the clock pulse or CLOCK of the AND gate activates the LATCH -D so that the DATA with the information from the lower sensor is transmitted to the LATCH output and causes the activation of the reserve tank outlet solenoid valve and the deactivation of the water supply valve and the grey water valve that fill the tank.
At that time, all the water stored in the tank can be used for the building's own needs until it is completely empty. When it is completely empty, the lower sensor will send a ZERO to the DATA and the LATCH output will deactivate the reserve tank outlet valve and activate the water supply and grey water valves to restart the process.

The operation is shown in detail in the diagram in figure 4.

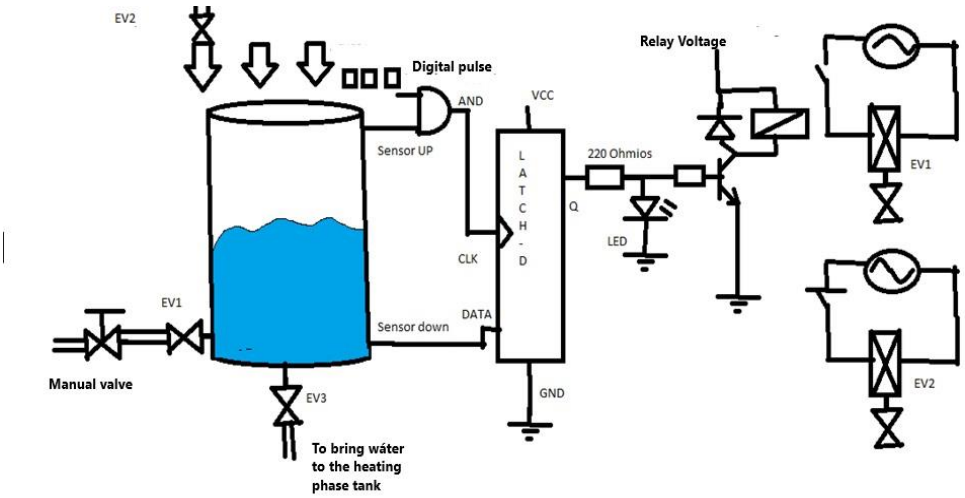


Figure 4. Operation diagram for water saving

The **second phase** of the system corresponds to the heating of the water with the help of a solar collector and a pump for circulation, powered by a DC-AC inverter system energized by batteries that are charged by photovoltaic panels.
In this phase, there is a thermal control device input and an inverter system availability input. These two inputs go to an ARDUINO that is used as a controller.
The controller verifies that the two inputs are enabled, high, (HIGH).
Note: the high level is defined by the designer for both the temperature and the voltage of the DC-AC inverter.

Then, the following maneuver is allowed to take place: First, solenoid valve 3 (EV3) is opened, and the motor pump is turned on to allow the circulation of water to auxiliary tank 2, and from there it passes through the collector coil, thereby transferring heat by forced convection to the water for the basic needs of the building.
Once the water in the initial tank is finished, the system turns off the motor pump to avoid damage.

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The design of the water saving and heating system has been developed with a scalable capacity, adapting to the gradual increase in hot water needs and allowing its use in the initial stages of processes for obtaining water vapor. This scalability contemplates the future integration of a steam boiler that could operate with biogas obtained from composting processes of organic matter in rural areas (Corona, 2007). Figure 4 shows details of the proposed solution, which include a steam and biogas boiler for scenarios with higher water heating requirements.

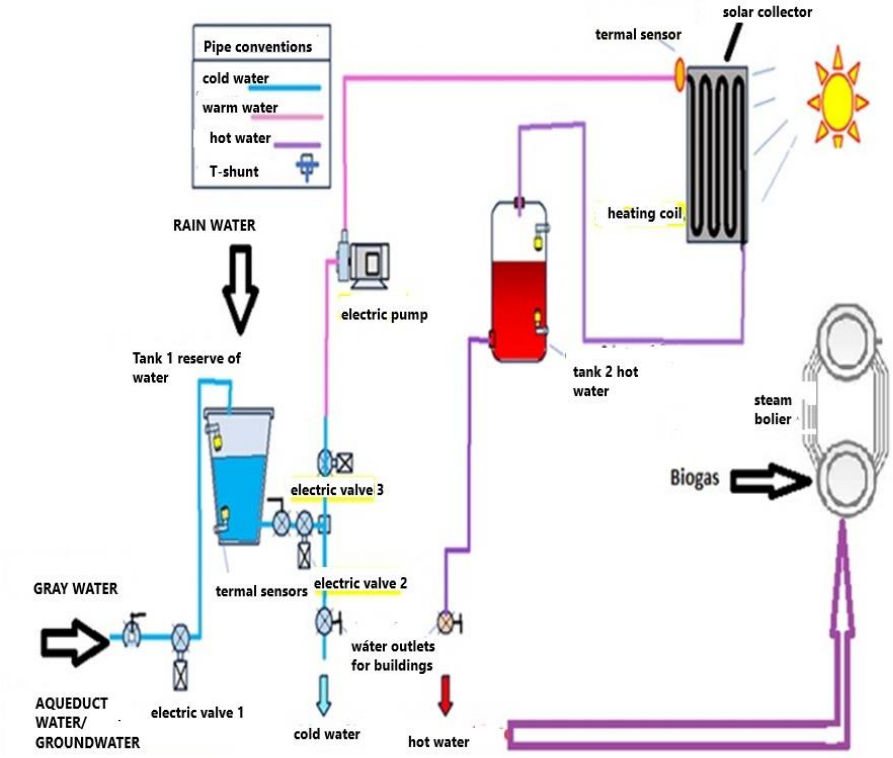


Figure 5. Detailed diagram of the water collection and heating system for the home, including a steam boiler and biogas supply

4. Operation details

For the operation of the storage system, water is taken from the conventional aqueduct system (or from groundwater or nearby water sources).

Figure 6 shows the sequence diagram for the operation of the entire water saving and heating system.

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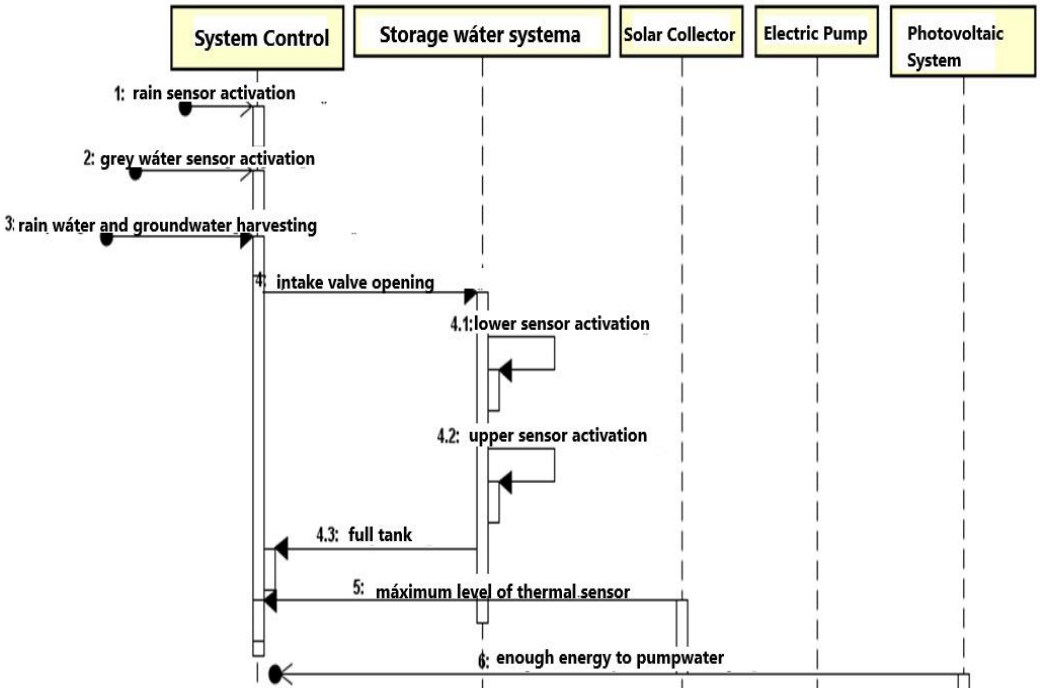


Figure 6. Water saving and heating system operation sequence diagram

As can be seen in the sequence diagram, once the water level detection sensors are activated, they send the signal to open the intake valve to the storage tank. Once it detects that the tank has been filled to the level pre-set by the user, it can be used by users for various needs such as flushing toilets, watering plants, washing floors, among others. The control system awaits the start of the second phase, which is activated only by two specific conditions: first, that the collector sensor detects the maximum temperature for operation and second, that the photovoltaic system has enough energy to be delivered to the pump and start the water recirculation process through the solar collector. It is important to highlight that when the collector is at its maximum temperature level, it facilitates the work of the pump thanks to the thermosiphon effect that helps the pump when pumping the water.

Hot water is used for the needs of building installations in urban or rural areas, but it can also be included as an initial preheating phase for steam generators.

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Conclusions

The water saving and heating system that uses a combined supply of rainwater, greywater, conventional water from the aqueduct and sometimes groundwater is presented as a technologically viable and efficient option that integrates both conventional and alternative energy solutions, which optimizes its performance and sustainability. The combination of the solar collector with the water recirculation pump optimizes the energy system by maximizing the efficiency of energy consumption from the photovoltaic system. This integration allows a more efficient use of the available energy resources. The design stages carried out guarantee that the project can be adapted and replicated to different regions of the country, both in urban and rural areas, making its implementation flexible in different geographical environments. The ability to scale the solution and use it in initial stages of steam generation processes provides great benefits. This could facilitate its eventual integration as an auxiliary service for thermoelectric plants or other industries that require saturated steam, optimizing its functionality and applicability

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ISBN 978-9930-617-71-7

Transformation of State Schools into Technical Schools: An Approach in São Paulo City Using Integer Programming

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Abstract. In recent years, there has been growing interest in technical courses in Brazil. The federal government, in fact, has been working to increase the availability of these courses, announcing the creation of new campuses of institutions offering them throughout the country. However, there is a need to evaluate the companies present around each open educational unit, with the aim of offering courses that facilitate the integration of students and graduates with the local job market. This paper proposes an integer linear programming model to identify regular schools that could be transformed into technical schools, evaluating distances between schools, neighborhoods, and business clusters. Experiments are conducted in two distinct scenarios in a case study in the city of São Paulo, where it is possible to verify the best combinations of neighborhoods, schools, and courses offered in the city.

Keywords: Facility Location · Technical Education · Integer Programming.

1 Introduction

The expansion of technical education has been a priority for the Brazilian federal government regarding education. With the announcement, at the beginning of 2024, of the creation of 100 new campuses for Federal Institutes, the Ministry of Education hopes to expand nationwide access to this type of education [6]. Unlike traditional high school education, in this modality, the student receives technical training in a specific field of knowledge either concurrently with or after high school. However, it is desirable that the courses offered by educational institutions align with the regional vocation of the area in which the educational unit is located. Otherwise, students will face difficulties when seeking internships, and graduates will struggle to enter the job market. In this way, the offered course and the educational institution itself lose their purpose of social

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transformation, becoming irrelevant [5]. Another key factor in planning is the location of each school. Its access must be facilitated, but there are generally budgetary restrictions in place, making the creation of a new educational unit "from scratch" costly. However, there is the possibility of taking advantage of existing structures and, through partnerships, establishing new units at a much lower cost.

In Brazil, according to data from INEP, the largest share of students in traditional high school is found in schools managed by state governments [4]. Therefore, under this federal government strategy to expand technical education, partnerships with the states could be formed to transform some of these schools into technical schools. This move would eliminate the costs of building new units while making it possible to expand the technical education network in a more streamlined manner.

This paper aims to analyze, for a given region of interest, which schools would be most advantageous to choose for conversion into technical schools. This choice takes into account the neighborhoods the schools could serve and the business profile of their surrounding areas, aiming for partnerships with these companies for internship activities and the subsequent insertion of graduates into the job market. Therefore, in addition to identifying which schools should be transformed into technical schools, it is also necessary to determine which business cluster should be associated with each educational unit, with the purpose of defining the courses offered. All of this seeks to balance the distance relationships between neighborhoods and schools, and schools and business clusters. To this end, an integer linear programming model is proposed, and scenarios are analyzed.

The remainder of this paper is organized as follows: in Section 2, similar works found in the literature are reviewed, highlighting their similarities and differences with our proposal. In Section 3, the methodology used is detailed. In Section 4, computational experiments are carried out, and their results are analyzed. Finally, Section 5 presents the conclusions of the paper, along with suggestions for future work.

2 Related Works

In this section, we address similar works found in the literature that are related either in terms of theme or methodology to the research developed.

Regarding works related to student allocation, [7] conducted research on the offering of workshops for primary school students using a bi-level model, where the upper level is responsible for minimizing the costs of opening and allocation, while the lower level is responsible for optimizing student preferences regarding the offered workshops. The problem is approached by the authors in different ways, with a reformulation and two metaheuristics.

In turn, the work of [1] focused on the allocation and reallocation of public primary schools in urban areas, with an emphasis on developing countries. The

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authors proposed a coverage model and a framework to assist in the analysis, applying this approach in a case study in Mexico.

In the same vein, the work of [2] proposed a model for the location and capacity modification of schools, aiming to reduce inequalities in rural areas of Chile. Their approach was based on the use of the Tabu Search metaheuristic, which they found to be an efficient and flexible methodology.

Finally, [8] developed a study focused on the expansion of the public school network in the state of Amazonas, Brazil. Their methodology utilized demographic and social criteria. Additionally, they employed three location models with three different variations, prioritizing the human development index, cities with larger populations, or both. The problem was approached using a genetic algorithm applied to each variation presented.

Table 1. Comparison between the developed work and related works. This paper uses an exact method to solve the proposed model, considering the relationships between neighborhoods/schools and schools/business clusters, through the distance between these pairs.

Authors	Exact Method	Neighborhoods/Schools Relation	Schools/Business Relation	Considers Distances	Considers Times
Polino et al.	X	X			
de Armas et al.	X	X		X	
Castillo-López e López-Ospina		X			X
Xavier et al.		X		X	
Our work	**X**	**X**	**X**	**X**	

Evaluating the works present in the literature, summarized in Table 1, it is clear that the use of optimization techniques is common for addressing problems related to education, particularly concerning the location of schools and the allocation of students. Thus, the work developed in this paper is in line with what has been investigated in the literature, differentiating itself by addressing not only the connection between schools and students but also the link between schools and businesses. This type of connection aims to integrate educational institutions with companies, enabling students and graduates to enter the job market. In this way, educational institutions fulfill their social role initially proposed through the offering of courses. It is also worth highlighting the approach using an integer linear programming model, which sets this work apart from related studies, most of which employ metaheuristics to address the problem. Furthermore, it is important to emphasize the absence of works in this direction, considering the Brazilian context.

3 Methodology

This section details the methodology used in this work. In Section 3.1, the proposed integer linear programming model is presented. In Section 3.2, the case

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study applied to the proposed model is defined, along with its assumptions. Finally, in Section 3.3, the process of creating the instances is detailed.

3.1 Model for Converting Regular Schools into Technical Schools

The problem presented in Section 1 can be approached as an optimization problem, based on a class of problems known as Facility Location Problems [3]. Considering a number N of schools for conversion (where N is a parameter that could be defined as a percentage of the available schools, for example), all neighborhoods in the area under analysis must have their demand met by the selected schools. Furthermore, it must be considered that each neighborhood can only be assigned to a single educational unit, which must be able to meet the entire demand of that neighborhood without exceeding its capacity. Similarly, each business cluster must be able to "absorb" the students enrolled in the schools linked to it. Another important point is that the distances between the students' residential neighborhoods, the school, and the location where they will carry out practical activities must be reasonable, so that daily commuting is feasible. Thus, based on the constraints and objectives presented, the following integer linear programming model can be defined to address the problem under study:

$$\min \quad \alpha \sum_{i \in E} \sum_{j \in B} d_{ij} x_{ij} + \beta \sum_{i \in E} \sum_{k \in I} \mathcal{D}_{ik} p_{ik} \tag{1}$$

$$\sum_{i \in E} y_i = N \tag{2}$$

$$\sum_{i \in E} x_{ij} = 1 \qquad \forall j \in B \tag{3}$$

$$\sum_{j \in B} w_j x_{ij} \leq C_i y_i \qquad \forall i \in E \tag{4}$$

$$\sum_{k \in I} p_{ik} = y_i \qquad \forall i \in E \tag{5}$$

$$\sum_{i \in E} p_{ik} \leq W_k \qquad \forall k \in I \tag{6}$$

$$p_{ik} \in \{0, 1\} \qquad \forall i \in E, k \in I \tag{7}$$

$$x_{ij} \in \{0, 1\} \qquad \forall i \in E, j \in B \tag{8}$$

$$y_i \in \{0, 1\} \qquad \forall i \in E \tag{9}$$

where $j \in B$ represents each neighborhood, $i \in E$ denotes the candidate schools and $k \in I$ represents each candidate business cluster. In addition, d_{ij} are parameters referring to the distance between school i and neighborhood j, while the binary variable x_{ij} indicates whether school i serves neighborhood j. On the other hand, $\mathcal{D}ik$ are parameters referring to the distance between school i and business cluster k. The binary variable pik indicates whether school i is served by

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business cluster k. Furthermore, the binary variable y_i indicates whether school i has been selected for conversion or not. Regarding demands and capacities, w_j refers to the demand of neighborhood j, C_i determines the service capacity of school i, and W_k indicates the capacity of business cluster k to absorb schools.

The Objective Function 1 determines that the sum of the distances between neighborhoods and schools, and schools and businesses, should be minimized. The parameters α and β allow for the adjustment of the importance of these two values, enabling various analyses. The value of α is defined as a value between 0 and 1, and $\beta = 1 - \alpha$. The Constraint 2 determines that exactly N schools should be converted. The family of constraints 3 defines that each neighborhood can only be served by one school. The family of constraints 4 requires that the sum of the demands of the neighborhoods served by a school does not exceed its service capacity, while the family of constraints 5 determines that each school selected for conversion must be linked to a business cluster. Finally, the family of constraints 6 defines that the number of schools linked to a business cluster cannot exceed its capacity. The families of constraints 7, 8, and 9 refer to the domain of the decision variables of the model, all of which are binary.

3.2 Case Study

For the evaluation of the proposed model, we defined a case study based on the city of São Paulo. This choice was made due to the importance of the city both nationally and internationally, being the largest city in Latin America.

Regarding the evaluation scenarios, two different approaches will be analyzed. The first scenario consists of evaluating the conversion of a predetermined number of schools without considering the already existing federal public technical education institutions in the city. The second scenario, on the other hand, considers these already existing educational institutions as open and able to meet the demands. The values of α and β were defined as 0.25 and 0.75, respectively. This choice was made because the number of distances between various neighborhoods and schools is always greater than the number of distances between schools and business clusters. Complementary analyses, with other combinations of percentages, did not result in significant differences in the results, so the analysis of these scenarios was discarded and will not be discussed. Regarding the number of converted schools, a value of 5% of the total available schools was assumed for this study.

3.3 Data Collection and Processing

After defining the case study and its assumptions, the acquisition and correct preprocessing of the data were carried out in order to create the instances to be analyzed. The geographic and population data of the city of São Paulo were obtained from the 2010 Census database, conducted by the Brazilian Institute of Geography and Statistics (IBGE). The use of the 2010 data is justified by the fact that the more recent data from the 2022 census are not yet fully available for consultation, especially the complete data of the current census sectors, which

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serve as the source for creating the maps and delineating the areas under analysis. After acquiring these data, the census sectors were grouped into neighborhoods. Based on the centroid of the most populous census sector in each neighborhood, its reference point for distance calculation was defined. Regarding the demands, a value of 0.55% of the population of each neighborhood was considered. This value was defined based on the enrollment records in technical education from the last school census in the city, relative to the total population.

Regarding the schools eligible for conversion, the data was obtained from the INEP School Catalog[1]. From this list, only large public schools (500 or more enrollments) belonging to the state network were considered. These decisions are justified by the fact that this administrative level is responsible for the majority of public high schools in the public network [4], in addition to the fact that the conversion process for small schools may not be of interest or even feasible, due to the subsequent low offer of vacancies. To define the capacity of each school, we considered the total number of enrollments reported in the last school census. Figure 1 shows the distribution of the selected state schools in the city of São Paulo, with a total of 826 schools.

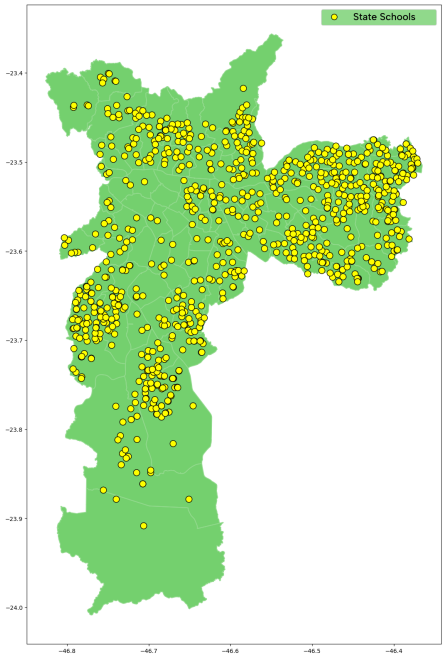


Fig. 1. Public large-scale state educational institutions in the city of São Paulo.

[1] https://www.gov.br/inep/pt-br/acesso-a-informacao/dados-abertos/inep-data/catalogo-de-escolas

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Regarding the second scenario, the same list of schools was consulted. This time, however, in addition to the schools selected previously, federal technical schools were also added to the data to be analyzed. Their capacities were defined in the same way as the state schools. The only difference is that, in the scenario where they are present, these federal schools are always marked as selected for conversion, along with those that the mathematical model will define. Figure 2 shows the distribution of schools in the city of São Paulo, totaling 829 schools (the 826 schools from the previous scenario and 3 federal technical schools located in the city).

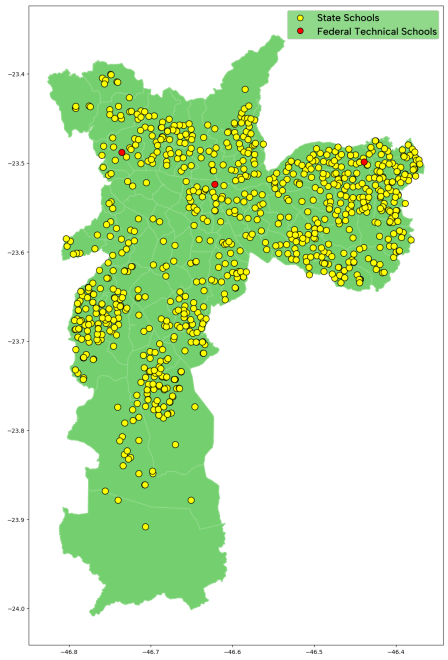


Fig. 2. Large public state educational institutions (in yellow) and technical educational institutions from the federal network (in red) in the city of São Paulo.

Regarding the companies, the data were obtained from the National Register of Legal Entities (CNPJ) catalog provided by the Brazilian Federal Revenue Office [2]. Since the data is not georeferenced, it was necessary to process it in order to calculate the distances later. For this, the Postal Address Code data present in the records were used to determine the approximate geographic location of the company based on its address. Subsequently, a grouping of companies within the same neighborhood was carried out, also taking into account their commercial

[2] https://dados.gov.br/dados/conjuntos-dados

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activities. The centroid of each grouping was used as the reference point. To define their capacities, the formula 10 was used:

$$\frac{\text{the number of companies in the cluster}}{\text{the number of schools converted}} \tag{10}$$

With respect to the distance calculation, the real road data of the city of São Paulo was used.

4 Computational Experiments

The computational experiments were executed on a computer equipped with an AMD Ryzen™ 5 5600G processor running at 3.9 GHz and 32GB of RAM. A Python 3.10 environment was used, installed on the Windows 11 operating system, and the solver used was IBM CPLEX 22.1.1, in conjunction with the Python DOCplex library. The experiments were executed using the parameter values defined in Section 3.2, and the results will be analyzed below.

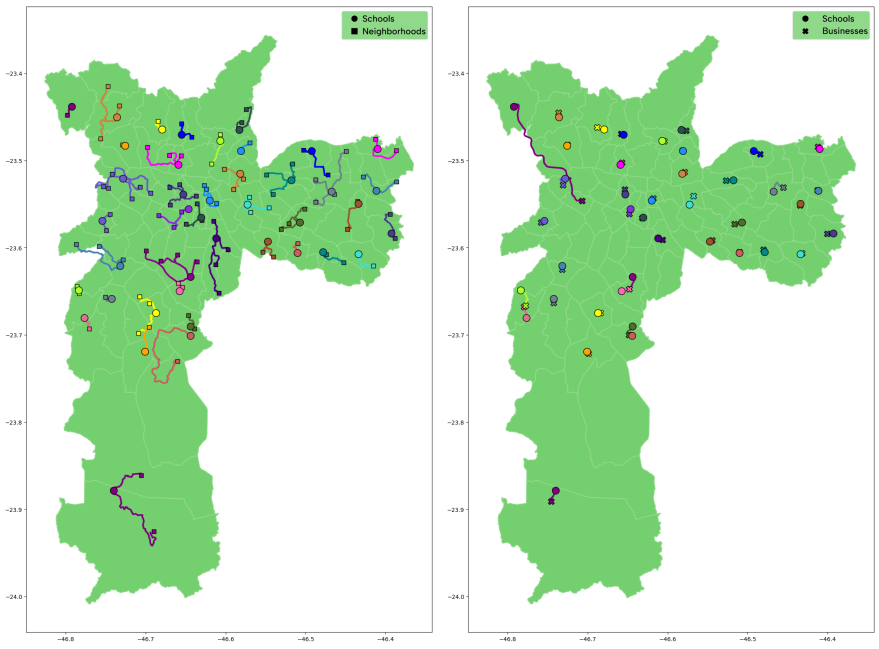
4.1 Disregarding Existing Federal Technical Schools

The first scenario analyzed disregards the already existing federal technical schools in the city, defining as candidates all the large public schools within the state system, as defined in Section 3.3. A total of 826 educational units were considered. Working with 5% of this value, 41 schools were selected for conversion. Among them, the Prof. Basilides de Godoy ETEC stood out, serving the largest number of neighborhoods, with 6 units. Considering the largest average distances to the served neighborhoods, the Doutor Ayres Neto school was the highlight, with 18 kilometers. This school serves only one neighborhood, Grajaú. In second place was the Prof. Hilton Reis Santos school, with 9.57 kilometers. This school serves two neighborhoods: Parelheiros, 5.56 kilometers away, and Marsilac, 13.6 kilometers away.

Regarding the use of the unit's capacity, 3 schools stand out: Prof. Isaltino de Mello, Solon Borges dos Reis, and Albert Einstein ETEC. All had a utilization rate (demand/capacity) above 99%, serving a total of 8 neighborhoods. Of all the selected schools, 32 of them operate above 80% of their capacity, and the number reaches 39 schools when considering those using at least 50% of their capacity. Figure 3 shows the location of these schools on the map, along with their relationships to neighborhoods and business clusters.

Regarding the relationships between schools and business clusters, the result of this scenario shows that, except for the real estate segment cluster in the Jabaquara neighborhood, which is responsible for 2 schools, each cluster was responsible for only 1 school. Therefore, a total of 40 distinct business clusters were selected. The minimum distance in this relationship was 41 meters, between the business cluster in the Accommodation and Food Services sector in Alto de Pinheiros and the Prof. Sebastião de Oliveira Gusmão school in Morro Doce. On the other hand, students from the Prof. Francisco de Paula Conceição Junior

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(1) (2)

Fig. 3. Relations between neighborhoods and schools (1) and schools and business clusters (2) in the city of São Paulo.

school in the Jardim Mitsutani neighborhood would need to travel 2.68 kilometers to the business cluster in the Financial Activities, Insurance, and Related Services sector in the Capão Redondo neighborhood to carry out their practical activities. In general, the average distance from a neighborhood to a school would be 3.5 kilometers, with a minimum of 538 meters and a maximum of 18 kilometers. In terms of schools and business clusters, the average distance would be 878 meters.

By detailing the relationships identified by the model, it is clear which course segments could be offered by each unit and which segments are most suitable overall. Of the 41 selected schools, the "Real Estate Activities" segment was the most indicated for 10 of them. On the other hand, the school with the largest number of neighborhoods served was recommended to offer courses in the "Administrative Activities and Complementary Services" segment. Table 2 details the results.

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Table 2. Lines of business associated with each school selected for conversion in the city of São Paulo.

School	Neighborhood	Line of Business (CNAE)	Neighborhood
Albert Einstein ETEC	Vila Baruel	L	Casa Verde
Albino Cesar	Vila Mazzei	L	Tucuruvi
Antonieta De Souza Alcantara	Jardim da Laranjeira	E	Iguatemi
Antonio Jose Leite Prof	Vila Amélia	K	Cachoeirinha
Aroldo De Azevedo Prof	Jardim Planalto	H	Sapopemba
Ascendino Reis Prof	Tatuapé	L	Tatuapé
Ayres Neto Doutor	Pq. Doroteia	E	Pedreira
Barro Branco II	Barro Branco	F	Cidade Tiradentes
Basilides De Godoy Prof ETEC	Vila Leopoldina	N	Vila Leopoldina
Caetano De Campos	Aclimação	H	Liberdade
Candido Goncalves Gomide Prof	Jd. Cidade Pirituba	Q	Pirituba
Carlos Augusto De Freitas Villalva Junior Doutor	Jabaquara	L	Jabaquara
Eliza Raquel Macedo De Souza Profa	Vila Odete	L	Lajeado
Etelvina De Goes Marcucci Profa	Jd. Pq. Morumbi	Q	Vila Andrade
Fidelino De Figueiredo Prof	Vila Buarque	L	Santa Cecília
Francisco De Assis Pires Correa Prof	Itaquera	K	José Bonifácio
Francisco De Paula Conceicao Junior Prof	Jardim Mitsutani	K	Capão Redondo
Francisco Mesquita Jornalista	Pq. Cisper	F	Ermelino Matarazzo
Gabriel Ortiz Prof	Penha de Franca	J	Penha
Getulio Vargas ETEC	Ipiranga	J	Ipiranga
Henrique Smith Bayma Doutor	Jd. Maia	Q	Jardim Helena
Hilton Reis Santos Prof	Embura	C	Marsilac
Isaltino De Mello Prof	Vila Gea	C	Campo Grande
Italo Betarello	Jd. São João Jaraguá	K	Jaraguá
Jacques Orlando Caminha D Avila Reverendo	Pq. Santo Antônio	K	Jardim São Luís
Joao Amos Comenius	Vila Santa Catarina	L	Jabaquara
Joao Camargo Prof	Cidade São Mateus	K	São Mateus
Joao Silva Prof	Jd. Soraia	N	Capão Redondo
Jose Chediak	Pq. São Lucas	L	São Lucas
Jose Vieira De Moraes Prof	Rio Bonito	L	Cidade Dutra
Julio Pestana	Tucuruvi	J	Jaçanã
Luiz Lazaro Zamenhof Doutor	Vila Medeiros	J	Vila Medeiros
Maria Jose	Bela Vista	I	Bela Vista
Milton Cruzeiro Prof	Cidade Ant. Est. Carvalho	H	Itaquera
Moacyr Campos Prof	Jd. Aricanduva	K	Aricanduva
Paulo Egydio De Oliveira Carvalho Senador	Vila Maria	F	Vila Maria
Romao Puigari	Brás	N	Brás
Sebastiao De Oliveira Gusmao Prof	Morro Doce	I	Alto De Pinheiros
Solon Borges Dos Reis	Jd. Ivana	L	Rio Pequeno
Tiago Alberione Padre	Cidade Julia	M	Pedreira
Walfredo Arantes Caldas Prof	Vila Souza	E	Brasilândia

Legend: C - Manufacturing Industries | E - Water, Sewage, Waste Management, and Remediation Activities
F - Construction | G - Trade; Repair of Motor Vehicles and Motorcycles
H - Transport, Storage, and Postal Services | I - Accommodation and Food Services | J - Information and Communication
K - Financial Activities, Insurance, and Related Services | L - Real Estate Activities
M - Professional, Scientific, and Technical Activities | N - Administrative and Support Services
Q - Human Health and Social Services

4.2 Considering Existing Federal Technical Schools

After analyzing the first scenario, where only state schools were considered and could be freely selected, this scenario also considers the existing federal technical schools in the city and requires them to be chosen by the model. As there are three such schools in the city, the total number of schools freely converted is reduced, leading to a different result from the one found earlier. Therefore, this scenario aims not only to evaluate the model's behavior under these predefined conditions but also to identify the similarities and differences compared to the first scenario.

Regarding the school that serves the most neighborhoods, in this scenario, the title went to the Prof. Basilides de Godoy ETEC and Dona Clara Mantelli

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CEEJA schools, each serving six different locations. In terms of distance, the school with the greatest average was the Doutor Ayres Neto school, just as in the previous scenario, with 18 kilometers. Looking at the utilization rate, five schools had usage above 99%, an increase of 66.67% compared to the previous scenario. These schools together serve 12 neighborhoods. Of all the selected schools, 31 operate above 80% of capacity, and 39 schools are considered if we include those with at least 50% utilization.

When examining the relationships between schools and business clusters, we can see that the "Real Estate Activities" sector was the most selected, linked to 11 schools, a result similar to the previous scenario. Regarding the Prof. Basilides de Godoy ETEC and Dona Clara Mantelli CEEJA schools, the sectors "Administrative and Complementary Services", from the Vila Leopoldina neighborhood, and "Manufacturing Industries", from the Tatuapé neighborhood, were the ones selected for course offerings. Table 3 details these results.

Table 3. Lines of business associated with each school selected to be converted in the city of São Paulo, taking into account the already existing federal technical schools.

School	Neighborhood	Line of Business (CNAE)	Neighborhood
Albert Einstein ETEC	Vila Baruel	L	Casa Verde
Albino Cesar	Vila Mazzei	L	Tucuruvi
Antonieta De Souza Alcantara	Jd. da Laranjeira	E	Iguatemi
Antonio Jose Leite Prof	Vila Amélia	K	Cachoeirinha
Aroldo De Azevedo Prof	Jd. Planalto	H	Sapopemba
Ayres Neto Doutor	Pq. Doroteia	E	Pedreira
Barro Branco II	Barro Branco	F	Cidade Tiradentes
Basilides De Godoy Prof ETEC	Vila Leopoldina	N	Vila Leopoldina
Caetano De Campos	Aclimação	H	Liberdade
Carlos Augusto De Freitas Villalva Junior Doutor	Jabaquara	L	Jabaquara
Ceeja Clara Mantelli Dona	Quarta Parada	C	Tatuapé
Eliza Raquel Macedo De Souza Profa	Vila Odete	L	Lajeado
Emilia De Paiva Meira Profa	Vila Carmosina	L	Itaquera
Etelvina De Goes Marcucci Profa	Jd. Pq. Morumbi	Q	Vila Andrade
Fidelino De Figueiredo Prof	Vila Buarque	L	Santa Cecília
Francisco De Paula Conceicao Junior Prof	Jd. Mitsutani	K	Capão Redondo
Francisco Mesquita Jornalista	Pq. Cisper	F	Ermelino Matarazzo
Gabriel Ortiz Prof	Penha de Franca	J	Penha
Getulio Vargas ETEC	Ipiranga	J	Ipiranga
Hilton Reis Santos Prof	Embura	C	Marsilac
Ifsp - Campus Avançado São Paulo - Sao Miguel Paulista	Vila Rosária	K	São Miguel
Ifsp - Campus São Paulo	Pari	F	Pari
Ifsp - Campus São Paulo Pirituba	Jd. Santo Elias	L	Pirituba
Isaltino De Mello Prof	Vila Gea	C	Campo Grande
Italo Betarello	Jd. São João Jaraguá	K	Jaraguá
Jacques Orlando Caminha D Avila Reverendo	Pq. Santo Antônio	K	Jardim São Luís
Joao Amos Comenius	Vl. Santa Catarina	L	Jabaquara
Joao Camargo Prof	Cidade São Mateus	K	São Mateus
Joao Silva Prof	Jardim Soraia	N	Capão Redondo
Jose Chediak	Pq. São Lucas	L	São Lucas
Jose Vieira De Moraes Prof	Rio Bonito	L	Cidade Dutra
Julio Pestana	Tucuruvi	J	Jaçanã
Maria Jose	Bela Vista	I	Bela Vista
Mario Kozel Filho	Vila Seabra	Q	Jardim Helena
Moacyr Campos Prof	Jd. Aricanduva	K	Aricanduva
Orville Derby	Vila Formosa	J	Vila Formosa
Sebastiao De Oliveira Gusmao Professor	Morro Doce	I	Alto De Pinheiros
Solon Borges Dos Reis	Jardim Ivana	L	Rio Pequeno
Suzana De Campos Dona	Vila Perus	K	Perus
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ISBN 978-9930-617-71-7

5 Conclusions and Future Work

This work presented the problem of converting regular schools into technical schools, introducing an integer linear programming model to solve it. A case study applied the proposed model to data from São Paulo, the largest city in Latin America, and two distinct scenarios were analyzed.

The results obtained show that it is possible to meet the city's demand with a low conversion rate of schools. Only 5% of the available units would be enough to accommodate all the demand. Additionally, it was observed that a significant portion of the converted schools, in both scenarios, showed a high utilization rate of their capacity.

The experiments demonstrated that, in both scenarios, the "Real Estate Activities" sector was the most indicated, present in at least 10 of the 41 selected educational institutions, 24.39% of the total. Overall, there were no major changes in the results of the two evaluated scenarios. The most significant finding was the 66.67% increase in the number of schools operating at over 99% of their capacity in the scenario where federal technical institutions were required to be considered open, compared to the scenario where they were not included.

For future work, exploring the theme in more depth in relation to the economic conditions of each region in the city seems promising. Additional information could further enhance the results found in this analysis. Furthermore, studying this problem from a multi-objective perspective, given its nature, is another promising path to follow.

ISBN 978-9930-617-71-7

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ISBN 978-9930-617-71-7

Transición energética y movilidad inteligente en la ciudad de Cali

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Abstract.

The energy transition faces significant challenges in the decarbonization of the energy sector, demanding technological innovations and a regulatory framework that provides legal certainty for investors. In Colombia, this process is considered "just," implying that the benefits of decarbonization should be distributed equitably among all citizens, including public transport users. The transition to a sustainable transport model is fundamental from both an environmental and social justice perspective, requiring mobility policies to address inequalities in access to transport. This article analyzes the public transport system in Cali, known as the Masivo Integrado de Transporte (MIO), which faces issues that hinder efficient mobility and has led to the proliferation of informal transport, exposing users to violations of their rights and safety risks. Despite an increase in passenger mobilization, the MIO does not adequately meet the city's needs. National planning has attempted to establish mass transport systems through various National Development Plans, but the financial sustainability of the MIO remains a challenge, heavily reliant on government subsidies. The legal framework for public transport in Colombia stipulates that this service must be regulated to ensure quality and safety; however, the lack of mechanisms for citizen participation limits its influence on the development of the system. Finally, solutions based on smart mobility and the use of advanced technologies, along with robust data analysis to optimize transport options, are proposed, ensuring that social justice is a central pillar of future mobility initiatives.

Resumen.

ISBN 978-9930-617-71-7

La transición energética enfrenta desafíos significativos en la descarbonización del sector energético, demandando innovaciones tecnológicas y un marco normativo que brinde seguridad jurídica a los inversores. En Colombia, este proceso se considera "justo", implicando que los beneficios de la descarbonización deben distribuirse equitativamente entre todos los ciudadanos, incluidos los usuarios de transporte público. La transición hacia un modelo de transporte sostenible es fundamental desde una perspectiva ambiental y de justicia social, requiriendo que las políticas de movilidad aborden la desigualdad en el acceso al transporte. Este artículo analiza el sistema de transporte público de Cali, conocido como Masivo Integrado de Transporte (MIO), el cual enfrenta problemas que dificultan una movilidad eficiente y ha propiciado la proliferación del transporte informal, exponiendo a los usuarios a vulneraciones de sus derechos y riesgos de seguridad. A pesar del aumento en la movilización de pasajeros, el MIO no satisface adecuadamente las necesidades de la ciudad. La planificación nacional ha intentado establecer sistemas de transporte masivo a través de diversos Planes Nacionales de Desarrollo, pero la sostenibilidad financiera del MIO sigue siendo un desafío, dependiente de subsidios gubernamentales. El marco legal del transporte público en Colombia estipula que este servicio debe ser regulado para garantizar calidad y seguridad; sin embargo, la falta de mecanismos para la participación ciudadana limita su influencia en el desarrollo del sistema. Finalmente, se proponen soluciones basadas en movilidad inteligente y el uso de tecnologías avanzadas, así como un análisis de datos robusto para optimizar las opciones de transporte, asegurando que la justicia social sea un pilar central de futuras iniciativas de movilidad.

Keywords: public transport, right to transportation, smart mobility, smart city, public services

Palabras clave: transporte público, derecho al transporte, movilidad inteligente, ciudad inteligente, servicios públicos

1 Introducción

La transición energética ha sido diseñada para responder a los desafíos de la descarbonización de la industria energética y lo países pioneros tenía claro los objetivos en términos de diseño de incentivos a las energías renovables, para eficiencia energética e

ISBN 978-9930-617-71-7

incluso la reducción del consumo de energía. Todo lo cual abordan desde dos frentes de trabajo el primero de ellos es la innovación tecnológica y el segundo es el sistema normativo para crear seguridad jurídica en los nuevos actores e inversionistas. Si bien en principio pareciera una cuestión muy técnica, lo cierto es que el Derecho desde su función de organización y cohesión social desempeña una función estructural en los cambios sociales. Por ende, el Derecho como ciencia de la promoción e incentivo de conductas deseadas en la sociedad, viabiliza la materialización del proceso de descarbonización de la industria eléctrica y también desde su función de integración social permite que se lleguen a nuevos consensos en términos de producción y consumo de energía.

En Colombia la transición energética ha recibido el calificativo de "justa" y eso tiene implicaciones teóricas, políticas y prácticas que son objeto de valoración cuando se cotejan con el diseño de la legislación y las políticas públicas. Detrás del calificativo de justicia se generan expectativas en la población respecto de la asignación de ventajas y desventajas de la transición energética. Sin duda alguna, la expectativa principal es que los beneficios de la descarbonización del sector energético logren permear a la universalidad de los usuarios de los servicios de servicios públicos que se asocian a este sector incluyendo el sector de transporte. Dado que es una ardua tarea, resulta imperioso que para el diseño de incentivos y de indicadores se tengan datos claros del estado actual de las problemáticas que envuelve el consumo de energía. Especialmente porque si el objetivo de la política pública es la justicia energética, resulta imperativo crear servicios energéticos asequibles, seguros y sostenibles.

En el presente caso, se explora el proceso de transición energética teniendo como objetivo dentro de la transición energética la movilidad sostenible y por otra parte se evidencian los desafíos que enfrenta en el sistema de transporte público de la ciudad de Cali, en el sur occidente colombiano. Reconociendo el impacto que la industria de transporte tiene en la contaminación ambiental y en el impacto que el transporte público tiene en la calidad de vida de los usuarios.

En el marco de la transición energética, uno de sus pilares fundamentales es la justicia, un concepto que se traduce en la necesidad de garantizar la inclusividad en todos los aspectos de la vida social, económica y ambiental. Al aplicar este principio al contexto de la movilidad urbana, surgen varios desafíos significativos, especialmente en ciudades como Cali, donde el transporte público enfrenta un panorama complejo y problemático.

2. Problemática del transporte público en Cali

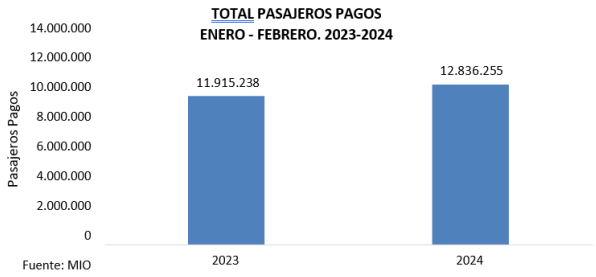
La movilidad en Cali no solo se caracteriza por su infraestructura limitada y una cobertura de servicios que no siempre responde a las necesidades de todos los ciudadanos, sino también por la desigualdad en el acceso al transporte y los riesgos asociados a la falta de acceso. La calidad del servicio de transporte público en Cali es un aspecto que

ISBN 978-9930-617-71-7

merece una atención especial. Muchos usuarios experimentan problemas como la congestión e incomodidad, la falta de frecuencia en las rutas, la falta de cobertura del transporte público y la inseguridad en los vehículos de transporte informal, lo que desincentiva su uso y limita la posibilidad de una movilidad inclusiva.

De acuerdo con los datos del MIO entre enero y febrero del año 2024, se han movilizado 12.836.255 pasajeros pagos, lo cual evidencia un incremento del 7,7% (+921.017 pasajeros pagos) con respecto al mismo periodo del año 2023, tal como se puede observar en la figura 1. Sin embargo, el sistema MIO no representa una solución radical como fuente de transporte entre el origen y destino de los usuarios, pues es justamente a las afueras de las estaciones del MIO donde se encuentran ubicados los transportes informales para completar el servicio y llevar a los usuarios a su destino final.

Figura 1: Total de pasajeros pagos

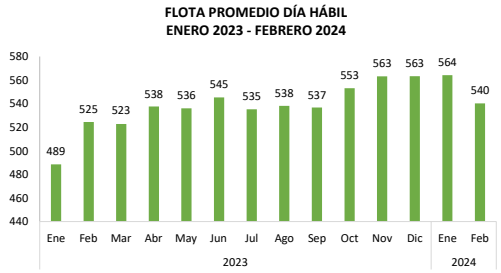


Fuente: MIO

Este volumen de usuarios es atendido por una flota de aproximadamente 500 vehículos que opera desde las 5:00 a.m. hasta las 11:00 p.m. de lunes a sábado y de 6:00 a. m. a 10:00 p. m domingos y festivos

Figura 2 Flota promedio día hábil

ISBN 978-9930-617-71-7



Fuente: MIO

Este escenario lleva a enfatizar las metas hacia la garantía de cobertura de todos los grupos sociales, especialmente aquellos más vulnerables, bajo el presupuesto de que el transporte público sea eficiente, asequible y seguro. Adicionalmente, la sostenibilidad ambiental debe ir de la mano con la justicia social. La transición hacia un modelo de transporte más ecológico es urgente, pero es vital que este proceso incluya a todos los sectores de la población. Esto plantea una nueva tarea en la que se implemente un sistema de transporte público que no solo reduzca la huella de carbono, sino que también fomente la equidad y el bienestar social. Es evidente que la justicia social en el transporte público de Cali no solo es una cuestión de accesibilidad, sino que también implica un análisis profundo de las dinámicas sociales y económicas que afectan a los ciudadanos y que puede estar incluso en el terreno del derecho sancionatorio (Grindlay & Lizarraga, 2012).

La problemática en torno a la movilidad en la ciudad de Cali tiene varios matices, ya que si bien existe una flota de sistema integrado de transporte público llamado Masivo Integrado de Transporte (MIO) este no logra tener la cobertura que las necesidades de la ciudad demandan. El MIO inició operaciones en 2009 y actualmente tiene 65 rutas, que cubren 16 de las 22 comunas que tiene Cali, con una flota actual de 632 vehículos operativos, lo cual representa un 60% de cobertura de la ciudad. El MIO tiene tres tipos de buses, teniendo todos ellos sistema de posición global (GPS) y sillas especiales de color azul para personas con movilidad reducida, personas de la tercera edad, mujeres embarazadas y/o con niños que aún no caminan. Funcionan con sistema de combustible diésel en su mayoría (370 buses) y 35 buses eléctricos. Los buses eléctricos tienen capacidad para 50 personas, autonomía de 320 kilómetros, aire acondicionado, freno de discos en las 4 ruedas 100% neumático con función ABS && EBS y plataforma para personas con movilidad reducida, red de wifi y no generan ruido.

Imagen No. 1: Mapa del sistema MIO en Cali

ISBN 978-9930-617-71-7



Fuente: MIO

El MIO también enfrenta problemas de administración debido a déficit operacional por lo que se hizo necesario gestionar recursos con el gobierno nacional, en 2023 se aprobaron $ 84.412millones con cargo al presupuesto general de la nación que estarían destinados a cubrir una deuda del MIO por valor de $47.000 millones. Respecto de la operación y administración del MIO uno de sus principales problemas lo representa la evasión del pago por parte de usuarios.

Entre los transportes masivos, la tarifa del MIO ha sido históricamente la más barata del país, cuando se compara con Bogotá, sin embargo, todos los operadores argumentan que si bien la tarifa cuesta $2.700 pesos colombianos en realidad el costo del trasporte por persona para el sistema es de por lo menos el doble. Esta situación evidencia que los problemas de sostenibilidad financiera del modelo de transporte, desde planeación nacional ha sido establecido que esto implica que haya un margen operativo que actualmente no se cumple (Aguilar, 2023).

La problemática en torno a la movilidad en la ciudad de Cali tiene varios matices, ya que si bien existe una flota de sistema integrado de transporte público Masivo Integrado de Transporte (MIO) tienen una limitada cobertura para atender las necesidades que la ciudad demanda. Muchas áreas de la ciudad no están adecuadamente atendidas por el sistema oficial, lo que obliga a los ciudadanos a buscar alternativas para satisfacer sus necesidades de movilidad con modelos de transporte informales entre los que se encuentran los bicitaxi y los vehículos privados piratas. Es habitual observar que, junto a las estaciones del MIO, operan vehículos informales que ofrecen sus servicios de transporte, creando un puente hacia destinos que el transporte público no alcanza. Esta dinámica es indicativa de una demanda insatisfecha, donde el transporte informal o comúnmente llamado “transporte pirata” se convierte en una solución diaria para muchos usuarios.

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El fenómeno del transporte informal no solo es una respuesta a la falta de cobertura, sino que también refleja una serie de características distintivas. En primer lugar, la tarifa en el transporte pirata no es fija; se negocia directamente entre el pasajero y el conductor, lo que puede resultar en variaciones significativas según el día, la hora y las condiciones socioeconómicas como por ejemplo los huelgas y protestas sociales. Esta flexibilidad en la tarifa atrae a muchos usuarios que buscan opciones económicas y rápidas (Valdés, 2014).

No obstante, esta informalidad acarrea riesgos significativos. La mayoría de estos vehículos no cuentan con un seguro de transporte, lo que implica que si los pasajeros llegan a sufrir un accidente no tendrán las coberturas por daños y resarcimiento de perjuicios. Además de que se expone a los pasajeros a situaciones peligrosas, especialmente porque siempre están evadiendo a las autoridades de tránsito y policía para evitar las multas y comparendos. Este panorama sumado a la falta de regulación y control de calidad en el servicio plantea preocupaciones sobre la seguridad de los usuarios. Además, la limitación a la competencia dentro del modelo de transporte del MIO crea un vacío que facilita la proliferación de la informalidad y, en ocasiones, de la ilegalidad. Se estima que en la ciudad operan alrededor de 6.000 vehículos particulares dedicados a este tipo de transporte (Cárdenas, 2023), incluyendo aquellos asociados a plataformas como Uber, Didi e InDrive. Esto demuestra la alta demanda por parte de la población que se siente desatendida por el sistema oficial.

En resumen, la problemática del acceso al MIO y la consiguiente expansión del transporte pirata refleja una necesidad de repensar el modelo de movilidad urbana. Es imperativo abordar las limitaciones del sistema oficial y buscar soluciones que no solo mejoren la cobertura, sino que también aseguren la seguridad y el bienestar de los ciudadanos. La regulación efectiva y el fomento de una competencia sana podrían ser pasos cruciales para mitigar la informalidad en el transporte y garantizar un servicio de calidad para todos (Carrillo, 2024).

3. Planeación institucional y transporte público

El tema de la movilidad en las principales ciudades ha sido abordado desde planeación nacional de hecho, desde el Plan Nacional de Desarrollo (PND) 2002, en el que se propone la implementación de los sistemas de transporte masivo de Bogotá-Soacha, Cali, Barranquilla, Pereira, Cartagena, Bucaramanga y el Valle de Aburrá. La finalidad además de proponer la solución del transporte masivo ha sido generar el desarrollo social y la generación de empleo. De la misma manera, el PND 2006 ratificó el apoyo de la Nación para la implementación de los SITM, impulsó la puesta en operación de los sistemas masivos de transporte y estableció que sus principios serían la eficiencia, seguridad, responsabilidad, equidad, competitividad y sostenibilidad ambiental.

ISBN 978-9930-617-71-7

PND 2010 Contempla la importancia del transporte masivo como componente de servicios de infraestructura, diagnostica sus problemáticas y enfatiza en la necesidad de brindar soporte financiero a los sistemas de transporte masivos.

En el Plan Nacional de Desarrollo de 2015 se contempló la opción de que los entes territoriales pudieran contribuir con sus recursos o de fuentes alternativas de ingresos destinados a los sistemas masivos de transporte. Teniendo en consideración la situación de déficit que han presentado los sistemas de transporte y con el fin de que no se vean perjudicados los principios de calidad y continuidad del servicio público. Lograr el punto de equilibrio de sostenibilidad financiera y calidad del servicio siempre ha estado en la discusión del sistema de transporte sin que se haya logrado una solución definitiva. De hecho, en la ciudad de Cali 2% del presupuesto del ente territorial está destinado al sistema masivo de transporte para que sea viable y mejore las condiciones de prestación incluyendo la operación y el mantenimiento. Por ello es importante pensar en alternativas de financiación alternativa que viabilicen la sostenibilidad financiera, alternando opciones contractuales mas modernas que el contrato de concesión como las asociaciones público privadas con sistemas de administración más eficientes y flexibles, así como atraer cooperación interinstitucional y financiación a la investigación de los sistemas de transporte (AbdulRafiu et al., 2022).

La continua inyección de recursos financieros por parte del gobierno nacional y de los gobiernos locales en los sistemas integrados de transporte, como el MIO en Cali, ha puesto de manifiesto una problemática crucial: la necesidad urgente de reestructuración del sistema de transporte masivo. Esta situación no solo refleja un problema de financiamiento, sino también de sostenibilidad y eficiencia en la movilidad urbana. Para abordar esta problemática, es esencial implementar una serie de cambios profundos y estratégicos. En primer lugar, es necesario revisar y actualizar el marco regulatorio que rige el funcionamiento de estos sistemas de transporte. Esto incluye la creación de normativas más flexibles que permitan adaptarse a las necesidades cambiantes de la población y a las nuevas tecnologías emergentes. Además, es fundamental establecer mecanismos de supervisión y evaluación que aseguren la calidad del servicio y la satisfacción del usuario.

Dentro del plan energético nacional 2024 -2054 diseñado por la Unidad de Planificación Energética UPME se han tenido como pilares la justicia y la inclusividad, la sostenibilidad y el carbono neutralidad, la seguridad y confiabilidad y la competitividad y el desarrollo económico se han construido una serie de planes estratégicos entre los que se encuentra el plan de movilidad sostenible. La movilidad urbana sostenible es uno de los objetivos que fue planteado desde París 2015 dado la importante contribución de las emisiones de CO_2 generada por la industria del transporte (Khurshid et al., 2023). Hay objetivos climáticos en materia de movilidad urbana que deben ser abordados de manera estratégica, con diversificación e inclusión.

ISBN 978-9930-617-71-7

4. Derecho al transporte públicos y alternativas para la ciudad de Cali

El transporte como servicio público es objeto de protección constitucional, pues al ser un servicio público se debe garantizar como derecho fundamental de segunda generación, sujeto a los lineamientos de continuidad, calidad, universalidad. Por ser un derecho fundamental está sujeto a protección vía acción de tutela y así lo ha dejado claro la Corte Constitucional colombiana en la sentencia T-604 de 1992, en esta misma sentencia se ha reconocido el vínculo entre el derecho al transporte con otros derechos como el derecho al trabajo, a la educación, a la libre circulación e incluso al libre desarrollo de la personalidad. En este sentido, los usuarios tienen derecho a transportarse a través del medio y modo que escoja de acuerdo con sus necesidades e intereses. Este derecho implica que, los usuarios puedan tomar decisiones de consumo libres y bien informadas, sin que nada ni nadie intervenga.

La trascendencia del derecho al transporte en cuanto servicio público es tal que incluso llega a constituir una limitación a otro derecho fundamental como el derecho a la huelga. Ciertamente cuando se trate de empresas de transporte público la huelga no puede implicar una paralización completa de las actividades y por ende los huelguistas tienen que observar los lineamientos propios de los servicios esenciales que no pueden ser interrumpidos. Esto llega a representar una confrontación entre derechos fundamentales pues el derecho a huelga también es un derecho constitucional e incluso trasciende al bloque de constitucional derivado de la aprobación de los convenios de la Organización Internacional del Trabajo (OIT) convenios 87 y 88, donde ser reconoce la importancia del derecho a la huelga y se garantiza su ejercicio. Así las cosas, a nivel de control y vigilancia del Estado se debe establecer un delicado equilibrio entre la necesidad de garantizar el derecho al transporte y el ejercicio del derecho a la huelga (de Lafont & Niño, 2014).

Por otra parte, dado que el transporte público es un servicio esencial, debe estar sujeto al control, vigilancia y regulación del Estado. De acuerdo con el marco normativo del servicio de transporte público (la Ley 105 de 1993 y la Ley 336 de 1996), el Estado colombiano tiene la responsabilidad de garantizar que este servicio se preste en condiciones de calidad, oportunidad y seguridad. Para ello es menester que a nivel regulatorio se establezcan incentivos que promuevan la calidad y la eficiencia. Para ello, es necesario definir indicadores que aseguren una movilidad digna y un transporte público confiable, estos indicadores deben estar orientados a evaluar aspectos como la puntualidad, la seguridad, la accesibilidad y la satisfacción del usuario. Igualmente, esta normatividad de transporte público debe ser interpretada sistemáticamente con la Ley de Ordenamiento Territorial (Ley 388 de 1997), que también reconoce la importancia del acceso y uso común de las infraestructuras de transporte y el rol de los entes territoriales en el sistema de transporte.

Es de advertir que la ley 105 de 1993 es la que define el transporte público y las condiciones de prestación de este servicio para lo cual se concibió un sistema que incluye aspectos como la libertad de acceso para los usuarios, la libertad de empresa y garantía a la libre competencia, la participación ciudadana, la colaboración entre entidades del sistema nacional de transporte para que la operación se efectúe con criterios de

ISBN 978-9930-617-71-7

coordinación, planeación, descentralización y participación, la actividad de transporte requiere de permisos o contrato de concesión suscrito con autoridades competentes. El sistema también prevé la posibilidad de subsidios para grupos de personas en condiciones de vulnerabilidad, como estudiantes, adultos mayores, discapacitados físicamente, entre otros.

Ciertamente el derecho al transporte, tiene otra cara de la moneda y es la obligación que tienen los usuarios de usar solamente el servicio público de transporte que es ofrecido por empresas legalmente constituidas y habilitadas. El derecho al transporte público claramente sufre una amenaza cuando los usuarios se ven obligados a hacer uso de transporte informal, o ilegal es decir cuando usan vehículos que no están asociados a empresas habilitadas por las autoridades competentes. Ello implica que no solo ponen en riesgo su seguridad, además, no pueden hacer ejercicio de otras garantías que si tendrían con el transporte legal como el derecho a la información de las condiciones de transporte y sobre las tarifas e incluso el derecho a la participación en las decisiones que los afectan como usuarios.

Otro de los aspectos que integra el derecho al transporte y que se asocia con otro derecho fundamental es el derecho a la participación de los usuarios. Ciertamente frente a todas las problemáticas descritas en la ciudad de Cali, no se han observado procesos de participación con información pertinente y suficiente que permitan hacer acompañar los procesos de toma de las decisiones institucionales referentes al transporte público. Si bien ha habido algunas audiencias públicas como la Audiencia Pública de Asignación de Riesgos de la Licitación Pública MC-5.8.5.01.10, para consultar sobre el "diseño, suministro, construcción, obra civil, montaje, puesta en funcionamiento y financiación del sistema de transporte aerosuspendido, mío cable, para la comuna 20 de Santiago de Cali que formara parte del sistema integrado de transporte masivo de Cali – MIO– modalidad llave en mano", la cual se realizó en 2010. Sin embargo, se advierte que ni el municipio ni el MIO tienen un historial consolidado en el que se evidencia el respeto a la participación ciudadana en temas de transporte.

Es crucial fortalecer la garantía del derecho a participar en las decisiones sobre el transporte público, fomentando un entorno colaborativo que promueva el consenso sobre soluciones de movilidad sostenibles, eficientes, confiables y seguras. Los usuarios deben adoptar activamente la innovación y las tecnologías de la información y la comunicación (TIC) para asegurarse de tener acceso a información relevante, lo que les permitirá tomar decisiones informadas. Al hacerlo, podrán participar de manera efectiva en la configuración de políticas y elecciones de transporte público que impactan sus comunidades. Empoderar a los usuarios de esta manera no solo mejora la calidad del transporte público, sino que también fortalece los lazos comunitarios y promueve una visión compartida para una movilidad urbana sostenible.

Dentro de las soluciones que ha buscado el gobierno nacional para diagnosticar y abordar las problemáticas asociadas al transporte, destaca el Plan Maestro de Sistemas Inteligentes de Transporte. Este plan integra aspectos fundamentales, como la seguridad

ISBN 978-9930-617-71-7

vial, que se considera una política de Estado prioritaria. Además, la sostenibilidad ambiental se ha consolidado como un criterio clave, especialmente en el contexto de la transición energética. Para ello, se han implementado políticas de combustibles limpios y se promueve el uso de vehículos de baja emisión. Asimismo, se ha diseñado una propuesta de transporte sostenible en línea con las recomendaciones del Global Environmental Facility, que ofrece asistencia para la estructuración de proyectos de transporte sostenible. Esto incluye la organización de programas de transporte urbano sostenible, los cuales forman parte del Plan de Inversión del Clean Technology Fund (CTF) para Colombia. Estas iniciativas buscan no solo mejorar la calidad del transporte, sino también contribuir a un desarrollo más sostenible y resiliente.

Con el panorama del transporte público en la ciudad de Cali resulta indispensable entender qué es la movilidad inteligente y cómo podría contribuir para mitigar los efectos problemáticos del sistema de transporte masivo. La movilidad inteligente está diseñada para promover modos de transporte con emisiones bajas o complementar el sistema de transporte que genera emisiones, para lo cual debe ser flexible y fácilmente adaptable a las condiciones topográficas de la ciudad y va desde caminar hasta la movilidad en trenes, pasando por monopatines eléctricos, bicicletas, vehículos monomotor, taxis, trenes, metrotranvías entre otros.

Adicionalmente, se encuentra en la movilidad inteligente el factor de conectividad que debe estar presente en los sistemas de transporte inteligentes, que permitan optimizar el uso de las diferentes opciones y se adapte a los eventuales cambios de lo que ocurra en la ciudad. La conectividad resulta crucial para resolver situaciones en un entorno complejo de movilidad donde idealmente debería coexistir la planificación simultanea de las decisiones de transporte y la toma de decisiones sobre las opciones de transporte, mediado por el intercambio de comunicaciones e interactividad en tiempo real entre los datos provenientes de los ciudadanos. Para ello la ciencia de datos resulta crucial con sus procesos de captura, procesamiento, mantenimiento, comunicación y análisis de la información que genera una información que lleva a tomar decisiones confiables, lo cual llevaría a incrementar la seguridad y eficiencia en el transporte (Jalil et al., 2024).

5. Conclusiones

El análisis del transporte público en Colombia, particularmente en la ciudad de Cali, revela la importancia de este servicio como un derecho fundamental, lo que implica una responsabilidad estatal de garantizar su calidad, continuidad y accesibilidad. A través de la sentencia T-604 de 1992 de la Corte Constitucional, se establece que el derecho al transporte no solo es intrínseco a la movilidad, sino que está interconectado con otros derechos fundamentales, como el trabajo, la educación y la libre circulación. Este marco legal implica que los usuarios deben tener acceso a decisiones de consumo informadas y a opciones de transporte que respeten sus necesidades.

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No obstante, el ejercicio del derecho a la huelga en el contexto del transporte público plantea un dilema significativo, pues debe equilibrarse con la necesidad de mantener la continuidad del servicio esencial. Las normativas vigentes, como las Leyes 105 de 1993 y 336 de 1996, establecen las condiciones para la prestación de este servicio, enfatizando la importancia de la regulación estatal para garantizar calidad y seguridad. El desafío reside en fomentar un entorno participativo donde los usuarios no solo consuman, sino que también influyan en la toma de decisiones que afectan su movilidad.

La falta de procesos de participación efectiva, como se evidenció en la Audiencia Pública de 2010 sobre el sistema de transporte aerosuspendido en Cali, subraya la necesidad de establecer canales claros y accesibles para que los ciudadanos se involucren en la gestión del transporte público. Esta participación debe estar acompañada por el uso de tecnologías de información que faciliten el acceso a datos relevantes y empoderen a los usuarios en la formulación de políticas de movilidad.

Además, el desarrollo de un Plan Maestro de Sistemas Inteligentes de Transporte es esencial para abordar los retos actuales del transporte urbano. La movilidad inteligente, que integra opciones de transporte con bajas emisiones y alta conectividad, emerge como una solución viable para optimizar el sistema de transporte masivo en Cali. La implementación de políticas sostenibles y la promoción de vehículos de bajas emisiones son pasos cruciales hacia un sistema de transporte más eficiente y menos contaminante.

En conclusión, el derecho al transporte público en Colombia, con sus implicaciones y desafíos, exige un enfoque integral que contemple la regulación estatal, la participación ciudadana activa y la implementación de tecnologías innovadoras. Solo a través de estas estrategias se podrá avanzar hacia un modelo de transporte que no solo satisfaga las necesidades de movilidad, sino que también contribuya al desarrollo sostenible y resiliente de las comunidades.

Finalmente, es evidente que para avanzar en la transición energética y lograr una movilidad sostenible e inclusiva en Cali, se requieren cambios estructurales profundos. Esto incluye una revisión del marco normativo y la implementación de políticas que fomenten la equidad y la sostenibilidad. Pues con las condiciones actuales de prestación del servicio público de transporte no es posible afirmar que exista una total garantía a los derechos de los usuarios.

Declaración de conflictos de interes. Como autora declare que acato todos los lineamientos de ética en investigación y que no tengo conflicto de intereses respect de la investigación contenida en este documento.

ISBN 978-9930-617-71-7

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Corte Constitucional. Sentencia T-604 de 1992 Magistrado Ponente: Eduardo Cifuentes Muñoz

ISBN 978-9930-617-71-7

Lightweight Consensus Cryptographic Protocol for Biosignal Monitoring in Wireless Body Area Networks

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Abstract. Wireless Body Area Networks (WBANs) play a crucial role in enhancing patient healthcare monitoring by facilitating continuous observation of vital physiological signals. However, existing WBAN implementations often do not meet quality-of-service (QoS) requirements due to challenges related to energy efficiency, adaptability, and security. This paper proposes a lightweight consensus cryptographic protocol that integrates blockchain technology, specifically the Practical Byzantine Fault Tolerance (PBFT) consensus algorithm, into the Intra-WBAN layer to improve data security and reliability. Designed with resource-constrained devices in mind, our protocol ensures data integrity and confidentiality while minimizing computational overhead. We provide a detailed cryptographic description of the protocol, a comparative analysis with existing work highlights the unique contributions of our protocol, including its focus on specific physiological sensors such as the electrocardiogram (ECG), photoplethysmography (PPG), and glucometer. Future work will involve designing the protocol with more sensors and performing a computational cost analysis via mathematical modeling to optimize efficiency and energy consumption. Our goal is to contribute to the development of secure, efficient and reliable WBANs, facilitating their widespread adoption for continuous patient monitoring in healthcare applications in smart cities.

Keywords: WBANs · Blockchain · Cryptographic Protocol · Biosignal Monitoring · PBFT · Cybersecurity

1 Introduction

Healthcare is a vital service in smart cities, which requires personal health monitoring systems, data collection and delivery infrastructure, and a system for diagnosis of symptoms to implement effective healthcare systems in these urban areas. Wireless Body Area Networks (WBANs) have recently captured significant

ISBN 978-9930-617-71-7

interest from researchers to meet the first requirement. Due to their unique characteristics compared to general wireless sensor networks, research on WBANs has concentrated on network topology around the body, implanted nodes, efficient resource allocation, security, and power control [8]. E-Healthcare networks are increasingly providing medical services by leveraging the rise in biomedical sensors, the Internet of Things, and advanced communication and network technologies within smart cities, particularly for remote physical supervision, with the aim of enhancing the quality and efficiency of traditional medical systems. The goal is to offer a robust and effective healthcare solution using wireless internet networks for data transmission and storage, integrating patient devices and blockchain technology into smart cities [13].

A Wireless Body Area Network (WBAN) is a sensor network specifically developed to improve patient healthcare monitoring, derived from IoT implementations. Numerous recent studies have concentrated on the use of WBANs for the continuous monitoring of patients, addressing the growing need for remote monitoring of vital physiological signals to consistently assess the health status of patients with COVID or post-acute sequelae of SARS-CoV-2 infection (PASC). However, WBANs often do not meet the necessary Quality of Service (QoS) standards for patients. The achievement of QoS in WBANs depends on addressing three main challenges: energy efficiency, adaptability through mobility prediction, and security.

The WBAN communications are generally divided into three layers: intra-WBAN, inter-WBAN, and beyond WBAN. Each of these layers has been the focus of recent research. As depicted in Fig. 1, WBANs are categorized based on the communication layer they utilize, with each layer introducing distinct security challenges and potential attack vectors [2]. The first layer, Intra-WBAN, is closest to the body, where sensors interact directly with a coordinator node, Central Unit (CU), or Personal Digital Assistant (PDA). Security at this layer is crucial due to the direct management of sensitive health data, making it susceptible to attacks like tampering and jamming. The second layer, Inter-WBAN, facilitates communication between the PDA and access points. This layer is critical for extending the network's range and ensuring the integration of WBANs into larger healthcare systems. However, attacks at this level can disrupt data flow and compromise the integrity of the entire network. The third layer, Beyond-WBAN, enables data transmission between access points and central medical servers, being vital for remote monitoring and centralized data storage. Attacks at this layer, including Sybil attacks or flooding, can have serious repercussions, potentially disrupting essential healthcare services.

The progress in Wireless Body Area Networks have notably influenced the domain of remote health monitoring and biomedical data transfer. With the increasing dependence on these technologies, maintaining the security, reliability, and efficiency of data transmission within these networks has become crucial. Researchers are increasingly adopting sophisticated cryptographic methods and network optimization strategies to address these issues. One of the promising strategies is the integration of blockchain technology into WBANs.

ISBN 978-9930-617-71-7

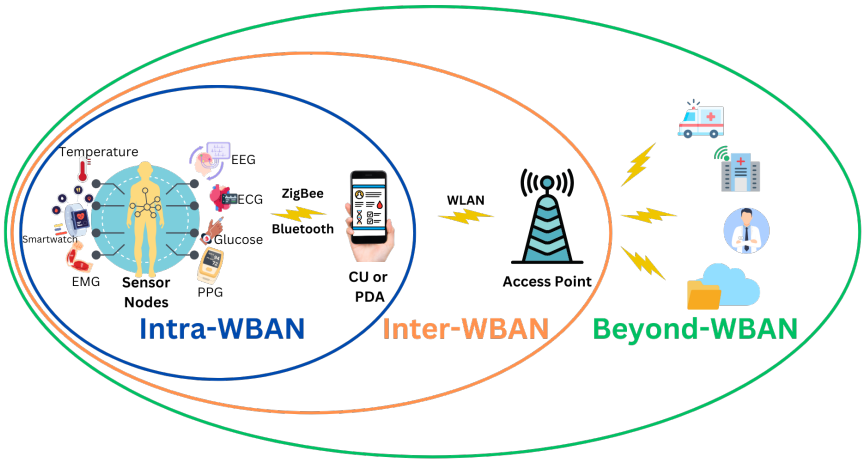


Fig. 1. Classification of the WBANs

Blockchain technology, known for its decentralization, immutability, and robust data management capabilities, has been suggested as a strong solution to address security issues in WBAN. Several studies have investigated incorporating blockchain into various WBAN layers, with the goal of improving data confidentiality, integrity, and access control. Essentially, a blockchain acts as a decentralized and secure database for transaction logs. In a Bitcoin network, if client A wishes to transfer bitcoins to client B, client A initiates a bitcoin transaction. This transaction must be validated by miners before being added to the Bitcoin network. To start the mining process, the transaction is broadcasted to all nodes in the network. Nodes that are miners then gather transactions into a block, verify them, and broadcast the block along with its verification through a consensus protocol to gain network approval [20]. This article will focus on the lightweight consensus cryptographic protocol for our primary design in the intra-WBAN layer.

To provide a comprehensive understanding of our work, the remainder of this paper is organized as follows. In Section 2, we review the state of the art in integrating blockchain technology with Wireless Body Area Networks (WBANs), highlighting recent studies and their approaches to enhancing security and efficiency in biosignal monitoring. Section 3 presents the design of our lightweight consensus cryptographic protocol, detailing the use of the Practical Byzantine Fault Tolerance (PBFT) consensus protocol within the Intra-WBAN layer and explaining the cryptographic operations involved. In Section 4, we discuss the results of our comparative analysis, emphasizing the advantages of our proposed protocol over existing methods and identifying areas where current research falls short. Finally, Section 5 concludes the paper and outlines directions for future

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work, including the planned design of the protocol with specific physiological sensors and a comprehensive computational cost analysis.

2 State of the Art

This section takes a closer look at recent studies that explore how blockchain technology can be used in Wireless Body Area Networks (WBAN) to improve security, privacy, and efficiency. Some of the research focuses on the practical side of things, showing how blockchain can be applied in real-world scenarios, while others go deeper into performance details like energy use and data security. Even though a few studies skip over certain aspects like mathematical modeling or cost analysis, the overall takeaway is that blockchain has a lot of potential to tackle important challenges in WBAN.

Pathak et al. in [12] investigate the integration of blockchain technology within WBAN to enhance data security and compression efficiency. The proposed system utilizes blockchain to ensure the integrity and confidentiality of data transmitted within WBAN, with a particular focus on intra-body area communication. While the study underscores the conceptual framework and practical implementation, it lacks detailed sensor analysis. The computational cost and efficiency of the proposed blockchain integration are briefly examined, indicating its potential to reduce overheads and improve data management within WBANs.

Anbarasan and Natarajan in [1] introduce a blockchain-based healthcare monitoring system within Wireless Body Area Networks (WBAN) with particular attention to delay and energy efficiency. The authors propose a system architecture that incorporates blockchain technology to secure data transmissions, considering the energy constraints and delay issues characteristic of healthcare monitoring. The research provides an exhaustive analysis of the computational costs associated with blockchain integration, rendering it a valuable reference for optimizing energy efficiency in WBAN settings.

Pawar and Kalbande in [13] examine the application of blockchain technology to improve the security of data transmission and storage within WBAN. The paper addresses the theoretical benefits of blockchain, especially its capacity to guarantee data authenticity and integrity in intra-WBAN communications. Although the study offers a compelling case for blockchain's effectiveness in securing WBAN, it concentrates on the broader consequences of blockchain deployment in these networks.

Ren et al. in [14] propose a blockchain-based data storage mechanism aimed at enhancing privacy protection within WBAN. The paper emphasizes the application of blockchain technology to secure data storage, ensuring that sensitive health information remains confidential and tamper-proof. While the study effectively demonstrates the potential of blockchain in securing data within WBAN, it concentrates mainly on the privacy and security aspects of the proposed mechanism.

Farhan, Farhan, and Hussein in [3] investigate a blockchain-based framework designed to augment the security and privacy of communications within

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WBAN. The authors present a system that employs blockchain technology to safeguard data transmission between body sensors and external devices, ensuring the confidentiality and integrity of the data. Although the paper focuses on the conceptual framework, certain aspects of the blockchain implementation, specifically its efficiency and scalability, remain unaddressed.

Gao, Yao, and Ma in [5] examine the security challenges inherent in the storage of WBAN data within cloud environments, proposing a blockchain-based solution to ensure the integrity and confidentiality of the data. The study primarily addresses Beyond-WBAN layers, where data is transmitted from WBAN to cloud storage systems. Although the paper elaborates on the security advantages of incorporating blockchain technology, it concentrates on the general security framework for cloud storage of WBAN data.

Lau, Alan, and Yan in [9] explore the utilization of blockchain for authentication within Internet of Things (IoT) networks, including Wireless Body Area Networks (WBAN). The paper introduces a blockchain-based authentication mechanism designed to enhance security by ensuring that solely authorized devices can access and transmit data within the network. Although the primary concentration is on IoT networks at large, the discussed principles are equally applicable to WBAN, particularly in reinforcing security and mitigating unauthorized access.

Manu and Bhaskar in [10] propose a blockchain-based security framework to safeguard sensitive data transmitted within BANET. The study elaborates on the utilization of blockchain to ensure data integrity, confidentiality, and access control, employing smart contracts to manage data interactions within the network. Specific sensors, including pulse rate, EEG, blood pressure, and respiration sensors, are cited as examples.

Shen et al. in [18] propose a lightweight, certificateless, multi-layer authentication protocol aimed at enhancing the security of Wireless Body Area Networks (WBANs). This protocol incorporates blockchain technology to achieve mutual authentication between sensors and Personal Digital Assistants (PDAs) within the network. The study provides a performance analysis comparing the computational costs of the proposed protocol with existing protocols, underscoring its efficiency and security advantages. However, the specific sensors are not detailed.

Hussain et al. in [7] deliver an exhaustive review of authentication techniques and methodologies utilized within WBAN, examining diverse mechanisms for securing data transmission across various WBAN layers. The survey encompasses an array of authentication strategies, including blockchain-based methods, and assesses their efficacy in augmenting data security. This article provides significant insights into the computational costs and efficiency associated with different authentication techniques, including those leveraging blockchain technology.

Gaikwad and Ananthakumaran in [4] provide a comprehensive review of the security and privacy challenges inherent in the applications of WBAN in healthcare, with a particular emphasis on Beyond-WBAN layers. Their review elucidates various blockchain-based methodologies employed to safeguard data in

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healthcare environments, underscoring the critical importance of maintaining data integrity and privacy.

3 Lightweight Consensus Cryptographic Protocol Design

The concept of blockchain was first introduced in 2008, followed by its initial open-source implementation in 2009 as a core component of Bitcoin, the pioneering decentralized digital currency system. Bitcoins were distributed through the open source release of peer-to-peer Bitcoin software, both developed by Satoshi Nakamoto [11]. The Bitcoin framework uses the blockchain as its distributed public ledger to log and authenticate all Bitcoin transactions within the open peer-to-peer Bitcoin network. A notable breakthrough of the Bitcoin blockchain is its ability to avoid double spending in bitcoin transactions within a fully decentralized peer-to-peer network, eliminating the need for any central trusted authority [20].

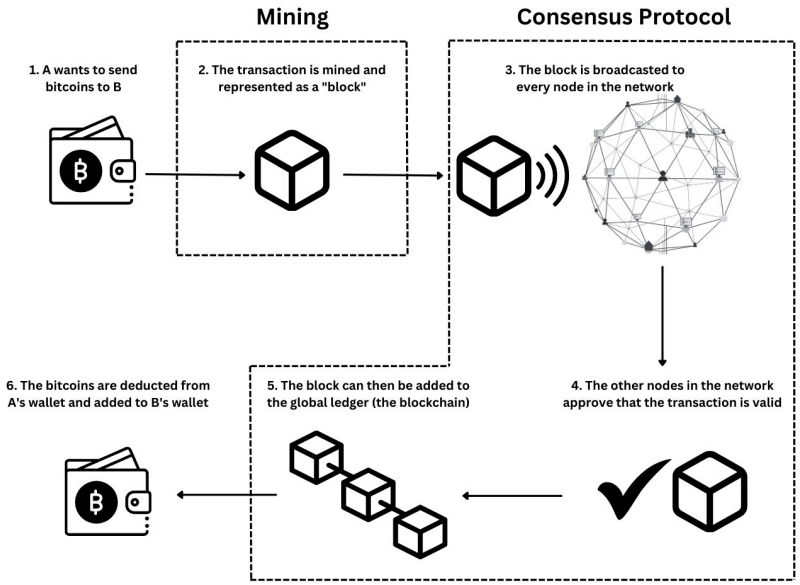


Fig. 2. The Operational Dynamics of Blockchain Technology: The initiation of the blockchain process is marked by mining, followed subsequently by the implementation of the consensus protocol.

The design delineated in this study exclusively addresses the lightweight consensus cryptographic protocol of the blockchain. Consequently, the mining aspect of the blockchain remains beyond the scope of this investigation.

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Our lightweight consensus cryptographic protocol was designed with energy efficiency in mind, using lightweight cryptographic algorithms and minimizing the computational overhead required to record data on the blockchain. The need for a consensus protocol specifically designed for IoT nodes comes from the unique characteristics and challenges these devices face. IoT devices often have significant resource limitations in terms of power, processing capacity, storage, and energy consumption, making traditional consensus protocols unsuitable for their more constrained environments. Energy efficiency is a crucial factor, as many IoT devices rely on limited power sources or batteries, so the protocol must minimize energy use to extend battery life and reduce the need for frequent recharging. In addition, many IoT devices operate in environments with limited bandwidth, which requires the protocol to be efficient in transmitting data to avoid overloading communication networks, especially in areas with restricted connectivity. Some IoT applications also require fast response times and low latency, which means that the consensus protocol must quickly reach decisions to meet real-time requirements. Finally, IoT devices are highly diverse in terms of architecture, hardware, and operating systems, so the protocol should be compatible with a wide range of devices and flexible enough to accommodate different systems [6, 19, 17].

The decision to use the Practical Byzantine Fault Tolerance (PBFT) protocol in our lightweight consensus cryptographic protocol design is driven by its appropriateness for resource-limited settings like Wireless Body Area Networks (WBANs). PBFT is recognized for its high efficiency and minimal computational overhead, making it more suitable compared to other consensus mechanisms such as Proof of Work (PoW) or Proof of Stake (PoS), which require significant computational power and thus are impractical for devices with limited processing capabilities and energy [15]. When considering the integration of blockchain technology with IoT devices, a key challenge lies in the considerable computational and energy demands of traditional consensus protocols. According to Salimitari et al. [15], most available consensus protocols were designed for nodes with extensive computational and storage resources, traits not found in IoT devices. Therefore, there is a critical need to develop consensus protocols that perform effectively on nodes with limited resources.

PBFT stands out as a consensus cryptographic protocol that can meet these requirements. Unlike PoW, PBFT does not rely on solving complex cryptographic puzzles, thereby reducing the computational load on participating devices. Instead, PBFT achieves consensus through a series of message exchanges among nodes, making it more suitable for environments where energy efficiency and low latency are critical [15]. Moreover, PBFT provides fast transaction finality and is designed to tolerate Byzantine faults, enhancing the reliability and security of the network without imposing significant overhead [16].

By adopting PBFT, our protocol ensures that the decentralized and secure nature of blockchain technology is maintained while aligning with the resource limitations of WBAN devices. This approach addresses the key challenges identified in previous research [15], enabling the practical implementation of

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blockchain in WBANs for biosignal monitoring. The use of PBFT allows for efficient consensus without overburdening the devices, ensuring that energy consumption is minimized, a critical factor for wearable medical sensors operating on limited battery life.

Table 1. PBFT Protocol Notation

Symbol	Definition
E	Owner
H	Hash Function
pk	Public Key
sk	Private Key
$\rightarrow$	Distribution
S	Signature
N_p	Primary Node
N_i, N_j	Replica Nodes
V	Verification
t	Timestamp
n	Number of Nodes
o	Operation
c	Client ID
v	View
ns	Sequence Number

The operation flow of our protocol is described in the following equations, and the notation used is stated in Table 1. This protocol starts when the owner prepares the transaction, signs the hash of the information, and then sends it to the primary node.

$$E : h = H(info) \tag{1}$$

$$E : S_E = S_{sk_E}(h) \tag{2}$$

$$E \rightarrow N_p : info \,||\, S_E \,||\, op \,||\, t \,||\, id_E \tag{3}$$

When the transaction reaches the primary node, it has to validate the owner's signature.

$$N_p : V_E = verify_{pk_E}(S_E) \tag{4}$$

If the signature is incorrect, the transaction is rejected. Otherwise, the primary node assigns a sequence number to order the transactions and a view to indicate which primary node is leading the generation.

These values, along with the transaction, are signed and sent to the rest of the replica nodes.

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$$N_p : S_{N_p} = S_{sk_{N_p}}(info||h||ns||v_k) \tag{5}$$

$$ns \in [r, R] \tag{6}$$

$$N_p \rightarrow N_i^{1 \leq i \leq n} : info \,||\, h \,||\, ns \,||\, v_k \,||\, S_{sk_{N_p}} \tag{7}$$

The replica nodes validate the signature of the primary node, the view, and then verify the integrity of the message.

$$N_i : V_p = verify_{pk_{N_p}}(S_{N_p}) \tag{8}$$

$$N_i : h_n = H(info) \tag{9}$$

$$N_i : h_n \oplus h \tag{10}$$

$$N_v : V_{info} = verify(v_k \,||\, ns) \tag{11}$$

If the verification of all data is true, each replica node signs the transaction and shares it with the other replica nodes, adding its identifier.

Each replica node verifies and expects to receive $2n+1$ confirmation messages from other nodes with the same v, n, and d. If they receive them, they confirm the established state and execute the request. Then, they send a response to the owner.

The owner expects to receive $n + 1$ responses from different nodes with the same v and ns, and $True$. If the signature is correct, the final result of the operation is sent.

Within the context of Wireless Body Area Networks (WBANs), Figure 3 illustrates the design of our consensus cryptographic protocol, which uses the Practical Byzantine Fault Tolerance (PBFT) protocol, where the process for adding data to the blockchain varies depending on the petitioner. Figure 4 presents the proposed cryptographic protocol, which employs a physiological sensor glucometer as the Owner, an electrocardiogram (ECG) sensor and a photoplethysmography (PPG) sensor as the Replica Nodes, and a central unit (CU) as the Primary Node. In other words, our proposal utilizes blockchain technology at the intra-WBAN level to ensure secure transmission of biosignal data among WBAN nodes.

4 Comparative Analysis

The comparative analysis depicted in Table 2 underscores vital elements in recent articles on blockchain deployment within WBANs. Our proposed protocol is distinct in its focus on the Intra-WBAN layer, offering security services and taking into account specific physiological sensors. This is in contrast to the bulk

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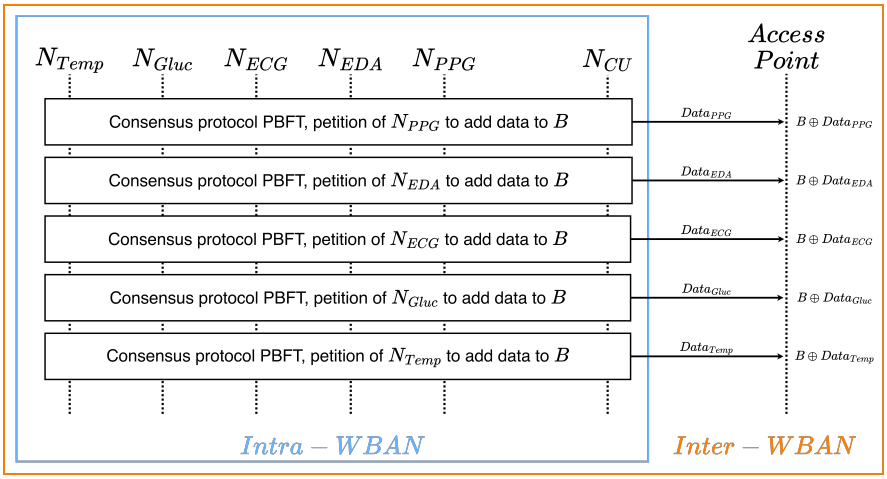


Fig. 3. A general cryptographic protocol diagram illustrating the design of the consensus protocol within the Intra-WBAN layer, and demonstrating how sensor data can be integrated into the blockchain of the access point in the Inter-WBAN layer.

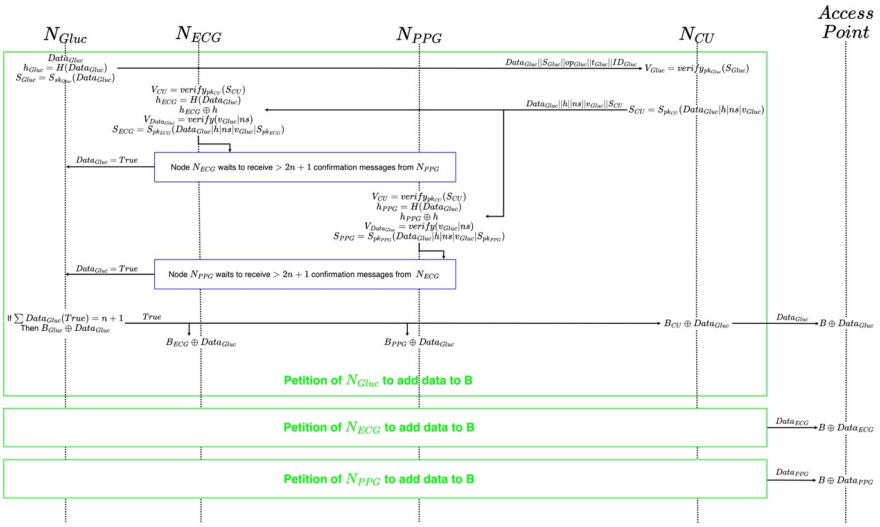


Fig. 4. Detailed description of the cryptographic protocol architecture, where the physiological sensor glucometer serves as the Owner, the electrocardiogram (ECG) sensor and photoplethysmography (PPG) sensor function as the Replica Nodes, and the central unit (CU) acts as the Primary Node, following the operational flow previously explained.

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of existing research, which mainly targets the Inter-WBAN or Beyond-WBAN layers and frequently neglects the crucial Intra-WBAN layer where data is initially gathered and most prone to attacks. Although all reviewed articles address security services, few consider the specific challenges of the Intra-WBAN layer, where our protocol stands out.

Furthermore, our work is among the few that consider specific sensors within the WBAN, such as ECG, PPG, EDA, temperature, and glucose sensors. This specificity enables us to tailor the security mechanisms to the unique data types and requirements of each sensor, enhancing the overall effectiveness of the protocol. In contrast, most existing studies, such as those by Pathak et al. [12] and Pawar and Kalbande [13], do not specify the sensors involved, potentially limiting the applicability of their solutions to various biomedical devices.

Another critical aspect is the computational cost analysis. Although some studies, such as those by Pathak et al. [12] and Shen et al. [18], include this analysis, many do not. Our current lightweight consensus cryptographic protocol lacks a detailed computational cost analysis, which we acknowledge as a limitation and an area for future work. Conducting such an analysis is essential to ensure that security enhancements do not adversely affect energy efficiency and latency, which are crucial parameters in WBANs due to the limited resources of wearable devices.

By identifying these trends and gaps, our comparative analysis underscores the need for comprehensive solutions that address security at the Intra-WBAN layer with mathematical rigor and sensor-specific considerations. Our lightweight consensus cryptographic protocol helps fill these gaps by providing a secure, efficient, and tailored approach to biosignal monitoring in WBANs. This positions our work as a step towards developing more holistic and practical solutions that can be effectively deployed in real-world healthcare applications.

Table 2. Comparative summary of key aspects in research articles focused on blockchain implementation in WBANs. Where A = Authentication, C = Confidentiality, I = Integrity, Av = Availability, PoW = Proof of Work and PoS = Proof of Stake

Article	Type of WBAN	Security Services	Sensors taken into account	Consensus protocol
Current	Intra	I, Av	✓	PBFT
[12]	Inter	C, I Av	×	Trust-Based
[1]	Intra	A, C, I Av	×	PoW or PoS
[13]	Inter	A, C, I Av	×	PoW or PoS
[14]	Inter	C, I Av	×	Improved Raft
[3]	Inter	C, I Av	×	PoW or PoS
[5]	Beyond	C, I Av	×	Raft consensus
[9]	Beyond	A, C, I Av	×	Not mentioned
[10]	Inter / Beyond	A, C, I Av	✓	PoW or PoS
[18]	Inter	A, C	×	Not mentioned
[7]	Inter / Beyond	A, C, I Av	×	Not mentioned
[4]	Beyond	A, C, I Av	×	Not mentioned

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The comparative analysis with existing work demonstrates that our approach not only addresses security requirements but also incorporates mathematical modeling and considers specific physiological sensors. This positions our work as a comprehensive solution that bridges the gap between theoretical cryptographic protocols and practical implementations in healthcare monitoring systems.

5 Conclusions and Future Work

This paper presents a cryptographic protocol that incorporates blockchain technology into the Intra-WBAN layer, aiming to enhance the security and reliability of biosignal monitoring within Wireless Body Area Networks (WBANs). Our Lightweight Consensus Cryptographic Protocol for Biosignal Monitoring in WBANs offers key features such as security, efficiency, and reliability. Additionally, it holds the potential to enable advanced healthcare applications in modern smart cities. By overcoming obstacles related to energy efficiency, adaptability, and security, our objective is to promote the extensive use of WBANs for ongoing patient monitoring, especially in contexts that demand remote healthcare services.

For future work, we plan to extend our protocol design to include a detailed implementation with five specific physiological sensors: electrocardiogram (ECG), photoplethysmography (PPG), electrodermal activity (EDA), temperature and glucometer. By modeling the computational costs associated with each of these sensors, we aim to perform an in-depth analysis of the protocol's efficiency and energy consumption. This will involve developing mathematical models that capture the energy profiles and processing capabilities of the sensors, allowing us to optimize the protocol parameters accordingly. In addition, we intend to simulate the proposed protocol to evaluate its performance under various conditions, such as battery consumption, interference, and varying data transmission rates.

6 Acknowledgments

The authors kindly acknowledge the financial support from the Instituto Politécnico Nacional (IPN) under grant SIP-20241113 and SIP-20240671.

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ISBN 978-9930-617-71-7

ZREM: sistema de extracción de noticias para el Monitoreo Nacional e Internacional de Amenazas Zoosanitarias

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Resumen. A nivel mundial existe un aumento en el riesgo y amenazas de enfermedades zoosanitarias de alto impacto y rápida propagación. Un brote en cualquier parte del mundo puede considerarse una amenaza para la sanidad agropecuaria e inocuidad de los alimentos, debido al impacto potencial en la economía, la salud humana y/o el medio ambiente. Por ende, un objetivo principal de la autoridad de sanidad animal pro-activa en cada país (incluyendo México), es la puesta en marcha de la inteligencia epidémica, que incluye: detección temprana, verificación y comunicación de señales de aparición de plagas y enfermedades a partir de fuentes de información formales e informales en la web. Se presenta el avance del software con nombre ZREM (Zoosanitary Risk Extractor for Mexico), especializado en la búsqueda, identificación, clasificación, análisis y selección automatizada, organizada y de consulta rápida, de noticias de fuentes abiertas, que contengan datos estructurados o no estructurados sobre amenazas potenciales para la salud animal de México. Se utilizan palabras clave para la búsqueda de documentos, y el procesamiento de lenguaje natural para la extracción datos relevantes de la noticia. Se describe sobre problemas en un desarrollo de recolección abierta de documentos y como se resuelven las respuestas vacías o con basura en ellas.

Palabras claves: webscrapping · riesgo zoosanitario · enfermedades zoosanitarias · inteligencia epidémica · extracción de noticias

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1 Introducción

Las plagas agrícolas de importancia cuarentenaria, las enfermedades de los animales de notificación obligatoria [2] y la presencia de contaminantes biológicos, químicos y/o físicos en productos agropecuarios, representan amenazas para la sanidad agropecuaria e inocuidad de los alimentos, debido a varios factores de impacto en la economía, la salud humana y/o el medio ambiente por parte de estos. La manera más eficaz de protegerse frente a este tipo de amenazas, consiste en fortalecer la capacidad de prevención, preparación y respuesta, procesos para los que la detección y alerta temprana son elementos esenciales. La mayoría de las autoridades de sanidad animal han establecido desde hace tiempo una vigilancia formal basada en indicadores, es decir, la recopilación y notificación de indicadores cuantitativos (por ejemplo, el número de casos) obtenidos a partir de programas rutinarios de vigilancia de enfermedades [3]. Sin embargo, se ha demostrado que la vigilancia basada en indicadores carece de puntualidad en la detección y notificación de brotes de patógenos exóticos.

En México, en febrero de 2007, fue inaugurada la Unidad de Inteligencia Epidemiológica y Sanitaria (UIES), dependiente de la Secretaria de Salud, en el Marco de seguridad sanitaria mundial jurídicamente vinculante [1], acordado por 196 países (incluidos los Estados Miembros de la OMS), con la finalidad de prevenir la propagación internacional de plagas, enfermedades y otros peligros, a través de la emisión de alertas tempranas. Por lo tanto, las actividades de inteligencia sanitaria realizadas en el Área de Sistematización y Análisis Sanitario (ASAS) del Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria (SENASICA) [4], mediante el monitoreo de amenazas fitozoosanitarias y de inocuidad agroalimentaria, resultan esenciales para la detección y comunicación oportuna de eventos de riesgo a los tomadores de decisiones de la Alta Dirección del SENASICA, mediante la generación de avisos y alertas tempranas. Sin embargo, para que tal monitoreo se realice con mayor eficiencia y precisión, es necesario contar con una herramienta informática que permita automatizar la búsqueda, identificación, clasificación y selección de noticias sobre eventos que representen amenazas para la sanidad agropecuaria e inocuidad de los productos agropecuarios de México.

1.1 Trabajos relacionados

En esta sección se revisa la literatura relacionada a los sistemas de biovigilancia en internet existentes, analizando las problemáticas y limitaciones que estas enfrentan actualmente.

Tal y como se describe en [6] la biovigilancia en Internet utiliza datos no estructurados de diversas fuentes basadas en la web con el objetivo de proporcionar una alerta temprana y conocimiento de la situación de las amenazas para la salud pública. Esta metodología es una modalidad oportuna que está a disposición de

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los funcionarios gubernamentales y de salud pública, de los trabajadores sanitarios y de los sectores público y privado, y sirve como enfoque complementario en tiempo real a los métodos tradicionales de vigilancia de enfermedades de salud pública basados en indicadores.

El proceso de biovigilancia en Internet varía, pero en general incluye: la recopilación y el almacenamiento de datos de Internet; el procesamiento de datos para producir información; el ensamblaje de información en análisis; y la difusión de los análisis a los usuarios finales. Entre los trabajos más influyentes en esta área se encuentra la herramienta descrita en [3]. La Plataforma para la Extracción Automatizada de Información sobre Enfermedades de la Web (PADI-web) recopila, procesa y extrae automáticamente información epidemiológica en inglés de Google News. El componente central de PADI-web es un método combinado de extracción de información (EI) basado en sistemas de reglas y técnicas de minería de datos. El método EI permite extraer información clave sobre enfermedades, lugares, fechas, anfitriones y número de casos mencionados en las noticias. Sin embargo, una de las principales limitaciones de PADI-web es el idioma y la cobertura geográfica de los proveedores de noticias, tal y como se describe en [7]. Actualmente, PADI-web recopila solamente noticias en un solo idioma (inglés) de una sola fuente (Google News), por lo que dicha herramienta podría dejar fuera eventos reportados por otras entidades.

Otro trabajo relevante en el área es la herramienta descrita en [8] llamada HealthMap. HealthMap es un sistema semiautomático de biovigilancia que se puso en marcha en 2006. A diferencia de PADI-web, este sistema recoge, procesa y muestra automáticamente señales de fuentes en línea disponibles en siete idiomas. Las fuentes de HealthMap para las señales de enfermedades animales incluyen agregadores de noticias (por ejemplo, Google News, Baidu, Soso, VeriSign), la Organización Mundial de Sanidad Animal (OMS), autoridades nacionales de sanidad animal y otros sistemas de biovigilancia.

Otra herramienta a destacar es ProMED, un sistema de biovigilancia moderado por humanos que funciona desde 1994 [9]. Es el sistema de biovigilancia de libre acceso más extenso y está disponible en cinco idiomas. La principal fuente de señales de enfermedades animales de ProMED es la OMS, seguida de los informes sanitarios enviados por suscriptores de todo el mundo. Los moderadores de ProMED verifican las señales antes de compartirlas con su red de suscriptores. Las principales señales de interés internacional se comparten en inglés a través de ProMED-mail, la red principal de ProMED. Las señales específicas de interés regional se comparten con las redes regionales de ProMED, por ejemplo, los mensajes en inglés de ProMED-MBDS (región de la cuenca del Mekong en el Sudeste Asiático), ProMED-EAFR (África anglófona), ProMED- MENA (Oriente Medio) y ProMED-SoAs (Sur de Asia).

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Las 3 herramientas descritas previamente son de las más relevantes en el área a trabajar. Sin embargo, existen otros sistemas automatizados de biovigilancia como el descrito en [10], que han logrado un alto rendimiento para determinadas regiones, fuentes e idiomas, como la región Asia-Pacífico; y el sistema desrito en [11], el cual favorece una cobertura más amplia de fuentes en más de 40 idiomas, pero su eficacia aún no ha sido evaluada.

La gran mayoría de estas soluciones operan bajo sus propios enfoques, es decir, extraen y comparten información que ellos consideran relevante a nivel internacional bajo sus propios criterios, además de utilizar cada uno sus propias fuentes de búsqueda. Cabe recalcar que el SENASICA actualmente hace uso de varias herramientas informáticas disponibles como lo es ProMED. Sin embargo, en México, se desea contar con un sistema de extracción y análisis propio, con el objetivo de poder actualizarlo acorde al crecimiento de las necesidades propias del país, teniendo en cuenta la lista de enfermedades zoosanitarias de alto impacto para México y las fuentes más recurrentes de las cuales el personal del SENASICA logra extraer información de interés para ellos. Es por ello que el presente trabajo, en desarrollo, busca cubrir con dichos objetivos.

1.2 Alcance y contribución

El objetivo general del proyecto es desarrollar una herramienta informática especializada en la búsqueda, extracción, identificación, clasificación y selección automatizada, organizada y de consulta rápida, de noticias de fuentes abiertas, que contengan datos estructurados o no estructurados sobre amenazas potenciales para la salud animal (descartando el enfoque fitosanitario y de inocuidad) de México, a partir de los cuales puedan generarse avisos y alertas tempranas a los tomadores de decisiones de la Alta Dirección de SENASICA.

En este artículo se muestra una primera versión del software ZREM, módulo de extracción de noticias zoosanitarias de la web del proyecto sobre detección de plagas y enfermedades fitozoosanitarias en México.

2 Metodología

2.1 Descripción general y arquitectura propuesta

La arquitectura general del proyecto se muestra en la Fig.1. Similar a otras herramientas, el sistema debe de ser capaz de extraer noticias de la web y almacenarlas de forma estructurada, considerando de primera instancia elementos importantes como el título de la noticia, enlace web de la página que la publica, fecha de la publicación y el contenido de la misma. Esta tarea se realiza en la primera versión de ZREM, la cual representa el "Modulo de extracción", y es el proceso sobre el cual se centra el presente artículo.

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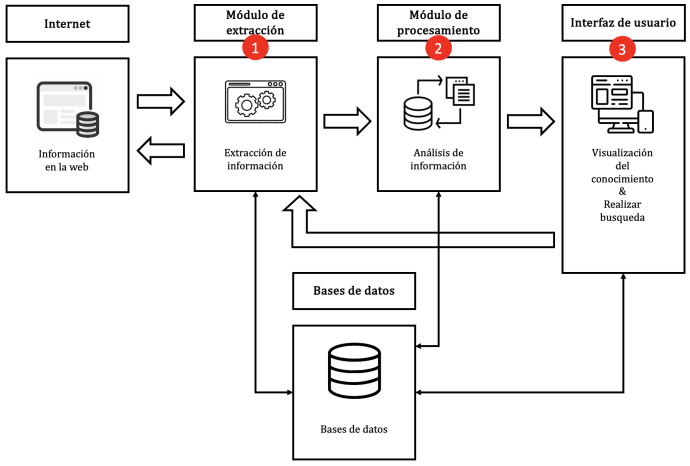


Fig. 1. Arquitectura general de la herramienta.

Como se observa en la la Fig.1, el módulo de extracción tiene conexión directa con la base de datos, la cual por el momento consta solo de dos tablas principales: (1) tabla de las enfermedades de los animales de notificación obligatoria [2] y (2) tabla de las noticias recolectadas. En esta primera fase, el software accede a la base de datos y extrae el listado de todas las enfermedades sobre las cuales se buscará la información (noticias). Una vez obtenido el listado de enfermedades, este utiliza cada una de las enfermedades como "consulta de búsqueda" y extrae las noticias encontradas en la web (un conjunto de noticias por cada enfermedad). Una vez recolectados los textos, estos serán procesados por un segundo módulo, el cual lleva por nombre "Módulo de procesamiento". El objetivo principal de este módulo es procesar los textos, incluyendo funciones como la comparativa entre noticias (similitud), verificación de la veracidad de estas y finalmente la extracción de información relevante de las mismas mediante el uso de técnicas de procesamiento del lenguaje natural y técnicas de minería de datos. Al tenerse un enfoque zoosanitario, algunos de los elementos más importantes que se desean extraer son la fecha y sitio geográfico donde se detectó el evento, especie a la que afecta el patógeno y si hubo o no mortalidad de animales. Una vez realizada la extracción de información, esta se mostrará de forma estructurada en una interfaz de usuario dirigida al personal del Monitor de Riesgos y Amenazas del SENASICA. Es importante recalcar que tanto el módulo de análisis como la interfaz de usuario se encuentran en desarrollo, y no se hablará a detalle sobre estos en el presente artículo.

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2.2 Sistema de extracción de noticias (Módulo de extracción)

Web scraping

El web scraping [12-14] es una técnica utilizada para extraer información de sitios web de manera automatizada. A través de un programa o script, se accede a una página web, se analiza su estructura (generalmente HTML) y se extraen datos relevantes. Esta técnica es comúnmente utilizada para recopilar grandes cantidades de información que no están fácilmente disponibles mediante una API (Application Programming Interface).

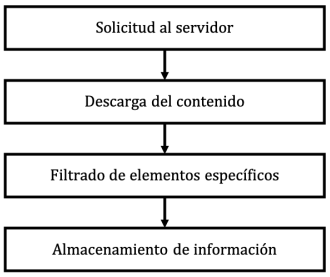


Fig. 2. Flujo de trabajo del web scraping.

El flujo de trabajo general del web scraping se muestra en la Fig.2. La descripción de este se muestra a continuación.

1. **Solicitud al servidor.** El script o la herramienta de scraping realiza una petición HTTP (Hypertext Transfer Protocol) para intentar acceder al contenido de la página web.

2. **Descarga del contenido.** Si la solicitud fue exitosa, se descarga el contenido (comúnmente contenido HTML) de la web.

3. **Filtrado de elementos específicos.** Normalmente se desean obtener solamente elementos específicos y no todo el contenido de la página web. Para ello se utliza una técnica que comunmente va de la mano con el web scraping llamada parsing o análisis sintáctico. El parsing es el proceso de analizar una estructura de datos (como un documento de texto, un archivo HTML o un conjunto de datos) y convertirla en un formato más comprensible o manejable por un programa o sistema.

4. **Almacenamiento de la información.** Una vez filtrados los elementos o contenidos de interés, estos son almacenados para su procesamiento posterior.

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Descripción general del módulo de extracción

La búsqueda de noticias se plantea realizarse sobre los siguientes medios de comunicación:

1. Google News
2. Páginas web de los Ministerios/dependencias de los países miembros de la Organización Mundial de Sanidad Animal (OMSA)
3. Redes sociales (Twitter, Facebook e Instagram)

En este artículo se presentan los avances del diseño y resultados respecto al primer medio de comunicación (Google News), ya que además de ser una fuente abierta de noticias bastante confiable y accesible, es una de las fuentes de búsqueda más utilizadas del SENASICA.

Como se observa en la Fig.3, la arquitectura propuesta del módulo extractor consta de dos procesos principales: (1) extracción de los enlaces de búsqueda y (2) extracción de los textos. La idea es la siguiente: para extraer los textos debe tenerse una lista de enlaces a los cuales se deben acceder. Sobre cada enlace se extraerá una noticia diferente. Dichos enlaces se recuperan dentro del primer proceso del módulo de extracción, el cual se describe a continuación.

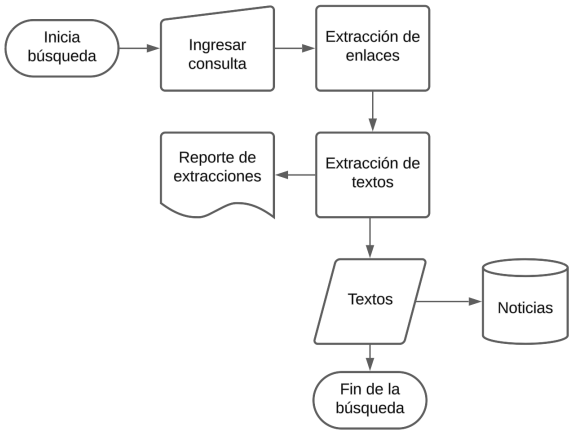


Fig. 3. Diagrama de flujo general de la extracción de textos.

Proceso de extracción de enlaces

Tal y como se observa en la Fig.4, el proceso recibe como entrada lo que denominaremos como una consulta. Esta consulta consta de una cadena sobre lo

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que se desea obtener información. Dicha cadena puede provenir de la base de datos de enfermedades en monitoreo (ver Fig.1) o bien puede ser ingresada manualmente por el usuario. Una vez ingresada la consulta, el proceso de extracción de los enlaces funciona de la siguiente manera:

1. **Construcción del enlace de búsqueda.** El enlace de búsqueda es el enlace principal que debe ingresarse en el buscador. Este enlace se construye en función a algunos de los parámetros que utiliza Google.

2. **Consulta por protocolo HTTP.** Utilizando el protocolo de comunicación HTTP, se realiza una consulta de tipo GET al servidor para extraer el contenido HTML en crudo de la página de Google News.

3. **Extracción de enlaces.** Mediante un análisis sintáctico o *parsing* sobre el contenido HTML, se extraen los enlaces que se encuentran dentro de ciertas etiquetas. Para ello, es importante analizar previamente la estructura del contenido HTML de Google News. Adicionalmente a los enlaces, se extrae también el título principal de la noticia y el tiempo de hace cuanto se publicó.

4. **Filtrado de enlaces.** Una vez extraídos los enlaces, se desean conservar solamente aquellos que contengan noticias "recientes". Cualquier enlace de noticia que tenga una fecha de publicación mayor a 1 día, será descartada.

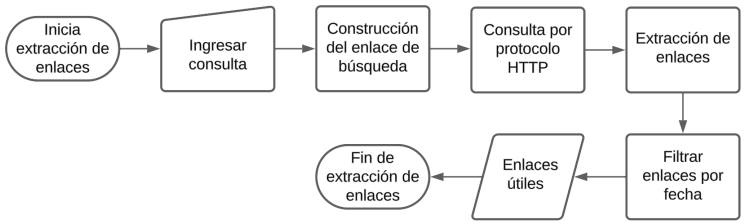


Fig. 4. Diagrama de flujo de la extracción de enlaces.

Proceso de extracción de textos

Una vez realizada la extracción de los enlaces, estos pasan como entrada a la siguiente fase del módulo de extracción, tal y como se muestra en la Fig.5, el cual tiene como objetivo extraer los textos de cada una de las páginas web obtenidas previamente. El procedimiento es el descrito a continuación:

1. **Consulta HTTP.** Utilizando de nuevo el protocolo de comunicación HTTP, se realiza una consulta de tipo GET a cada una de las páginas web para ex-

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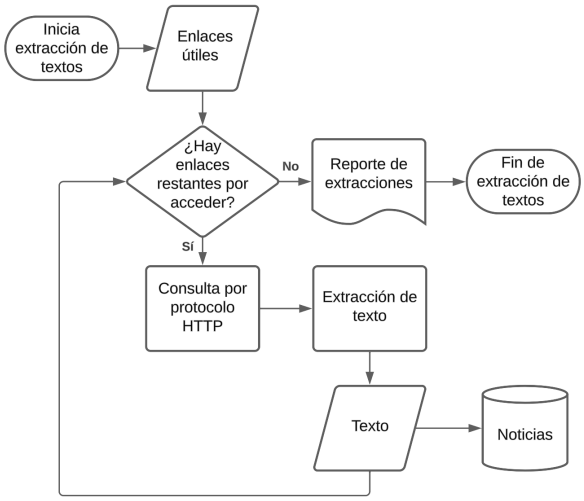


Fig. 5. Proceso de extracción de los textos de las diferentes páginas web.

traer el contenido HTML en crudo de cada una de estas.

2. **Extracción de textos.** Se realiza un análisis sintáctico sobre el contenido HTML para poder extraer solamente los párrafos que se encuentran dentro de ciertas etiquetas, dejando fuera todo contenido irrelevante para nuestro estudio, como imágenes, enlaces, publicidad, etc.

Cada uno de los textos extraídos se almacena en un archivo de extensión txt, considerando la siguiente estructura del archivo:

1. Título de la noticia
2. Enlace de la noticia
3. Tiempo de antigüedad de la publicación
4. Texto extraído

2.3 Construcción del sistema y herramientas utilizadas

Se desarrolló un programa en el lenguaje de programación Python, ya que, además de su simplicidad, en campos como análisis de datos, procesamiento del lenguaje natural y machine learning, Python es el lenguaje dominante gracias a bibliotecas como Pandas, Scikit-learn y nltk.

El extractor esta diseñado para recibir como entrada una consulta o lista de consultas sobre las cuales este buscara y extraera información en la web (Google news). Los contenidos extraídos son filtrados por fecha de antigüedad en función a como le indique el usuario.

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3 Resultados

3.1 Descripción del experimento

El Monitor de Riesgos y Amenazas de parte del SENASICA publica diariamente un documento denominado Monitor Zoosanitario, en el cual se incluyen varios reportes sobre algunas enfermedades zoosanitarias que deben estar en constante monitoreo. Cada uno de estos reportes menciona lo más destacado del evento al que hace referencia, como nombre de la enfermedad, fecha y lugar geográfico del evento, especie a la que afecta el patógeno, si hubo o no mortalidad de animales, si la enfermedad afecta al ser humano, entre otras cuestiones importantes, tal y como se puede observar en la Fig.6.



Fig. 6. Ejemplo del reporte publicado en el Monitor de riesgos y amenazas.

Lo que se desea corroborar es que el extractor construido logré extraer noticias de la web que sean relevantes para para los procesos posteriores de extracción de información que se plantean dentro del proyecto. En otras palabras, se desea comprobar si es posible extraer noticias dentro del feed de Google News que mencionen los eventos a los cuales el SENASICA hace referencia dentro de sus reportes diarios del Monitor Zoosanitario.

3.2 Resultados de las extracciones

Durante un periodo de 20 días no continuos, se obtuvo un listado de 126 consultas en total. Cada una de estas consultas se construyo a partir del nombre de la enfermedad y el sitio geográfico al que hacía referencia cada uno de los reportes publicados diariamente. Una vez que se tenían listas las consultas del día, estas

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Fig. 7. Porcentaje de noticias encontradas y no encontradas.

se ingresaron al extractor, aplicándose un filtro de 1 día de antigüedad como máximo.

De primera instancia se puede observar en la Fig.7 que un 40.5% de las consultas tuvieron resultados positivos, es decir, el extractor encontró al menos 1 noticia en la cuál se menciona la consulta.

En promedio, se obtuvo un resultado de 1 noticia extraída por consulta. Sin embargo, es posible observar una diferencia bastante notable si se analiza el número de extracciones totales encontradas por enfermedad (sin considerar el lugar geográfico), los cuales se observan en la Fig.8. Se puede observar que la enfermedad sobre la cual se han encontrado mayores resultados es la peste porcina africana, seguida de la Viruela del mono y el Ántrax.

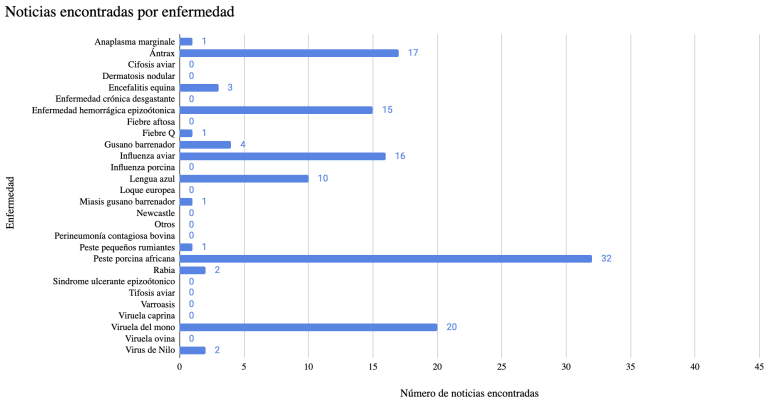


Fig. 8. Número de noticias extraídas por enfermedad.

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Por otro lado, es importante verificar que las noticias extraídas se encuentren "completas", es decir, que el extractor no haya omitido partes importantes de la noticia en la web. En la Fig.9 se puede observar que un 89.6% de las noticias extraídas se encuentran completas, mientras que solo un 10.4% se extrajeron incompletas o vacías.

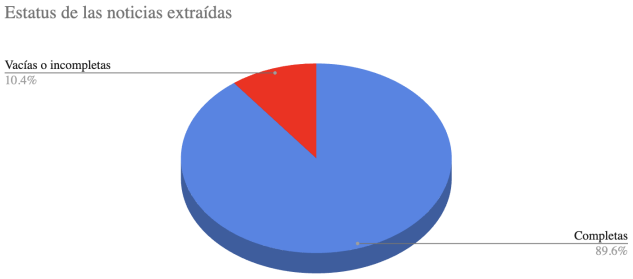


Fig. 9. Estatus de las noticias extraídas.

El problema de las extracciones vacías e incompletas se debe a que algunas de las páginas web no muestran la noticia completa sino se cuenta con una suscripción a las mismas, mientras que el problema de la extracción vacía se debe a las políticas de cookies o detección de bots que algunas páginas presentan. En la Fig.10 se puede observar a detalle el porcentaje de noticias que presentaron estos problemas.

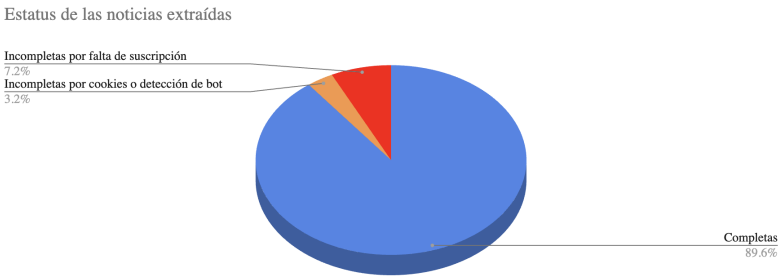


Fig. 10. Estatus a detalle de las noticias extraídas.

Como bien se menciono al principio de esta sección, el objetivo principal de este análisis es verificar que el contenido de las noticias que se encuentran completas, presenten información similar a la información publicada por el SENASICA.

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De forma manual, se realizó un comparativo entre cada una de las extracciones obtenidas contra la información publicada en el reporte diario dentro del Monitor de riesgos, tal y como se muestra en la Fig.11.

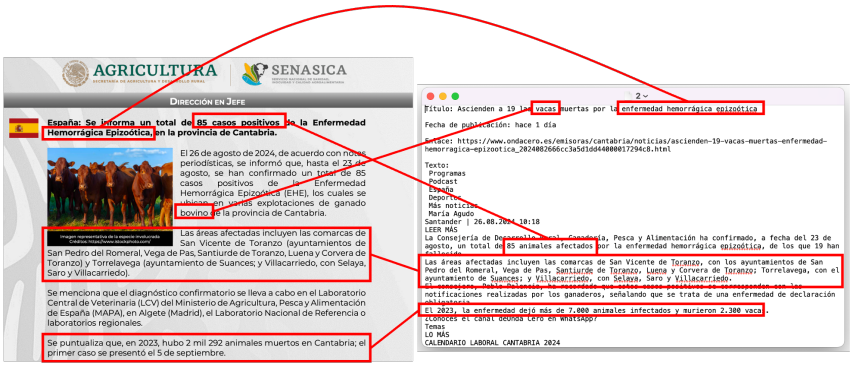


Fig. 11. Ejemplo de comparativa de similitud entre el reporte publicado y las noticias extraídas.

Se considera un resultado positivo o exitoso si la noticia menciona la misma enfermedad, el mismo sitio geográfico y parte de la información relevante dentro del reporte publicado. En la Fig.12 se puede observar que un 81.6% de las noticias presentaron un contenido similar a la información reportada por el SENASICA.

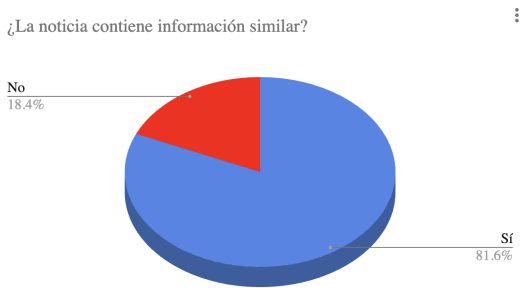


Fig. 12. Resultados de la similitud entre los reportes publicados y las noticias extraídas.

4 Trabajo a futuro

Como se mencionó, ZREM es una primera versión, y actualmente existen mejoras a desarrollar en la parte extractora de información como en otros módulos

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del proyecto. A continuación, se describen las tareas en proceso como trabajo a futuro.

Agregado de nuevas fuentes búsqueda. Actualmente se están agregando las funciones requeridas para la extracción de información sobre las páginas web de los ministerios de los paises miembros de la OMSA y sobre 3 de las redes sociales utilizadas en la búsqueda de información por el SENASICA (Twitter, Facebook e Instagram).

Desarrollo del módulo de procesamiento de información. Mediante técnicas de procesamiento del lenguaje natural y minería de datos, se desea resolver el problema de "texto basura" en las extracciones obtenidas. Asimismo, se desea realizar extracción de información (EI) sobre cada una de las noticias descargadas, como el nombre de la enfermedad, la fecha y el sitio geográfico del evento, especie a la que afecta el patógeno, si hubo o no mortalidad de animales, entre otras elementos.

5 Conclusiones

El monitoreo de eventos nacionales e internacionales en la web sobre enfermedades zoosanitarias es un componente clave del sistema de alerta temprana para las autoridades de sanidad animal en cada país. Es un elemento de la inteligencia sanitaria de bajo costo y estratégico. Dicho monitoreo genera información que coadyuva para la toma de decisiones, planeación estratégica e implementación de acciones de respuesta oportuna, con el fin de conservar la salud humana y minimizar las pérdidas agroalimentarias y económicas dentro del país.

En este artículo se introdujo ZREM, una herramienta en desarrollo diseñada para la extracción y procesamiento de información en la web sobre noticias nacionales e internaciones de enfermedades zoosanitarias de alto impacto para México. Hasta el momento, ZREM presenta buenos resultados de extracción. Sin embargo, como ya se menciono en la sección anterior, es necesario ampliar el rango de búsqueda de noticias mediante el agregado de nuevas fuentes, además de solucionar los problemas encontrados hasta ahora, como las extracciones incompletas o vacías de noticias y limpieza de las mismas. La herramienta ZREM se encuentra en desarrollo y módulos adicionales serán incorporados con el objetivo de lograr obtener un software especializado en la búsqueda, identificación, clasificación y selección de noticias relacionadas con eventos que representen amenazas zoosanitarias para México.

Agradecimientos. Los autores agradecen al Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria (SENASICA) por la información requerida para el desarrollo de este proyecto, con número de registro 20242048 asignado por la SIP.

Declaración de intereses Los autores declaran que no existen conflictos de interés relacionados con este artículo.

ISBN 978-9930-617-71-7

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ISBN 978-9930-617-71-7

Governance and Citizenship

Análisis Comparativo del Gobierno Digital en Ciudad de México y Buenos Aires

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Resumen. Este estudio compara las estrategias de digitalización de los servicios públicos implementadas por la Agencia Digital de Innovación Pública (ADIP) de Ciudad de México y la Secretaría de Innovación y Transformación Digital de Buenos Aires. A través de un análisis cualitativo basado en entrevistas semi-estructuradas, se exploran temas clave como la interoperabilidad, la confianza, la participación ciudadana, la eficiencia administrativa y la lucha contra la corrupción. Los hallazgos revelan que Buenos Aires ha avanzado significativamente en la implementación de una identidad digital autosoberana y en la interoperabilidad de sistemas, lo que ha mejorado la eficiencia administrativa y la confianza ciudadana. En contraste, Ciudad de México ha centrado sus esfuerzos en la digitalización de trámites y en la participación ciudadana, con un enfoque en la transparencia y la reducción de la corrupción. El estudio concluye que ambas ciudades pueden beneficiarse mutuamente al adoptar las mejores prácticas identificadas, fortaleciendo así sus políticas de digitalización y mejorando la relación entre el gobierno y los ciudadanos.

Palabras clave: Digitalización, Interoperabilidad, Participación ciudadana.

1 Introducción

En el contexto actual de globalización y avances tecnológicos, la digitalización de los servicios gubernamentales se ha convertido en una prioridad para muchas ciudades y países alrededor del mundo. La implementación efectiva de tecnologías digitales puede mejorar significativamente la eficiencia, transparencia y accesibilidad de los servicios públicos. Esta investigación, se enfoca en un análisis comparativo de las estrategias de digitalización de las agencias de gobierno digital de la Ciudad de México y Buenos Aires, basado en entrevistas realizadas a representantes clave de ambas ciudades.

El objetivo de este análisis es identificar temas recurrentes, similitudes y diferencias en las estrategias de digitalización adoptadas por estas dos ciudades. Además, se busca ofrecer interpretaciones y conclusiones que puedan servir de guía para futuras iniciativas de digitalización en contextos gubernamentales. Para ello, se explorarán aspectos como el involucramiento ciudadano, la digitalización de trámites, la interoperabilidad de sistemas, la eficiencia administrativa, la ciberseguridad y la educación digital.

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2 Metodología

El presente trabajo se basa en un diseño de investigación cualitativa, utilizando entrevistas semi-estructuradas como principal fuente de datos. Este enfoque permite explorar en profundidad las experiencias, percepciones y prácticas de las agencias gubernamentales en relación con la digitalización de servicios públicos en Ciudad de México y Buenos Aires. La investigación cualitativa es adecuada para este tipo de estudio ya que busca comprender los fenómenos sociales en su contexto natural, proporcionando una visión detallada y rica de los temas en cuestión (Creswell, 2018).

Los participantes del estudio fueron seleccionados mediante un muestreo intencional, eligiendo a representantes clave de las agencias de gobierno digital en ambas ciudades. En Ciudad de México, se entrevistó a un representante de la Agencia Digital de Innovación Pública (ADIP). En Buenos Aires, se entrevistó a un representante de la Secretaría de Innovación y Transformación Digital. Estos participantes fueron seleccionados debido a su conocimiento y experiencia directa en la implementación y gestión de iniciativas de digitalización en sus respectivas ciudades.

Se utilizaron entrevistas semi-estructuradas para recopilar los datos. Este tipo de entrevista permite una flexibilidad en la exploración de los temas, permitiendo al investigador seguir nuevas líneas de investigación que surgen durante la conversación (Kvale, 2007). Las entrevistas fueron grabadas y transcritas textualmente para su posterior análisis. Las preguntas de la entrevista fueron diseñadas para abordar temas clave como la interoperabilidad, la confianza, la participación ciudadana, la eficiencia administrativa y la lucha contra la corrupción.

El análisis de datos se realizó mediante un proceso de codificación temática, siguiendo los pasos recomendados por Braun y Clarke (2006). Primero, se leyeron y relevaron las transcripciones para familiarizarse con los datos. Luego, se identificaron códigos iniciales que representaban conceptos o temas recurrentes. Estos códigos se agruparon en categorías más amplias para identificar patrones y temas principales. Finalmente, se compararon los temas identificados en ambas entrevistas para encontrar similitudes y diferencias.

Codificación temática:

- Interoperabilidad: Se identificaron iniciativas y desafíos relacionados con la integración de sistemas y la gestión de datos.
- Confianza: Se exploraron las estrategias para construir y mantener la confianza de los ciudadanos en los servicios digitales.
- Participación Ciudadana: Se analizaron las formas en que los ciudadanos participan y se involucran en el proceso de digitalización.
- Eficiencia Administrativa: Se evaluaron los impactos de la digitalización en la eficiencia de los trámites y procesos gubernamentales.
- Corrupción: Se investigaron las medidas implementadas para reducir la corrupción y mejorar la transparencia.

Para asegurar la validez y fiabilidad de los hallazgos, se realizó una comparación sistemática de los temas y patrones identificados en las entrevistas de ambas ciudades. Esta comparación permitió encontrar similitudes y diferencias en las estrategias de digitalización y sus impactos. Además, se utilizaron fuentes secundarias, como

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informes y estudios recientes sobre gobierno digital y administración pública para triangular los datos y enriquecer el análisis (Patton, 2015).

Por último, se aseguraron todas las consideraciones éticas pertinentes a la investigación cualitativa. Los participantes fueron informados sobre los objetivos del estudio y se obtuvo su consentimiento informado para participar y para la grabación de las entrevistas. Se garantizó la confidencialidad de los datos y el anonimato de los participantes, asegurando que la información proporcionada se utilizara exclusivamente para fines de investigación.

3 Contexto teórico

Este trabajo, tiene como fundamento los estudios sobre gobernanza digital, participación ciudadana, interoperabilidad de sistemas, eficiencia administrativa, ciberseguridad y reducción de la brecha digital. Se destaca la importancia de estos aspectos para mejorar la relación entre el gobierno y la ciudadanía, optimizar recursos y aumentar la transparencia en la administración pública (Bannister & Connolly, 2014; Gil-Garcia, 2012).

La gobernanza digital se refiere al uso de tecnologías digitales para transformar la administración pública, facilitando la comunicación y la interacción entre el gobierno y los ciudadanos (Linders, 2012). La participación ciudadana en la era digital se ha visto facilitada por herramientas como las redes sociales, los portales web y las aplicaciones móviles, que permiten a los ciudadanos expresar sus opiniones y contribuir a la toma de decisiones (OECD, 2016).

Por otro lado, la participación ciudadana en el contexto de los servicios digitales implica la inclusión de los ciudadanos en la toma de decisiones y en la mejora de los servicios públicos. La participación activa de los ciudadanos no solo mejora la calidad de los servicios, sino que también fortalece la democracia y la confianza en el gobierno. En este sentido, la participación ciudadana es un componente clave para la gobernanza digital, ya que permite a los ciudadanos influir en las decisiones que afectan sus vidas y garantiza que los servicios públicos se adapten mejor a sus necesidades.

Aunado a ello, la interoperabilidad de sistemas es crucial para la eficiencia administrativa, ya que permite que diferentes áreas gubernamentales puedan compartir información y colaboren de manera efectiva (Janssen et al., 2012). Por su parte, la ciberseguridad y la protección de datos personales son esenciales para garantizar la confianza de los ciudadanos en los servicios digitales (Bertot et al., 2012). Finalmente, la educación y la capacitación digital son fundamentales para reducir la brecha digital y asegurar que todos los ciudadanos puedan beneficiarse de los avances tecnológicos (Van Dijk, 2006).

Esta capacidad es crucial para la prestación de servicios públicos digitales, ya que facilita la integración de datos y procesos, mejorando tanto la eficiencia administrativa como la experiencia del usuario. En suma, la interoperabilidad permite a los gobiernos ofrecer servicios más coherentes y centrados en el usuario al eliminar barreras tecnológicas y organizativas (OECD, 2024).

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En sintonía con esto, de acuerdo con el Banco Interamericano de Desarrollo (2018), “prestar trámites digitales le cuesta al gobierno hasta cuarenta veces más de lo que podría costar el servicio equivalente en una plataforma digital”. La digitalización de trámites y procesos es una estrategia clave para mejorar la eficiencia administrativa; con ello, se puede reducir significativamente los costos y tiempos asociados con la prestación de servicios públicos, además de mejorar la precisión y la transparencia, optimizando los recursos públicos y mejorando la calidad de estos.

Finalmente, se encuentra el tema de la corrupción, como uno de los mayores obstáculos para el desarrollo económico y social. La digitalización de los servicios públicos puede desempeñar un papel crucial en la lucha contra la corrupción al reducir la necesidad de intermediarios y aumentar la transparencia. La transparencia y la trazabilidad que ofrecen las tecnologías digitales, como el blockchain, pueden ayudar a prevenir y detectar prácticas corruptas. “Los tramites digitales se demoran 74% menos que tramites presenciales, cuestan mucho menos, y reducen la incidencia de corrupción” (BID, 2018).

A partir de estos elementos, la presente investigación retoma las entrevistas realizadas a funcionarios públicos encargados de dirigir y ejecutar las estrategias de digitalización en las ciudades de México y Buenos Aires, con el objetivo de encontrar elementos comunes al contexto teórico y qué áreas de crecimiento se tienen en ambas urbes.

4 Principales hallazgos

4.1 Involucramiento ciudadano y participación

Ciudad de México:

En Ciudad de México, la participación ciudadana es un componente central en el desarrollo de las estrategias de digitalización. El representante de la Agencia Digital de Innovación Pública (ADIP) destacó que "recabamos las necesidades ciudadanas durante las campañas políticas y tenemos un consejo ciudadano compuesto por expertos en tecnología" (Entrevista ADIP, 2024). Este enfoque proactivo asegura que las necesidades y expectativas de los ciudadanos sean consideradas en la implementación de nuevas tecnologías y servicios digitales.

Además, se utiliza activamente las redes sociales y tiendas de aplicaciones para recibir retroalimentación directa de los ciudadanos. Esta estrategia permite a la ADIP mantenerse conectada con la población y adaptar sus servicios en función de la retroalimentación recibida. Por ejemplo, el uso de aplicaciones móviles permite a los ciudadanos evaluar y comentar sobre los servicios, facilitando un canal de comunicación bidireccional entre el gobierno y los usuarios.

Por tanto, la ADIP tiene un enfoque integral para fomentar la participación ciudadana en el desarrollo y mejora de sus servicios digitales. Para ello, se utilizan canales como la recopilación de necesidades ciudadanas durante los periodos de campañas políticas, las cuales se traducen en objetivos claros para la administración pública. También, mediante el consejo ciudadano, compuesto por expertos en tecnología y ciudadanos interesados en participar en la mejora de los servicios digitales.

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Finalmente, mediante el uso de redes sociales del gobierno de la ciudad y las evaluaciones de aplicaciones móviles en tiendas como Google Play y App Store, las cuales proporcionan una fuente adicional de retroalimentación.

Buenos Aires:

En Buenos Aires, aunque la participación ciudadana no se gestiona a través de consultas directas, el feedback o retroalimentación recibida en plataformas digitales, juega un papel crucial. "No hay un mecanismo que implique una consulta a la ciudadanía, lo que sí tomamos es esencialmente el feedback que nos dejan en nuestras plataformas digitales" (Entrevista Secretaría de Innovación y Transformación Digital, 2024). Las herramientas principales utilizadas para recoger esta retroalimentación son el sitio web de trámites y un chatbot, los cuales cuentan con mecanismos automatizados para recolectar datos y analizarlos, con el objetivo de mejorar los servicios digitales.

Estas plataformas permiten a los ciudadanos expresar sus opiniones y sugerencias, lo que ayuda a la Secretaría de Innovación y Transformación Digital a identificar áreas de mejora. Por ejemplo, el chatbot no solo facilita el acceso a información y servicios, sino que también recopila datos sobre las interacciones de los usuarios, lo que permite un análisis detallado de las necesidades y problemas más comunes.

Comparación y análisis:

La comparación de las estrategias de involucramiento ciudadano en ambas ciudades revela enfoques complementarios. Mientras que Ciudad de México adopta un enfoque más estructurado y proactivo, Buenos Aires se basa en la retroalimentación pasiva a través de sus herramientas digitales. Ambos enfoques son efectivos, pero podrían beneficiarse de una combinación de estos. Buenos Aires podría incorporar mecanismos más directos de consulta ciudadana, mientras que Ciudad de México podría mejorar el uso de plataformas propias automatizadas para recoger feedback de manera constante.

En lo que respecta a la construcción del plan de digitalización de la ciudad o la adopción de nuevas estrategias, se evidenció que en la Ciudad de México se establecieron mecanismos de consulta directa con la ciudadanía y estos fueron tomados en cuenta en el diseño de las políticas públicas de digitalización; mientras tanto, en Buenos Aires no existió una herramienta de participación ciudadana específico para dicho fin, sino que únicamente existen como parte del ciclo de mejora continua.

4.2 Digitalización y trámites

Ciudad de México:

La digitalización de servicios en la Ciudad de México se centra en la eficiencia y la frecuencia; por ejemplo, en el caso de los trámites vehículares, se considera "uno de nuestros mayores logros, que ha reducido significativamente los tiempos de espera y el costo administrativo" (Entrevista ADIP, 2024). Este enfoque no solo mejora la experiencia del usuario, sino que también optimiza los recursos del gobierno, permitiendo una asignación más eficiente de los mismos.

Además, la digitalización facilita el acceso a los servicios gubernamentales, reduciendo la necesidad de desplazarse a oficinas físicas y permitiendo que los ciudadanos realicen trámites desde cualquier lugar y en cualquier momento. Este

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enfoque también contribuye a la reducción de la corrupción, ya que disminuye las interacciones cara a cara que pueden dar lugar a prácticas corruptas.

En materia de adopción de servicios digitales por parte de la ciudadanía, no se mencionó en entrevista un porcentaje específico de penetración, aunque sí se menciona un crecimiento continuo en el uso de aplicaciones como App CDMX y Llave CDMX. Sumado a esto, se ha puesto especial atención al aumento de infraestructura urbana digital, como los miles de acceso a WiFi gratuito del gobierno y la calidad de conexión que ofrecen.

Buenos Aires:

En Buenos Aires, la interoperabilidad y la disponibilidad de documentación en formato digital son aspectos clave de la estrategia de digitalización. "Principalmente lo que estamos buscando atender es reducir la carga que tiene la demanda de interacción con el gobierno para la sociedad" (Entrevista Secretaría de Innovación y Transformación Digital, 2024). La disponibilidad de una identidad digital autosoberana permite a los ciudadanos acceder a múltiples servicios sin necesidad de presentar repetidamente su documentación.

La interoperabilidad de sistemas no solo facilita la interacción entre el gobierno y los ciudadanos, sino que también mejora la eficiencia interna del gobierno. Al permitir que diferentes departamentos compartan información de manera fluida, se reduce la duplicación de esfuerzos y se mejora la coherencia en la prestación de servicios.

Por otro lado, se destaca que un alto porcentaje de la población utiliza los servicios digitales del gobierno. "Hoy más del 75% de los ciudadanos hacen sus trámites digitales. Además, el 95% de los usuarios de entre 18 y 70 años han interactuado alguna vez con servicios digitales" (Entrevista Secretaría de Innovación y Transformación Digital, 2024).

Este alto nivel de adopción se atribuye a varios factores clave; por un lado, la disponibilidad de una identidad digital autosoberana que facilita el acceso a múltiples servicios sin necesidad de presentar repetidamente documentación; en segundo lugar, la accesibilidad y simplicidad de los servicios digitales que aumentan la confianza y el uso por parte de los ciudadanos; finalmente, la mejora continua, con lo que se asegura que los servicios se adapten a las necesidades y expectativas de los ciudadanos.

Comparación y análisis:

Ambas ciudades muestran un fuerte compromiso con la digitalización, la interoperabilidad y la creación de una plataforma de identidad digital. La Ciudad de México, se enfoca en la digitalización de trámites específicos y recurrentes, como los vehiculares, para mejorar la eficiencia y reducir costos. Buenos Aires, por otro lado, pone un mayor énfasis en la interoperabilidad y la creación de una identidad digital más robusta. Integrar ambas perspectivas podría ofrecer una experiencia más optimizada para los ciudadanos, combinando la eficiencia en trámites específicos, con la accesibilidad y simplicidad de una identidad digital interoperable.

En cuanto a los niveles de adopción de los servicios digitales, se observa que Buenos Aires muestra un alto nivel de penetración, lo que conlleva que su foco de atención se dirija a otros aspectos como la interoperabilidad y el desarrollo de una identidad digital autosoberana. Por su parte, en la Ciudad de México, la estrategia de digitalización

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apunta a aumentar la adopción mediante la mejora de la eficiencia y accesibilidad de los servicios.

4.3 Interoperabilidad y confianza

Ciudad de México:

La interoperabilidad de sistemas es vista como una solución para mejorar la transparencia y la confianza ciudadana en el gobierno. "Mejorar la interoperabilidad de nuestros sistemas es fundamental para reducir la desconfianza en el gobierno" (Entrevista ADIP, 2024). La capacidad de diferentes sistemas para comunicarse entre sí, facilita la transparencia y reduce la burocracia, lo que puede contribuir a aumentar la confianza de los ciudadanos en la administración pública.

Con ello, los ciudadanos pueden completar trámites de manera rápida y sencilla, sin la necesidad de presentar documentación en múltiples ocasiones. La ADIP utiliza plataformas comunes para la gestión de datos y la prestación de servicios, lo que facilita la interoperabilidad entre diferentes plataformas y dependencias, permitiendo el acceso a datos en tiempo real y mejorando la capacidad de respuesta del gobierno ante emergencias y situaciones críticas.

La interoperabilidad permite una mejor coordinación entre diferentes áreas del gobierno, lo que puede resultar en una prestación de servicios más coherente y eficiente. Esto es particularmente importante en contextos donde la desconfianza en las instituciones gubernamentales es un problema significativo, ya que puede ayudar a demostrar el compromiso del gobierno con la eficiencia y la transparencia.

Buenos Aires:

En Buenos Aires, la interoperabilidad es un pilar central de la estrategia de digitalización. "Estamos avanzando en todo lo que es la disponibilidad de documentación personal en un formato de identidad digital basado en el protocolos internacionales" (Entrevista Secretaría de Innovación y Transformación Digital, 2024). Este enfoque permite a los ciudadanos acceder a múltiples servicios sin necesidad de repetir la presentación de su documentación, lo que no solo simplifica la interacción con el gobierno, sino que también mejora la seguridad de los datos personales.

Se destaca la creación de un sistema de identidad digital autosoberana que permite a los ciudadanos acceder a múltiples servicios sin necesidad de presentar repetidamente documentación. La implementación de este identificador, es un avance significativo en la interoperabilidad, ya que permite a los ciudadanos controlar su propia información y decidir qué datos compartir con diferentes áreas del gobierno y servicios. Esto no solo aumenta la eficiencia, sino que también refuerza la confianza de los ciudadanos en la seguridad y la privacidad de sus datos.

Aunado a esto, se ha trabajado en la integración de los diferentes sistemas y plataformas del gobierno para comunicarse entre sí, permitiendo un flujo de datos eficiente y seguro. La interoperabilidad facilita la prestación de servicios complejos, como el registro de vehículos o la solicitud de permisos, que requieren la coordinación de múltiples departamentos. Además, se reduce la redundancia y los errores, mejorando la precisión y la rapidez de los trámites.

Comparación y análisis:

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La comparación de los enfoques de interoperabilidad en ambas ciudades muestra que Buenos Aires tiene un enfoque más avanzado y detallado. La implementación de una identidad digital, desde un enfoque autosoberano, y el avanzado desarrollo de la interoperabilidad de sistemas, son aspectos clave en los que Buenos Aires es un buen referente en la región. La interoperabilidad no solo mejora la eficiencia y la experiencia del usuario, sino que también puede contribuir significativamente a aumentar la confianza ciudadana en el gobierno.

La construcción de la confianza en los servicios digitales es un desafío continuo que requiere un enfoque integral y transparente. Buenos Aires ha demostrado cómo la interoperabilidad y la seguridad pueden trabajar de la mano para crear un ecosistema digital confiable. La implementación de medidas robustas de protección de datos, junto con la interoperabilidad de sistemas y la identidad digital autosoberana, han permitido a Buenos Aires ofrecer servicios digitales eficientes y seguros. Estos esfuerzos no solo mejoran la experiencia del usuario, sino que también incrementan la confianza de los ciudadanos en el gobierno.

La Ciudad de México puede beneficiarse significativamente al adoptar prácticas similares. La integración de sistemas y el desarrollo de una identidad digital autosoberana fortalecerían sus políticas y prácticas digitales. Además, fomentar la participación ciudadana a través de mecanismos innovadores y transparentes aumentaría la confianza pública en los servicios digitales. Al aprender de la experiencia de Buenos Aires, Ciudad de México tiene la oportunidad de no solo mejorar la eficiencia de sus servicios digitales, sino también de construir una relación más sólida y confiada entre el gobierno y los ciudadanos.

4.4 Corrupción y eficiencia administrativa

Ciudad de México:

La digitalización se utiliza en Ciudad de México como una herramienta para combatir la corrupción y mejorar la eficiencia administrativa. "La digitalización nos ha permitido reducir el costo administrativo y optimizar los recursos, combatiendo así la corrupción" (Entrevista ADIP, 2024). Al reducir la necesidad de interacciones cara a cara y automatizar procesos, se disminuyen las oportunidades para prácticas corruptas.

El uso de plataformas digitales para hacer que los procesos sean más transparentes y accesibles permite que los ciudadanos puedan seguir el estado de sus trámites y entender los requisitos y pasos necesarios, esto ayuda a prevenir y reportar posibles actos de corrupción, fortaleciendo la confianza hacia las instituciones del gobierno local.

Otro aspecto clave es la optimización de recursos que se logra mediante la digitalización, lo que permite al gobierno reasignar esfuerzos y fondos hacia áreas que requieren más atención. Este enfoque no solo mejora la eficiencia interna, sino que también puede tener un impacto positivo en la percepción pública de la administración, al mostrar un compromiso con la transparencia y la integridad.

Buenos Aires:

En Buenos Aires, la eficiencia administrativa es un aspecto central de la estrategia de digitalización. "Hemos ahorrado más de 300 años por año, en tiempo que la sociedad

ISBN 978-9930-617-71-7

tiene que hacer trámites tanto digitales como analógicos" (Entrevista Secretaría de Innovación y Transformación Digital, 2024). La reducción de la carga administrativa para los ciudadanos no solo mejora la experiencia del usuario, sino que también permite al gobierno operar de manera más eficiente.

La implementación de sistemas interoperables y la disponibilidad de documentación digital también contribuyen a esta eficiencia, eliminando la necesidad de duplicar esfuerzos y reduciendo los tiempos de espera. Estos avances pueden tener un impacto significativo en la percepción pública de la administración, mostrando un interés por la eficiencia y la modernización.

Comparación y análisis:

Ambas ciudades demuestran un énfasis en la mejora de la eficiencia administrativa a través de la digitalización. La Ciudad de México se enfoca en la reducción de la corrupción como uno de los principales beneficios de la digitalización, mientras que Buenos Aires pone mayor atención a la eficiencia operativa y la reducción de la carga administrativa. Estas perspectivas buscan mejorar la experiencia del usuario.

La Ciudad de México pone un fuerte énfasis en la transparencia y la participación ciudadana como mecanismos para combatir la corrupción. La digitalización de trámites y la accesibilidad a la información son estrategias efectivas para reducir las oportunidades de corrupción y mejorar la eficiencia.

Por su parte, Buenos Aires, aunque no menciona explícitamente la corrupción, también implementa medidas que indirectamente reducen las oportunidades de prácticas corruptas. La interoperabilidad de sistemas y la identidad digital autosoberana son ejemplos de cómo la tecnología puede mejorar la eficiencia y reducir la corrupción.

Por tanto, la transparencia, la participación ciudadana y el uso de tecnologías avanzadas son elementos clave en el combate a la corrupción y la eficiencia administrativa. Al integrar las mejores prácticas de ambas ciudades, se puede construir un sistema más robusto y confiable que no solo mejore la eficiencia, sino que también fortalezca la confianza de los ciudadanos en sus gobiernos.

4.5 Satisfacción y experiencia del usuario

Ciudad de México:

La satisfacción del usuario en la Ciudad de México se mide a través de redes sociales y la evaluación de aplicaciones. "Utilizamos la retroalimentación de las redes sociales y las evaluaciones de nuestras aplicaciones para mejorar continuamente los servicios digitales" (Entrevista ADIP, 2024). Esta estrategia permite una evaluación constante y un ajuste continuo de los servicios en función de las opiniones y sugerencias de los usuarios.

La integración de herramientas digitales para recoger feedback en tiempo real no solo mejora la experiencia del usuario, sino que también permite al gobierno identificar y resolver problemas rápidamente. Esta capacidad de respuesta es crucial para mantener la satisfacción del usuario y demostrar el compromiso del gobierno con la mejora continua.

Buenos Aires:

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En Buenos Aires, la satisfacción del usuario se recoge principalmente a través de interacciones en la web y el chatbot. "La ciudadanía tiene la opción de dejar feedback, de expresar su satisfacción o insatisfacción, lo que nos permite identificar los puntos de dolor para poder solucionarlos" (Entrevista Secretaría de Innovación y Transformación Digital, 2024). Este enfoque permite un análisis detallado de las necesidades y problemas más comunes, facilitando la identificación de áreas de mejora.

El uso de chatbots y plataformas digitales para recoger feedback también permite una evaluación constante y un ajuste continuo de los servicios. Al igual que en la Ciudad de México, esta capacidad de respuesta es crucial para mantener la satisfacción del usuario y la mejora continua.

Comparación y análisis:

Ambas ciudades utilizan herramientas digitales para medir la satisfacción del usuario y recoger feedback. La Ciudad de México se enfoca más en la retroalimentación a través de redes sociales y aplicaciones móviles, mientras que Buenos Aires utiliza principalmente interacciones en la web y chatbots. En este sentido, las redes sociales tienen la particularidad de ser un más accesible para el usuario, por su uso cotidiano para otro tipo de interacciones; sin embargo, el chatbot, al ser un canal oficial del gobierno de la ciudad, permite recolectar datos y feedback de forma directa, sin que estos pasen por plataformas de terceros.

4.6 Ciberseguridad y protección de datos

Ciudad de México:

La ciberseguridad y la protección de datos son reconocidas como aspectos cruciales en la Ciudad de México, aunque los detalles específicos son menos prominentes. "Contamos con políticas de ciberseguridad para proteger los datos personales de los ciudadanos" (Entrevista ADIP, 2024). La implementación de políticas y prácticas de ciberseguridad son esenciales para salvaguardar los derechos de los ciudadanos y su información personal en el uso de los servicios digitales de la ciudad.

Además, la protección de datos personales es un aspecto crucial para mantener la confianza de los ciudadanos en los servicios digitales. Las políticas de ciberseguridad deben ser robustas y estar actualizadas para enfrentar las amenazas cibernéticas emergentes y garantizar la integridad y confidencialidad de los datos.

Buenos Aires:

En Buenos Aires, la ciberseguridad es un aspecto central de la estrategia de digitalización, con un enfoque detallado en la protección de datos. "Tenemos uno de los dos centros de ciberseguridad más importantes del país, el BA-CSIRT, que sigue la lógica de los CSIRT de todo el mundo" (Entrevista Secretaría de Innovación y Transformación Digital, 2024). La existencia de un centro de ciberseguridad específico, con base en estándares internacionales, muestra un avance significativo en la protección de datos y la seguridad cibernética.

El BA-CSIRT (Centro de Ciberseguridad del Gobierno de Buenos Aires) se encarga de monitorear y responder a incidentes de seguridad, garantizando que los datos personales de los ciudadanos estén protegidos. Este enfoque proactivo y preventivo es

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crucial para mantener la confianza de los ciudadanos y asegurar la integridad de los sistemas digitales.

Comparación y análisis:

La comparación de los enfoques de ciberseguridad en ambas ciudades revela que Buenos Aires tiene una estrategia más detallada y avanzada, con la implementación de un centro de ciberseguridad dedicado. La Ciudad de México podría beneficiarse de adoptar prácticas similares para fortalecer su estrategia de ciberseguridad y protección de datos. La existencia de un centro enfocado en la ciberseguridad no solo mejora la protección de datos, sino que también refuerza la confianza de los ciudadanos en los servicios digitales.

4.7 Educación y capacitación digital

Ciudad de México:

La educación digital en la Ciudad de México se enfoca en reducir la brecha digital mediante escuelas de código y certificaciones. "Estamos implementando escuelas de código y ofreciendo certificaciones para reducir la brecha digital" (Entrevista ADIP, 2024). Este enfoque asegura que los ciudadanos tengan las habilidades y conocimientos necesarios para beneficiarse de los servicios digitales y participar activamente en la sociedad digital.

Las escuelas de código y las certificaciones no solo mejoran las habilidades digitales de los ciudadanos, sino que también promueven la inclusión digital y aseguran que todos tengan acceso a las oportunidades que ofrece la digitalización. Este enfoque es crucial para reducir la brecha digital y garantizar que todos los ciudadanos puedan participar plenamente de la digitalización.

Buenos Aires:

En Buenos Aires, se utilizan chatbots y campañas de difusión para educar a los ciudadanos sobre riesgos de ciberseguridad. "Utilizamos nuestro chatbot y campañas de difusión para alertar sobre riesgos como el phishing" (Entrevista Secretaría de Innovación y Transformación Digital, 2024). Este enfoque busca que los ciudadanos estén informados sobre los riesgos cibernéticos y sepan cómo protegerse.

La educación digital no solo se centra en la capacitación técnica, sino también en la concienciación sobre la ciberseguridad y la protección de datos. Las campañas de difusión y el uso de chatbots permiten llegar a un amplio público y asegurar que todos los ciudadanos estén informados sobre los riesgos y las mejores prácticas de ciberseguridad.

Comparación y análisis:

Ambas ciudades muestran una estrategia en materia de educación digital, aunque con enfoques diferentes. La Ciudad de México se enfoca en la capacitación técnica a través de escuelas de código y certificaciones, mientras que Buenos Aires pone un mayor énfasis en la concienciación sobre ciberseguridad. En este sentido, la Ciudad de México muestra un avance más sólido en la ruta por elevar el dominio de las herramientas digitales. Por tanto, es importante combinar la capacitación técnica con la concienciación sobre ciberseguridad para asegurar que todos los ciudadanos estén preparados para participar en la sociedad digital.

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4.8 Síntesis de resultados

Con base en los datos obtenidos, se construyó un gráfico de radar que muestra los cinco ejes principales de análisis a partir de la identificación de patrones y temas recurrentes en las entrevistas, los cuales se agruparon en categorías clave. Asimismo, se asignó un valor numérico en escala de 1 a 10, que reflejan el grado de avance de cada ciudad; dicha estimación, es una representación ordinal del nivel de avance observado en cada categoría, donde 1 indica un desarrollo muy limitado y 10 representa un nivel sobresaliente.

La justificación de todo lo anterior, proviene de las descripciones cualitativas detalladas en las entrevistas y el análisis posterior, así como en la triangulación de datos con fuentes secundarias como los informes y estudios sobre gobierno digital, previamente discutido en este artículo.

A partir de este análisis comparativo entre las dos ciudades, se logró contrastar las estrategias de digitalización utilizadas en cada contexto, lo que ayudó a identificar las similitudes y diferencias en términos de eficacia, enfoque y resultados. Las diferencias cualitativas observadas en los temas clave fueron transformadas en valores numéricos comparativos.



Fig. 1. Síntesis de resultados

4.9 Justificación de los valores asignados

Los valores numéricos en el gráfico de radar son una respresentación cuantitativa de resultados cualitativos, basados en el análisis comparativo, la codificación temática de las entrevistas realizadas y datos secundarios. A continuación, se presenta el detalle de cada valor asignado.

Interoperabilidad (Buenos Aires 9, Ciudad de México 7): Justificado por el desarrollo más avanzado de Buenos Aires en la identidad digital autosoberana, mientras

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que en Ciudad de México se encuentra en una fase de mejora de la eficiencia administrativa.

Participación ciudadana (Buenos Aires 7, Ciudad de México 9): Buenos Aires se encofca en una retroalimentación pasiva, mientras que Ciudad de México ha implementado mecanismos de participación proactivos y estructurados.

Ciberseguridad (Buenos Aires 9, Ciudad de México 6): El centro de ciberseguridad de Buenos Aires otorga mayor confianza en sus sistemas digitales, mientras que Ciudad de México cuenta con políticas menos robustas.

Eficiencia administrativa (Buenos Aires 9, Ciudad de México 8): Ambas ciudades presentan avances pero Buenos Aires destaca por su interoperabilidad avanzada que mejora la eficiencia de sus servicios.

Confianza (Buenos Aires 8, Ciudad de México 7): Buenos Aires ha logrado mejorar la confianza ciudadana a través de tecnologías avanzadas, mientras que Ciudad de México sigue trabajando en reducir la desconfianza histórica.

5 Conclusiones

Como pudo apreciarse, las dos ciudades analizadas comparten la mayoría de las prácticas expuestas, pero desde enfoques particulares; esto se debe al contexto que les precede. Por ejemplo, mientras que en la Ciudad de México, el tema de la desconfianza en el gobierno local y la necesidad por enviar un mensaje a la ciudadanía sobre combate a la corrupción, hacen que la estrategia de digitalización tenga un elevado enfoque en transmitir la transparencia y confianza ciudadana. En Buenos Aires, existe un tema más orientado con colocar sus estrategias con base en estádares internacionales y llevar a la ciudad a una digitalización en sintonía con otros referentes globales.

En cuanto a las mejores prácticas observadas, la Ciudad de México muestra un mayor avance en el involucramiento de la ciudadanía dentro de los procesos de digitalización, como son los mecanismos de participación directos a través de diversos canales, como las redes sociales del gobierno de la ciudad. Por su parte, Buenos Aires refleja un desarrollo avanzado en materia de ciberseguridad, sobre todo en lo que respecta a las instituciones específicas encargadas de este rubro.

En ambas ciudades se observó la interoperabilidad como uno de los objetivos centrales en sus estrategias de digitalización; con ello, no solo se mejora la eficiencia interna, sino que se facilita la interacción con los ciudadanos, permitiendo un acceso más fácil y rápido a los servicios gubernamentales.

Asimismo, se han implementado herramientas automatizadas para recoger retroalimentación continua, con el propósito de mejorar la experiencia del usuario. La retroalimentación en tiempo real permite identificar y resolver problemas rápidamente, asegurando que los servicios se adapten continuamente a las necesidades de los usuarios.

Finalmente, se concluye que un enfoque combinado en la capacitación estructurada y asistencia práctica puede ser más efectivo para reducir la brecha digital en las dos ciudades. La combinación de educación técnica y concienciación sobre ciberseguridad

ISBN 978-9930-617-71-7

asegura que todos los ciudadanos tengan las habilidades necesarias para participar en la digitalización y proteger sus datos personales.

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ISBN 978-9930-617-71-7

A Reference Model for Formulation of Citizen Science Projects

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Abstract. Citizen science, also referred to as public participation in scientific research and knowledge production, is gaining increasing recognition as a well-developed and valued approach. This approach has a global reach and is employed across a diverse spectrum of scientific domains and disciplines. Presently, literature highlights several concerns related to citizen science data and processes, leading to insufficient quality levels and, consequently, unacceptable situations within citizen science projects. To alleviate these undesirable effects, we posse that the standardization of some best practices around citizen science projects can lead to a better performance of the processes and their results. The main contribution of this work is twofold: on a hand to identify which are the best practices related to citizen science projects, and on the other hand to investigate how these best practices can be enriched with some other related to data quality management. As a result, we produced a reference model that can be used to support institutions to better propose and execute their citizen science projects.

Keywords: Citizen Science Project, Data Quality Management

1 Introduction

The first recorded use of the term Citizen Science (CS) in the form that we currently use can be traced to three decades ago, according to the researchers of the Oxford English Dictionary. The term appeared in an issue of the MIT Technology Review from January 1989. The article 'Lab for the Environment' covers three examples: community-based laboratories that explore environmental hazards, laboratory work by Greenpeace, and Audubon's recruitment of volunteers in a 'citizen science' programme [1].

The most important factor that defines citizen science is that non-professional scientists contribute to scientific research. Therefore, it is important to recognize the perspectives and experiences of these participants. Projects may provide ways for participants to contribute to scientific research at different stages of the scientific process according to different levels of engagement. These non-scientists, the 'citizens' in citizen science, can collaborate with scientists in all stages and aspects of the scientific process, but, in most projects, they contribute to data collection and data analysis [2].

ISBN 978-9930-617-71-7

While scientists are often skeptical of the ability of unpaid volunteers to produce accurate datasets, a growing body of publications clearly shows that diverse types of citizen-science projects can produce data with accuracy equal to or surpassing that of professionals. Successful projects rely on a suite of methods to boost data accuracy and account for bias, including iterative project development (task and tool design), volunteer training and testing, use of standardized and calibrated equipment, expert validation, etc. Each citizen-science dataset should therefore be judged individually, according to project design and application, and not assumed to be substandard simply because volunteers generated it [3].

Some studies have shown that volunteers (citizens) have the potential to provide a valuable contribution to complex research projects. To reach this outcome, the environment in which contributors are engaged must be carefully configured to foster collaboration while designing tasks with low interdependence. The broad term defining this integration of external contributions in scientific research is “citizen science”. Being this phenomenon relatively innovative in its capillary applications, theoretical frameworks and operative guidelines are still evolving [4].

Citizen science projects often deal with large datasets, whether they are monitoring projects (e.g. Butterfly Monitoring Germany). It is important to decide before the start of a project which data can be collected, who should have which rights relating to the data and how they can be secured and made available in the long-term. This includes metadata (such as time, method or location of collected data). Sometimes, it is impossible to further use data without such information [5].

Citizen science is a form of research collaboration in which professional scientists engage with members of the public in order to accomplish scientific research. Due to the wide variability in skills and expertise between contributors (specialist and not specialist), issues such as data governance, data management, and data quality often rise to the forefront in considering the validity of this research.

Although an increasing variety of projects are using methods for improving specifically data quality issues and research validity, no review of these mechanisms is readily available for reference. Our thesis is that while most scientists’ initial impulse may be to employ the data quality methods standard in their field, when formulating citizen science projects, a different approach to ensuring aspects of data governance, data management and data quality may be necessary, taking into consideration the scale of participation and expectations around contributors’ skills.

The lack of well-defined hypotheses to define data collection protocols and individual variability in skill levels and data collection processes are major obstacles in accurately interpreting citizen science data that must be recognized and addressed during analysis [6]. Applying Citizen Science Data (CSD) can be problematic if researchers and participants are not aware of data quality issues that could affect their analyses or contributions. In particular, data bias, errors, uncertainty, and ethical issues pose challenges that should be assessed regularly as part of CS research projects [7]. In this investigation, the researcher team posed that to mitigate or at least to alleviate these problems, it was possible to gather, and set of best practices (also known as process) that can be used to ensure homogeneous behavior during the citizen science´ project formulation (design and execution stages), and during the use of the resulting data either

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internally in between participant (scientific or citizen) or externally when these participants or research institutions needs to ex-change data with third parties like governments. This set of best practices should cover aspects of the citizen science process as well as some other aspects of data quality management and data governance.

In this sense, the research team relied on the idea of the process-based approach set forth in international standards such as ISO/IEC 8000-61 [8] for data quality management or ISO 12207 [9] for the case of software process to develop a framework called CIEN_FORM to better support the design and execution stages in CS projects. Thus, the idea of CIEN_FORM is to serve as reference that every researcher can use to customize their own set of citizen science project formulation (CSPF) practices according to their own restrictions, possibilities, and requirements. CIEN_FORM consists of two main components:

- A **Process Reference Model (PRM)**, containing four groups of processes addressing specific aspects of the citizen science activities considering the various stages of the data lifecycle (from collecting until dissemination). This PRM meets the data governance, data management and data quality management process requirements included in norm UNE 0080:2023 [10], an ISO 8000-61-framework compliant.
- A **Process Assessment Model (PAM)**, containing the elements required for organizations to assess and improve their citizen science project´ activities according to the provided PRM. This PAM will be built by meeting the requirements of ISO/IEC 33003 [11] along with some other parts of ISO/IEC 33000 series. The CIEN_FORM Maturity Model has being developed now, meeting the requirements of ISO/IEC 33004 [12], and it is compliant with UNE 0080:2023Assessment Model based on ISO 8000-62 [13].

2 State of the art and related works

2.1 Existing works on Citizen Science Project Formulation

Once done a literature review in the main research databases (Scopus and Web of Science) to find related works to citizen science, we were able to find seven proposals, which said different proposal of activities or stages involved in the planning of specific citizen science project.

Bonney et al. in [14], it is perhaps the first attempt to propose a general model for building a citizen science project (released in 2009). This general model was worked out over time by a group of individuals with expertise in education, population and conservation biology, information science, computational statistics, and program evaluation. This model is divided 9 processes, and it can simultaneously fulfill the project´s goals such as: recruitment, research, conservation and education. Tweddle et al. in [15], this guide is aimed to support people already involved in citizen science. It is based on detailed information gathered and analyzed as part of the UK-EOF funded project “Understanding Citizen Science & Environmental Monitoring”, which semi-systematically reviewed 234 projects and included 30 case studies. The authors show 5 stages, and few activities defined into each. The GEWISS Consortium [5] proposes a guide which

ISBN 978-9930-617-71-7

describe how citizen science is practiced in Germany, besides how this participatory approach can be used in different research disciplines and issue areas: education, conservation or arts and humanities. This proposal shows 6 stages, and few activities defined into each. The Citizen Science Foundation developed a handbook [16], it offers a set of useful tools associated with a methodology for the design of Citizen Science projects. This handbook was made through conversations with people who have done Citizen Science, besides of reflection days with local actors, adaptation of different material collected in other languages and the own experience of authors. The methodology showed in the handbook is based on the Canvas Model besides that every stage is aligned to the 10 principles defined by the European Association of Citizen Science [17]. The General Service Administration through its web page [18] has published a Toolkit with five basic process steps for planning, designing and carrying out a crowdsourcing or citizen science project. Each step defined in the Toolkit shows a list of tips that participants can use to keep your project on track; these steps are in sequence, but each is also independent, besides each step proposes resources to help answer its specific questions. In [19], the authors proposes a contributory citizen science focus as a valuable method to scientists and practitioners within the environmental and ecological sciences, focusing on the full life cycle of citizen science practice, from design to implementation, evaluation and data management. By other hand, Bolici and Colella in [4] propose a theoretical framework designed to support activities mainly focused to robotics research projects, besides the authors compare and select a set of methodologies for designing citizen-science strategies, this theoretical framework has a "hybrid focus", once that the authors merge activities directly related to CS (considering as key reference [14]) with principles of action research methodology. As consequence, it can be said that there does not exist a general framework which can take be taken as base for the formulation of citizen science projects, in this way, the data obtained in this kind of projects are lacking the quality expected by the different participants, independently of the application area of the citizen science project.

2.2 Norm UNE 0080:2023

The norm UNE 0080:2023 is a guide for Data Improvement, it is a framework to assess and improve the maturity of the organization's processes related to data management, governance and quality. UNE 0080:2023, which is publicly accessible, is aligned to several international open standards such as ISO/IEC 8000-61 [8], ISO/IEC 8000-62 [13], ISO 38505-1 [20], ISO 38505-2 [21], and it also gather some best practices from standards like COBIT 2019 [22] or DAMA's DMBOK 2 [23]. It consists of two main components: (1) A *Process Reference Model* (PRM) consisting of 22 processes grouped in three categories: 5 processes in Data Governance (DG), 13 processes in Data Management (DM) and 4 processes in Data Quality Management (DQM). (2) A *Process Assessment Model* (PAM), with indications to assess and improve the maturity of an organization regarding the capability of their DM, DQM and DG processes.

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3 Research method

To produce the CIEN_FORM framework, we are following the Action Research (AR) Method [24] because it is necessary to "*focus on social systems and put knowledge into action as soon as possible*". AR is a collaborative research form that seeks to unite theory and practice between researchers and practitioners through a process that is cyclical in nature, producing new knowledge that is useful in practice. AR has been successfully used in Information Systems [25] and Software Engineering [26], and given the very nature of the citizen domain of our research we feel it can be successfully used given the strong component about the "social" fact. In this case, the research goal is the "*design and testing of citizen science project formulation framework*". To achieve our goal, three AR cycles has been planned. For each AR cycle we identified different critical reference groups, but we maintained as potential beneficiaries, any researcher or research institution (mainly Universities or Research Centers) that wants to customize and institutionalize their own Citizen Science Project Formulation (CSPF) process.

- An Initial **AR Definition Cycle**, where the main goal is to build a first version of CIEN_FORM PRM. In this initial cycle, we explored the corresponding literature and existing documentation to identify the common problems in the citizen science project formulation process; once identified the problems, we proposed an initial version of the processes in the PRM grouped in four groups (see section 4) with the idea of tackling the specific problems, along with common ways to address data quality problems by means of the alignment of the proposed processes with UNE 0080:2023. This first version was validated with a group of experts in the designing of proposals of citizen science projects, who acted as critical reference group. Through 3 cycles of meetings with the underlying refinements, we produce the first version of the PRM, which is introduced in this paper.
- A Second **AR Acceptance Cycle**, where the main goal is to present the whole framework to several preidentified stakeholders with different responsibilities for the citizen science process in various projects, to identify its weaknesses and strengths from various points of view. This is to be done by means of surveys and interviews. With the obtained feedback, we will produce a more refined PRM version.
- The Third **AR Validation Cycle**, where the final version of CIEN_FORM will be applied to some projects proposed in the "Observatorio de la Ciencia Ciudadana en España" following the case study research methodology.

4 The CIEN_FORM Process Reference Model

In this section the PRM is to be introduced. The main purpose of the PRM is to identify the processes that can be used to describe and characterize the entire lifecycle and formal pathways of citizen science project formulation applied for any kind of research area (biodiversity, environment, technological, wildlife, health, humanities, etc.), helping either person and institutions in charge, to identify differences and constraints to

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achieve higher data quality under the perspective of the various stakeholders, ranging from rooky participants to expert researchers.

The structure of the organization of the sixteen processes included in the PRM is adapted from the concept of Primary, Support and Organizational process in ISO/IEC/IEEE 12207:2017 [9]. This enables a better understanding of the purpose of every process, and it can be also used to better determine the contribution of every process to the general goal of the CSPF. As a result, we identified the following groups of processes: (1) Strategic Processes (G Processes), (2) Main Processes (M Processes), (3) Support Processes (S Processes), and (4) Other Processes (O Processes). See sections 4.1 to 4.4. for a larger description of this groups of processes. As said, the definition of the PRM has been aligned to UNE 0080:2023. Due to this reason, and for the sake of interoperability with other process-approaches based on ISO standards, the process description of every process in the CIEN_FORM PRM has been done according to ISO/IEC/TR 24774 [27], and it consists of the following elements:

- Title, which is a descriptive heading for the process at task.
- Purpose, which describes the main goal of the researcher or institution when executing the corresponding process.
- Outcomes, which represent the observable results expected from the successful execution of the process.
- Activities, which is a list of actions (best practices) that can achieve the outcomes.

It is worthy to state that, due to length paper restrictions, unfortunately we will not include the full description (e.g., the full description of the four previous elements for every process). However, we will show the title and purpose of everyone, and some outcomes and activities of the first group related to Strategic Processes.

4.1 The Strategic Process Group

This group of processes address the concerns related to the governance of the CSPF activities (see Table 1), namely, those related to the creation of internal standards, identification of best practices, norms, guidelines, and policies to rule all details -including data quality concerns from the institutional point of view- regarding the various stages of all data considered for citizen science projects. It is also worthy to note the special focus on the organizational structure and human resource parts.

Table 1. The Strategic Processes.

Process Title	Purpose
G.01. Creation or Selection, implementation, and maintenance of standards, best practices, and policies.	The main goal of this process is to set up the management environment required to execute the citizen science project activities according to the specific research area on which the project will be executed, and the capabilities of the institutions (research centers or universities) and following the criteria and recommendations provided by the authorized organizations at a national level.

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G.02. Development and improve of controls to meet policies.	The main aim of this process is to develop and maintain the corresponding controls to check if the proposed policies are being met during the execution of the citizen science activities.
G.03. Organizational Structure Management	This process is aimed to establish and maintain a supportive organization for the citizen science data processes, identifying roles and responsibilities and to also define the competences and skills that are required for every responsibility. In addition, communication means, and protocols are also observed in this process.
G.04. Stakeholders' skills and competences management.	The process is aimed at maintaining a catalogue of the training required for assuring different participants can achieve the associated competences and skills required to play their roles during all the project lifecycle.
G.05. Data risks identification	The purpose of this process is identifying the different kind of risk of the data that will be collected by the different participants, e.g. privacy, rights, security, reputation, etc.

Just an example, we introduce the *outcomes* we identified for G.01 process: (a) Updated list of best practices in CSPF. (b) Updated list of CSPF data guidelines. (c) Updated list of CSPF data policies. (d) Resources to propagate the best practices, norms, policies, and guidelines. To achieve and manage the previous outcomes for the processes G.01, the next *activities* were identified:

- AG01.1. To select and define the best citizen science practices for the specific research area of the project (if exists).
- AG01.2. To assign episodes to participants in the CS project according to pre-defined rules.
- AG01.3. To list and define the most important norms and regulations regarding data protection/security, quality, and access/use, to comply with the General Data Protection Regulation (EU GDPR).
- AG01.4. To define norms regarding standard reference books, supporting instruments and citizen science project guidelines.
- AG01.5. To define and harmonize documentation sources to be considered for the specific citizen science project.
- AG01.6. To ensure continuous awareness, training, and preparation on particular terminologies.
- AG01.7. To define norms and standards regarding software and hardware resources to be used within the citizen science project data lifecycle.
- AG01.8. To identify a list of data risks involved during the data lifecycle.

4.2 The Main Process Group

This group of six processes is aimed at covering all the concerns related to the proper citizen science project itself describing the various activities related to the data lifecycle, from data collecting (e.g. records obtained by citizen) to the use and exploitation of data for researchers or institutions. Table 2 shows the purpose of every Main process.

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Table 2. The Main Processes Group

Process Title	Purpose
M.01. Data acquisition	This process is aimed at selecting and acquiring the required data from the typical data sources depending on application area of the project (e.g., data or records both paper-based or electronically, like images, text, audio, pictures, etc.).
M.02. Data Integration (internal)	In this process, the integration coming from the various data sources should be achieved to create a solid basis for the citizen science process.
M.03. Metadata Coding	This process is aimed at properly identify each one of the metadata associated to the data collected from different sources.
M.04. Submission of the collected data towards a project central repository	This process covers the sending of the data and their corresponding metadata to the project central repository.
M.05. Data exploitation for project´s stakeholders	The objective of this process is to support all the necessary operations for each stakeholder of the project, researchers, citizens, universities and organizations.
M.06. Data exploitation for future research	The main purpose of this process is to produce research reports to possibly propose and lead future research projects, mainly by experienced researchers.

4.3 The Support Process Group

In this group of four processes, the details of quality management of the data used as input (collected by citizens and researchers) and output (classified data and metadata) of the citizen science project is covered. In addition, the concerns related to technological infrastructure management along with the maintenance of the reference data standards are also covered. See Table 3 to see the process title and purpose.

Table 3. The Support Processes Group

Process Title	Purpose
S.01. Data quality management of citizen science original (input) data	The main aim of this process is to evaluate the level of the quality of the CS documents and data collected.
S.02. Data quality management of CS data	Once produced the data, the main aim of this process is to evaluate the quality of the resulting CS data.
S.03. Reference Data Management	This process is aimed at maintaining the various reference data involved in the specific CS project, according to the discipline or area of application.
S.04. Technological Infrastructure Management	This process is aimed at establishing the required technology to support the flow of information through all the main processes, as well as to interact with some other participants or stakeholder (e.g., some other organizations, universities, government).

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4.4 The Other Process Group

Finally, in the other processes group, consists of the process shown in Table 4.

Table 4. The Other Group Processes Group

Process Title	Purpose
O1. Disseminate results process	This process is aimed at publishing and disseminate the results of the CS project. This process should look for the specific publishing spaces according to the research discipline or area, in order to describe the most relevant details of the project. In addition, many projects publish technical reports to disseminate results to target audiences. Likewise, results frequently are reported in popular literature such as newspapers and newsletters published by a variety of organizations ranging.

4.5 Customization of the framework for a specific context.

We intended the PRM of CIEN_FORM would be complete and flexible enough to be adapted and suitably customized for various context, disciplines, or areas (e.g., specific countries). In this sense, the outcomes and activities should be selected and reinterpreted for the specific context. This involves, for instance, to identify who are the most relevant actors and stakeholders for the various process groups in every context. In this sense, however, we have identified actors/stakeholders that are very relevant for any kind of CS projects, hence, independently of the discipline or area of application of the project. We classify them in three considerable groups:

Consultive Roles and Responsibilities. General policy-makers or policy-proposers for the specific domain of the CS project, that are typically outside of the organization in charge to execute the CS project, mainly in the regional or national government. They provide some hints about general concerns and recommendations for some activities, for instance, publishing of results. Some of these concerns consists in recommendations for technical support, while others are more related to management and interoperability support. These are not typically active roles, we can list: 1) Government agencies and departments. 2) Civil society organizations, informal groups, and community members.

Active Roles and Responsibilities for the process. Workers that are somehow involved in CS project tasks at institutional level for the Strategic and Main and Support Processes. 1) Main researchers. 2) Academic community. 3) Citizens involved in the CS Project (volunteers or participants). 4) Research institutions managers. 5) Technological specialist.

Benefited Roles, played by stakeholder that will use the collected and classified data for the various purposes. 1) Academic and research organizations. 2) Researchers (from other areas or disciplines related to the CS project). 3) General citizens (community). 4) Formal learning institutions. 5) Business or industry.

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Customization of CIEN_FORM for specific CS project. The institutionalization of **CIEN_FORM** involves the identification and customization of the various outcomes and activities for the reality of the research institutions, by considering the specifics for the regular flow of data following the main processes. As part of the customization of the activities, the specific positions in the research institutions corresponding to the previously introduced roles must be identified and their responsibilities conveniently assigned, and the communication protocol and means adequately established. Regarding outcomes and work products, every research institution or main researchers should raise consensus on how to name, store and establish guidelines by means of policies and procedures to exploit them.

5 Conclusions and Future Work

This research has been motivated by the hypothesis that having and implementing a framework for citizen science projects will not only contribute to a greater homogenization of their processes for specific research institutions, or particular research disciplines and areas, but also to enable better interoperability between other organizations, enabling even benchmarking. In addition, the institutionalization of the framework will make the citizen science project much more efficient, interoperable, and error-free, by facing the list of problems listed in section 2.1 in a unified and controlled way from an organizational point of view.

The main expected impact of this PRM is not only to identify, map and structure the various processes and activities related to citizen science project in day-to-day life at research institutions, but also to provide a working tool to promote data reuse, good CS practices and to organize processes, promoting data quality improvement, and body of knowledge.

As part of our near-term future work, we will conduct the AR acceptance cycle, in which we aim to gain buy-in from the community involved in the citizen science processes. To this end, we will conduct a series of questionnaires and interviews with representatives of the various stakeholders described in section 4.5. The feedback obtained will be used to refine both the process reference model and the evaluation model. Once the framework will be refined, we will disseminate it in different forums.

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ISBN 978-9930-617-71-7

The Challenges of Citizen Participation in the Development of Citizen-centered Smart Cities: Lessons Learnt from two European initiatives

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Abstract. Citizens have become the forefront of every urban transformation in the pursuit of more citizen-centered cities. The involvement of residents in any smart city initiative is key for establishing resilient and inclusive smart cities that cater to the needs of the entire community. Thus, the representative participation of citizens in any transformation process becomes a pillar for acquiring the necessary information. Nevertheless, some barriers arise that prevent a successful participatory process when developing smart cities. These barriers become a challenge to develop truly citizen-centered and inclusive smart cities. This paper analyses two European initiatives, DROP and URBANAGE, where specific actions have been taken to overcome these barriers. Utilizing engagement methodologies, cocreation processes have been systematically implemented to organically integrate citizens into the strategic design framework. Although targeting different citizen groups and objectives, both projects encounter common challenges in achieving citizen participation and awareness. Lastly, the paper highlights five main lessons learnt and proposes several guidelines to help overcome these barriers in other participatory processes.

Keywords: participation, engagement, human-centered design, case study.

1 Introduction

A proper urban development can be achieved through the development of smart cities [1]. The concept of smart cities has significantly gained in importance and relevance, as urbanization and population shift are expected to increase considerably by the year 2050 [2]. However, the origins of this concept remain somewhat ambiguous. Some authors trace it back to the Smart Growth Movement that emerged in the late 1990's [3], [4]. Other authors identify its roots in the earlier "cybernetically planned cities" of the 1960's or in proposals for networked or computable cities within urban development plans from the 1980's onwards [5], [6].

ISBN 978-9930-617-71-7

Regardless of their origins, smart cities are characterized by their innovative performance across various domains: governance, mobility, economy, environment and lifestyle [7]. Most of the definitions of smart cities in scientific literature revolve around the use of Information and Communication Technologies (ICTs). The dependence on technology, however, leads to a digital society with the emergent issue of the digital divide, as smart city citizens are often assumed to have a high understanding of technology [8]. Nevertheless, while often associated with digital technologies, such as sensor data collection [9], the "smart" aspects of smart cities also encompass attitudes related to awareness and self-sufficiency [10]. Therefore, a more human-centered characterization of smart cities is increasingly gaining strength [2] that emphasizes the importance of the social dimension of cities and places the citizens in the center of smart cities [11].

This focus on social well-being is a core objective of citizen-centered cities. Citizen-centered cities focus on improving the quality of life, wellbeing and satisfaction in urban contexts by creating them for and with the citizens that live in or transit them[11]. Conceiving citizen-centered cities can be achieved through citizen participation initiatives. Citizen participation processes bring several benefits to the citizens, the city and the corresponding authorities, highlighting: multi-directional approach to problem solving [12], [13], [14], community empowerment [15], social cohesion [15], [16], resilient communities [15], [16], awareness [17], [18], increased accountability [15], [18], inclusivity and diversity [19], [20] and innovative ideas [14].

However, like any complex process, the application of citizen participation initiatives can face several barriers, both internal and external, that can undermine its successful implementation. In this case, seven barriers can be: representativeness [21], [22], political interference [23], power relations [23], [24], time constrains [22], limited resources [22], technology [12] and expertise gap [18].

2 Barriers for successful citizen participation in smart city development

This section outlines the main barriers identified in scientific literature that undermine a participatory process in smart city development.

i. **Representativeness**. Ensuring that participation to be truly representative of the entire community can be difficult [22], [23]. The subset has to be representative of the relevant population, important interests have to be included, participants have to possess enough information to make good judgements and have to be accountable for those that do not participate [21].
ii. **Expertise gap.** Citizens often lack the expertise in urban planning, architecture, and design, making it challenging for them to fully grasp the technical aspects of regeneration projects. Many critical views defend that citizens do not have the expertise to contribute to the process [18].

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iii. **Political interference**. Politicians or special interest groups may manipulate or co-opt the participation process for their own agendas, undermining the genuine involvement of residents. According to Wamsler et al. [23], the main issue is that citizen participation in the least of priorities of the corresponding authorities and, therefore, there is not a systematic way to collect peoples' needs and wishes. Thus, this will end in the lack of supporting policies, regulations and planning tools for participation.

iv. **Power structures**. Complex bureaucratic processes and regulations can deter citizen participation. A lack of transparency can frustrate community members. Moreover, the existing institutional structures and power relations lead to a lack of trust and accountability due to pre-existing conflicts [20], [23], [24]. By the same token, capturing citizens needs and the local context is often too expensive and fails due to lack of personnel [22].

v. **Time constraints** are also a relevant barrier for citizen participation. Participating in urban regeneration initiatives can be time-consuming, and many residents may have other commitments, such as work and family, that limit their availability [22].

vi. **Limited resources**. Communities may lack the financial or technical resources needed to actively participate in the regeneration process. This can create disparities in participation between affluent and disadvantaged neighborhoods. Maas et al. [22] highlight that involving citizens in the design process takes a huge amount of time and resources in order to establish a meaningful relationship with the community.

vii. **Technology**. Technology and "technology first" mindset that has built upon the smart city context. Authorities believe that implementing existing technology will be cheaper than designing solutions from scratch and together with the citizens [22] . However, within this context, another limitation is the difficulties facing the collection and processing of the correct data from citizens [12].

3 Methodology

This section describes the methodology applied to the collection and analysis of the data in both case studies. It followed a Descriptive-Analytical Method, where both cases have been studied independently and then analyzed to understand the participatory process in each case (see **Fig. 1**). When applying this method in the case study analysis it generates a detailed and exhaustive description of the cases, while allowing understanding of the context and the particular characteristics of the case deeper [25]. In this case, it has added special value in the identification of challenges between the two phenomena to assess the validity of the methodology in different cases.

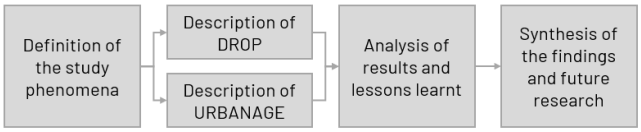


Fig. 1. Steps of the Descriptive-Analytical Method in this study

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This paper analyses two Europe based case studies that have applied the same principles in order to overcome the barriers of participation and enhance citizen engagement in participatory initiatives. It outlines the actions taken and the lessons learnt from both initiatives.

4 Results and discussion

This section describes both case studies analyzed in this paper and outlines the actions taken in both of them as well as the results obtained.

4.1 Definition of the study phenomena

Both case studies have been selected due to the methodology used in order to overcome the barriers of citizen participation in the development of inclusive and smart cities. The methodology applied in the two case studies has its origin in the Human-Centered Design (HCD) principles. The concept of HCD has its roots in Design Thinking [26]. It was popularized in the 1990s as an approach to foster innovation in business strategies through the development of user-driven products and services [27]. The principal goal of HCD is to develop solutions that cater to the needs of its users while maintaining its feasibility in the market, concluding with solutions that are feasible, meaningful and effective, addressing the needs of its users. It divides every step into a divergent and convergent sub-step, where activities are approach through a human-centered approach while balancing them with real-world limitations such as time and resources [28].

It is an approach that places a primary emphasis on ensuring that whatever is being designed, whether it's a product, service, or system, effectively meets the needs and preferences of its intended users. Its standards follow the international norm ISO 9241-210, which defines 5 main principles a process must follow in order to be human-centered (see **Fig. 2**).

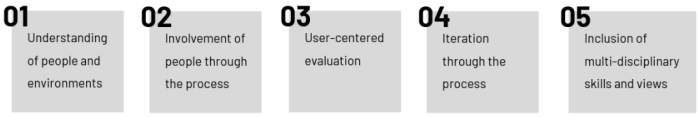


Fig. 2. Main principles of HCD

Hence, it relies on techniques that facilitate communication, interaction, empathy and engagement with the individuals involved in a process [29]. Through the use of these methods, designers strive to attain a deeper understanding of users' needs, desires and experiences, often uncovering aspects that users may not initially recognize or express. Within HCD approaches, the designer's role is to have an integrated vision, making it inclusive and finding a way to gather users from different backgrounds [30]. Thus, the role of the user or, in this case, the citizen, increments as the successful implementation of this approach concludes in citizen-centered cities with truly transformative

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governments [31]. The principles of HCD have been adapted to the specific objectives of each case study.

4.2 Case study 1: drOp

The first case study analyzed in this paper was the Horizon EU project drOp: "Digitally enabled social district renovation processes for age-friendly environments driving social innovation and local economic development". The core ambition of drOp is the development of an integrated renovation methodology (IRM) aiming to transform social housing districts into inclusive smart neighborhoods. To achieve this goal, drOp employs a human-centered approach and incorporates cutting-edge technologies to generate growth. The model developed in this study is being tested in a case study in the Santa Ana neighborhood in Ermua (Spain) and followed by in two other European municipalities: Elva (Estonia) and Matera (Italy).

Within this context, three main action lines have been developed to overcome the barriers of citizen participation through a human centered design approach: (i) communication of the participatory process, (ii) definition of a collaboration structure and (iii) co-creation sessions.

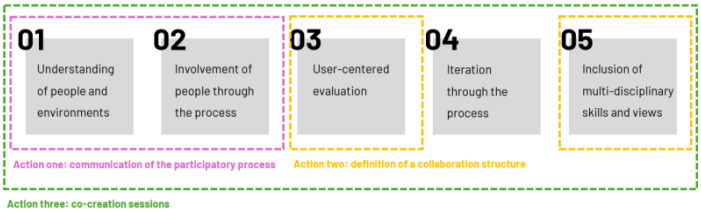


Fig. 3. How every drOp action reflects in the principles of HCD

Each of these actions addresses different principles of the human centered design approach (see **Fig. 3**) in order to overcome the identified barriers:

- Action one: Communication of the participatory process. This action is directly tied with the HCD principles 1 and 2 as it helps to better **understand the people** living in the neighborhood and their environment and also ensures the **involvement of people through the process**.
- Action two: Definition of a collaboration structure. This action focuses on the HCD principles 3 and 5 by putting the **evaluation activities** in the hands of the residents and **integrating multi-disciplinary skills and views** into the team.
- Action three: Co-creation sessions. The last action covers all five HCD principles, as co-creation sessions are the basis of the entire process and involve citizens and other stakeholders to achieve different objectives.

Action one: communication of the participatory process. The first action focuses on techniques to facilitate both communication with involved citizens and their

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understanding of the process and its potential outcomes. To do so diagrams, visuals and illustrations were developed to show the process and possible results of the project to the participants. Participants are experts of their own experience but not necessarily experts in the topic in hand. They take part in a process to help planners, designers or authorities understand the day-to-day life of the neighborhood and the needs they may have around it. Therefore, it is in the hands of the planners or designers to make the process as inclusive as possible by not using a mere technical language.

The project's progress and key decisions were communicated to the community through a series of infographics (see **Fig. 4**). These visuals were shared with residents via mailed pamphlets and displayed at the neighborhood office, ensuring that the community remained informed and engaged throughout the process. This approach also helped minimize the expertise gap mentioned beforehand, as visual representations made it easier to understand the more complex technical aspects.



Fig. 4. Information pamphlets through the process

For the understanding of the possible outcomes of the process, some images were created with the help of Artificial Intelligence (AI), where the neighborhood was visualized in several possible future scenarios, depending on the different actions taken during the development of the project. These images showed the actual neighborhood but with different features such as greener spaces, more social encounters, enhanced economic development or smart dwellings (see **Fig. 5**). Having pictures of their actual neighborhood but with a few adjustments has helped in understanding better the possible outcomes of the project from the outset of it.



Fig. 5. Images of the neighborhood created with AI

Action two: definition of a collaboration structure. The second action line relies on the definition of a work structure for the project, encompassing community members, key stakeholders, project team members and the council. This structure, defined as a

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Local Task Force (LTF), describes a three leveled structure defining different standards of implication for each level. The LFT represents a coalition of relevant stakeholders working collaboratively to address the challenges presented by the community and reach a consensus on the decisions at hand. Thus, it entails the distribution of the decision-making authority and responsibilities among different stakeholder groups. It functions as a local hub that guides the bottom-up initiatives, divided into three main levels: a coordination structure, an executive commission and an extended commission.



Fig. 6. Structure of the Local Task Force

Action three: co-creation sessions. The third and last action line was the design and development of the co-creation sessions in the identification and the co-design of the projects to develop in the neighborhood. Several sessions were conducted, where both citizens and relevant stakeholders took part (see **Fig. 7**). These sessions were designed following the principles of HCD, where they main focus relied in the understanding of residents and their environment. This was made by facilitating bidirectional conversation spaces where participants could express their feelings and opinions. Thus, they were designed in a quite open-ended format, so that they were easy to adapt to the needs and desires of the participants. The residents were involved through the entire process and were the ones that evaluated and prioritized the projects to be co-designed based on the needs of the community. They were held in the neighborhood to ease the participation and ensure accessibility to all residents.



Fig. 7. Overview of some of the co-creation sessions

In some cases, digital tools were used to conduct the sessions, where the facilitators would use an app to manage all the data citizens were sharing. These tools were used by the facilitating team, with the inputs of the residents, so that they would only need to focus on sharing their problems and needs. This way the time of both the actual

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session and the processing of the data afterward were reduced significantly and efficiency, overall, enhanced.

4.3 Case study 2: URBANAGE

The second case study examined in this paper is URBANAGE, a Horizon 2020 project titled "Enhanced URBAN planning for AGE-friendly cities through disruptive technologies." This initiative aims to assist urban planners and policymakers in leveraging new technologies for more inclusive and evidence-based decision-making. URBANAGE promotes the creation of age-friendly cities by implementing a new decision-support ecosystem, co-developed by key stakeholders (public servants) and end-users (older adults). This ecosystem, designed with a deep understanding of users' needs, has been tested through pilot use cases in three European local planning systems: Helsinki, Santander, and Flanders.

The URBANAGE project was conceived to assess the potential benefits, risks and impact of implementing a long-term sustainable framework to support evidence-based decision-making processes in the field of urban planning for age-friendly cities. This framework has been developed through an inclusive co-creation strategy with relevant end users (public servants and older adults).

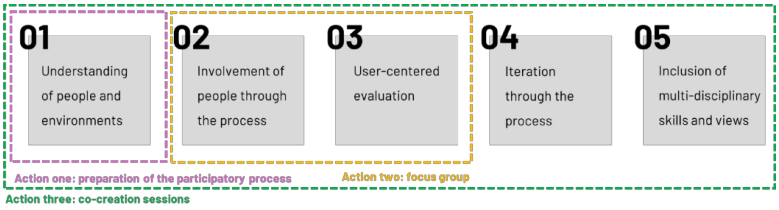


Fig. 8. How every URBANAGE action reflects in the principles of HCD

The methodology employed to facilitate citizen participation following the human-centered principles in the URBANAGE project encompassed the following stages:

- Action one: Preparation of the participatory process. This action is directly tied with the HCD principle 1 as it helps to better **understand the people** living in the neighborhood and their environment.
- Action two: Focus group. This action focuses on the HCD principles 2 and 3 by **involving** citizens and other stakeholders together **through the process** and by putting the **evaluation activities** in the hands of the residents.
- Action three: Co-creation sessions. The last action covers all five HCD principles, as co-creation sessions are the basis of the entire process and involve citizens and other stakeholders to achieve different objectives.

Action one: preparation of the participatory process. This action line serves as the foundation for conducting focus group and co-creation activities with end-users. This

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activity necessitates a comprehensive understanding of the stakeholders who can influence and contribute to a project such as URBANAGE. It is also crucial to identify whose interests should be considered during the development and implementation of policies or urban plans. Detailed stakeholder mapping will facilitate pilot sites in pinpointing the key actors essential to URBANAGE activities.

URBANAGE aimed to engage two distinct groups: older adults and civil servants. To ensure inclusiveness in the URBANAGE approach, participants had to represent the diversity of ageing populations in terms of age, gender, ability, and digital literacy. Additionally, older adults from various social classes, races, and ethnicities have to be included when relevant [32]. When engaging civil servants, "The Global Age-Friendly Cities: A Guide" delineates eight distinct domains that a city must consider to be deemed age-friendly. Civil servants involved should encompass all domains identified as falling under the urban environment's jurisdiction at the city level. Specifically, those with urban planning competencies should focus on outdoor environments, housing, and transport and mobility. Conversely, public servants from departments traditionally responsible for interactions with older citizens, such as social services, should also be included. Although these departments may not be directly involved in city planning, their actions in other fields can influence urban planning, and they possess valuable knowledge about the older citizen demographic. Additionally, departments responsible for citizen participation, communication, and information should be actively engaged.

Action two: focus groups. The primary objective of focus groups is to elucidate and identify the motivations, challenges, and barriers that influence the participation and engagement of older adults in the pilot areas. The focus group activities aim to identify effective mechanisms to motivate older adults to engage in citizen participation by examining the factors that encourage or hinder their motivation and understanding their perceptions of digital technology in these activities. Additionally, it explores how gamification techniques can be utilized to enhance their engagement, and which specific techniques are perceived as motivational by older adults in this context.

Three focus groups were conducted, one per pilot site (Flanders (Ghent), Santander, and Helsinki). The comprehensive process encompassed literature research, designing the methodology and protocol, conducting train-the-trainer sessions with pilot sites, executing the focus groups, and analyzing the collected data.



Fig. 9. Overview of one of the focus groups

Action three: co-creation sessions. The co-creation activities aim to uncover the challenges that older citizens encounter in urban environments. This gathered information will help refine the use-case definitions and establish the user requirements from civil

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servants. Additionally, it will guide the development of solutions, such as data sources, visualizations, simulation models, and AI, necessary to address these challenges effectively.



Fig. 10. Summary of the co-creation sessions

The objective of the cocreation session 1 (CC1) was to ascertain the user requirements of older citizens concerning the development of an accessible and age-friendly urban environment. Through the implementation of a co-creation workshop format, a structured dialogue was facilitated between the moderator and older citizens. Specifically, the workshop aimed to elucidate the challenges, needs, desires, and opportunities experienced by older citizens to derive comprehensive insights.

The second co-creation workshop (CC2) focused on civil servants in URBANAGE pilot cities. Its main goals were to validate the requirements from CC1, assess their feasibility, and gather information on relevant initiatives and departments. The workshop introduced the URBANAGE project and its pilot objectives, mapped existing age-friendly initiatives, challenges, and collaborations, and identified key actors. It also addressed challenges civil servants face in age-friendly projects, assessed collaborations between city departments, and validated user requirements from CC1, while identifying technical constraints and challenges for implementation.

The goal of co-creation session 3 (CC3) was to combine the insights from earlier sessions with older adults and public servants. CC3 brought these groups together to validate and negotiate user requirements from CC1, incorporating the feedback from public servants and findings from CC2. The session helped prioritize these requirements based on their importance and feasibility, while also identifying technical challenges related to implementation. Additionally, older adults were consulted on their preferred ways to give input and receive information, with site-specific adaptations considered to validate current solutions and communication methods.



Fig. 11. Overview of the co-creation sessions

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5 Conclusions

The overall methodology of both case studies is different but they both share the common principles of HCD. They both approach the process with emphasizing in the people that are affected by the issue at hand and put a special focus in understanding their needs from the very outset of the project and involving residents in every step of the process. This ensures that the process will be better adapted to the people that takes part in it, enhancing the participatory process and generating more tailored solutions to the current issues of the city. There is still significant progress to be made in fully addressing the barriers identified in the literature. However, this paper highlights the main lessons learnt in the development of the two mentioned participatory processes and proposes several guidelines as a reference guide for practitioners who want to design truly citizen-centered smart cities tackling the barriers for successful citizen participation.

Lesson 1: Create a structure that endorses long time and multi-level engagement. The development of smart cities often involves lengthy and exhausting participatory processes for citizens. For these processes to be effective, the structure must be consistent and transparent, providing clear support and adequate resources. A common challenge is that citizens, driven by previous unsuccessful participatory experiences, may lose motivation, leading to inconsistent participation or dropping out altogether. To address this main challenge, it is crucial to establish a structure that clearly outlines the decision-making process and provides the necessary resources to support meaningful involvement. Furthermore, individuals should have the autonomy to decide if, and to what extent, they wish to participate in this structure as they should be free to choose whether they want to engage and how.

This structure helps endure the above mention barriers of representativeness [21], [22], [23], power structures [20], [22], [23], [24] and political interference [23] as it co-creates a clear framework among all the interested parties defining how the involvement of each stakeholder is going to be and how the decision-making process is going to be held.

Lesson 2: Offer engagement activities that cater to the needs of the entire community. Citizens are a heterogeneous group, so the process needs to adapt in order to cater to the needs of the community. It is imperative to create an offer of participatory choices and activities that allow citizens to contribute to different commitment levels. Accordingly, some participatory processes can get too lengthy and overload participants with too many activities. Thus, it is recommendable to use one gathering to discuss different topics, without the need to generate one workshop per issue and adapt it to the people that will take part in it. This way citizens will feel more willing to participate and it will be a better use of time and resources.

By following these actions, the barrier of time constrains and limited resources [22] can be revised. The offering of the activities mentioned will help in the management of time and resources into more practical and efficient participatory activities.

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Lesson 3: Promote self-efficacy and capability. When engaging with citizens, and especially older residents, it is essential to build their confidence in their ability to make a meaningful contribution to their community. When citizens see concrete and visible results they gain a sense of accomplishment, reinforcing their belief in their capability to make a difference. These visible outcomes not only motivate them to continue contributing but also inspire others in the community to take part as this tangible recognition serves as an extra layer of motivation, fostering a community spirit that encourages continued participation. However, communication must be tailored to ensure inclusivity, avoiding overly technical or bureaucratic language that may alienate or confuse participants. Instead, adopt clear, visible, and relatable methods of communication that resonate with the community.

This overcomes the abovementioned barrier of expertise gap [18] and representativeness [21], [22], [23] as it promotes the capableness of the citizens by using an inclusive language and making the process visible for all.

Lesson 4: Technology as an enabler of the process instead of the actual outcome. Technology needs to be a tool that helps enhance the experience without creating a digital divide. Therefore, the integration of new technologies in citizen engagement requires a thoughtful approach, especially for individuals who are less digitally savvy. It is essential to clearly communicate the added value of technology, explaining why it is preferable over traditional methods, and highlighting its practical benefits to avoid skepticism. Transparency about the motivations behind adopting new technologies can help build trust and acceptance among participants. Additionally, a dual-track policy that includes both digital and non-digital alternatives ensures inclusivity, preventing the exclusion of those who are unwilling or unable to adopt new technological tools.

This contributes to minimizing the barrier of technology [12], [22] as it helps cope with the “technology first” mindset that usually builds upon smart cities and places a more meaningful emphasis on the people that need to use the technology rather than the technology itself.

Lesson 5: Be transparent and communicate the real impact of their decisions. Citizens will contribute to the improvement of their neighborhoods and cities, under the condition that the cause is clear, and they feel they can have an impact. If the real impact of their contribution is not made explicit and sustained, then they will lose trust in the process and, overall, stop their engagement. Therefore, a communication campaign through the process is key to bolstering their motivation towards the project and sense of usefulness. Additionally, communication needs to be clear and continuous, with a non-technical language so that the community feels included and valued. Lastly, it is important to leave some room for feedback with every communication so that residents can share their input in order to ensure longer and more meaningful engagement.

This can contribute to reducing the expertise gap [18] by informing residents of the overall process and by using adequate language to do so. Also, by leaving space for feedback, there is a great chance to get input for more community members, increasing the representativeness [21], [22], [23]. Lastly, with a clear communication of the progress and the decisions of the process, the power structures [20], [22], [23], [24] will

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became clearer, reducing the mistrust citizens may have against the decision-making organs.

These insights represent the primary lessons learned throughout both processes; however, a more comprehensive understanding would benefit from a detailed evaluation of both the process and its outcomes.

Acknowledgments. This research was supported by funding from the URBANAGE project from the European Union's Horizon 2020 research and innovation program under grant agreement No. 101004590 and the drOp project from the European Union´s Horizon Europe research and innovation program under grant agreement No. 101080025**.**

Disclosure of Interests. The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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ISBN 978-9930-617-71-7

Activismo urbano y ciudadanía inteligente en San José, Costa Rica: la tecnología cívica al servicio de la transformación del espacio público entre el 2012 y el 2022.

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Abstract. Este estudio mapeó los actores y espacios en San José, Costa Rica, que han impulsado iniciativas para revitalizar el significado del espacio público local. Se analizó su uso de tecnología cívica y plataformas digitales para promover la participación ciudadana activa y contrarrestar la pérdida de estos espacios entre el 2012 y el 2022. A través del surgimiento de un contenedor de colectivos urbanos, se identificaron movimientos que han articulado alternativas de gobernanza colaborativa y bottom-up frente a la planificación tecnocrática asociada a la agenda neoliberal. Estas iniciativas han generado nuevas formas de apropiación del espacio urbano, donde diversos grupos sociales han logrado una voz autónoma y un rol activo en los procesos de gobernanza y toma de decisiones urbanas.

Keywords: espacio público; colectivos urbanos; redes sociales; ciudadanía inteligente; renovación urbana; tecnología cívica.

1 Introducción

1.1 Objeto de estudio

El rol de la ciudadanía está mutando de forma acelerada de la mano con los cambios en las dinámicas sociales (Blasco Fontecilla, 2021). Como resultado, las ciudades están aprovechando las nuevas tecnologías para explotar de manera estratégica los datos recopilados en diversas áreas y así mantenerse a la vanguardia (Bremser, Piller, & Rothlauf, 2019). La amenaza que enfrentan las ciudades radica en su histórico rol de red social por excelencia, el lugar tradicional de encuentro, intercambio y relación entre los seres humanos (Valle Pilia & Baietto, 2013).

Cada día toma una importancia creciente el uso de la red, en conexión con los numerosos canales que nos simplifican la comunicación y la búsqueda de información. La aparición del fenómeno conocido como "vida paralela digital" está llevando a los usuarios a adoptar una existencia en dos dimensiones: una real y otra virtual (Rosen, y otros, 2022). Este proceso también se está manifestando en el ámbito de los lugares físicos, desde establecimientos como cafeterías y tiendas hasta ciudades enteras; todos estos elementos están experimentando un proceso de virtualización y están al alcance de todos en el entorno digital (por ejemplo, con aplicaciones como Swarm y Fourquare (Swarm App, 2023)).

A la par de ese fenómeno de “tecnologización” de la sociedad y a partir del distanciamiento provocado por la pandemia de Covid-19, se está re-descubriendo la presencialidad para actuar sobre el medio físico en comunidad (Quindimil, 2021). Esto ocurre debido a que, aunque la tecnología y sus sistemas pueden generar dependencia y, de alguna manera, empobrecer la experiencia en el mundo real, la sociedad civil ha aprendido a utilizar los medios digitales para simplificar la coordinación y compartir conocimientos. Como resultado, se están consolidando tendencias que, en un amplio espectro de teorías y campos, promueven una nueva concepción de comunidad, en la que la red se convierte en un espacio para el debate político, la autoorganización territorial, el intercambio de conocimientos técnicos y proyectos que se alinean con la filosofía "open" (conocido en español como software libre), la de “peer to peer” (red de pares) y de “hack”, entre otras (Himanen, 2001). Justamente esta última postura fue rescatada por Catherine Bracy en su ponencia “Why Good hackers make good citizens”[1] (2013) cuando brindó el ejemplo de Benjamin Franklin como precursor del concepto de "hackers cívicos", siendo un fautor de ingeniería social, abogó por una ciudadanía activa en la construcción gubernamental. Sus valores, como colaboración y participación, reflejan la esencia de una democracia saludable y se entrelazan con la cultura de Internet como ecosistema de participación difuso.

En este contexto de transformación, la ciudad se convierte en un elemento crucial debido a que todavía exhibe los rasgos del antiguo paradigma basado en el capitalismo y el consumismo. La experiencia de la pandemia, seguida por

[1] En español: “Por qué los buenos *hackers* crean buenos ciudadanos”. En este contexto decidimos no traducir el término hacker, puesto que perdería su matiz arraigado a una contracultura informática y activismo ético.

ISBN 978-9930-617-71-7

los actuales acontecimientos bélicos en Europa, han producido múltiples debates y propuestas para su futuro, abriendo reflexiones críticas sobre la movilidad, los medios de producción, la injusticia social urbana, la generación de energía y alimentos desde la proximidad (Balbaa, Eshov, & Ismailova, 2022). Las condiciones globales actuales incitan a derribar conceptos tecnócratas y de control, en boga en la agenda neoliberal de los últimos años, como las *smart cities* (Linares García & Vásquez Santos, 2018) (Ferrer Rojas & Castillo Büttinghausen, 2021), centrando el debate en las iniciativas de pequeña escala que surgen desde la ciudadanía (Verdaguer Viana-Cárdenas, 2023).

En muchos casos la etapa de discusión ha sido superada, para dar lugar a la era de la acción, de las políticas públicas desde abajo: desde la ciudadanía se están ensayando modelos de autogestión local que prototipan nuevas gobernanzas de los espacios públicos e idea de ciudad. En fin, se afirma el Principio de Subsidiariedad horizontal de los bienes comunes (Gutiérrez, 2009) con ejemplos concretos. Como bien lo subraya Sassen, se están configurando nuevas expresiones de ciudadanía (Vega Solís y Gil Araujo, 2003). La ciudad experimenta una transformación, que la convierte en la escena política donde individuos políticamente no convencionales pueden actuar de manera directa, por medio de intervenciones y autogestiones como la ocupación de espacios, asambleas barriales y luchas por los derechos de población más vulnerable. Este proceso posibilita la formación de subjetividades innovadoras y áreas de experimentación que están al margen del sistema formal, tanto político como de mercado. Según Sassen, la actual redefinición de la ciudadanía global encuentra su escenario ideal en la ciudad y su trasposición desmaterializada en las redes que se apoyan en las nuevas tecnologías (pág. 26).

La decisión de hacer un estudio, sobre los actores locales, en San José Costa Rica, y su relación con los medios de comunicación digitales, surge de la necesidad de tener un entendimiento más profundo del medio. Se propuso conocer la situación del contexto más próximo, el Gran Área Metropolitana de San José Costa Rica, y las tendencias de los últimos 10 años entre grupos de la sociedad civil que se acercaron a los llamados “colectivos urbanos”. Esta investigación ofreció la oportunidad de estudiar una muestra de iniciativas ciudadanas y el empleo que éstas hacen de las nuevas tecnologías para la organización y promoción de sus acciones urbanas.

1.2 Planteamiento del problema

El imperar del sistema virtual en la vida cotidiana podría suponer un empobrecimiento en el sistema de interacción y socialización en la ciudad, conformado por lugares de encuentro, de intercambio y de organización, hasta llegar a perder su significado a favor del encuentro virtual (ver Diagrama conceptual en Figura 1). Partiendo de este supuesto se plantearon las siguientes preguntas de investigación:

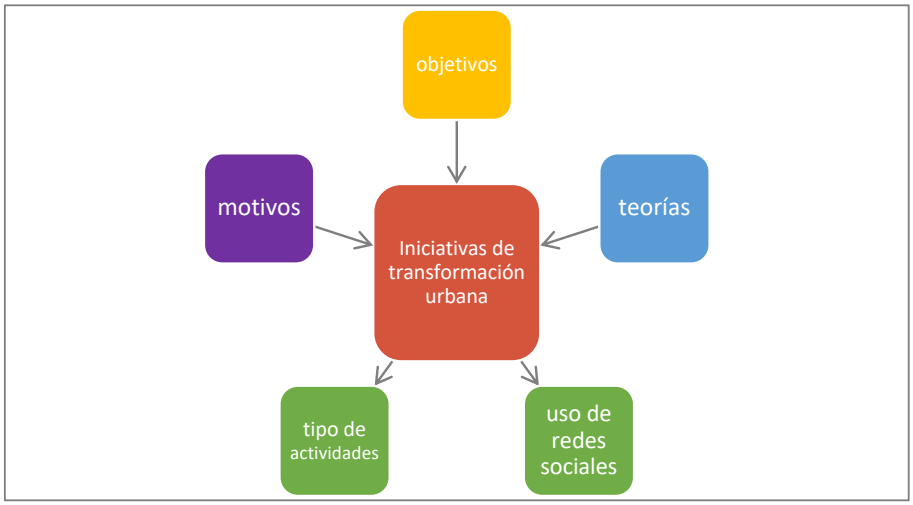


Figura. 1. Diagrama conceptual de componentes del estudio. Elaboración propia.

- ¿Cuáles son los motivos, los objetivos y teorías detrás de las iniciativas de transformación urbana?
- ¿Cómo estas iniciativas han logrado contrarrestar las tendencias neoliberales de privatización, segregación, fragmentación, exclusión de espacios y en temas urbanos controversiales?
- ¿De qué manera, estas transformaciones urbanas a pequeña escala crean nuevas redes de tecnología cívica que desestabilizan las dinámicas típicas del poder?

ISBN 978-9930-617-71-7

1.3 Justificación

La creciente importancia de las redes sociales (en adelante también RRSS) y la utilización de la red informática en la sociedad contemporánea están desempeñando un papel cada vez más destacado en la promoción de la democracia, la libertad y la interacción social. En este contexto, el presente estudio no solo tiene como objetivo recopilar y analizar diversos ejemplos de movilización ciudadana en la ciudad de San José, sino también reflexionar sobre las diversas formas en que las redes sociales pueden ser empleadas para difundir ideas vanguardistas que contrarresten la creciente pérdida de significado en el espacio público local.

Las implicaciones prácticas desde lo analizado, tanto para los mismos participantes, como para futuros proyectos a nivel local, quieren ofrecer una reflexión para que se promuevan y se potencien nuevas formas de organizar y actuar en la ciudad, desde la iniciativa ciudadana, aprendiendo de las experiencias de la última década.

El estudio pretende servir como punto de partida y motivación para la formulación de estrategias relacionadas con la utilización y creación de redes sociales en el proceso de construcción de lo público desde el ámbito virtual. En este sentido, se consideró necesario mapear las iniciativas que han surgido en Costa Rica en los últimos 10 años, identificar los desafíos que han enfrentado, señalar las limitaciones encontradas, y destacar las estrategias y visiones que han guiado sus acciones. Esto nos permitirá evidenciar, ante las autoridades gubernamentales, la presencia y los esfuerzos de los actores locales en la gestión y mejora de nuestros espacios públicos.

Pese a ello, es importante destacar que los principales beneficiarios de este estudio son los propios participantes en la investigación y la comunidad activa, quienes pueden seguir las pautas trazadas en los últimos 10 años en la capital. Con ello, buscamos fomentar un mayor compromiso cívico y la participación de la ciudadanía en la construcción y transformación de nuestra sociedad a través de las herramientas que proporciona la era digital.

1.4 Objetivos

1. Realizar un levantamiento de actores y espacios que, en San José, Costa Rica, han emprendido y difundido ideas y acciones de vanguardia para contrastar la pérdida de significado del espacio público local entre el 2012 y el 2022.
2. Analizar su actividad partiendo de la utilización que hacen de los nuevos medios de comunicación para el logro de sus objetivos.

2 El Activismo Urbano y Ciudadanía Inteligente en la Sociedad de la Red

Las iniciativas ciudadanas desde la base desempeñan un papel crucial en contrarrestar la planificación tecnocrática asociada a la agenda neoliberal. El neoliberalismo es una ideología económica y política que enfatiza la intervención limitada del gobierno en el mercado, la privatización y la promoción del capitalismo de libre mercado. La planificación tecnocrática, a menudo vinculada a las políticas neoliberales, se basa en la toma de decisiones de arriba hacia abajo por parte de expertos y funcionarios gubernamentales. En contraste, las iniciativas ciudadanas desde la base empoderan a individuos y comunidades para participar activamente en la formación de sus propios destinos. Para una comprensión holística del fenómeno la presente investigación se basó en fuentes primarias enfocadas en temas complementarios: partiendo de la concepción política del espacio público, pasando por el planteamiento de nuevas economías colaborativas, hasta la ciudadanía conectada digitalmente.

Un ejemplo importante de la dicotomía del espacio público, en términos de significado político, es tomado de Hannah Arendt, la cual subraya el aspecto colectivo del mismo: “el espacio público es el lugar común donde se produce la colectividad” (Valle Pilia & Baietto, 2013, pág. 180). Es decir, lo público es un acontecimiento, más que una estructura física, tan así que se podría extrapolar el postulado: el lugar que produce colectividad es un espacio público. Este podría ser también un entorno digital.

No lejos de reflejar el pensamiento de Delgado, el espacio público es un elemento esencial para la realización de la democracia, es decir tiene vocación normativa (Delgado, 2008). A prueba de ello Manuel Castells discutió ampliamente acerca de los movimientos ciudadanos que comenzaron a expresarse y organizarse gracias a las herramientas y los entornos digitales, iniciando por la *Wikirrevolución del jazmín* en 2011, siguiendo en España, Grecia, Portugal, Brasil, Turquía, Chile y México (Castells, Redes de indignación y esperanza, 2015). En la era de la auto comunicación de masas, las sociedades civiles adquieren capacidad autónoma para “conformar el proceso de cambio social” (2009, pág. 398). La definición por antonomasia del espacio público, la calle o la plaza, son para Habermas la ejemplificación de la “publicidad política”, es decir el contexto donde se hace manifiesto el nexo entre sociedad civil y Estado, atravesado por las circunstancias producidas por el capitalismo (Carmenati González, 2016).

¿Y si, como aludía Lefebvre, la arquitectura no fuese un tema de dibujo, sino de mediación entre actores sociales (1974, pág. 226)? el mismo discurso podría equivaler para el espacio público. Al punto que la mediación tecnocrática deja de importar, en un contexto en donde la sociedad civil tiene las herramientas para trabajar de manera autónoma a la indivi-

ISBN 978-9930-617-71-7

duación, análisis, negociación y producción de soluciones, "establec[iendo] una conexión activa [y directa con] sus creaciones" (Sennett, El cuerpo y la ciudad, 1997). La clave para sostener esta autonomía es la cooperación, una cooperación que cada día más se apoya, por lo menos en unas etapas, en la web 2.0 (Sennett, 2012, págs. 44-52).

La definida "ciudadanía digital" (Richards, 2010), empero sigue resistiendo la linealidad de la virtualización y anhela, en última instancia, encuentros "cara a cara" para "poner en práctica un pensamiento lateral más eficaz" (Sennett, 2012, pág. 49). Las limitantes de las herramientas del plano digital parecieran derivar de las modalidades de interacción, las cuales limitan la cooperación a lo dialéctico y no permiten lo dialógico, confundiendo la información con la comunicación (2012, pág. 50). El uso del lenguaje denotativo ralentiza la interacción, resta expresión y provoca pérdida de sentido, reduciendo el mensaje a su mínima expresión sin promover "condiciones que favorezcan la complejidad" (págs. 50-51). Porque es en la informalidad de los procesos de organización comunitaria, caracterizados por ausencia de rigidez, que se da el "intercambio dialógico de verdad" (pág. 79).

Si por un lado las teorías sobre el espacio público apoyan a la idea más amplia de un lugar de/para/por la colectividad, es cierto que en paralelo a la revolución del web 2.0 se han ido fortaleciendo planteamientos de nuevos modelos económicos. El afirmarse de un "gran número de personas trabajando, de forma continua, voluntaria y gratuita, en la clasificación del material" puso las bases de la "inteligencia colectiva" (Ribes Guàrdia, 2007, pág. 39), desde la red distribuida de Paul Baran (Piscitelli, 2004 y Yoo, 2018) hasta el modelo *peer-to-peer* (Bauwens, Kostakis, & Pazaitis, 2019). Mientras la red distribuida de Baran está intrínsecamente relacionada con la historia de internet y con su concepción estratégica, porque lo distribuido garantiza mayor estabilidad al sistema; el modelo entre pares se desvincula del contexto de infraestructura tecnológica para evolucionar como una alternativa en términos sociales y económicos. En términos sociales porque redefine las relaciones humanas en un marco de participación libre. En términos económicos porque ofrece la posibilidad de modificar los modos productivos y de consumo hacia una transición positiva para las personas y la naturaleza (pág. 1). Para ello guarda una estrecha vinculación con el concepto de bienes comunes.

2.1 Sociedad Digital y Transformación Urbana

En 1999 William J. Mitchell, profesor de arquitectura y planificación urbana en el MIT (Massachusetts Institute of Technology, por sus siglas en inglés), publica "E-topia: Urban life, Jim - but not as we know it"[2] (2005) signo indiscutible que ya hace años se viene hablando de la relación entre revolución tecnológica y urbanismo. No es el único, Josep María Montaner reconoce los efectos de los nuevos medios cuando define la arquitectura de finales del siglo con el término "energías" en su libro Las formas de siglo XX.

El arquitecto Vincente Guallart, ya parte del proyecto Metápolis, en una entrevista, habla de nuevos proyectos para Barcelona refiriéndose a: "hábitat urbano, que combina urbanismo, medio ambiente y tecnologías de la información" (Moix, 2011). En la misma entrevista, contesta acerca de cuál es el futuro de una grande ciudad como Barcelona, después de los planteamientos teórico-utópicos de Metápolis: "Necesitamos barrios de baja velocidad, en los que se pueda vivir, trabajar y descansar, integrados en una ciudad de alta velocidad, hiperconectada con el territorio. Slow cities en el seno de smart cities" (2011).

La arquitecta Mimi Zeiger expresó de manera contundente la tendencia del urbanismo táctico en la serie *The Interventionist's Toolkit*[3] (Zeiger, 2011). Desde su perspectiva esta técnica, si así la podemos definir, se caracteriza por emplear la ciudad como un terreno de experimentación y responder a los retos espaciales implementando parques pop-up, revitalizando espacios comerciales en desuso o manipulando elementos de mobiliario urbano no convencionales para reconfigurar el ámbito urbano. Tradicionalmente, esta práctica ha situado al activista en un contexto vinculado a factores medioambientales, políticos, culturales y económicos. No obstante, a medida que esta práctica ha sido asimilada por la corriente de pensamiento predominante, resulta crucial analizar minuciosamente ambas suposiciones y los efectos que estas conllevan.

Esta dinámica se ubica en un contexto de transformación en la sociedad, donde la red toma el papel de la herramienta para la autoorganización y la autorregulación. En este contexto, la ciudad se revela como el territorio de primordial intervención, según la demanda expresada por los ciudadanos.

Latinoamérica ha sido históricamente un terreno propicio para la experimentación, tanto en el ámbito arquitectónico como en el urbanístico. No casualmente numerosas propuestas, investigaciones y debates emerjan en esta región, promoviendo un enriquecedor intercambio de información y experiencias con países europeos, específicamente de España.

2.2 Planificación urbana a partir de la agenda neoliberal

En el contexto costarricense existe una interconexión entre neoliberalización, reconfiguración estatal y desarrollo territorial, tal y como lo presenta Brenner (2003). El proyecto de implementación de estas políticas está intrínsecamente vinculado a un proceso de reestructuración del Estado, a la evolución geopolítica de la organización territorial y la influencia

[2] En español: "E-topia: vida urbana, Jim – pero no como la conocemos".
[3] En español: "La caja de herramientas para los intervencionistas".

ISBN 978-9930-617-71-7

de nuevos marcos institucionales a nivel subnacional, específicamente ligados a la producción local y su consecuente adaptación de condiciones. Este proceso se vino desarrollando con el objetivo de impulsar la competitividad global de ciudades y regiones en términos estructurales.

Bajo la óptica neoliberal mencionada anteriormente, analizar la ciudad en Costa Rica implica considerar la reconfiguración socioespacial de ciertas áreas de la Gran Área Metropolitana, a la luz del proceso de reajuste estatal. Dentro de este contexto, es importante también el redimensionamiento de la urbanización, la cual, ha ido reforzando las tendencias de segregación. El redimensionamiento de la urbanización está guiado por las fuerzas del mercado, y no solo se traduce en una distribución desigual de los grupos sociales, sino que se manifiesta en el espacio mediante la formación de estructuras urbanas aisladas y fragmentadas, por fronteras no solamente físicas sino también simbólicas. Este es el caso del desarrollo polarizado a lo largo del eje este-oeste en la Gran Área Metropolitana, con la generación de "coágulos" residenciales, comerciales y corporativos, identificados con los anglicismos "*gated communities*", "*malls*" y "*corporate centers*", destinados a un solo sector de la sociedad y relacionados directamente con empresas transnacionales (Montes Ruiz & Durán Segura, 2019).

2.3 La gobernanza de los colectivos urbanos como voz autónoma en la redefinición del espacio público

Según la perspectiva de Mora y Durán, presentada en su último estudio "Los agentes inesperados de la recuperación: colectivos urbanos y espacios públicos en San José, Costa Rica (2000-2020)", los colectivos urbanos se han convertido en actores clave que respaldan las políticas de recuperación urbana, aunque inicialmente no fueron formalmente considerados a nivel gubernamental (Mora Obando & Durán Segura, 2022). A pesar de no haber sido incluidos en procesos institucionales, estos colectivos han apoyado activamente los ideales y valores que promueven la revitalización y revalorización de la capital costarricense. Su participación ha tenido un impacto tangible en el entorno urbano y han ganado reconocimiento y legitimidad. Según los investigadores, hasta marzo de 2020, varios de estos colectivos contaban con una amplia base de seguidores en redes sociales y colaboraban en proyectos con gobiernos locales, empresas privadas e incluso organizaciones internacionales. Desde la óptica de Mora y Durán, estos colectivos van más allá de "apropiar", "activar" y "construir" espacios públicos, como ellos mismos declaran, también tienen la capacidad de influir en la toma de decisiones y en la forma en que se concibe el pasado, presente y futuro del centro de San José.

A partir del año 2000, se han propuesto iniciativas para revalorizar el casco central de San José, buscando transformar su imagen deteriorada en un espacio más atractivo, funcional y productivo. Este proceso fue impulsado por grupos de poder económico y respaldadas por discusiones sobre sus posibles beneficios económicos, culturales y sociales.

En este contexto, tal y como enfocaron Mora y Durán, inició la conformación de diversos grupos de individuos unidos por su afecto hacia la ciudad. Estos actores, ante la escasez de mejoras tangibles, especialmente en lo que concierne la socialización y el esparcimiento, optaron por unirse y colaborar de manera coordinada para abordar y proponer soluciones a estos retos urbanos. Surge ante este *momentum* el fenómeno de los colectivos urbanos, agrupaciones ciudadanas que, en sus respectivas esferas de influencia, agrupan principalmente un sector de la población profesional joven que quiere liderar en la regeneración del espacio público, buscando legitimar sus acciones ante la comunidad en general y ante los actores formales y técnicos en la gestión urbana.

3 Metodología

3.1 Diseño de la investigación

La presente investigación de tipo descriptivo se diseñó siguiendo un enfoque estructurado en las fases que presentamos a continuación. En primer lugar, se realizó una revisión bibliográfica y análisis documental enfocada en la relación entre las iniciativas cívicas de tipo abajo-arriba y la planificación tecnócrata, en particular influenciada por la agenda neoliberal, para establecer un marco teórico sólido y definir las variables de interés. Dicha búsqueda se realizó a partir de estudios que ya han recopilado y discutido con mayor profundidad este tema. Se identificaron seis categorías a partir de la literatura: empoderamiento comunitario, participación democrática, modelos económicos alternativos, solidaridad, innovación y flexibilidad, resistencia a la privatización. Por otro lado, las variables incluyeron: i) años de actividad y estatus actual; ii) tipología/figura jurídica; iii) temas tratados; iv) objetivos, escala geográfica de impacto; v) redes sociales empleadas; vi) número de seguidores, así como vii) la utilización de las redes sociales y viii) las acciones principales emprendidas.

La siguiente fase consistió en la selección de una muestra representativa de 45 actores y espacios dentro de la Gran Área Metropolitana de San José, que estuvieron activos en el período comprendido entre 2012 y 2022, dentro del ámbito de las intervenciones urbanas autoorganizadas, como se presentará más adelante en el apartado "Muestreo".

La fase de análisis de datos incluyó técnicas cualitativas y cuantitativas para examinar las relaciones y patrones emergentes entre las variables estudiadas. Con la intención de evidenciar dos aspectos fundamentales: en primer lugar, cómo estos actores y espacios han logrado contrarrestar las tendencias neoliberales de i) privatización; ii) segregación social; iii) fragmentación espacial y iv) exclusión, ofreciendo un espacio para trabajar temas controversiales en búsqueda de soluciones. En segundo lugar, se buscó de qué manera estas instancias urbanas han creado, a partir de plataformas digitales

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y redes sociales, un bagaje de conocimiento y efectos que reta y desestabiliza las dinámicas típicas del poder: jerárquicas, centralizadas, de control y gobernadas por el beneficio económico. Los resultados de esta investigación quieren proporcionar un panorama acerca de la escena de acción de los actores y los espacios en el período estudiado y su rol en las dinámicas sociales y urbanas en la región.

3.2 Desarrollo de las temáticas

Como parte del proceso se incluyó una búsqueda exhaustiva de literatura en bases de datos académicas reconocidas, como JSTOR, Google Scholar, Scopus y Web of Science, junto con bases de datos especializadas en ciencias sociales. En esta búsqueda, se emplearon términos clave relevantes para la temática del estudio, con el objetivo de hallar investigaciones que profundizaran en la relación entre aspectos predominantemente urbanos, críticas político-económicas y avances en innovación tecnológica (ver en Tabla 1).

Tabla 1. Términos clave identificados en la literatura para explorar la relación entre ámbitos urbanos, críticas político-económicas e innovación tecnológica.

Ámbito urbano	
Activismo urbano	Urban activism
Activismo en el espacio público	Public space activism
Movimientos sociales en contextos urbanos	Social movements in urban contexts
Urbanismo participativo	Participatory urbanism
Espacios Urbanos	Public spaces
Procomunes urbanos / Bienes comunes urbanos	Urban Commons
Espacios comunitarios	Community spaces
Espacios urbanos alternativos	Alternative urban spaces
Pérdida de Significado del Espacio Público	Public space degradation
Sentido de lugar	Sense of place
Identidad urbana	Urban identity
-	Placemaking
Revitalización de espacios públicos	Revitalizing public spaces
Regeneración liderada por la comunidad	Community-led regeneration
Renovación urbana	Urban Renewal
Acupuntura Urbana	Urban Acupuncture
Diseño Social Urbano	Urban Social Design
Crítica político-económica	
Actores urbanos	Community activists
-	Grassroots organizations
ONGs (Organizaciones No Gubernamentales) locales	Local NGOs (Non Governmental Organizations)
Líderes cívicos	Civic leaders
Iniciativas Ciudadanas	Civic/ Citizen initiatives
Co-gobernanza	Co-governance
Participación Ciudadana	Civic Participation
Colectivos Urbanos/Iniciativas urbanas	Urban Collectives/Urban Iniciatives
-	Bottom-up
Neoliberalismo Costa Rica	Neoliberalism in Costa Rica
Gobernanza en la Era Digital	Digital-Era Governance
Globalización	Globalization
Creatividad horizontal	Horizontal Creativity
Innovación social	Social Innovation
Diseño cívico	Civic Design
Inteligencia Colectiva	Collective Intelligence
Acción Colectiva	Collective Action
Activistas digitales	Digital Activists
Innovadores sociales	Social Innovators
Emprendedores sociales	Social Entrepreneurs
Innovación tecnológica	
Ciudadanía inteligente	Smart citizen
Ciudad inteligente	Smart city
Sociedad de la red	Network society
Redes sociales y activismo	Social media and activism
Activismo digital	Digital activism
Participación cívica en línea	Online civic engagement
Redes Sociales Ciudadanas	Citizen Social Networks
Hibridación Espacial/Hibridación físico-digital	Spatial Hybridization/Physical-Digital Hybridization

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	Activismo urbano y ciudadanía inteligente en San José, Costa Rica.	7
Espacios sensibles/Ciudad sensible	Sentient Spaces/Sentient City	
Ciudades de código abierto	Open Source Cities	
-	Smart Street	

El objetivo primordial de esta búsqueda era la identificación y revisión crítica de estudios previos, teorías relevantes y enfoques metodológicos apropiados para analizar la interacción entre actores y espacios en contextos metropolitanos. Paralelamente, se realizó un minucioso examen de las referencias bibliográficas en los artículos y libros seleccionados, lo que permitió identificar investigaciones relacionadas y fuentes adicionales de relevancia. Este proceso sistemático de búsqueda y revisión bibliográfica ha sido fundamental para contextualizar y fundamentar teóricamente nuestra investigación.

3.3 Variables de estudio

En el contexto de esta investigación, fue esencial delinear de manera precisa las variables de estudio a abordar. Estas variables constituyeron los elementos clave que nos permitieron analizar y comprender la dinámica de actores y espacios en la Gran Área Metropolitana de San José durante el período de 2012 a 2022. Cada una de estas variables se seleccionó cuidadosamente con el propósito de evidenciar la interacción entre dichos actores y espacios, así como su impacto en el entorno urbano y social. Con el objetivo de lograr esto, procuramos analizar las variables a la luz de las seis categorías presentadas en el Diseño de la investigación (§ 3.1), las cuales se resumen en la tabla a continuación.

Tabla 2. Resumen de las seis categorías metodológicas utilizadas para el análisis de las variables.

Categorías	Variables
Empoderamiento comunitario	Acciones principales emprendidas
Participación democrática	Objetivos; Escala geográfica de impacto
Modelos económicos alternativos	Tipología/figura jurídica
Solidaridad en la comunidad digital	Temas tratados; número de seguidores
Innovación y flexibilidad	Redes sociales empleadas; Utilización de las redes sociales
Resistencia a la privatización	Años de actividad; Estatus actual

A continuación, se presenta una descripción detallada de estas variables, destacando su relevancia y el papel que desempeñaron en la investigación.

1. Variables temporales:
    a. Años de actividad: representa la duración en años durante la cual los actores y espacios estuvieron activos en la Gran Área Metropolitana de San José. Proporciona una medida del tiempo que se tuvo en cuenta para evaluar su influencia y cambio a lo largo del período de estudio.

    b. Estatus actual: describe la situación o condición actual de los actores y espacios en el momento de la investigación, lo que permite diferenciar entre aquellos que siguen activos y los que pudieron haberse disuelto o modificado.

2. Variables Cualitativas:
    a. Tipología/figura jurídica: indica la categoría o estructura legal bajo la cual operan los actores y espacios, lo que proporciona información sobre su naturaleza organizativa, si está o no institucionalizada, como organizaciones no gubernamentales, colectivos, empresas, entre otros.
    b. Temas tratados: identifica y clasifica los temas o áreas de interés abordados por los actores y espacios, lo que permite analizar las prioridades temáticas de su actividad.
    c. Objetivos: describe los objetivos y metas perseguidos por los actores y espacios, proporcionando una visión de su propósito y finalidad.
3. Variables Cuantitativas:
    a. Escala geográfica de impacto: mide la extensión geográfica de la influencia o alcance de los actores y espacios en la Gran Área Metropolitana de San José, lo que permite evaluar su impacto territorial.
    b. Redes sociales empleadas y número de seguidores: registran las plataformas de redes sociales utilizadas por los actores y espacios, junto con la cantidad de seguidores en cada plataforma, proporcionando una medida cuantitativa de su presencia en línea.
    c. Utilización de las redes sociales: detalla la forma en que los actores y espacios emplearon las redes sociales, destacando las estrategias y enfoques utilizados.
    d. Acciones principales: describe las acciones o actividades principales emprendidas por los actores y espacios, lo que ofrece una visión general de su contribución en el ámbito urbano y social.

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3.4 Muestreo

El muestreo de esta investigación se llevó a cabo de manera intencional y selectiva, con el objetivo de identificar un total de 45 actores y espacios que estuvieron activos en la Gran Área Metropolitana (GAM) durante el período comprendido entre 2012 y 2022.

Los actores fueron identificados por medio de una revisión en redes sociales y el material publicado en el grupo público Facebook de “Colectivos Urbanos” (https://www.facebook.com/groups/1442279012703184). Con el fin de recopilar datos, se diseñó una ficha individual que permitió registrar información detallada sobre cada actor y espacio. Esto incluyó todas las variables mencionadas anteriormente, garantizando así la representatividad de la muestra al tener en cuenta la relevancia y diversidad de los actores y espacios en el contexto metropolitano de San José. Posteriormente, se construyó una matriz de variables que incluyó categorías clave identificadas en la revisión teórica y que se utilizaron para sistematizar y analizar los datos recopilados.

Para conformar la muestra del estudio se empleó un muestreo intencional. Al tratarse de un estudio cualitativo descriptivo sobre un grupo específico de actores, se buscó la variedad de experiencias y perspectivas de los participantes, además de la disponibilidad de información. No buscando representatividad estadística, dicho estudio no aplicó un grupo de control. Sin embargo, aunque la documentación existente no reporta un número exacto de la población de los colectivos urbanos, sabemos que entre los que participaron activamente a las reuniones se estiman 30-50 actores (Mora Obando & Durán Segura, 2022, pág. 11), por lo cual podemos decir que al trabajar una muestra de 45 actores, cubrimos un alto porcentaje de la población total, aunque no coincida estrictamente con los que conformaron el grupo inicial de los “colectivos urbanos” detallados por Mora Obando y Durán Segura.

3.5 Instrumentos

Para la recopilación de datos en esta investigación, se emplearon dos instrumentos estratégicos. En primer lugar, se diseñó una ficha individual para cada actor y espacio seleccionado, en la cual se registraron los valores correspondientes a cada una de las variables de estudio. Esta ficha sirvió como una herramienta detallada que permitió recoger información específica sobre cada entidad en cuestión. En segundo lugar, se construyó una matriz de variables que abarcó los resultados obtenidos de las fichas individuales, lo que facilitó la organización y sistematización de los datos recolectados. Esta matriz de variables se convirtió en una herramienta esencial para llevar a cabo un análisis más estructurado y riguroso de los datos, lo que posibilitó la evaluación de las relaciones y patrones emergentes entre las variables y, por ende, contribuyó significativamente a la comprensión de las dinámicas urbanas y sociales estudiadas en la investigación.

4 Análisis de Resultados

En esta sección, para cada variable del estudio se expone el gráfico correspondiente, el cual detalla los datos recopilados, seguido del análisis de los resultados obtenidos.

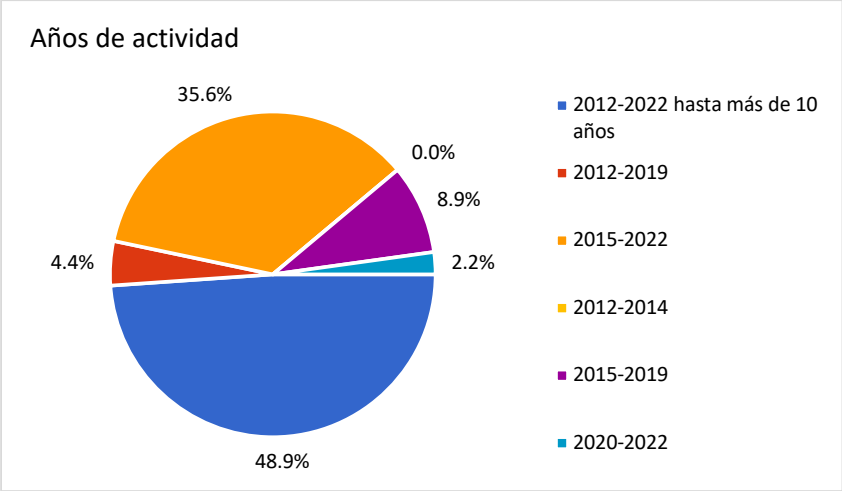


Figura 2. Representación de los años de actividad de los actores y espacios estudiados. Elaboración propia.

La Figura 2 nos muestra la distribución porcentual de los años de actividad de los actores y espacios estudiados en diferentes intervalos de tiempo. La categoría más grande es "2012-2022". Esto indica que una parte significativa de los actores

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y espacios estudiados han estado activos durante todo el período de diez años, evidenciando su capacidad para mantenerse a lo largo del tiempo a pesar de las posibles dificultades y desafíos. El segundo intervalo más grande es "2015-2022", lo que sugiere que una parte sustancial continuó su actividad durante los últimos siete años, incluso más allá del período de una administración de gobierno municipal o nacional (4 años), lo que destaca su resistencia y capacidad de trascender los cambios en políticas nacionales y locales. Los intervalos de "2015-2019" y "2012-2019", representan un total del 13.3% de actores y espacios que dejaron de funcionar antes del período 2020-2022, posiblemente relacionado con la pandemia de COVID-19. Por lo contrario, sólo el 2.2% inició a partir del 2020. Esta gráfica nos ofreció una visión detallada de cómo se distribuyó la actividad de los participantes a lo largo de la década. Estos hallazgos subrayan la capacidad de las iniciativas estudiadas para mantenerse activas a lo largo del tiempo, desafiando las expectativas convencionales sobre la sostenibilidad de las actividades sin ánimo de lucro en un entorno neoliberal. Según Zeynep Tufekci, en la actualidad, los movimientos sociales se apoyan en las redes sociales sin la necesidad de establecer vínculos sólidos como ocurría antes del advienta de internet; basta con una publicación viral (Tufekci, 2017). Sin embargo, tan rápido como surgen, los movimientos pueden desmoronarse con la misma facilidad, por falta de liderazgos claros y de una estrategia coordinada (2017).

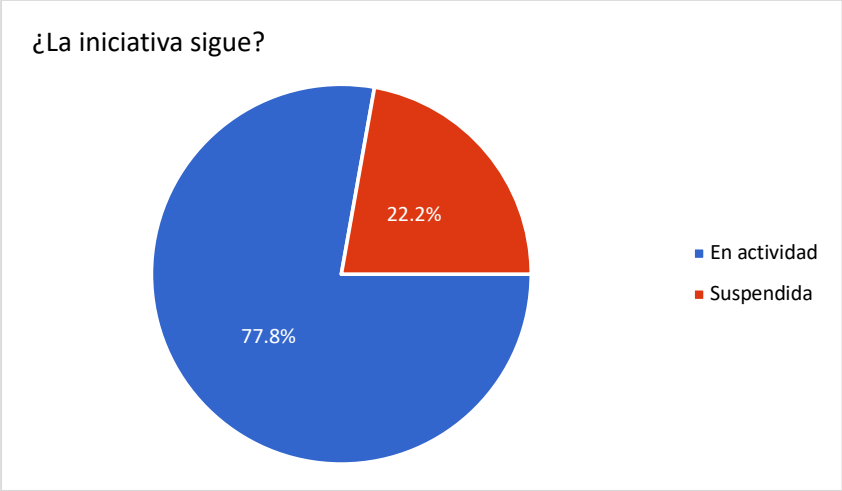


Figura 3. Representación de la continuidad de la iniciativa promovida por los actores y espacios estudiados. Elaboración propia.

La Figura 3 revela que la mayoría de los encuestados, reportó que la iniciativa aún está "en actividad". Esta alta tasa de continuidad sugiere que las iniciativas estudiadas han logrado mantenerse activas a pesar de posibles desafíos externos, lo que podría interpretarse como una resistencia a la privatización y una afirmación del compromiso con el bienestar comunitario. Por otro lado, el restante 22.2% de los encuestados indica que ya se encuentra "suspendida". Aunque este porcentaje es significativo, sugiere que una parte considerable de las iniciativas aún enfrenta dificultades o ha sido interrumpida por diversas razones. Tal como interpretó Osorio-Vargas en su estudio acerca de las narrativas ciudadanas en América Latina: “pueden leerse como una crisis de ilusiones y hastío con la modernización ofrecida por el orden neoliberal” (2022, pág. 22). No obstante, el hecho de que la mayoría permanezca activa puede interpretarse como un signo de resiliencia y resistencia frente a las presiones privatizadoras, ya que iniciativas de este tipo continúan “a manifestar un malestar radical con las formas desiguales de distribución del poder político y de los beneficios materiales, culturales, educacionales, y jurídicos en el marco de largos años de aplicación de políticas neoliberales” (pág. 23).

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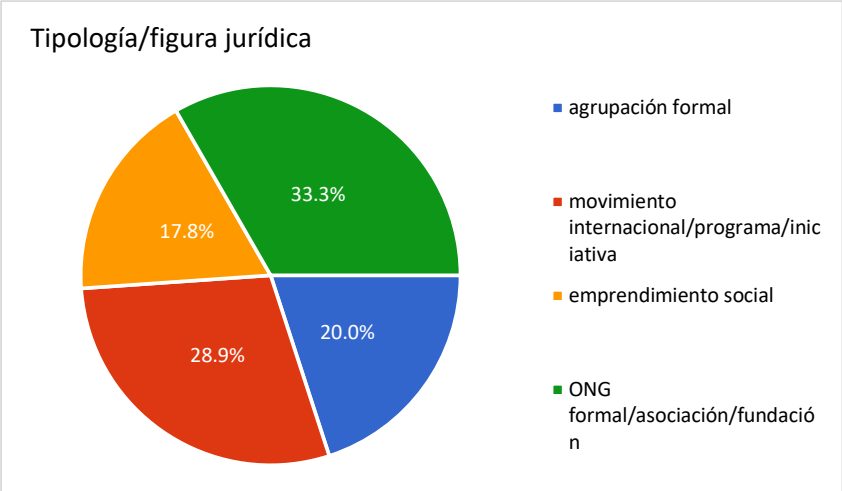


Figura 4. Representación de la tipología jurídica de los actores y espacios estudiados. Elaboración propia.

La Figura 4 muestra la distribución de actores y espacios estudiados según su estructura legal. Las ONGs (Organizaciones No Gubernamentales) representan el 33.3%, reflejando un enfoque en organizaciones no lucrativas que desafían la lógica neoliberal al priorizar valores sociales (Carmenati González, 2023; Saura, 2020, pág. 160). Un 29% se asocia con "movimientos internacionales" que aplican en San José iniciativas globales, promoviendo visiones innovadoras que van más allá de la gobernanza local (García-González & Bailey, 2021). Aunque estas conexiones globales a veces se alinean con el "filantrocapitalismo" (Puche et al., 2012), los actores buscan aplicar enfoques que cuestionen el sistema establecido.

Como reporta el informe "La ONG del siglo XXI, en el Mercado por el cambio" las nuevas ONGs del siglo XXI se integran progresivamente al sistema, en lugar de retarlo como las del siglo XX, además de centrarse en "las soluciones que se logran a través de los mercados" e "invertir […] fuertemente en redes" (SustainAbility, 2003, pág. 2). De la misma manera que evidencia el informe del Observatorio de las Elites "[…] las elites se apoyan en varias organizaciones no gubernamentales (ONGs) y fundaciones […] para difundir en el espacio público el nuevo paradigma que propician." (Castellani, 2019, pág. 3). Esto va abriendo camino a la divulgación del modelo de emprendimiento social, como veremos más adelante.

Por otro lado, el 20% corresponde a agrupaciones informales que operan con flexibilidad, ofreciendo alternativas al modelo público-privado (Monzón Campos, 2004). Finalmente, el 17.8% se enfoca en emprendimientos sociales híbridos que, aunque generan ingresos, buscan resolver problemas sociales (Méndez Bravo et al., 2018).

Por esta razón existen opiniones divergentes al respecto: algunos autores argumentan que el emprendimiento social, en lugar de ser una alternativa al libre mercado, es una continuación de este, en particular si abordado desde la visión de "innovación social" (Portales, 2018). Para otros autores el impacto en el desarrollo económico puede tener una intensa orientación social, en particular cuando es generado por emprendimientos digitales femeninos (Tejeiro Koller, Molina López, & García Villalobos, 2021). Dada la limitación de este estudio, destacamos la controversia de este modelo, especialmente al analizar organizaciones que evolucionan de iniciativas informales a emprendimientos sociales.

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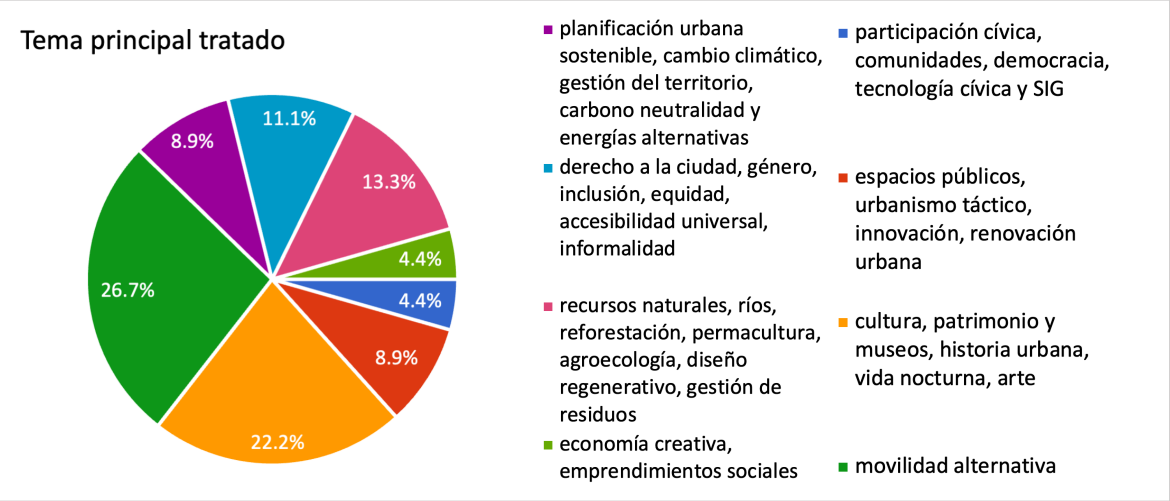


Figura 5. Representación de las temáticas principales tratadas por los actores y espacios estudiados. Elaboración propia.

La Figura 5 muestra que la "movilidad alternativa" (26.7%) es prioritaria, promoviendo transporte público y bicicletas como alternativas al modelo neoliberal de transporte privado, que fomenta vehículos individuales (SustainAbility & the United Nations Environment Programme (UNEP, Programa de las Naciones Unidas para el Medio Ambiente, por sus siglas en inglés), 2001). El McKinsey Center for Future Mobility señala que: "Si se mantiene el statu quo, los problemas de movilidad se intensificarán a medida que el crecimiento de la población y el PIB impulsen el aumento de la propiedad de automóviles y de los kilómetros recorridos" (Conzade, y otros, 2021).

El 22.2% de las iniciativas enfocadas en "cultura, patrimonio y equidad urbana" sugieren una respuesta a la falta de planificación cultural y a la mercantilización del patrimonio, que favorece el turismo rápido (Saborido Yudín, 2014; Ramírez Cover, 2020). Esto ocurre a expensas de la oferta para la población local, exacerbando la inequidad urbana (Mazorra Rodríguez, 2022) y convirtiendo la ciudad en un escenario ficticio más, con un patrimonio y un pasado mitificados (Boukhris, 2012) por el "capitalismo verde" (Isla, 2015), como lo es en los fenómenos locales de gentrificación (Mansilla López, 2019; Cabrera-Jara, 2019).

A pesar de su baja representación (8.9% y 11.1%), la sostenibilidad y la equidad son temas transversales para los actores estudiados, quienes los integran desde objetivos específicos compartiendo una visión común.

Áreas como "economía creativa" y "participación cívica" (4.4% cada una) tienen baja presencia, posiblemente por requerir recursos especializados o porque los actores priorizan temas más urgentes en su contexto local.

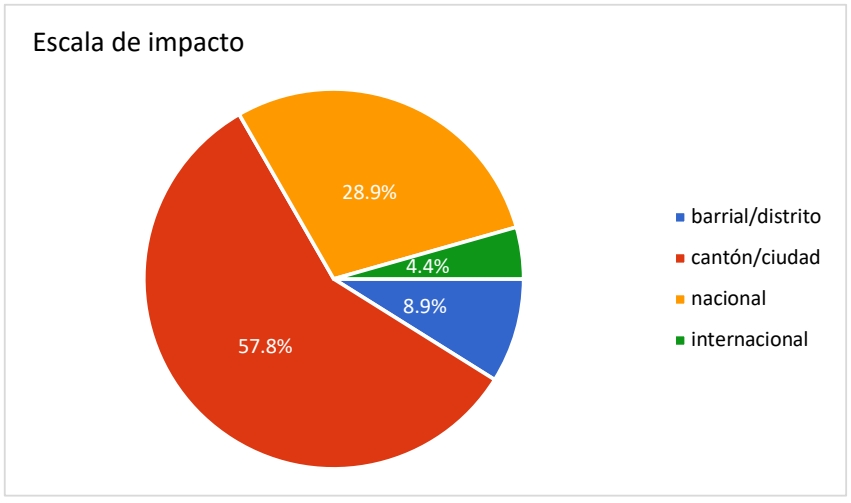


Figura 6. Representación de la escala de impacto geográfico de los actores y de los espacios estudiados. Elaboración propia.

La Figura 6 muestra cómo los actores definen su impacto en términos de participación democrática. El 57.8% centra sus acciones a nivel de cantón o ciudad, reflejando un fuerte compromiso con la participación local. Aquí, las redes

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sociales permiten involucrar a la comunidad y movilizarla en temas de interés local. Un 28.9% tiene impacto nacional, usando las redes para llegar a un público más amplio y fomentar el debate en temas de interés nacional. El 8.9% de los actores trabaja en ámbitos barriales y distritales, destacando la importancia del trabajo directo con comunidades locales, donde las redes sociales complementan la participación presencial y facilitan la colaboración vecinal. Aunque menor, el 4.4% con alcance internacional utiliza redes para promover solidaridad y colaboración global, compartir experiencias y buenas prácticas, y apoyar proyectos internacionales que requieren amplia participación (Tufekci, 2017). Este análisis destaca el rol de las redes sociales en facilitar la movilización y sensibilización a diferentes niveles geográficos.

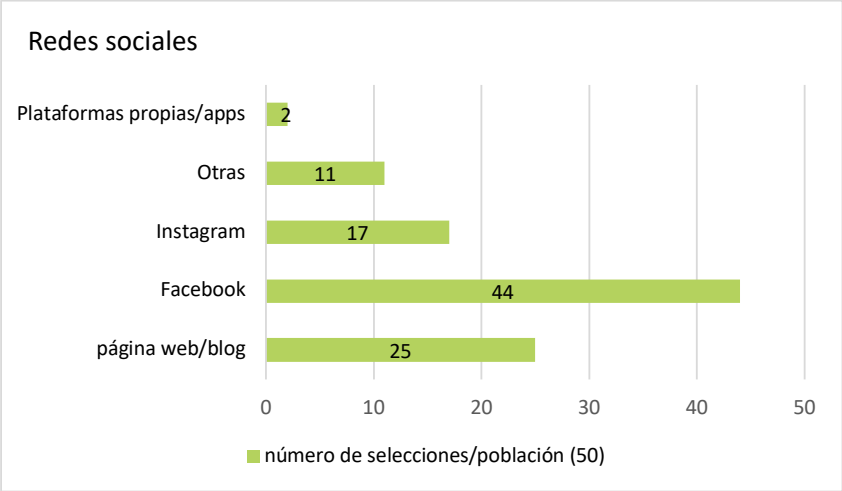


Figura 7. Distribución del uso de distintas plataformas de redes sociales por la población estudiada (actores y espacios). Elaboración propia.

La Figura 7 muestra el uso de plataformas de redes sociales por los actores y espacios estudiados, donde Facebook destaca como la opción más popular. También es relevante el uso de sitios web o blogs, lo cual indica la importancia de contar con un espacio propio para compartir información. Instagram juega un papel importante como plataforma visual, mientras que otras redes como WhatsApp, Twitter (X desde 2023) y TikTok amplían el alcance de estos actores. Como los encuestados podían seleccionar múltiples plataformas, los resultados reflejan la frecuencia de elección y no usuarios únicos, lo que resalta la diversidad en estrategias de redes sociales y la adaptabilidad a las preferencias cambiantes de la audiencia. Además, algunos actores utilizan plataformas personalizadas, reflejando una diversificación en su estrategia digital. Estos datos subrayan cómo las redes facilitan la formación rápida de grupos y reducen los costos de coordinación en la acción colectiva, factores clave para los movimientos sociales globales (Millaleo & Velasco, 2013, pág. 9).

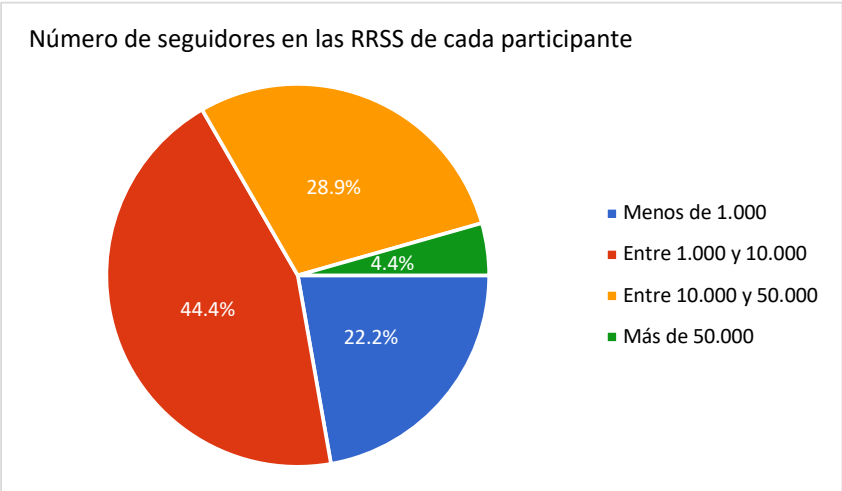


Figura 8. Número de seguidores en redes sociales de los actores y espacios analizados. Elaboración propia.

La Figura 8 muestra que el 44.4% de los participantes tiene entre 1,000 y 10,000 seguidores, reflejando un nivel sólido de apoyo y "solidaridad en la comunidad digital". Otro 28.9%, con entre 10,000 y 50,000 seguidores, sugiere una mayor

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consolidación y visibilidad en redes, que aumenta su influencia. El 22.2% posee menos de 1,000 seguidores, lo cual indica actores en etapas iniciales de su comunidad en línea, mientras que el 4.4% supera los 50,000 seguidores, reflejando un alto compromiso y respaldo en línea.

La variabilidad en la cantidad de seguidores destaca el apoyo comunitario a diferentes niveles de desarrollo. Aunque no se evaluó la gestión de comunidades digitales, es evidente el uso de conocimientos autodidactas, similares a los de influencers o bloggers. Para estudios futuros, sería útil implementar métricas de éxito en redes, como crecimiento de usuarios e interacción, lo cual requeriría competencias en marketing digital.

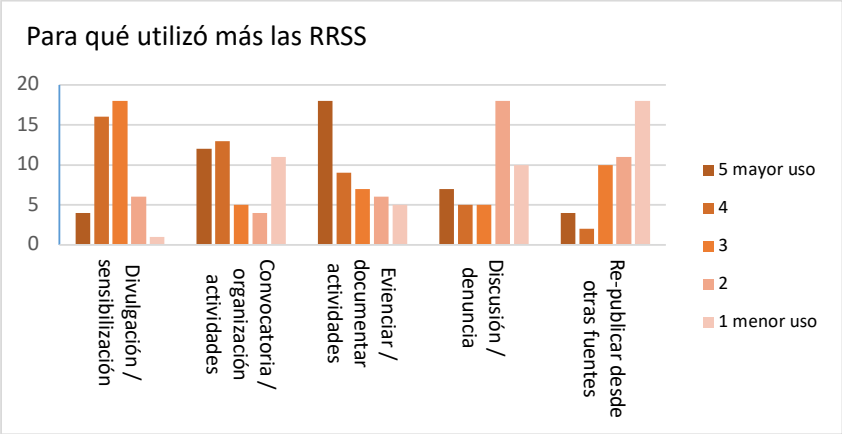


Figura 9. Principales funciones de uso de las redes sociales por las entidades analizadas. Elaboración propia.

La Figura 9 revela que los participantes utilizan redes sociales principalmente para "evidenciar/documentar actividades", lo cual subraya la importancia de registrar sus proyectos. La categoría de "divulgación/sensibilización" también es destacada, con una concentración alta en los valores 3 y 4 de la escala, lo que indica el papel clave de las redes para informar y sensibilizar a la audiencia. Otras funciones relevantes son "convocatoria/organización de actividades" y "discusión/denuncia", que reflejan el rol de las redes en la convocatoria de eventos y el fomento de diálogos presenciales y virtuales. Por otro lado, "re-publicar desde otras fuentes" es menos prioritario, indicando que compartir contenido ajeno es secundario frente a otras actividades.

En conjunto, los datos sugieren que los participantes emplean las redes sociales estratégicamente para documentar, divulgar y organizar sus acciones y eventos, maximizando su impacto en la participación y la sensibilización.

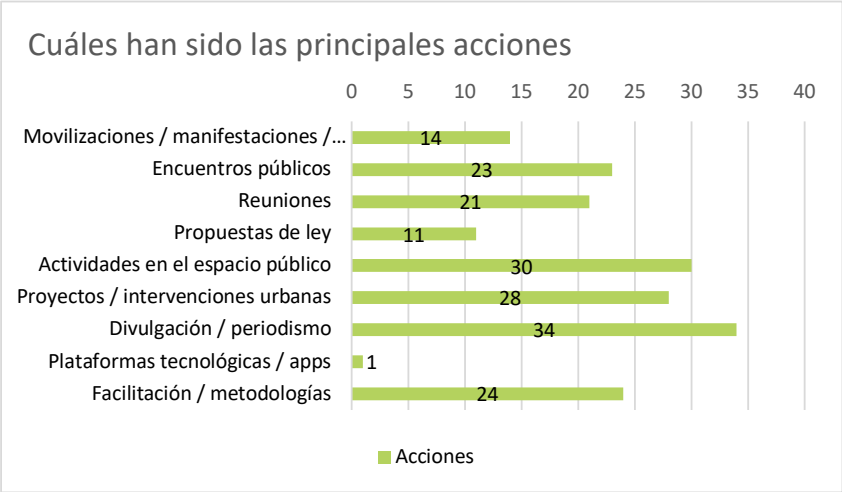


Figura 10. Representación de las principales acciones logradas por los actores y espacios estudiados. Elaboración propia.

La Figura 10 revela el enfoque en "empoderamiento comunitario" a través de varias acciones clave. La participación en "Encuentros públicos" (51.1%) y "Reuniones" (46.7%) muestra un interés significativo en fomentar la interacción comunitaria en espacios públicos, promoviendo la cohesión social e involucrando a la ciudadanía en la vida urbana. Este énfasis en la participación en persona ayuda a revitalizar el espacio público y crear masa crítica en diversos temas.

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La alta proporción de "Actividades en el espacio público" (66.7%) y "Proyectos/intervenciones urbanas" (62.2%) refleja el compromiso de las organizaciones con la mejora del entorno urbano, promoviendo la calidad de vida y fortaleciendo la implicación de la comunidad en el diseño y ejecución de proyectos locales. Además, el 75.6% de "Divulgación/periodismo" subraya la importancia de mantener informada a la comunidad, generando una base de apoyo y compromiso hacia los proyectos.

Aunque menos frecuentes, las "Movilizaciones y manifestaciones" (31.1%) y la "Promoción de proyectos de ley" (24.4%) evidencian el valor que los actores otorgan a la acción directa en la esfera pública y el cambio normativo, reflejando un compromiso hacia transformaciones sociales y políticas. A su vez, el 24.4% dedicado a talleres de participación ciudadana fortalece la capacidad de la comunidad para abordar retos y mejorar su calidad de vida mediante el aprendizaje de metodologías participativas.

En contraste, la baja presencia en "Plataformas tecnológicas/apps" (2.2%) sugiere que estas organizaciones ven la tecnología principalmente como un medio y no un fin en sus esfuerzos de empoderamiento comunitario.

5 Conclusiones

> *[…] actores y movimientos sociales que, como proceso y tendencia, se han dado social y conflictivamente la capacidad de incidir desde sí mismos en la existencia sociopolítica creando escenarios (campos) y formas de lucha en el mismo movimiento en que procuran, también como proceso,* ***darse los medios para alcanzar el éxito/fracaso en sus emprendimientos.*** *Estos actores, movilizaciones y movimientos sociales encarnan, desde condiciones que ellos no determinan enteramente, el principio universal de agencia humana que es una de las ofertas culturales nucleares de la modernidad.*
>
> (Gallardo, 2011)

La presente investigación buscó comprender cómo los instrumentos de comunicación digital están impactando las estrategias de los actores urbanos, y hemos hallado que el componente tecnológico ha jugado un rol central y común para la mayoría de ellos.

Las redes sociales han dado protagonismo al ciudadano en su contexto, permitiendo agilizar procesos, como generar bases de datos, evidenciar el estado de la infraestructura y más en general crear masa crítica. La relativa horizontalidad del sistema ha permitido cierto nivel de autogestión, enfocando la resolución de problemas en la innovación y la respuesta "modular" es decir, en acciones rápidas y prácticas de llevar a cabo y que puedan ser replicables a partir de la retroalimentación de su ejecución inicial.

El aspecto "proximidad" es otro que queremos destacar. Este enfoque ha permitido que, aunque las plataformas digitales permitan un alcance espacial vasto y hasta global, los grupos han preferido organizarse desde la territorialidad de escala local, partiendo desde la identidad y trabajando en los centros urbanos medianos.

Los actores e iniciativas estudiados están fundamentalmente motivados por las problemáticas vinculadas con la movilidad urbana. Reconocen que la movilidad es una pieza clave para una ciudad habitable y sostenible, y esta conciencia impulsa sus esfuerzos para abordar los desafíos asociados con el transporte, el acceso y la calidad de vida en la ciudad.

Su objetivo se extiende más allá de simplemente crear conciencia sobre los problemas de movilidad. Aspiran a influir directamente en las políticas públicas tanto a nivel nacional como local. Buscan desempeñar un papel activo en la formulación de políticas que aborden las cuestiones críticas de movilidad, lo que refleja su compromiso con una transformación social y urbana significativa.

Además, estos actores no siguen un solo enfoque teórico, sino que integran y enriquecen diversas corrientes. Parten de teorías globales reconocidas, como el derecho a la ciudad, y las enriquecen con perspectivas locales, como el movimiento *maker* y el regionalismo crítico. Esta síntesis teórica les proporciona un marco conceptual sólido y enriquecido que informa sus acciones y les otorga una identidad única.

Por otro lado, un logro significativo radica en su habilidad para utilizar las redes sociales de manera efectiva. Han logrado crear un periodismo ciudadano de concienciación, además de organizar acciones que no dependen exclusivamente de los medios de comunicación tradicionales y de las estructuras institucionales. Esta autonomía digital ha redefinido las reglas para denunciar y proponer acciones en contra de la comercialización de la planificación urbana y la mercantilización del transporte, demostrando su capacidad para cuestionar el *status quo*.

Estas iniciativas están creando nuevas reglas en el juego urbano. Su enfoque innovador desafía las normativas existentes y propone acciones disruptivas en contra de la comercialización y segregación del tejido urbano. Por consiguiente, aspiran a un futuro donde la equidad y la inclusión sean realmente fundamentales, y están fortaleciendo las bases para un cambio positivo y duradero en las dinámicas urbanas.

ISBN 978-9930-617-71-7

These global networks of protest that do not fit into traditional political demarcations are no flash in the pan. Their roots go back decades and their latest iterations are linked to the rise of the internet, which provided, for the first time, a cheap and easy way to be part of a global communication system without being part of the global elite.[4]
(Tufekci, 2017, pág. 85)

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ISBN 978-9930-617-71-7

A SYSTEMIC PERSPECTIVE ON EDUCATION 3.0: NAVIGATING 4TH INDUSTRIAL ERA AND NURTURING EMERGING DIGITAL COMPETENCIES – STUDY CASES ON UNIVERSITY-BUSINESS STRATEGIC ALLIANCES

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Abstract. Recent research suggests that the confluence of globalization and emerging business trends, such as Industry 4.0 as well as the ongoing embedding of smart technologies in educational environments (such as Education 3.0) in pursuit of digital literacy and customized learning, pose challenges and crossroads for universities. Given this accelerated setting, reassessing traditional educational models becomes essential whilst innovating to strengthen the university-industry synergy through new ways of thinking that comprehensively address these trends.

Furthermore, faced with this dilemma, Tecnológico de Costa Rica has embraced the Constructivist-Complex Systems (CSC) pedagogical model, a strategy to guide the development of integral professionals, who are able to face the uncertainty and complexity of the 21st century. The challenge lies on how to implement in a practical way the constructivist principles into learning environments, where the student becomes the epicenter of a complex and interconnected system, enhanced by technology.

The aim of this paper focuses on exploring partnerships between academia and businesses regarding the practical real-world application of this pedagogical model. Additionally, it seeks to link the potential interaction of immersive technologies within the classroom and small and medium-sized enterprises (SME) support, considering the approach proposed by Industry 4.0 in the field of education and its contribution to learning.

Keywords: Education 3.0, Immersive Technologies, Complex Systems.

1 Introduction

Due to the adverse repercussions derived from pandemic health containment policies, particularly on the Costa Rican economy, and especially on SMEs, the university-business partnership has been a viable response to this problem. On a parallel path, overall trends, such as Industry 4.0 or Education 3.0, have accelerated digital evolution - having a strong incidence on educational processes [1]. Thus, entailing new skills along with an interdisciplinary background of the professionals of the future [2]. Such

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changes involve understanding the interactivity and synergy within systems, the much more active role in learning on the part of the learner, etc.

Meanwhile, under the IV Institutional Congress, held in 2019, has been approved a relevant addendum to the "Academic Model", previously established. This new element has been entitled "Contextual and theoretical-epistemic foundation for the pedagogical model of the Instituto Tecnológico de Costa Rica (TEC)". This reflects TEC's commitment to contemporary academic evolution and its willingness to redefine the Educational Process.

The purpose of this learning initiative was to encourage the deployment of innovative pedagogical practices - particularly immersive technologies (XR) - inside the academic context. Within the framework of the Productivity Management course at the Business Administration School, a series of student practical tasks were designed and executed. These projects fulfilled a twofold aim: firstly, they allowed an active educational setting consistent in line with the institutional learning model; and also, it has contributed towards strengthened the link between academic training and the needs of the business sector in a period of economic recovery.

2 Background of the experience

The university-industry alliance has emerged as an effective strategy to address the economic challenges generated by pandemic containment measures in Costa Rica, particularly for SMEs. This learning initiative was conceived with the purpose of promoting the implementation of innovative pedagogical practices, with emphasis on XR, within the academic context. Within the Productivity Management course at the Business Administration School, a series of practical student projects using XR technologies was designed and executed. These projects, developed from the first semester of 2021 until the second semester of 2022, fulfilled a dual objective:

1. Providing an active educational environment aligned with the institutional learning model.
2. Strengthening the link between academic training and the needs of the business sector during a period of economic recovery.

This initiative is particularly relevant for students and future professionals seeking to develop transferable skills and expertise necessary to navigate the complexities of Industry 4.0 and Education 3.0. Furthermore, it highlights the challenges faced by Costa Rican´s SME, especially those affected by pandemic containment policies, in forming strategic partnerships with academic institutions to enhance their competitiveness and economic resilience. The pilot project has been implemented in the regions of Turrialba, Orosí, and Frailes, focusing on the tourism, agri-food, and orange economy sectors. The execution of this project has demonstrated its effectiveness as a strategy to foster innovation and collaboration between academia and industry, thus contributing to the recovery and economic development of these regions.

ISBN 978-9930-617-71-7

3 Literature Review

Below, it will examine the convergence among Industry 4.0, Education 3.0 and immersive technologies related to education. It will analyze how these elements are transforming traditional pedagogical models and its implications in order to prepare students in today's world of work.

3.1 Industry 4.0

Industry 4.0, a concept pioneered by Germany on 2011, it embodies the IV Industrial Revolution. As a result, it has incorporated new technologies including IoT, AI, robotics and data analytics into production, thereby, creating smart factories that optimize productivity, as well as efficiency, agility, and customization [3, 4]. These cyber-physical systems enhance interaction among machines, processes and personnel, improving decision making on real time [5]. This transformation seeks to optimize the supply chain, promote sustainability and redefine business models. In essence, Industry 4.0 revolutionizes industrial production and management, driving innovation and competitiveness in a global market [3].

Furthermore, the digital transformation driven by Industry 4.0 forces a reconfiguration of traditional educational models [6]. Also, these authors have argued that the inclusion of concepts and tools specific to this industrial revolution in university curricula is imperative to train professionals capable of meeting the challenges and seizing the opportunities of the new productive paradigm.

In that sense, it has proposed a generic framework for Industry 4.0 engineering education at Turkish German University (see Figure 1) is presented [6]. This framework consists of three main stages: curriculum, laboratory, and student club, which are interrelated and dependent on each other.

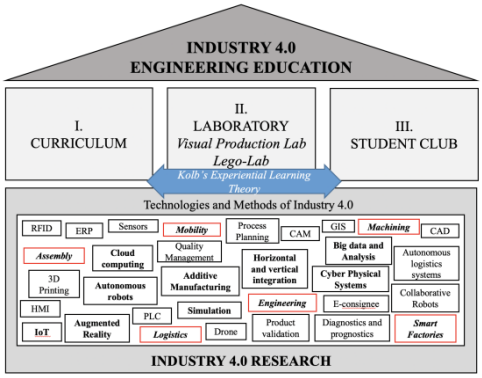


Fig. 1. Generic framework of Industry 4.0 in engineering education of a Turkish University. Source: [6]

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3.2 Education 3.0.

Education 3.0 is a modern outlook answering to both technological and social transitions in education and learning [1]. Additionally, being characterized by the integration of digital tools, it has been promoting customized, collaborative and student-centered learning. Moreover, this framework fosters further growth on digital proficiency along with 21st century skills, i.e., critical thinking, creativity, or troubleshooting [7]. Moreover, [8], this 3.0 inquiry builds resilient learning settings beyond conventional classes, leveraging virtual platforms and streaming resources. Continuing, this transformation boosts motivation, personalizes instruction, and more importantly, it will prepare individuals for an ever-changing business climate [9]. Its growing uptake across educational organizations highlights a commitment to innovation and adaptation to contemporary educational needs.

Additionally, the EDUCAUSE Horizon Report has been publishing surveys mapping out key trends and cutting-edge technologies which illustrate an overall scenario regarding the future of higher education [10]. They address various settings to be adopted and its potential repercussions.

In synthesis, it is argued that universities must align themselves with worldwide demands by targeting opportunities and gaps in the current academic context due to the IV Industrial Revolution trends, as well as the need for Higher Education to respond to a complex and interdisciplinary reality of knowledge.

3.3 Constructivist Complex Systems Model

For The Constructivist-Systemic-Complex Pedagogical Methodology combines Constructivism together by a systemic and complex vision of architecture and education, claiming that knowledge is actively acquired thru the students' interaction and critical thinking. This perspective recognizes the interconnectedness and dynamism inherent in the teaching-learning process [11, 12].

Under the constructivist view, learners are proactive players who construct their insights by means of collaboration and problem-solving [13]. The systemic-complex dimension treats education as a complex system in which all components - cognitive, emotional, social, cultural and technological - work together, focusing on learning as a non-linear, adaptive and interdependent process.

This approach stimulates profound and contextualized knowledge, valuing the interrelationships and complexity of the educational network, and is distinguished by its capacity to face the demands of an evolving world [14].

The TEC has determined, throughout its IV Institutional Congress: a theoretical-epistemic basis for its academic approach [15]. This new strategy, denominated "Constructivist-Complex Systems", is a response to the current worldwide changes with respect the university's educational process. It proposes guiding principles which allow the better understanding over the interactions between different components of this educational system, thereby contributing to an integral change of the teaching-learning process.

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This strategy highlights learning as an active, constructive process within a complex, interconnected system [11]. Further insight can be gained by breaking it down into its main components:

- **Constructivism.** It has a strong emphasis upon embracing that learning becomes an active process whereby students build their knowledge through interaction with its environment and classmates [16]. Given this framework, VR affords a platform from which learners are able to both create and explore their own experiences of learning, encouraging the construction of meaning along with critical reflection**.**
- **Complex Systems:** the prevailing perspective regarding science and education has been typified by its disarticulating, reductionist and linear nature, although it has been proven very effective and will continue to be so into the future, however, it has also shown its constraints in tackling the complexity of reality [17, 18].

As a way forward, to better comprehend the emergence of complex structures in education, it is crucial to bear in mind the relationships among the whole learning system, its context and different building elements, in line with both systems theory and the Constructivist perspective [7].

In summary, Education 3.0 complies with the constructivist-complex systems interface by encouraging active student interaction with complex digital environments, thereby promoting the construction of knowledge from these interactions [19, 20].

4 Methodological design considerations

In support of its pedagogical proposal, a new point of view that responds to the global demands in the field of higher education is the "Constructivist-Complex System" perspective. It provides guidelines for understanding the interactions between the components of the educational system by contributing to a complete transformation of the teaching-learning process.

The Constructivist Complex Systems pedagogical methodology embraces constructivism as well as a complex systems view of education. It postulates that knowledge is actively constructed through interaction and critical reflection by students. This framework embraces the interconnectedness and dynamism inherent in the teaching-learning process.

Students are active agents who develop their understanding through collaboration and problem solving from a constructivist perspective. Approaching learning as a non-linear, adaptive, and interdependent process, the systemic-complex dimension views education as a system in which cognitive, emotional, social, cultural, and technological components interact. This methodology promotes deep and contextualized learning that values the interconnectedness and complexity of the educational system and is characterized by its ability to respond to the challenges of a world that is constantly changing.

For example, the simultaneous merging of Education 3.0, Industry 4.0 and immersive technologies supports the constructivist-complex systems paradigm by allowing students to play an active role - within complex and dynamic learning environments -

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where they can build their own self-understanding through relevant and contextualized interaction.

The methodology used is that of Maker, an educational approach that promotes hands-on learning through project-based activities. By engaging in the creation of tangible projects, students develop technical skills.

5 Results obtained.

An assessment of the main concerns of SMEs shows that the highest priority in 56% of cases corresponds to the financial aspect, while 28% focus on digital marketing, followed more specifically by business strategy (17%) and human talent management (6%). Addressing these needs, approximately 50 business technical support initiatives have been undertaken, including pre-feasibility studies, strategic plans and marketing surveys, among others. In addition, workshops and presentations were held regarding productivity management, focusing on the 5S Program and Kaizen. On the other hand, students were able to offer innovative solutions thanks to technology and immersive research (XR) aimed at improving learning processes, product design and customer experience. Thus, this work effectively tackled the critical areas that were identified, strengthening the competitive capacity and viability of SMEs in the field of digital and physical marketing.

The university students have implemented several technological proposals to boost the economic revival of SMEs. Among the most outstanding projects are:

- **Case #1. Finca 3X**: This tourist destination, sited in Turrialba, Cartago, Costa Rica, is immersed in a tropical mountain ecosystem. The area provides ideal settings for seeing native flora and fauna, with particular emphasis on birds and amphibians, among other natural attractions. To enhance the visitor experience, content has been developed in PDF format that reproduces the songs and vocalizations of the bird and frog species present on the property. Additionally, QR codes have been installed at various strategic points throughout the premises, thus facilitating tourists' access to this information (see Figure 2).



Fig. 2. Tourism sector app; QR deployed at Finca 3X.

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- **Menu Engineering including XR:** This technique is a strategic management approach that evaluates the profitability and popularity of menu offerings. It aims to optimize the design of culinary options to strategically influence patrons' consumption choices. As depicted in Figure 3, an innovative augmented reality system has been implemented to enhance the dining experience. This system enables customers to visualize dishes through QR codes, providing an interactive and immersive preview of the menu items. The initiative has been successfully deployed across multiple dining establishments in the Turrialba and Orosí regions, revolutionizing the way local restaurants present their gastronomic offerings.



Fig. 3. Menu Engineering technique applied to a Restaurant.

- **Cabañas Mirada al Cielo**: represents a SME in the tourism sector, offering a natural sanctuary in Turrialba, Cartago. This establishment is distinguished by its exceptional panoramic landscapes encompassing the Turrialba Volcano and the expansive valley below. As evidenced in Figure 4, the collaborative initiative of students has significantly contributed to enhancing the business's digital presence. Their efforts have focused on developing user-friendly digital tools that enable tourists to efficiently locate the accommodation and explore nearby attractions. This project exemplifies the potential of academic-industry partnerships in bolstering rural tourism, demonstrating how technological interventions can augment the accessibility and appeal of off-the-beaten-path destinations.

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Fig. 4. Mirada al Cielo free online app for tourists´ assistance.

- **Education 3.0, from the production process to the classroom**: this case study the application of virtual reality (VR) as a pedagogical tool in teaching industrial engineering techniques. Particularly, it explores its effectiveness in instructing about the spaghetti flow diagram and the analytical flow diagram, comparing it with traditional on-site visits to production plants. To this end, a prototype immersive VR experience was designed and developed, simulating an automotive seat assembly line production process (see Figure 5). This innovative didactic attempt aims to evaluate the potential of VR to overcome the logistical and safety limitations associated with physical visits, while maintaining or improving the quality of learning.



Fig. 5. Process flow classes using XR

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6 Conclusion

The deployment of new technologies in academic communities has proven to be a key factor in enhancing the interdisciplinary skills and competencies of future graduates. This initiative has shown that the incorporation of digital tools, such as immersive ones, not only personalizes educational experiences, but also strengthens the connection between universities and business demands in the post-pandemic era.

Such findings suggest that the alliance between universities and businesses is essential to establish practices and norms that ensure the responsible and beneficial use of such platforms. At the same time, students not only gained technical knowledge in the development of immersive applications, but at the same time acquired basic soft skills. Having worked closely with SMEs, the students have demonstrated their empathy, adaptability and effective communication skills, enabling them to understand the particularities of each company. Additionally, they developed teamwork, time management, and project presentation abilities by collaborating on prototyping and presenting their results to stakeholders.

The impact resulting from this trial is significant; for example, the integration of XR in higher education contributes to innovation and economic growth, ensuring a successful transition to a more connected and technology-driven culture. Our results suggest that collaboration between education and businesses can generate practices and standards that ensure the responsible and beneficial use of these technologies, positively influencing future research and practical applications.

Ultimately, the findings highlight the importance of integrating technologies into higher education to prepare students for the future job market. Recommendations are encouraged for educational institutions to pursue further efforts toward developing immersive technologies, and for businesses should keep partnering well with universities on building upon practices and standards to guarantee responsible and profitable use of these technologies. This will not only improve the employability of graduates but also drive innovation and economic growth in an increasingly technological future.

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ISBN 978-9930-617-71-7

A Qualitative Methodology for Identifying Governance Challenges and Solutions in European Positive Energy Labs

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Abstract.
Cities play a significant role in energy-related climate change, yet they also have considerable potential to implement solutions for sustainability challenges. Furthermore, cities and local governance can act as innovation "hubs," driving sustainable urban transitions. Urban Living Labs are becoming essential for achieving sustainability goals in cities, operating at the crossroads of research, innovation, and policy. These labs are designed to create, demonstrate, and evaluate urban interventions in real time. Despite their growing prominence, our understanding of their nature and purpose is still limited, with a lack of critical analyses. This study employed a qualitative methodology to identify critical aspects for deploying Positive Energy District (PED) Labs, structured into three steps: questionnaire distribution, qualitative analysis of responses, and formulation of

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research questions. The questionnaires focused on barriers, drivers, and stakeholders, yielding valuable insights into the factors influencing the implementation of PED Labs. Key findings revealed nine categories of barriers, with social and financial factors emerging as the most significant challenges. In terms of drivers, the necessity for climate change mitigation, strong local networks, and improved political frameworks were identified as essential conditions for fostering PED Lab initiatives. The analysis highlighted seven stakeholder groups involved across six phases of PED Lab deployment, with governments recognized as pivotal actors in the process. To further guide implementation, the study proposes a SWOT matrix to encapsulate resources, capabilities, and requirements necessary for successful operation or replication of PED Labs, emphasizing that while specific conditions may vary, general principles must be considered in all contexts

Keywords: Urban Living Labs, PEDs, online survey, qualitative methodology.

1 Introduction

To address the challenges generated by climate change and the rapid urbanization of inhabited areas, it is necessary to develop an urban framework that allows reversing energy and environmental trends and reducing strong inequalities. Under this context, different governance initiatives are being proposed that are capable of managing several urban flows through climate-friendly models. One of these initiatives focuses on testing solutions under real conditions of use through Urban Living Laboratories [1], a crucial step in learning how to design inclusive, sustainable, and climate-resilient urban environments [2]. These labs embody an experimental governance model that facilitates the evaluation of different solutions and the proposal of enhancements. Ultimately, they are designed to create a collaborative environment where various stakeholders can explore, develop, and experiment with solutions to urban challenges, all while involving local communities [3].

Their innovative approach to urban development and public-private partnerships underscores the need for adaptability, transparency, and informality in their processes. As a result, they generate highly valuable insights that can inform decision-making for city stakeholders. The innovation drivers in these projects stem from agglomeration effects, where innovation activities cluster around urban initiatives. However, these effects are not evenly distributed, nor are they consistently beneficial for all participants [4]. Other authors explore the application of Living Labs to foster gendered energy technology innovation in impoverished urban settings [5]. Additionally, challenges and dilemmas associated with strategic urban experimentation have been assessed through a review of the literature on Socio-Technical Systems, alongside insights from transdisciplinary research on living labs [6].

Several urban strategies tailored to the local context can be assessed, creating a comprehensive map of solutions to tackle the climatic and energy challenges facing cities. Current literature presents various concepts related to climate-friendly neighborhoods,

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including Zero Emission Neighborhood, Zero energy District, Smart Energy Community, Nearly Zero Carbon Neighborhood or Positive Energy District (PED) [7]. The latter concept, introduced by Set Plan Action 3.2 [8], encompasses three topics related to energy: flexibility, efficiency and production [9]. The implementation, analysis and optimization of innovative urban solutions necessitates flexible laboratories that facilitate synergies among different urban factors such as energy, social, economic or governance, and that are equipped to monitor and quantify urban fluxes [10].

Within this study framework, the activities of WG3 of COST-PED-EU-NET CA19126 [11] titled `PED Laboratories, Monitoring and Replication' are encompassed, in particular Task 3.1 aims to review existing concepts, projects and facilities relevant to PED Labs [12]. Under this objective, the activities carried out in this task have tried to position PED Lab concept within the international debate, attempting to formulate and answer some research questions related to the development of PED Lab concept. This paper presents some of the results obtained in this task 3.1.

2 Methodology

A qualitative methodology is employed to identify the main aspects that must be considered in the deployment of PED Labs. The approach consists of three steps: administering questionnaires to focus groups, conducting qualitative analyses of the responses, and proposing research questions. Figure 1 presents a schematic representation of the methodology implemented in this study.

In the first step, appropriate questions are crafted to gather comprehensive information based on existing literature on Smart Cities and Positive Energy Neighborhoods. Three categories of questions are proposed to collect data on barriers, drivers, and main actors. In the second step, a qualitative analysis is performed by processing the answers and discussing the results within several working groups formed by members of WG3 of COST-PED-EU-NET CA19126 [11]. Finally, a series of research questions are formulated to identify the main aspects and gaps to be addressed in the implementation and replication of a PED Lab.

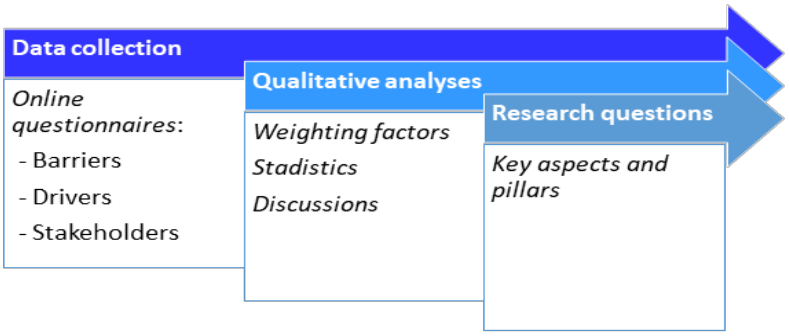


Fig. 1. Diagram of the methodology implemented in this research.

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2.1 Questionnaires

To gather information on real PED and PED lab initiatives from Action Cost WG3 Task 3.1 members, several online discussions were held, averaging participation from 20 experts in the field. This work was structured in two phases: the online completion of questionnaires followed by open discussions to refine the results of the questionnaires and reach a consensus. To obtain weighted responses on these issues, three actions were proposed through online working tools such as MURAL:

- Approve a proposed list of items in each of the three proposed issues, suggesting groupings and modifications where necessary.
- Weigh the importance of each listed item by scoring them on a Likert scale from 1 to 5 where 1 indicates low relevance and 5 indicates high relevance.
- Discuss the questionnaires results collectively to extract some learnings.

Three main topics were addressed in these workshops: barriers, drivers and stakeholders.

Barriers. A series of questions were developed to identify the key aspects that hinder or block the implementation and development of PED Labs. These questions were formulated based on existing bibliography on Smart Energy Cities projects [13, 14, 15, 16, 17], although they were subsequently adapted, updated and ranked based on feedback from a WG3 workshop with 18 experts from COST-PED-EU. In this workshop, a series of questions were formulated based on the premise that the existing barriers to implementing a Smart Energy City are similar and scalable to the PED-LAB concept. Nine types of barriers were suggested to the Workshop participants: policy, administrative, legal and regulatory, financial, market, environmental, technical, social, information and awareness; resulting in a total of 51 questions.

Drivers and unlocking factors. Additional questions aimed to identify the key factors that drive the adoption of initiatives or establish favorable starting conditions for the implementation and development of PED Labs. These questions are derived from the existing literature on Smart Cities and Urban Laboratories [18, 19, 20]. Based on the area of action, these factors are classified into two categories: drivers and unlocking factors. Drivers are the key elements that motivate the initiation and execution of a laboratory, while unlocking factors are those that enhance or improve the initial conditions, thereby facilitating the deployment of these urban laboratories.

Stakeholders and processes. PEDs require collaboration among diverse stakeholders, necessitating engagement methods that systematically identify stakeholder types throughout the development phases. Cheng et al. [21] proposed a stakeholder mapping framework that addresses dynamic roles at the building, district, and city levels, and suggests incorporating managerial tools into the PED development toolbox. Other authors evaluate stakeholders' perceptions of energy vulnerability mitigation through PEDs by conducting interviews, promoting an inclusive transition in urban areas [22]. However, harmonizing design phases, stakeholder interests, and scales can be challenging due to their frequent intersections. In practice, these elements are interconnected by

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critical decision-making moments known as "intervention points," where it is essential to identify the key stakeholders and the tools to be used at each point [23].

Similarly, further questions sought to identify the main actors as well as the processes involved at each stage of deploying PED Labs. In these questionnaires, six phases were identified: vision, decision, planning, execution, evaluation (check/act) and scaling and replication. Seven stakeholder groups were proposed: people, industries and companies, planners and architects, academia, financial institutions, governments and developers. Figure 2 shows an outline of the key aspects considered in these three blocks of questions.

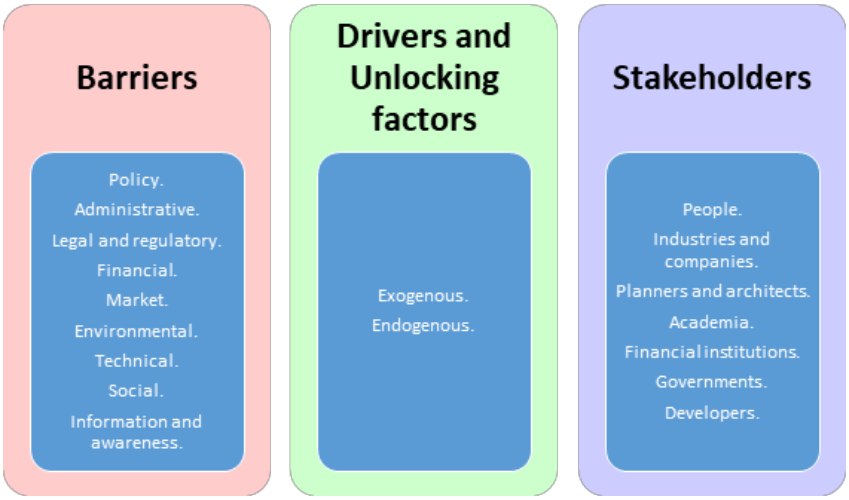


Fig. 2. Scheme of the key aspects considered in the three blocks of questionnaires proposed.

2.2 Qualitative analysis

Once the database is generated from the responses to the questionnaires, a qualitative study is conducted to identify the main challenges faced by the PED Labs. Key aspects of the three proposed blocks - barriers, drivers and stakeholders - are analyzed. This qualitative approach allows for the collection of diverse perspectives from different stakeholders, leading to the formulation of a set of research questions that highlight the main pillars to consider.

2.3 Research questions

Research questions summarize the objectives of our research, identifying the key aspects to consider. To formulate these questions, a series of online discussions and a

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qualitative analysis of the responses are carried out, enabling a focused examination of the main pillars and challenges faced by PED Labs.

3 Results

Once the questionnaires are completed among the participants in WG3 of Action Cost CA19126 regarding the three raised topics, the data were analyzed on a weighted basis. The importance of each aspect was assessed using the Likert scale from 1 to 5, where 1 represents a factor of little relevance and 5 is equivalent to a very relevant factor.

3.1 Barriers

Nine topics are proposed within the group of blocking factors, considering aspects such as:

- *Policy*: energy plans, governance body visions, or political commitment.
- *Administrative*: coordination, public participation, dissemination, ownership or authorization procedures.
- *Legal and regulatory*: regulations, instability, building codes, incentives or privacy protection.
- *Financial*: cost, financial support, access to capital, economic crisis or risks and uncertainty.
- *Market*: split incentives, energy price distortion or energy market actors.
- *Environmental*: lack of information or negative effects on the natural environment.
- *Technical*: tested solutions, technical commitments, qualified personnel, computational scalability, grid instability or accurate urban models.
- *Social*: inertia, interest, acceptance, engagement, rebound effect, attitudes, exclusion or lack of trust.
- *Information and awareness*: insufficient information, awareness, perceptions or information asymmetry.

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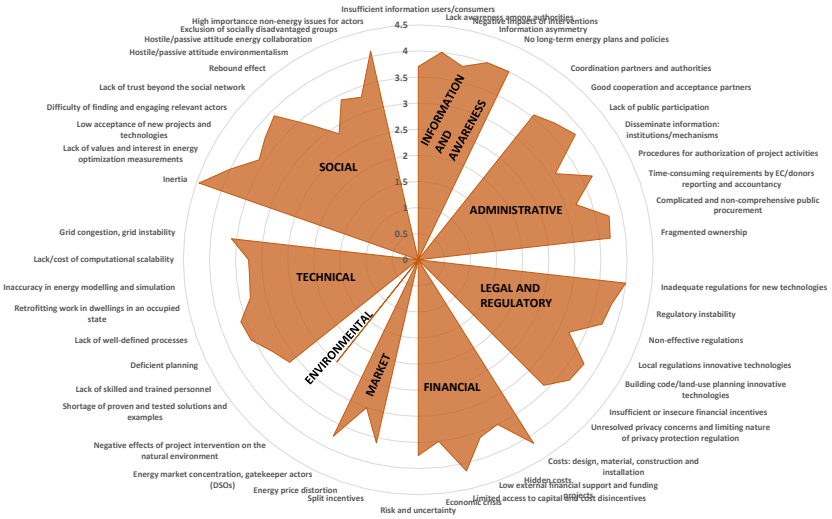


Fig. 3. Radar graph showing the blocking factors weighted from 1 to 5 by the participants of the questionnaires.

Figure 3 shows the results of the questionnaires on this topic. As illustrated in the radar graph, the social aspect of inertia is the most significant barrier to the development of PED Labs, while environmental factors are the least obstructive. Analyzing each topic reveals that administrative, legal, financial and some social factors pose challenges. Conversely, the aspects that least hinder the implementation of these laboratories are environmental along with many technical and market factors.

3.2 Drivers and unlocking factors

Two categories are defined for the group of driver factors, considering aspects such as:

- *Drivers*: climate change, urbanization trends, urban redevelopment, economic growth, market attractiveness, environmental quality or energy autonomy.
- *Unlocking factors*: technological improvements, innovative solutions, prefabricated packages, energy communities, prosumers, storage systems, decreasing cost, benefits, awareness, engagement, social acceptance, policy frameworks, funding or multidisciplinary approaches.

Figure 4 presents the results of the questionnaires regarding driving factors. As illustrated in the radar graph, the factors that most enhance the implementation of a PED Lab, according to respondents, include climate change mitigation, energy autonomy and independence, economic growth, financial mechanisms, strong existing local networks and associations, improved local and national policy frameworks, technological

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improvements for RES production, energy efficiency and prefabricated packages for buildings.

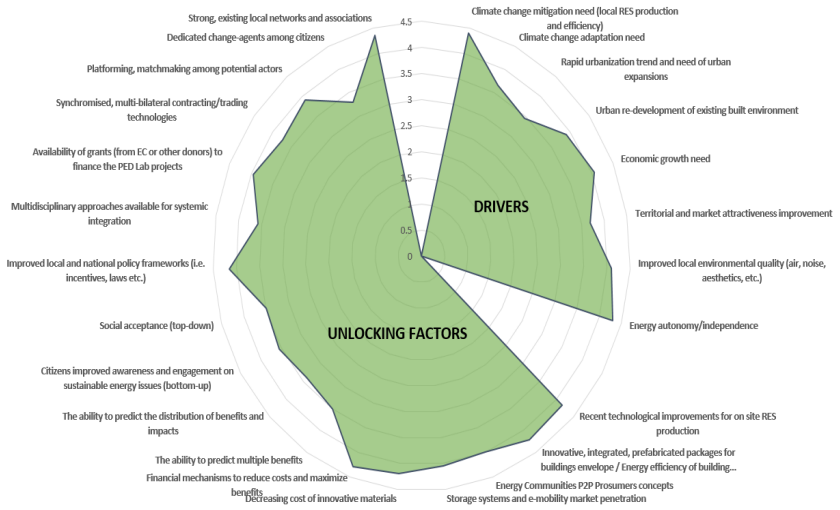


Fig. 4. Radar graph showing the unlocking factors and drivers weighted from 1 to 5 by the participants of the questionnaires.

Conversely, the aspects that contribute least to these urban laboratories involve aspects such as social acceptance, multidisciplinary approaches for systemic integration, matchmaking among actors, urban re-development of existing urban environments, territorial and market attractiveness improvement and the ability to predict benefits and impacts.

3.3 Stakeholders and processes

The correct mapping of stakeholders requires identifying who will participate in each of the processes of these laboratories. Six phases are considered in the life cycle of a PED Lab: vision, decision, planning, implementation, check/act and upscale and replicate. Seven groups of stakeholders are proposed: people, industries and companies, planners and architects, academia, financial institutions, governments and developers.

Figure 5 shows the influence of each stakeholder in the six proposed phases. As shown, the influence of each stakeholder varies throughout the implementation process, and it's important to note that some stakeholders may change their positions or reconsider their participation as they move from one phase to another.

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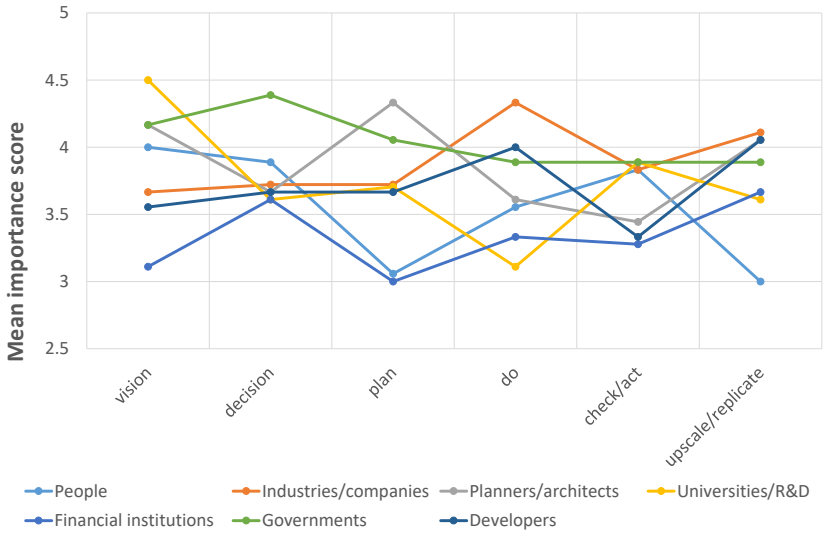


Fig. 5. Line graph showing the stakeholders involved in each of the proposed processes weighted from 1 to 5 by the participants of the questionnaires.

The distribution of stakeholder roles in each phase is as follows:

- *VISION phase:* the participation of universities and the R&D sector is determinant along with that of government and planners. Consulting with citizens is also a high priority.
- *DECISION phase:* the government is the main actor, supported by citizens.
- *PLAN phase:* in this phase, planners manage the process with support from the government, assisted by industry, universities and developers.
- *DO Phase:* industry and developers are the primary actors operating within a framework promoted by the government. The role of financial institutions as investors also becomes prominent.
- *Check/Act Phase:* all stakeholders must be involved in this phase in various capacities.
- *Upscale/replicate phase:* this phase is linked to the do phase and features a similar distribution of roles. Notably, the lack of citizen involvement in this phase is surprising.

3.4 Research questions

The implementation of this methodology leads to the formulation of three research questions that highlight the main aspects to consider in the deployment of a PED Lab. The three proposed questions are:

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What are the current barriers to the implementation of PED-LABS?

This research identifies nine categories of factors that hinder the development of a PED Lab. The qualitative analysis reveals that social and financial factors stand out as the most relevant, followed by administrative, regulatory and legal, and information and awareness aspects.

What are the drivers and incentive factors (unlocking) that determine the "fertility of the soil" for PED-LAB initiatives?

This research formulates forty-two questions related to unlocking and driving factors. The qualitative analysis identifies the need for climate change mitigation measures, the presence of strong local networks, and the improvement of local and national political frameworks as the primary aspects that most encourage the development of a PED lab.

What processes and actors define the steps, power relationships, and subsidiarity in responsibilities and decisions within PED LAB initiatives?

In this work, seven groups of stakeholders have been identified that influence the achievement of urban laboratory objectives across the six proposed phases, depending on the activities required at each phase. Governments stand out as one of the main actors throughout the process.

Once the key aspects and main actors are identified, it is necessary to structure the results to highlight the available resources and necessary requirements for the successful operation or replication of a PED Lab. To this end, the creation of a SWOT matrix is proposed, underlining factors that may constitute barriers (weaknesses, threats) or promote (strengths, opportunities) the deployment of these urban laboratories, as illustrated in Figure 6. Although these factors are highly dependent on the specific characteristics of each laboratory, this matrix will highlight general aspects that must be considered.

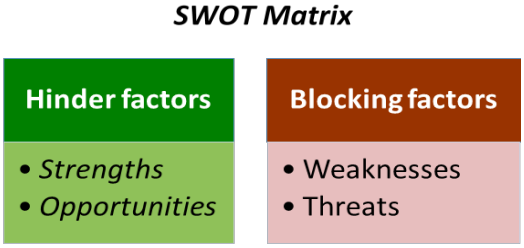


Fig. 6. Swot matrix proposed to underline the main factors that block or hinder the deployment a PED Lab

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4 Discussion and conclusions

When implementing a PED Lab, the first challenge is to establish a clear definition of what this type of urban laboratory entails. The initial concept is rooted in the Smart Energy City, Near Zero Energy Buildings and Urban Living Labs frameworks, with a focus on the district scale and a robust monitoring component within controlled environments. This approach merges the capabilities of a laboratory with sustainability and energy positivity objectives, enabling experiments to be conducted in real urban settings to validate innovative solutions on small and medium scales.

A PED Lab serves as a platform for conducting a variety of experiments, allowing for the analysis and validation of integrated solutions across similar or diverse urban contexts.

To identify key aspects in the implementation, development, and operation of a PED Lab, a methodology was employed based on qualitative analyses of responses gathered from questionnaires and working groups. Three main topics emerged: barriers, drivers, and stakeholders. Responses were quantified to assess the influence of each aspect, revealing nine categories of blocking factors, with social and financial aspects identified as the most significant. Climate change mitigation measures, strong local networks, and improvements in local and national political frameworks were noted as the primary driving factors. The mapping of stakeholders is essential, revealing the dynamic roles of various groups throughout the six phases of a PED Lab's life cycle. The findings underscore the pivotal role of government actors and the importance of citizen involvement, particularly during the vision and decision phases. Based on this analysis, the formulated research questions serve to guide future investigations, focusing on the most relevant aspects for implementing a PED Lab (barriers, drivers, and stakeholder processes), particularly when replicating this model in other contexts.

The research suggests creating a SWOT matrix to identify available resources, capabilities, and requirements for the successful operation or replication of a PED Lab.

The proposed SWOT matrix offers a framework to analyze available resources, capabilities, and requirements for effective operation and replication of PED Labs, emphasizing that while specific challenges may vary, overarching themes remain consistent across different environments.

Finally, this methodology promotes greater stakeholder participation and engagement in the deployment of PED Labs, as it identifies challenges and gaps through qualitative analyses derived from the questionnaires completed by these stakeholders.

The development of PED Labs can be instrumental in generating trust among governments, homeowners, and residents by facilitating the evaluation and experimentation of various technological combinations. This approach promotes proactive innovation while ensuring the solutions remain fit for purpose. Additionally, these initiatives could enhance the ability of governments and decision-makers to swiftly implement effective recovery measures that address immediate needs while also driving systemic change to improve the quality of life for all citizens.

ISBN 978-9930-617-71-7

Acknowledgments. This article/publication is based upon work from COST Action Positive Energy Districts European Network, CA19126, supported by COST (European Cooperation in Science and Technology).

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article. All authors are members of WG3 of the CA19126 PED-EU-NET.

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ISBN 978-9930-617-71-7

Pilot Proposal for Curriculum Adaptation Using AI and Big Data in Vulnerable Communities for CINJUDESCO and Attention Deficit Hyperactivity Disorder (ADHD)

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Abstract. This pilot project explores the implementation of Artificial Intelligence (AI) and Big Data to develop personalized educational curricula in vulnerable communities, specifically addressing Attention Deficit Hyperactivity Disorder (ADHD) in children. The initiative, carried out in collaboration with CINJUDESCO in Bogotá, aims to improve both academic and social outcomes through early identification of ADHD-related behavioral patterns such as impulsivity, inattention, and hyperactivity. Using Conditional Density Estimation (CDE) models, AI is applied to analyze data gathered through systematic observation, enabling real-time adjustments to teaching strategies. This level of personalization, often unavailable in resource-constrained environments, allows educators to respond dynamically to students' specific cognitive and emotional needs.

The project highlights how AI can address a gap in traditional educational methods that often fail to serve vulnerable populations effectively. By leveraging AI, educators can not only monitor and detect behaviors early but also implement timely interventions, preventing negative impacts on academic performance. The methodology involves a three-phase process: training educators, systematically observing students, and applying AI-driven analytics to tailor educational content in real time. This personalized approach includes adjusting break times, employing multisensory activities, and minimizing task duration to meet individual learning needs.

Ethical considerations are integral to this pilot, particularly concerning data privacy and the prevention of algorithmic bias. Ensuring equitable access to AI-powered tools while protecting students' privacy in vulnerable settings is a

ISBN 978-9930-617-71-7

priority. Although still in its pilot phase, this project lays a solid foundation for future large-scale applications, aiming to foster more inclusive and effective educational practices in underprivileged communities.

Keywords: Artificial Intelligence, Personalized Learning, Vulnerable Communities, ADHD, Curriculum Adaptation, Big Data, CINJUDESCO.

1 Introduction

The Potential Effects of AI on Customer Engagement in Service Industries - An Introduction That Isn't Really an Introduction at All. It was, in fact, the explosion of the Smart Cities concept a few years ago, propelled by technological developments—most emphatically by those in Artificial Intelligence (AI) and Big Data. These developments have caused a refinement not only in infrastructure and public service but also a definite increase in quality of life for citizens. One of the areas most influenced by this wave of new technology is education, which has to do with the analysis and support to child development, based on predictive modeling and Big Data technologies. The increasing integration of AI components in educational systems potentially allows the near future to design personalized interventions for children's needs specifically in urban settings [1].

Recent research has indicated that AI and ML models can mimic human behavior with competency in personality assessment. Intervention based on patterns detection at an early stage can influence transformation in a child's development by improving their educational as well as social outcomes. One possible pertinent way to solve the current challenge is the utilization of Conditional Density Estimation models to predict sophisticated personality traits in children from large datasets. The information could be used by educators and policymakers in developing interventions that are custom-made to individual needs, thereby rendering education systems more responsive and efficient [2].

While smart cities have succeeded in the management of resources, transport, and energy, the role of AI in transforming urban education has rarely been discussed. The paper tries to fill this gap by coming up with a framework that integrates AI and Big Data technologies into the process of making educational policies within an urban context [3].

One of the keystones in this research is the systematic observation of teachers about the evaluation tool of behavioral patterns in students. An objective analysis, purposing as a future work to adapt curricula through AI. Note, that this work is a pilot at Centro Infantil y Juvenil para el Desarrollo Comunitario (CINJUDESCO), an organization that works in vulnerable communities in Bogotá, Colombia untested before. This pilot study aims to develop tools for using AI in adapting curricula and enhancing the educational outcomes of children with respect to academic and developmental attainments; thus, this will be done with a specific case of attention deficit hyperactivity disorder.

Moreover, AI and Big Data integration in education poses vital ethical concerns to be considered while enforcing them, namely data privacy along with information

ISBN 978-9930-617-71-7

security and algorithmic bias. The contribution is critical because those students are already experiencing several social and economic limitations, creating learning opportunities in a digital environment for vulnerable communities. The key focus area regarding the introduction of AI technologies should be done responsibly, ensuring the right equilibrium between personalization and protection of privacy [4].

This pilot project at CINJUDESCO is the first initiative for curriculum adaptation that arises from teacher systematic observation, supported by AI and Big Data tools. With this study, the purposes would be to set the first stones of research and applications on a greater scale in the future, improving educational systems in vulnerable contexts, and promoting more equitable and effective child development.

1.1 Socioeconomic Context of ASOVEG-CINJUDESCO

CINJUDESCO has its seat in Bogota, having been created from the neighborhood-building process of Granjas de San Pablo. What were the reasons for the birth of this organization? The lack of infrastructure and basic services such as potable water, electricity, schools, and community spaces in the neighborhood. In the 1950s, residents mostly of rural origin from Boyacá and Santander formed a community that settled in an area characterized by urban marginalization and absence of the State [11].

The community eventually came up with self-run programs oriented towards education and socialization of the children and youth in the neighborhood, resulting in initiatives like Jardín Comunitario Mafalda, a precedent to CINJUDESCO [11]. This, along Biblioteca Comunitaria Manuela Beltrán and the Neighborhood Association of Granjas de San Pablo (ASOVEG), would later be consolidated as spaces of an educational and cultural platform destined for the integral formation of children and young people from situations of vulnerability [11].

CINJUDESCO was very important in that it focused its interventions on artistic, recreational and political education, breaking down the barriers which impede access to education and personal fulfillment in a context of social exclusion. The implemented projects managed to create social cohesion and to create a base for community organization, even though they were experiencing economic difficulties as Serzedelo indicates [11].

2 AI and Personality Assessment in Education: Curriculum Adaptation in Vulnerable Contexts

These are technologies that have changed and are changing the conformation of didactic guides within educational systems: Artificial Intelligence and Big Data. From tracking datasets on students' behavior, preferences while learning, and personality traits, teachers and educators have been enabled to do an analysis. The execution of AI-guided curricula becomes a reasoning business considering the vulnerable settings, supported by CINJUDESCO in Bogotá. Issues about making interventions are personalized by taking AI as the champion in giving key, data-centered insights into fitting curricula compositions for individual students' challenges [1].

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2.1 Curriculum Adaptation through AI and Big Data

The development of curricula that cater to special needs learning disabilities, such as ADHD, is vital—especially in disadvantaged areas where access to special education resources is little. Traditional techniques may be so ineffective because they are non-specific to the cognitive and emotional needs of the individual student. More sophisticated models, such as Conditional Density Estimation, help to carry out an analysis of patterns that accompany the main symptoms of ADHD: hyperactivity, impulsivity, and inattention. According to the meta-analysis, individuals with ADHD tend to score low on conscientiousness and high on neuroticism, thus affecting performance in academics due to lack of concentration and emotional regulation, and completion of tasks [2].

By using AI to identify these traits at an early stage, information can be created that will help educators to design personalized interventions tailored to the specific needs of each student. AI, in this case, becomes critical in aiding better evaluation of behavior on the onset of ADHD or any other kind of learning disorder before the conditions drastically bring down a child's academic performance [4]. It allows not only proactive educational interventions but also real-time teaching effectiveness of the proactive educational interventions by providing continuous feedback to teachers. Hence, based on the urgent requirements of a learner, changes can be made in teaching strategies like adding more breaks and making activities multisensory or cutting down time of exposure to task demanding goals for the learner [5].

Other studies have proved the efficacy of AI in personalizing curricula for at-risk communities. AI-based monitoring and adjustment of learning for at-risk students lead to notable positive changes in academic performance and social outcomes [12]. Also, AI has the potential to spot intricate patterns of behavior, far beyond the observational capacities of teachers, ensuring interventions are timely and targeted [13].

Real-Time Adaptation. Theoretically, real-time curriculum adaption can be realized when AI-collected data is instantly conveyed for processing and analysis to then inform a change in the pedagogical strategy based on student behavior. For instance, if a student with ADHD shows reduced attention during group activities, AI recommends that the learning techniques be individualized or the frequency of breaks between activities is increased. Similarly, if impulsive behavior is too high during transitions or when starting some activities, the teacher may decide to change the timings of transitions by providing some support that would give better structure to those critical moments [9].

This line of action is of special importance in communities such as CINJUDESCO, where there is a scarcity of special educational resources and further support through technologies like AI can arm the teachers with powerful tools for managing the learning differences more effectively

2.2 The Case of CINJUDESCO: A Pilot Project for Personalized Learning through AI

Operating in the vulnerable sectors of Bogotá, CINJUDESCO implements programs from formal education to dance and urban music in order to develop the personality of the individual and the community. This center aims at at-risk behavior prevention, such

ISBN 978-9930-617-71-7

as substance use, through cultural and educational engagement [6]. The AI contribution is particularly important in terms of identifying behavior patterns among students, the majority of whom come from very difficult environments.

This predictive model will give a warning to the teacher when any student exhibits signs associated with ADHD. It takes an analysis of performance data and behavior from the different activities to be able to identify these patterns. This will enable educators to put in place interventions that are timely and very effective for the concerned students. For this, CINJUDESCO will be better placed to tailor its programs in meeting the students' needs by ensuring that they are supported adequately in their academic and personal development [7].

Curriculum adaptation at CINJUDESCO is not only limited to ADHD. AI is expected to be used to analyze attendance to community activities and other factors that frame the socioeconomic context and therefore get the broader view of each student's needs [8]. This sort of comprehensive approach to the problem of educational programs to develop at the center reflects much wiser attitude, compassion, and humanity in relation to different difficulties of the students in these communities.

2.3 Challenges Related to Ethics in Implementation of AI in Education

Integration on AI in education has several benefits, but it also raises critical ethical challenges, more so with vulnerable communities. AI in educational settings must be accompanied by strong protective measures for student privacy, data security, and algorithmic bias risk management [4]. This could particularly expose vulnerable students to risks of having biased algorithms applied or when appropriate protective measures for their personal data are not in place. This is why the development of AI-driven educational systems must have a system of ethical safeguards that place students' well-being and rights first.

At CINJUDESCO, considerations of ethics are very forceful since, in the students who come from environments with more marginalization, data of a very sensitive nature is gathered. The center works with such initiatives directed at ensuring responsibility use of student data and AI systems that are transparent and fair in return for benefit from AI and deliver personalized learning and early intervention, without risking student privacy or equity [6].

3 Methodology

This pilot project will set up an observation system to help teachers at CINJUDESCO identify and document behavior patterns of ADHD in students, based on the meta-analysis [2]. Keyed to systematic observation, this will produce through effective informative data that can enable AI based personalized educational interventions on a large scale.

The major goal of the project is to fashion a systematic observation protocol for teachers to be able to collect both quantitative and qualitative information on student behaviors for those manifesting symptoms of ADHD. This data shall be input to an AI

ISBN 978-9930-617-71-7

system for identifying patterns of behavior that will inform curriculum adaptation and personalized educational interventions.

3.1 Curriculum Adaptation through AI and Big Data

Design Phase of the Systematic Observation Protocol. All observable behavior is to be assessed against the list developed via meta-analysis [2], which identifies three primary traits within children with ADHD: low conscientiousness, high impulsivity, and high neuroticism. These qualities will be used as a base for identifying specific behaviors to be observed.

Teacher Training Phase. Trainers will be trained on conducting objective, non-intrusive observations and recording them in real-time using simple tools (such as mobile applications, digital observation sheets), and managing observational bias. They will be taught how to manage observational bias.

Implementation and Data Collection Phase. Teachers will observe the students for 3 months during daily classroom activities and outside class. They will take notes of specific behavioral incidents revealed by four major ADHS symptoms. Some observations take place at set times during the day, such as during group or individual activities or during the transition between activities.

Phase of Analysis Based on AI. The gathered data will be fed to an AI system that is developed to recognize behavioral patterns through techniques of machine learning. This system will produce behavior profiles for each student, which can help adjust the curriculum based on detected needs.

3.2 Design of the Systematic Observation Protocol

Key Behaviors to Observe. En base al meta-análisis [2], se diseñará una lista de comportamientos que los docentes deben observar y registrar, específicamente relacionados con las tres dimensiones clave del TDAH:

Conscientiousness. (A) Difficulty completing academic tasks. (B) Frequent loss of school materials. (C) Frequent forgetting of instructions and tasks. (D) Constant need for reminders to stay on task.

High Impulsivity. (A) Peers or teachers are frequently interrupted. (B) Difficulty in waiting for one's turn in group activities. (C) Hasty responses or incorrect answers in class activities. (D) Behaves recklessly in games or physical activities without thinking about the consequences.

ISBN 978-9930-617-71-7

High Neuroticism. (A) Very strong emotional reactions to criticism or correction. (B) Frustration or failure tolerance is very low. (C) Preoccupation with worry that may be related to academic results or relationships with peers.

Observation Instruments. Teachers will use the following tools to help them collect data: (A) Mobile apps or tablets: These will enable the teacher to record real-time data during the school day. Each entry will include the time, observed behavior, and context (the activity the child was engaged in, whether in a group situation, etc.). (B) Structured observation sheets: Standardized forms that will help the teacher make consistent observations. These forms will have predefined observable indicators based on the three key traits.

3.3 Implementation and Data Collection

Duration of the Observation Period. This shall not exceed three months. During the observation period, teachers shall record the following key behaviors at strategic points in the school day:

Group Activities. Interaction during group activities gives a good context for observing impulsive behaviors and low conscientiousness.

Transitions between Activities. Often, transitions represent critical moments for the ADHD student, where impulsivity and a lack of structure combine to produce disruptive behavior.

Individual Work. Individual academic tasks are useful for observing levels of conscientiousness, persistence, and ability to stay on task.

3.4 AI-Based Analysis: Full Process and Tools

Data Integration into the AI System: Observational Data. A key step to take is integrating AI into the analysis of observational data to identify patterns of behavior in students, which will make curricula personalized and ensure early intervention development in the case of ADHD. In this section, complete in full is the process of data analysis using AI, the algorithms, technological tools, and predictive models applied, and their impact on personalized education. The first stage of AI analysis is to integrate teacher-recorded observational data into a specially developed artificial intelligence system for behavior pattern recognition.:

Data Collection and Storage. (A) Observational Data: Information will be collected by the teacher using mobile apps or structured forms that describe the behaviors observed throughout the school day. Such data includes time, context, behavior severity, and relevant observations of the student's environment. (B) Cloud Storage: Data will be retained in a secure cloud environment that allows easy access and is highly scalable.

ISBN 978-9930-617-71-7

Secure storages provided by Google Cloud Platform or Amazon Web Services for big data also allow real-time access from many devices at many locations for such large-scale data analysis.

Example Database Structure: The database may be organized into multiple tables that store the information related to students, their observed behaviors, and the contexts/activities along with results obtained from AI analysis. For example:

- Student Table:
  - Student_ID: Unique identifier for each student.
  - Age: Student's age.
  - ADHD_Diagnosis: Indicator of ADHD diagnosis.
  - Behavioral_Profile: A general profile based on previous observations.
- Observations Table:
  - Observation_ID: Unique identifier for each observation.
  - Student_ID: Relationship with the student table.
  - Date: Date of the observation.
  - Time: Time of the observation.
  - Context: Type of activity (e.g., recess, group class, individual task).
  - Behavior: Description of the observed behavior (e.g., impulsivity, inattention).
  - Severity: A scale from 1 to 5 assessing the severity of the behavior.
- Interventions Table:
  - Intervention_ID: Identifier for the intervention.
  - Student_ID: Relationship with the student table.
  - Intervention_Date: Date when the intervention was applied.
  - Intervention: Description of the intervention (e.g., break, physical activity).
  - Outcome: The effect of the intervention on the student's behavior.

Data Preprocessing. Data preprocessing is one of the most crucial steps to handle consistent and usable data in an AI system. Steps that follow, with respect to raw teacher-collected data, may contain inconsistencies; thus, the following will be done: (A) Data Cleaning: It will consist of removing duplicate entries, missing data, and outliers. Pandas and NumPy are tools that can do this in Python. (B) Data Normalization and Standardization: Since observed behaviors can vary in intensity, data will be normalized for fair comparison among students. This step ensures that values of observations are within a consistent range and usable by AI models.

Machine Learning Algorithm. Conditional Density Estimation (CDE) is basically defined as modeling the distribution of some dependent variable given conditioning on other observable variables. In the case of the pilot project in CINJUDESCO, CDE will be applied in modeling the behavioral patterns exhibited by students with ADHD based on conditions such as activity type, time of day, and social interactions. This will enable one to come up with educational intervention programs that are specifically suited for the identified needs, through an analysis of observed patterns. CDE will be applied to model the distribution of observed behaviors in students based on: (A) Activity Type

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A CDE may show whether impulsive behaviors vary according to whether students are in group or individual activities. For example, events that define an individual as impulsive are likely to increase during recess and decrease in more structured classes [2]. Time of Day: CDE can also identify time-of-day patterns, such as impulsive or inattentive behaviors rising at specific times, like after lunch or nearing the end of the school day [2]. It is this type of analysis that will enable the personalization of educational interventions based on critical times of the day [5]. In both cases, CDE will help to create a behavior map identifying moments or activities where students with ADHD struggle the most, which allows adapting the curriculum accordingly [3].

Tools and Algorithms for Implementing CDE. We will implement CDE in this project by combining machine learning tools and statistical analysis to model the observational data at CINJUDESCO. The following tools and libraries as implemented in Python will be essential for preprocessing data and executing algorithms for conditional density estimation implementation: (A) SciPy and NumPy. Analyses of density, using the functions in SciPy, will form the basics on which behavioral variables will be modeled. Innumerable features can be attributed to the contribution of SciPy and large datasets generated throughout this study implementation [8]. (B) TensorFlow Probability. This is important, especially when accurate conditional density estimation has to be undertaken in modeling behavioral variables within a complex educational environment like CINJUDESCO. Models for TensorFlow Probability have been developed for the estimation of densities based on previous patterns of any observed and observable behavior and later harnessed to make or break many young souls at a go based on behavioral variables [9]. (1c) Scikit-Learn: Provides a variety of machine learning algorithms, including Kernel Density Estimation, for carrying out non-parametric conditional density estimation; this can help to identify patterns in observational data without assuming the distribution is fixed, which is crucial when dealing with complex behaviors or changing contexts [10].

4 Expected Results Based on AI and CDE for Curriculum Adaptation

The use of Artificial Intelligence in the analysis of observed data through Conditional Density Estimation will allow generating detailed behavioral profiles, which can be used as a base for curricular personalization and implementing early interventions for the cases of ADHD students at CINJUDESCO.

4.1 Behavioral Profiles and Curriculum Adaptation

The output of the algorithms after analysis of the observational data will be specific behavioral profiles generated for each student, which will provide a detailed view of behavioral patterns for better precision in curriculum adaptation.

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Adjusting Attention Span. For example, AI can flag a student who is inattentive for long based on the patterns available to the teachers. They can subsequently change the curriculum by adding more breaks or increasing the activity's dynamism to keep the student engaged. For instance, project-based learning or educational games make students actively involved and, hence, more flexible in their attention spans compared to traditional teaching methods. Some of them are then in a position to act as complementary and supplementary methods in the regular system [2, 9].

Differentiated Teaching Strategies. As for students manifesting high levels of impulsivity, independent variable teaching strategies may be considered. Independent variable may suggest using collaborative learning techniques or independent variable providing more structured learning environments so that impulses are not triggered independent variable as much. Independent variable would be possible by recognizing specific situations independent variable where impulsivity is more frequent (for example, during group activities, or during transitions) [5, 9].

Personalized Support Resources. Teachers can base the generated behavioral profiles on it and come up with a way of targeting their students. This might include personalized tutoring, adapted digital tools or intervention programs, specifically designed to meet the mental and emotional needs of students with ADHD [2].

AI Analysis Phase. The data that has been gathered will be plugged into an AI system that is capable, through machine learning, of identifying behavioral patterns. This system would generate behavioral profiles for each student, thus availing in the adjustment of the curriculum on an identified needs basis.

4.2 Early Interventions

AI is going to be very instrumental in the early identification of students who need special interventions before the behavior starts having a considerable impact on their academic performance. The automatic alerts that are a result of AI will enable teachers to act preventively.

Automatic Notification. When it detects patterns of concern, such as an abrupt increase in impulsivity or sustained attention decrement, the AI shall generate automatic alerts for teachers to come up with interventions before the behaviors escalate. Such early alerts facilitate proactive intervention that will improve one’s academic performance in terms of managing disruptive behaviors [9].

Personalized Intervention Plans. After these alerts, what the teacher and educational psychologist can come up with are personalized intervention plans. These may include making changes in the curriculum or having sessions with educational psychologists to apply new teaching methodologies that cater to the needs of the students [2, 9].

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4.3 Impact of CDE on Curriculum Personalization

Data processed through CDE will be analyzed to come up with a detailed report on students' behavioral patterns, which will be the right base for proper curriculum personalization.

Adjusting Activity Schedules. CDE identifies the times of day when students are most impulsive or inattentive as a way to enable teachers to adjust pedagogical activities to the times when students perform better. For example, if data shows that students have difficulty concentrating after lunch, other sources recommend that more dynamic activities be scheduled during that period [2, 10].

Differentiated Teaching Strategies. Another area stride by CDE is in the implementation of differentiated pedagogical strategies based on observed patterns in each learner. Teachers will develop their approaches based on the characteristics observed in them, putting specific interventions into practice for those who show impulsive or inattentive behaviors on most instances during certain activities [9, 10]**.**

4.4 Continuous Assessment and Feedback

The AI system shall continuously assess behavior profiles of students, allowing pedagogical strategies to be adjusted at any moment.

Progress monitoring. It monitors progress continuously at each student and provides teachers with timely feedback. This allows curriculums to be dynamically modified and pedagogical approaches tailored to meet the evolving needs of each learner [9].

Longitudinal trend analysis. Only when behavior patterns are analyzed over the long run will certain trends be discernible for teachers and administrators. The AI system will manage to identify pattern changes reflecting a specific student's changed behavior and, in the long term, this information will be very important for curricular adaptation [2, 5]**.**

5 Conclusión

The present pilot project of the implementation of a system of curriculum adaptation, using AI and Big Data within the framework of CINJUDESCO, concerns the tendency of education to be personalized in vulnerable communities, i.e., specifically children with Attention Deficit Hyperactivity Disorder. It is expected to offer innovative tools for teachers to identify complex behavioral patterns and make real-time curricular adjustments.

The application of Conditional Density Estimation models in the characterization of behaviors like Impulsivity, Inattention, and Hyperactivity presents a more accurate and

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effective was to personalize student learning which enhances academic and social outcomes. This may lead not only to timely, fine-scaled interventions but also equips the implementation of a rather strong data education driven policy regime particularly in resource poor communities.

While not perfect or final, what has been proposed with the tools and methodologies does point to a real basis that future research and application on the subject may reach. Ethical and responsible considerations should underpin efforts to integrate AI into education, more so when engaged in contexts with a higher degree of vulnerability, as discussed through this paper. The impositions that would have to be placed to protect the privacy rights of students and that of equity will stand as an enabler to the success of this initiative.

With this project being implemented in the future it can be envisioned that not only will the educational experience at CINJUDESCO for students be enhanced but also that this will foster the development of pedagogical methodologies more inclusive and adaptive, through the use of new technologies and in this case AI to generate an equitable and efficient learning environment.

Acknowledgments. This pilot proposal would not have been possible without the valuable support of the organizations and entities that have collaborated. We are deeply grateful to ASOVEG-CINJUDESCO for their commitment to community development and for opening the doors to the implementation of this initiative in their community. We also extend our thanks to the NGO Tierra Sin Males, whose continuous efforts in education and empowerment in vulnerable contexts have been fundamental for this proposal. Finally, we thank the University of Valladolid, specifically the Office of Social Responsibility, for their academic support and for providing the resources and infrastructure necessary to carry out this study. Their vision and support have allowed us to take the first steps toward implementing this pilot project, which aims to improve the academic and social development of students in vulnerable environments. Their collaboration has been essential for this research to move towards a positive impact on the lives of children and young people.

Disclosure of Interests. The authors have no relevant conflicts of interest related to the content of this article. This pilot project has been developed solely to improve the academic and social development of students in vulnerable environments, with no ties to commercial or financial interests..

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ISBN 978-9930-617-71-7

Examination of citizens' perceptions towards urban agriculture and its contribution to food security – worldwide and two cases evaluated in Spain

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Abstract. We are currently facing a growing preoccupation with healthy, local food and individual well-being, an increasing awareness of the benefits of being in touch with nature, and where the urban food sector has become a topical issue attracting major interest, particularly with the ongoing population growth. This article aims to examine public attitudes toward urban agriculture and to evaluate the implementation of these practices in ensuring a higher guarantee of food security. The methodology used consisted of developing and distributing an open survey, following the Theory of the Planned Behavior, assessing our respondents' attitudes, subjective norms and perceived control over behavior, along with their capabilities, opportunities and motivations. Moreover, interviews were conducted with project leaders in two cities in Spain, Valladolid and Segovia. The survey results show that most of our respondents are familiar with the concepts of urban agriculture and food security, but more efforts are needed to improve this in terms of awareness and benefits. Regarding the interviews, several common points emerged, such as the desire to ensure that people are properly educated and aware of the value of integrating the food sector in cities, as well as the adequate organization of activities and workshops. The responses from the interviews and survey were positive in terms of knowledge of the subject, but it still needs to be developed to make it more accessible and understandable to everyone, by encouraging small organizations and start-ups linked to local production and consumption for example.

Keywords: Urban Agriculture, Food Security, Benefits, Survey, Interviews.

1 Introduction

The United Nations Human Settlements Program has estimated that 60% of the population will reside in urban areas by 2030 [1]. This will increase pressure on urban resources, particularly in low and middle-income countries, making it necessary to guarantee a certain level of food autonomy and independency in urban areas [2]. In addition, rapid urbanization and industrial agricultural production have led to a growing disconnection between urban residents and their food sources, with urban agriculture

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increasingly seen by policy makers and urban researchers as a very promising pillar of food security [4,5]. Indeed, in 2007, the FAO defined urban agriculture as "the growing of crops and the raising of animals for food and other uses in and around cities, together with related activities such as production and delivery of inputs, processing and marketing of products" [6]. This definition allows us to clearly understand that urban agriculture is the cultivation, processing and distribution of food products by growing plants in and around cities to feed local populations [7]. It is also characterized by the systematic and expanded occupation of unused land in urban areas, with the establishment of individual, community or collective gardens and allotments [8].

Meanwhile, we are living in an era of concern for people's mental health and wellbeing. Indeed, in 2017, according to the World Health Organization, depression is now the leading cause of ill health and disability, with over 300 million people affected [9]. In fact, there is a growing realization that the connection with nature, which can be diminished in urban environments, makes an important contribution to our mental health and wellbeing [10, 11]. Consequently, there has been a growing interest in urban agriculture, which is recognized for its potential socio-cultural, public health, environ-mental and economic development benefits [12], notably through initiatives such as Milan's Urban Food Pact, which encourages local food production. Moreover, researchers note that the success of urban agriculture is strongly linked to its positive perception by the public: both those who live nearby and urban society as a whole [13].

Given the current situation, the aim of this article is to examine public attitudes towards urban agriculture and to evaluate the implementation of urban practices in cities in order to better guarantee a safer level of food security, through the implementation and distribution of an open pilot survey, which will help to provide empirical results on the link between urban agriculture and food security, along with the analysis of two practical studies on urban agriculture carried out in Spain, in the cities of Valladolid and Segovia.

2 Materials and Methods

This study aimed to explore the attitudes of the population toward urban agriculture. A mixed-methods approach was adopted involving a questionnaire survey and semi-structured interviews allowing to gain a better detailed understanding of the actual situation and a comprehensive qualitative analysis [14]. The survey has been distributed in an online way, i.e. through our networks, by email, through other colleagues etc. and its creation has been done through Google form platform, for its effectiveness, simplicity and feasibility. The interviews were carried out in two initiatives located in two different cities in Spain, Valladolid and Segovia. The motivation to work on these two initiatives was linked to their prior knowledge, regarding the number of activities they carry out and their importance within the cities, where all the inhabitants are very supportive of this type of projects and where their neighbors lead them to develop similar approaches.

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2.1 Sample frame and Sampling technique

The survey was distributed and interviews conducted between May and June 2022. This is a pilot study, so the aim is to understand exactly what the population's perspective is on urban agriculture as well as having direct contact with the project leaders to understand in more detail how the initiatives work, the obstacles and their main challenges. To this end, our first objective was to obtain a minimum of 100 responses, which we were able to achieve and could even get more than double. Regarding the interviews, they were conducted with project managers of two initiatives to better understand changes that may have occurred in gardeners' lives during their implementation within those initiatives as well as their experiences and techniques in a collective learning process.

2.2 Sample frame and Sampling technique

The questionnaire comprised of demographic questions, dependent variable (adoption of urban agriculture) and influencing factors. Indeed, this series of questions helped us to better identify the population being evaluated, which allowed to base our answers around this target population. Moreover, the development of the questions in relation to the adoption and influencing factors were underpinned by the Theory of Planned Behavior [15] and the COM-B model [16].
Regarding the interviews, the theory used is that of social practices (SPT), developed by Shove et al [17]. It offers a very precise approach to understanding the behavior of individuals in the face of our problem, by examining the words of our participants. This theory allows us to better explore and evaluate the results through the responses collected, by assessing their engagement in certain practices, their applications in their daily lives, and how changes in materials, skills and meanings can influence their behavior. Analysis using Social Practice Theory (SPT) shows how changes in practices can contribute to lasting changes in behavior and attitudes

2.3 Content of the questionnaire and interviews

To better understand the content of these questionnaires and interviews, different variables were defined and targeted. These were attitude towards urban agriculture, Perceived control over behavior (ability), Subjective norm, Opportunity and Behavior etc. Table 1 provides a more detailed explanation of each of these variables, as well as presenting the questions that were asked along these lines, both in the questionnaires and in the interviews:

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Table 1. Variables used and targeted in interviews and questionnaires and related questions asked.

Variable name	Actual question used in survey	Actual question used in interview
Behavior (intention)	Would you support Urban Agriculture in your city?	If you had to give advice to other initiatives like yours, what kind of advice would you give to the actors involved in these initiatives?
Behavior (Actual)	Have you ever been involved in some Urban Agriculture initiatives?	What was your motivation for working on this project/initiative?
Attitudes towards UA	How important do you think the concept of Urban Agriculture is?	What do you think of the concept of urban agriculture?
Subjective Norm	To what extent are the themes of urban agriculture and food security relevant to your daily life?	According to you and your experience, what are the main indicators you could rely on to differentiate which urban systems are suitable or not?
Project	Do you think your city needs the implementation of such initiatives?	What do you think makes this initiative successful?
Capability	Would you support Urban Agriculture in your city?	How do you try to promote your idea in your city? What method was the most effective?
Other motivation?	Would you like to tell us more about your thoughts/ideas on this subject?	What was your motivation for working on this project?

Table 1 gives a very clear explanation of the different variables highlighted in this research, as well as presenting the questions that were asked to our interviewees and survey respondents, where we can clearly see that this is a very good method of bringing the two approaches together, ensuring that they are both brought coherently into one overall framework.

Indeed, this theory followed is that developed by Ajzen (1991), which consists of analyzing the data from the interviews carried out, which makes it possible to understand the psychological factors that influence the behavior and attitudes of individuals in various contexts, as well as their decision-making in terms of actions [15]. In this section, we will detail these methodological approaches, including the analysis process and the identification of the components of the theory in the participants' responses. In addition, this methodology could be complemented by that of Michie et al. in 2011, which provides an understanding of human behavior, since it identifies three interdependent and identifying dimensions: Ability, Opportunity and Motivation, which are considered to be essential for behavior to occur [16]. Capacity refers to the individual's necessary skills and knowledge, Opportunity encompasses the environment and external conditions that enable the individual to identify better, while Motivation includes intrinsic and extrinsic motivations. This theory therefore enables a profonde evaluation to be carried out to analyze the behaviors of those involved

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2.4 Supplementary questions

In addition to the above series of questions, various other questions were addressed, such as defining “urban agriculture” and “food security” according to their own understanding, through a series of proposed answers. Indeed, through their answers, we can better frame the population being evaluated, better understand how they assimilate this knowledge and therefore better draw the appropriate conclusions.
Indeed, answering these questions would present a clearer idea of understand the current knowledge of the insertion of the food sector in cities through the involvement of urban agriculture and therefore, in case of negative answers and a lack of interest from stakeholders, what should be done to correct this.

3 Results

In the following sections, the results obtained from each of the questionnaires and interviews have been presented and explained using tables and figures to make them easier and more effective. In addition, the results obtained are then interpreted in the discussion to draw further conclusions.

3.1 Results from the survey

The dissemination of the survey has been carried out using a random sampling method to guarantee that the sampling is representative. Within our extensive network of workplaces, the questionnaire was distributed via various channels such as e-mail, colleagues and social networks. Using this multi-faceted distribution approach, we were able to reach a wide range of potential respondents from different professional backgrounds and geographical locations. As a result, we were able to collect a substantial sample of 250 participants from many different geographic regions. This diversity of respondents contributes to the robustness and generalizability of our results, as it encompasses the perspectives of individuals from different cultural, social and economic backgrounds.

Characteristic of the respondents
The demographic profile of respondents to the following: we can clearly notice that the number of female respondents exceeds the number of male respondents by a large margin, with 68% of responses from the female gender. 72% of our respondents are single and belong to the age category between 18 and 35 years (72% of our target population), as well as the majority not having children. As for the place of residence, most of our respondents live in cities and only 18% live in villages. It is also worth noting that the demographic profile of the respondent resembles a young woman with a college education - a city resident.

It should be noted that the questionnaire was conducted on a global basis, bringing in participants from various geographical regions. For instance, the results have shown that 76.4% of the responses were from the European countries, indicating significant

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representation by Spain (26.74% out of 76.4%), followed by the Dominican Republic with 20.3% of respondents. These findings highlight the significant presence of these two categories in the sample, and which points to the broad geo-graphical distribution of our survey (Fig.1).

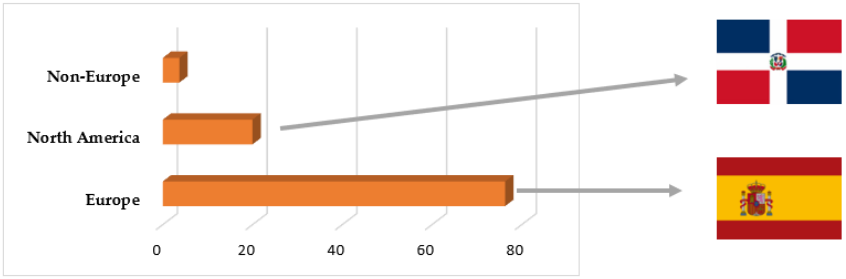


Fig. 1. Residency of respondents from the survey.

These results reveal the global nature of our study and provide valuable information about the perspectives and experiences of individuals from different parts of the world.

Knowledge about Urban Agriculture and Food Security

In this section, most of the respondents have heard of the two concepts but have not fully understood it. However, there are still a significant number of respondents who have not heard of the subject at all. Indeed, from the results obtained, almost 80% of the answers regarding the definition of Urban Agriculture are correct, which means that our surveyed population has a clear idea of the meaning of this concept. Regarding the meaning of food security, only half of the surveyed population knows the correct answer, while 34% of the answers are wrong and think that food security is an international law.

Furthermore, the graph presented in Fig.2 illustrates an important trend: about 88% of respondents say it is important to integrate urban agriculture in cities to promote health and sustainability of the food system. However, when it comes to assessing support for these initiatives, the data highlights an interesting finding: A significant proportion of participants indicate that they are 'likely' to support these initiatives, although they do not express absolute certainty (Fig.2). This remarkable aspect draws attention to the need for further investigation and action to address the underlying concerns or un-certainties of respondents.

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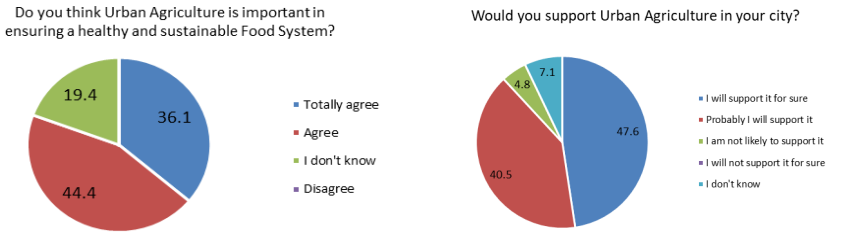


Fig. 2. UA and ensuring a healthy food system - Supporting Urban Agricultural practices (in %)

By acknowledging this differentiation, we can better understand the attitudes and multiple perspectives surrounding the involvement of urban agriculture in urban environments, which allows for informed decision making and policy development in this area.

Involvement of the respondents

This part will allow us to better understand whether people think that the two concepts of Urban Agriculture and Food Security are related, whether they are interested in the involvement of urban agriculture in their city, and whether they have already been involved in urban agricultural projects. This would allow a better interpretation of the results and draw conclusions that are relevant to our research topic.

We can see in the Fig.3, that most of the responses agree and would support the implementation of initiatives in their cities, but most of them have never been involved in an urban agriculture initiative, think that this should be taken into consideration by organizing more activities, workshops and other inclusive work.

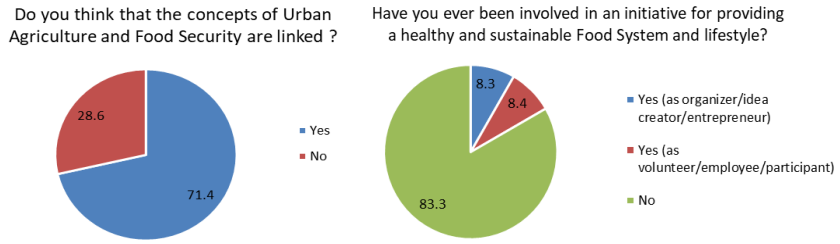


Fig. 3. Urban Agriculture and its relation to the Food Security concept (in %)

Regarding the link between the two concepts, we find that 70% of the responses agree and believe that urban agriculture and food security are linked and that this link will ensure a healthy and sustainable food system (Fig.3).

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3.2 Results from the interviews

By carrying out interviews with project managers of the two initiatives, "Alimenta Conciencia" de Segovia" and "Estrategia Alimentaria de Valladolid", we were able to obtain a considerable amount of information about two projects in Spain which would allow us to gain a general ideal about the situation in Spain, as well as gathering, through their own statements, information about the activities carried out, the objectives they would like to achieve and the obstacles they are encountering. The following sections illustrate the previous points in further detail, enabling us to gain a better understanding of each of the two initiatives and to draw appropriate and relevant conclusions.

"Alimenta Conciencia" In Segovia

Segovia is an active city in terms of health and equity, education, and participation. To achieve a sustainable and healthy food system, Segovia's sustainable food strategy has the objectives of coordinating between the different administrations and promoting better administrative coordination.

The main objectives of this initiative are to better know what is produced and consumed and how they affect the local economy and depopulation, as well as promoting a more sustainable, local, healthy, and seasonal diet. The interview was conducted with the coordinator of the "Alimenta Conciencia" project.

With the aim of combating food insecurity and promoting awareness, this innovative initiative was launched in 2019. However, due to the far-reaching effects of the Covid-19 pandemic, the expected timeframe for completion of the project has been postponed from 2022 to the end of 2023. This delay was imposed due to major unexpected challenges posed by the pandemic, such as limited access to resources, restricted supply chains and the necessity to adjust project activities to ensure the safety of the participants.

According to the interviews conducted, the motivations about this project are the following: "I am aware of the importance of food in this area", which means to ensure a sustainable development; and: "I have a conception of the university academy as an information transfer", which means to contribute as much as possible to a better world for all.

These challenging objectives are being achieved through a carefully designed framework, consisting of four key steps:

Collaboration and Cooperation

With all social actors involved in the project. Recognizing that the success of such an initiative depends on collective efforts, our interviewee stressed out that meaningful engagement and partnerships are essential to the global impact of the project.

Moreover, a strong cooperation and collaboration are needed, the project's objectives would be ineffective and the potential impact would be diminished. By building a network of interconnected social actors, projects can leverage collective knowledge, pool resources, and create synergies beyond individual efforts.

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Increase organic production

Our interviewee envisioned the future of the "Alimenta Conciencia" project, oriented towards organic farming, since it offers many benefits, including environmental sustainability, improved soil regeneration and the production of healthier food for consumers.

Consumption

Our interviewee explained an important aspect of the "Alimenta Conciencia" project: local consumption, while encouraging citizens to give priority to products grown in the city or nearby, known as "Segovia Eco Kilo 0". Emphasize the purpose of increasing. In fact, there are many benefits to encouraging citizens to consume local products. First, it supports the local economy by directly contributing to the livelihoods of local farmers and producers, sustaining rural communities, and creating jobs.

Communication and education

Fundamental aspects of the "Alimenta Conciencia" project. Indeed, the project aims to raise awareness and encourage people to adopt sustainable practices, ensuring a more sustainable and healthier future for current and future generations. Indeed, various educational and educational activities such as school workshops and programs about building sustainable local food systems are realized.

Activities and challenges in Segovia

Current steps and activities carried out

The city of Segovia is deeply involved in a series of actions and activities that are aligned with the objectives of the "Alimenta Conciencia" project. These initiatives aim to promote a sustainable and healthy food system in and around the city (Table 2).

Table 2. Actions and activities developed by "Alimenta Conciencia".

	Actions and activities
1	3 local stores in Segovia
2	Working on sustainable gastronomic tourism
3	Working with restaurants
4	Organizing several awareness raising activities
5	Explore the distribution opportunities to develop food products
6	Working with students on food security and sustainable development projects

Table 2 clearly shows that the "Alimenta Conciencia" project aims to implement measures and activities to ensure a more sustainable and healthier food system. This was achieved by establishing three local shops in Segovia, which encouraged farmers in the province to sell their local produce in these shops and encouraged consumers to go to other markets. You'll be able to buy healthy local groceries without having to trade other closed towns around the city of Segovia.

In addition, "Alimenta Conciencia" is committed to ensuring sustainable gastronomic tourism by organizing various awareness-raising activities to increase local knowledge

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about local production for local consumption and to encourage continued support for initiatives of this kind. According to our interviewee, it is necessary to carry out many educational activities to students to clarify the importance of local healthy food.

Main challenges and problems encountered

The main challenge "Alimenta Conciencia" wants to ensure is mainly to share more knowledge and a more positive attitude towards these food systems. Another very important aspect is to change the way of consumption, switching to the consumption of local and neighborhood products (Segovia Eco Km0) instead of buying products in non-local stores outside the city.

Regarding the problems encountered during the project, the results from the conducted interview emphasized the lack of economic resources, which is above all a problem in driving action, but at the same time the lack of participants, people usually stressed that although they wanted to participate, they did not necessarily participate actively.

Finally, another aspect was highlighted and which is related to the war in Ukraine. In fact, our interviewee acknowledged that this has caused a global food crisis and led to higher product prices. However, it is necessary today to create a healthy and comfortable environment to provide people with local products.

"Estrategia Alimentaria de Valladolid"

The city of Valladolid has developed a process of reflection on the local agri-food system. This process of research and reflection has led to a participatory process for drafting a Food Strategy for the city, which will then be translated into an action plan. At the same time, the strategy has begun its implementation phase, which is currently underway.

This project was launched by the City Council of Valladolid, the Foundation Entretantos and the University of Valladolid, which has been joined in 2019 by MercaOlid and the VallaEcolid associations.

The principal objective of the project is to promote a space for collective transformation of the food system, work with other sectors for a more prolonged use of processed foods, as well as broadening the sales channels, opening a niche in collective catering and even the possibility of developing new allergen-free products and innovation. This would generate very positive learning, relationships and synergies for the local food system.

The interview was done with the councilor for the environment and the fourth deputy mayor of the City Council of the city of Valladolid (Ayuntamiento de Valladolid). Indeed, our interviewee mentioned that the project started on 2016, highlighting its main objectives, which are:

- "People who work the land are the local producers of Valladolid and the surrounding area of Castilla y León and can develop their activities in a politically responsible manner. »; and,
- "People can have access to food close to their homes, without having to travel (called "km 0")

Furthermore, our interviewee highlighted that the city of Valladolid and its surroundings have been developing a process of reflection on the local agri-food system over

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the last few years to start launching a participatory process for the development of a food strategy of its own and ensure new strategies such as "Valladolid's Agri-Food Strategy: participatory process".

Activities and challenges in Valladolid

Activities organized

Table 3 shows the main activities carried out by the "Estrategia Alimentaria de Valladolid" initiative:

Table 3. Main activities realized at the "Estrategia Alimentaria de Valladolid".

Main activities	Explication
Local markets	Organization of a local markets once a month that brings together several local producers in the city of Valladolid.
Pedagogical activities	Organize pedagogical activities within educational systems to ensure a well insertion and participation of children within the importance of eating healthy and locally and also to show them how to plant a certain fruit or vegetable
Encourage local consumption	Organize activities and workshops open to the public to explain the importance of eating locally for our health and wellbeing, as well as encourage them to start cultivating their own fruits and vegetable in their gardens and/or balconies etc., if possible.

In the words of our interviewee, the main activity organized is the setting up of local markets. This market will connect the community by showcasing the diversity of the city's products, creating a thriving and dynamic local market for vendors and visitors alike. The second activity highlighted is the organization of educational activities, with the aim of emphasizing the importance of good nutrition. These activities will enable students to learn more about good nutrition and the positive impact it has on our well-being. To achieve this, a number of practical exercises are organized, such as practical advice on meat planning from experts, nutritional information and healthy cooking techniques, together with how these can improve our health and our daily lives. The final main activity of Estrategia Alimentaria de Valladolid is to encourage local consumption in the community, by supporting local businesses and raising awareness of the benefits of buying local produce. For this, various events, open days and activities are organized to show local people the positive impact on the environment and its impact on our daily lives.

Main challenges encountered

Based on the interview conducted, it was possible to identify the main challenges and obstacles encountered by the project during its implementation and progress; these aspects are presented in Table 4 in greater detail.

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Table 4. Main challenges that "Estrategia Alimentaria de Valladolid" is facing.

Main challenges	Explication
Implementation of markets	Implement local places for markets that encourage local producers of the city of Valladolid and its surrounding to sell their products.
Share knowledge and awareness	Organize more activities to children to help them to know the importance of eating healthy and locally .
Own business	Putting a stain in a land bank so that local producers can take it to their business in Valladolid.
Local consumption	That people eat healthy and locally without worrying about the origin Encourage buying from the near province.

Table 4 clearly demonstrates that Valladolid City Council plans to set up permanent local markets where farmers can sell their produce to consumers. It will also encourage them to open their own businesses in the city, and to put a stain on a piece of land to make it easier for them to access property and sell their local produce to residents. In addition, the project aims to organize more activities to share knowledge and raise awareness, to highlight the importance of eating locally and to encourage local people to buy from local markets.

4 Discussion

From the in-depth analysis of the results presented above, there is clear evidence that there is an urgent need for action to create a healthy and sustainable urban environment that meets the needs of current and future populations.

According to the answers obtained from the survey, the results reveal an interesting pattern: the majority of respondents are familiar with the concept of urban agriculture, although this remains at a theoretical level. However, when it comes to practical implementation, there is a notable lack of active engagement. It is interesting to note that despite this gap, the respondents are clearly willing to participate in urban agriculture initiatives.

This finding highlights a challenging aspect of our current landscape: urban agriculture has inevitably become part of our daily lives, with widespread public awareness. Nevertheless, the limited dissemination of information about urban agriculture is evident: For example, most respondents claimed to have heard of urban agriculture, knew what it meant, but had never been directly involved in its projects. This is probably due to the fact that the term is relatively recent in their environment, and is barely used in everyday life in a way that is not commonplace. Furthermore, most of the respondents associate urban agriculture with sustainability and bioproducts, which is real, but less with personal well- being and health issues, which is essential, since urban agriculture is seen more as a public good for society than as an individual good [18].

Regarding food security, we can see that it is a term that is not well understood by our population, contrary to Urban Agriculture. Indeed, according to the survey outcomes, only half of the respondents understand exactly the definition of food security, while the other half have wrong answers, something that attracts our attention in this research,

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since it is a term that should be very common, given its importance and usefulness in our daily life.
In terms of information sources, the main source of public information on urban agriculture is social media, which is characteristic of today's generations. This means that this should be widely developed to be able to target a larger population and thus increase awareness on the subject contributing to a well sustainable future for the whole population. Indeed, according to the survey, the main obstacles to the implementation of urban agriculture initiatives are the lack of public knowledge about the mechanisms of implementation of these initiatives.
Secondly, from the interviews conducted, it emerged that the two Spanish initiatives had several points in common. Both projects are willing to ensure that people are properly educated and aware of the value of integrating the food sector into cities, we need to organize more and more activities and workshops along these lines [19].
In addition, small organizations and start-ups need to be supported, as they are the foundation of any future project [20]. Both initiatives also confirmed that there is a lack of local production and sales in the two cities of Segovia and Valladolid since that farmers don't have their own premises, so one of the fundamental actions that needs to be considered is to encourage them to open their own business and sell their local products to residents, encouraging the km0 consumption, instead of having to travel to another city [21].

5 Conclusion

Urban agriculture has become a key research area because of its relevance to current challenges and future considerations. The changing living conditions, including drought, climate change and increasing urbanization, require a closer look at the role of urban agriculture, where a number of studies underline the importance of urban agriculture in reducing the effects of climate change and boosting food security in urban areas, by guaranteeing food self-sufficiency, reconnecting with nature and acquiring new knowledge in this field. In this regard, the incorporation of agricultural practices in urban spaces has been recognized as a strategic approach to promoting sustainable urban development.
Furthermore, the involvement of the food sector in cities has become a topical issue [1]. In the current context, increasing awareness of the importance of urban agriculture and ensuring food security is of fundamental importance [11]. According to the results of the questionnaire and the interviews carried out above; to achieve this effectively, the following points need to be given due consideration:

- Education and awareness: It is necessary to implement educational programs and awareness campaigns that highlight the importance of urban agriculture and its role in achieving food security. Examples include educational initiatives in schools, community workshops and public awareness events to disseminate information and promote understanding among the population.
- Encourage the establishment of local shops: The creation of shops run by local producers can make a significant contribution to the development of urban

ISBN 978-9930-617-71-7

agriculture and enhance food security. To achieve this, it is important to ensure financial support as well as to provide training and technical assistance, as well as stimulating new calls for projects, to encourage and support local producers to establish independent local shops.

- Ensure urban planning of cities by experts: Expert urban planning is crucial for the successful integration of urban agriculture and the creation of sustainable urban environments. To achieve this efficiently, urban planning needs to draw on the expertise of urban planners, architects, designers and other skilled professionals who have knowledge and experience in incorporating agriculture into urban spaces, since collaboration between these professionals and the stakeholders is essential for developing inclusive and sustainable urban plans.
- Nowadays, we live in a world concerned with the mental health and well-being of individuals, including the growing population in modern urban areas. There is a growing awareness that the connection with nature, which can be reduced in urban areas, contributes significantly to our mental health and well-being, hence the interest in reconnecting individuals with nature, to keep this connection that can only bring good to humans.

Finally, this article allowed us to gain a partial understanding of people's perception of urban agriculture, its effects and its contribution to the population, which also enabled us to ensure a deeper understanding of this concept with food security and autonomy. Furthermore, the interviews highlighted several common points, such as the desire to ensure that people are properly educated and aware of the value of integrating the food sector into cities, along with appropriate organization of activities and workshops. In general, the responses from the interviews with the managers of the two urban agriculture projects in Spain and the worldwide pilot survey were positive in terms of knowledge of the subject, but it still needs to be developed to make it more accessible and understandable to everyone, such as encouraging small organizations and start-ups linked to local production.

Acknowledgments. This research was funded by the European Union supporting this work through the FUSILLI Project (H2020-FNR-2020-1/CE-FNR-07-2020), grant number No. 101000717; website: https://fusilli-project.eu/. Ouiam Fatiha Boukharta has been financed under the call for University of Valladolid 2021 predoctoral contracts, co-financed by Banco Santander.

Disclosure of Interests. The authors declare that they have no competing interests.

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ISBN 978-9930-617-71-7

Ciudades Inteligentes Desde La Perspectiva De Los Sistemas Regionales De Innovación

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Abstract. El desarrollo sostenible es un reto global, impulsado por el cambio climático, la demografía, la calidad de vida de la población, la tecnología y otros. Buscando dar respuesta a estas problemáticas, nace el concepto de ciudad inteligente, que, comprendida desde el Sistema de Innovación, pretende fomentar el desarrollo regional, el mejoramiento de la calidad de vida de sus ciudadanos a través del uso de tecnologías y la generación de políticas que fomenten la investigación, el desarrollo y la innovación en los territorios. Para integrar estos conceptos, se analizaron artículos científicos relacionados con las ciudades inteligentes y los sistemas regionales de innovación, así como la búsqueda de diferentes índices sobre ciudades inteligentes, que permitiera seleccionar aquellas unidades territoriales más eficientes y allí realizar el análisis de sus sistemas de innovación. Finalmente se identificó que la literatura no suele relacionar ambos conceptos, debido al bajo número de publicaciones por año, también se identificó una fuerte relación entre el concepto de triple hélice, Universidad, Empresa y Estado, las ciudades inteligentes y las tipologías que tienen las ciudades para adoptar tecnología (Restrictivo, reflexivo, Racionalista y Critico), lo que direcciona la manera de analizar las ciudades según su capacidad de producir o adoptar tecnología.

Keywords: Cuidad Inteligente, Sistema Regional de Innovación, Triple Hélice, Smart City.

1 Introducción

Existe una continua preocupación por la sostenibilidad de las ciudades [1–4], debido a que la población en ellas continúa presentando un crecimiento demográfico exponencial [5, 6]. De ahí que, en 1959 aproximadamente el 30% de la población mundial vivía en las ciudades, en la actualidad ha alcanzado un 56% y para 2050 se espera alcanzar un 70%, lo que indica que 7 de cada 10 personas habitarán espacios urbanos, es decir que 6.3 billones de habitantes estarían aglomerados en las zonas urbanas del planeta [5, 6]. Por otro lado, en 2016 las ciudades aportaron aproximadamente el 70% del producto interno bruto (PIB) mundial, generando más del 60% del consumo de energía, 70% de la producción de residuos sólidos, y 70% de las emisiones de gases de efecto

ISBN 978-9930-617-71-7

invernadero; evidenciando el impacto que tienen de las aglomeraciones urbanas en el riesgo ambiental y sostenibilidad del planeta [7].

Estas problemáticas han permitido identificar la necesidad de políticas y tecnologías que impulsen la construcción de urbes sostenibles y que contribuyan al mejoramiento de la calidad de vida de sus habitantes [8–10]. De ahí que, se hayan generado diversas alternativas orientadas al desarrollo social, ambiental y económico de los territorios; a través de sistemas tecnológicos denominados ciudades inteligentes; los cuales permiten analizar el desempeño desde diferentes factores como gobierno, medio ambiente, economía, entre otros [3, 11, 12], o mediante el análisis de los Sistemas Nacionales y Regionales de innovación, inmersos en estas [13–16]

Por otra parte, la investigación sobre ciudades inteligentes se aborda desde la perspectiva de ciudades interconectadas [17] o a través de las interacciones entre los actores del Sistema Regional de Innovación (SRI) [18–21]. De ahí que, los indicadores o métricas de ambos sistemas no concuerden, ni se entrelacen, ocasionando divergencias a la hora de realizar mediciones. Un ejemplo de esto es que desde la interconectividad se miden factores como: la velocidad de tránsito, el consumo de energía, el acceso a internet, entre otros, mientras que desde los sistemas de innovación evalúan la producción científica y tecnológica, y/o las capacidades de innovación; sin embargo, aunque ambas perspectivas parecen ser diferentes, se orientan a un mismo fin.

De acuerdo con esto, algunos autores presentan las ciudades inteligentes como la evolución de los Sistemas de Innovación, o como el impacto de estos sobre las ciudades en donde las capacidades de aprendizaje, investigación y desarrollo generan una nueva perspectiva de políticas de ciudad; creando así oportunidades para el desarrollo local, a través de la incorporación de la tecnología y la cooperación entre los agentes del Sistema Regional de Innovación (SRI) [15, 22, 23]. De ahí que, una de las problemáticas identificadas sea la falta de claridad del papel de los Sistemas Regionales de Innovación en la construcción de las ciudades inteligentes, considerando los retos que afrontan los territorios al momento de trazar metas claras que permitan el desarrollo de este concepto.

2 Marco Teórico

2.1 Sistema Regional de Innovación (SRI)

Este concepto ha evolucionado a partir de la noción de Sistema Nacional de Innovación (SNI), para ajustarse a las problemáticas y características de los territorios. De ahí que, diversos autores definan SRI, tomando características del SNI.

De acuerdo con esto, Cooke [24], define SRI como un conjunto de subsistemas de generación y explotación de conocimiento que interactúan y se vinculan a otros sistemas a nivel regional, nacional y global, en busca de comercializar de nuevo conocimiento.

Por otro lado, Llisterri y Pietrobelli [25], lo definen como “la infraestructura institucional de apoyo a la innovación y su difusión que se desarrolla en la estructura productiva de una región” (p. 105). Así mismo, este término se basa en la idea de que el proceso de innovación y aprendizaje es esencialmente “social”, al involucrar la interacción

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de las empresas, agencias de promoción de la innovación, instituciones académicas y centros de investigación de un territorio; mostrando de esta forma. De ahí que, ese proceso no se genere únicamente al interior de estas instituciones y que la acumulación del conocimiento obtenido por los diferentes actores pueda contribuir a que las características de un territorio, redes y capacidades específicas influyan en su desempeño innovador [26, 27].

Es así como, el término de SRI ha sido vinculado con los conceptos de clúster territorial, aglomeración productiva local, "distritos industriales" y "polos de crecimiento". Lo que muestra una visión desde diversos enfoques, sin dejar de dar relevancia a los factores: proximidad espacial, externalidades, cultura e identidad regional y procesos de aprendizaje colectivo [27]. De ahí que, [28], indique que las regiones, especialmente cuando han desarrollado clúster y una administración que apoya a la empresa innovadora, presenten comunidades más relevantes en cuanto los intereses económicos, definición de actividades económicas propias y aprovechamiento de vínculos y sinergias entre estos actores.

Lo que nos permite deducir que, dentro del SRI cada agente tiene un rol definido y las relaciones generadas entre los actores de este, permiten a los territorios desarrollar un trabajo colaborativo en pro de un objetivo común, que para este caso se enfoca en el desarrollo de políticas y estrategias que contribuyen a la consecución de territorios inteligentes y sostenibles, gracias a la co-creación de soluciones desde lo local a lo regional [29–31].

2.2 Concepto de ciudad inteligente.

La investigación sobre las ciudades inteligentes combina aproximaciones desde la planeación espacial [32, 33], geográfica, económica [34, 35] economías del conocimiento [33, 36, 37], tecnología o innovación urbanas[15, 35, 38, 39], marketing de las ciudades [40], entre otros, que se centran en la calidad de vida para sus ciudadanos. Sin embargo, dichos estudios se encuentran en una etapa temprana de investigación, de ahí que el concepto de ciudad inteligente se plantee desde diferentes perspectivas [41].

De acuerdo con esto, existen diferentes corrientes para analizar el concepto de ciudad inteligente, la tecnocentrista y la antropocentrista [42], adicionalmente, se explican desde diferentes clúster (cúmulos de conceptos): Smart governance (refiriéndose a la participación), Smart economy (relativo a la competitividad), Smart human capital (relacionado con las personas), Smart living (refiriéndose a la calidad de vida) y Smart environment (relacionado con los recursos naturales) [21], o según los indicadores de ciudad: la economía, el capital humano, la cohesión social, el medio ambiente, la gestión pública, la gobernanza, la planificación urbana, la proyección internacional, el transporte, la tecnología y la movilidad [43]. Partiendo de esto, se han generado una serie conceptos sobre ciudad inteligente desde la perspectiva de diversos autores que integran algunos de estos elementos en ellos.

Para Leydesdorff & Deakin [44], las ciudades inteligentes son "espacios dinámicos se puedan entender mejor como espacios de tecnologías de información y comunicación (TIC) omnipresentes, donde el conocimiento es clave para los sistemas regionales de innovación, creando la noción de ciudades inteligentes" (p. 53).

Ahora, aunque si bien las TIC juegan un papel relevante en la visón y construcción de ciudad inteligente, el capital humano también es altamente relevante en la

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concepción de esta. De ahí que, Kummitha & Crutzen [42], hagan referencia a la Escuela de pensamiento racionalista o pragmática, argumentando que:

> *...Las ciudades inteligentes tendrían que enfocarse en las personas y sus capacidades más que solo concentrarse en las TIC o la tecnología. Los académicos de esta escuela imaginan la construcción de ciudades inteligentes impulsadas por la comunidad y argumentan que la mejora de las habilidades y capacidades de las comunidades daría como resultado su creación activa y el uso de tecnologías. Por lo tanto, se requiere un mecanismo integrador que medie la interacción humana con la tecnología (...) (p. 46).*

Komninos [45], las presenta como territorios con gran capacidad de aprendizaje e innovación, construidos en la creatividad de su población, sus instituciones de generación de conocimiento y su infraestructura digital para la comunicación y la gestión del conocimiento.

Ahora, otro aspecto a considerar dentro del concepto de ciudad inteligente son las personas y comunidades como parte fundamental en la construcción de estas. Cambiando así la perspectiva que da mayor relevancia a la comprensión de los aspectos tecnológicos y políticos, que a la participación integral de su sociedad civil en la propuesta soluciones a los problemas y la consecución de la visión de ciudad que se desea conseguir. De esta forma, los proyectos de ciudad inteligente generan un impacto en la calidad de vida de los ciudadanos y buscan fomentar ciudadanos más informados, educados y participativos. Además, las iniciativas de ciudades inteligentes permiten a los miembros de la ciudad participar en el gobierno y la gestión de la ciudad, y convertirse en usuarios activos, que, si son actores clave, pueden tener la oportunidad de comprometerse con la iniciativa en la medida en que puedan influir en el esfuerzo para ser un éxito o un fracaso [46].

De ahí que, son pocos autores los [19, 47, 48] que han abordado el tema de ciudad de inteligente desde una perspectiva de Sistema Regional de Innovación y aún más pocos los que han propuesto indicadores que integren ambos conceptos.

3 Metodología

Este artículo es resultado de una investigación de tipo cualitativo, descriptivo no experimental, en donde se identifican las características de los Sistemas Regionales de Innovación y su relación con las ciudades inteligentes.

De acuerdo con Hernández Sampieri, Fernández Collado, & Baptista Lucio [49], las investigaciones no experimentales pueden ser clasificadas en transaccionales y longitudinales. Partiendo de esto, la investigación tuvo un diseño transaccional descriptivo el cual busca recolectar datos de las diferentes variables y categorías para comprender los componentes del objeto de estudio, sin pretender buscar su correlación.

Así mismo, contó con un diseño documental desarrollado en dos etapas: la revisión y el análisis documental, para la construcción de las teorías que soporten el problema. De acuerdo con esto, la etapa de revisión se basó en las fuentes de información disponibles más relevantes (Scopus y Science Direct), en el sentido de que se consideraron trabajos de investigación sometidos a revisión de pares, así como fuentes de

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información adicionales sobre temas relacionados con el objeto de estudio.

Por otro lado, para la etapa de análisis se seleccionaron los artículos según su contenido y pertinencia acorde al objeto de estudio, lo que permitió la comprensión mediante la construcción y visualización de redes bibliométricas con ayuda de la herramienta VOSviewer.

4 Resultados

4.1 Revisión bibliográfica

Se realizó una búsqueda de información, utilizando los conceptos Ciudad Inteligente y Sistemas Regionales de Innovación en los idiomas español e inglés y sus formas plural y singular, en las bases de datos SCOPUS y Science Direct, lo que permitió generar una perspectiva sobre el concepto de ciudad inteligente y su contextualización con el objeto de investigación propuesto, entregando los resultados, como se observa en la Tabla 1. Ecuaciones de búsqueda y número de resultados.

Table 1. Ecuaciones de búsqueda y número de resultados.

Fuentes	Ecuación de búsqueda	Número de resultados
Scopus	(TITLE-ABS-KEY (*"smart city"* OR *"Smart cities"*) AND TITLE-ABS-KEY ((*"innovation system"* OR *"regional innovation system"* OR *"national innovation system"* OR *"TRIPLE HELIX"*)))	81
Science Direct	Find articles with these words ("innovation system" OR "regional innovation system" OR "national innovation system" OR "TRIPLE HELIX") With words in title, abstract or keywords "smart city" OR "Smart cities"	146

Fuente: Elaboración Propia.

Analizando los datos de coocurrencia de palabras, en el software VOSviewer, se obtiene que existen relaciones entre los constructos de Ciudad inteligente y el Sistema Regional, algunas de sus relaciones son los nuevos modelos de ciudad, gobernanza y sostenibilidad.

En total se pudieron analizar 6 clúster de palabras, en verde se pueden ver palabras relacionadas con el ecosistema de ciudad inteligente, Sistemas de innovación, planificación urbana, gobernanza, planeación urbana, entre otros; En rojo, relaciones sociotécnicas como la calidad de vida, la internet de las cosas, la analítica de big data, las TIC y la sostenibilidad; en azul se aprecian elementos de investigación emergentes como la cuádruple hélice, el desarrollo urbano sostenible, la innovación urbana, open innovation entre otros; en amarillo se observan temas de gran importancia como la gestión del conocimiento, los sistemas regionales de innovación, la economía del conocimiento y triple hélice. En esta, también se observa una temporalidad de los temas entre

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el 2012 y el 2017. Inicialmente se habló de Triple hélice, cultura, nuevos modelos de relaciones sociales, isla de la innovación, entre otros, pero actualmente se está hablando de Gobernanza, Internet de las cosas, infraestructuras digitales, sistemas de gestión de datos, entre otros.

Mediante un análisis de coautores se validó la actividad científica y las relaciones entre ciudad inteligente y Sistema Regional de innovación. Es así como, los principales autores que realizan estudios que relacionen estos temas son Dameri, Etzkowitz, Leydesdorff, Kummitha, Deakin y Lombardi. Estos autores han trabajado acerca del desarrollo de las ciudades inteligentes desde la perspectiva de los SRI y la relación de sus actores, siendo los precursores en esta temática y aportando conceptos relevantes en el estudio de este tema.

4.2 La perspectiva de las ciudades inteligentes desde los sistemas regionales de innovación.

Los constructos de Ciudad Inteligente y de Sistema de Innovación pretenden simplificar un concepto complejo de desarrollo regional, orientado a la eficiencia del sistema y la promoción de la innovación por medio de políticas que fomentan la investigación, el desarrollo y la innovación en un territorio. De ahí que, sea natural que la innovación genere oportunidades laborales, incremento de la productividad y creación de valor en las empresas, contribuyendo al desarrollo en los países [50–52]. Sin embargo, el concepto de ciudad inteligente promueve la eficiencia de las ciudades, mejorando la calidad de vida y las condiciones de los ciudadanos a través del uso de la tecnología.

De acuerdo a esto, se observa que la literatura científica que relaciona ambos conceptos es poca, ya que de los 227 artículos analizados solo 26 hablan sobre ambos temas, y de allí 31 son casos explicativos del fenómeno abordando el tema en ciudades particulares como Barcelona, Viena, Seúl, San Francisco etc., Por otra parte, la revisión permite resaltar que los artículos hablan poco del sistema de innovación, haciendo mayor referencia a los factores de una ciudad innovadora, aunque en su mayoría no conceptualizan las relaciones existentes en las ciudades para generar Investigación, Desarrollo e innovación. Es decir, en la búsqueda se identificaron algunos artículos tecnocentristas, orientados al uso de la robótica, el internet de las cosas, el big data, la recolección de datos en tiempo real, entre otros, que no son de interés para este artículo. Por otra parte, los resultados obtenidos de la revisión bibliográfica científica y otros referentes, se han clasificado las categorías en Modelos conceptuales sobre las ciudades inteligentes, la medición y desempeño de las ciudades, casos y ejemplos de ciudades que son exitosas como ciudades inteligentes, abordan en general el concepto de ciudad inteligente, abordan exclusivamente los sistemas de innovación, se abordan ambos temas como la ciudad inteligente y el sistema de innovación y finalmente algunos se

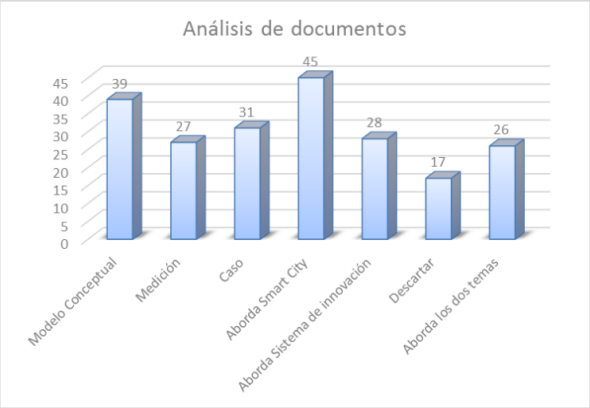
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descartan.

Fig. 1. Análisis de artículos. **Fuente:** Elaboración propia.

Luego de la revisión de los 26 documentos, solo 7 artículos presentaron una conceptualización que incluye el modelo de Sistema de Regional de Innovación en la concepción de la ciudad inteligente, como se puede observar en la **Tabla 2.** La cual recopila la perspectiva de los autores sobre ciudad inteligente en torno a los SRI, posibilitando comprender diferentes concepciones en torno a la visión de ciudades inteligentes y sus componentes.

Table 2. Ciudades inteligentes desde la perspectiva de los SRI



Título	Autores	Discusión
The Triple-Helix Model of Smart Cities: A Neo-Evolutionary Perspective	[53]	Demuestra cómo la triple hélice habilita el estudio de economías basadas en conocimientos soportado por la evolución de las ciudades como componente clave para un sistema de innovación. Se analiza desde la creación de riqueza por las empresas, la generación de conocimiento por las universidades y el uso de la democracia por la sociedad civil. Presenta las tecnologías de la comunicación como instrumento para incrementar la comunicación de manera ubicua entre los actores del sistema de innovación.
Smart Cities (inter) Regional Academic Network (SCRAN): The network	[54]	Los modelos de triple hélice hablan constantemente de las redes que se tejen entre los actores del sistema de innovación, sin embargo, no abordan temas de infraestructura y componentes que esta debe tener, por tanto, este artículo aborda temas de infraestructura tecnológica para las operaciones del sistema de innovación. El modelo busca sistematizar las buenas prácticas de las ciudades en una **SCRAN** wiki. Finalmente, presente una estructura que permite comprender los niveles de participación de los actores

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		Universidad Empresa Estado en el desarrollo del capital intelectual, la creación de riqueza y la definición de reglamentaciones y en nivel de ciudades y regiones.
Modelling the smart city performance	[10]	Clasifica las ciudades en 4 niveles, las ciudades emprendedoras, las pioneras, las habitables y las conectadas, analizando los indicadores de ciudades en dos dimensiones, ciudades inteligentes y triple (cuádruple hélice). Para la ciudad inteligente se utiliza el siguiente clúster: Gobierno, economía, capital humano, vida y medio ambiente. Para la triple hélice analiza: Universidades, Gobierno, sociedad civil e industria. Con la ayuda de expertos se realiza una batería de indicadores para las ciudades teniendo en cuenta la triple hélice y el desempeño de la ciudad. Se realiza un proceso analítico en red para determinar los componentes principales del modelo de desempeño.
An advanced triple helix network framework for smart cities performance	[55]	Se soporta en el modelo **SCRAN** para evaluar si la región del mar del norte es inteligente. En un marco jerárquico analítico permite que el modelo de red en cuestión capture la triple hélice avanzada de las ciudades inteligentes y verifique si la transformación que esto introduce se basa no solo en la creación de riqueza, sino también en la gobernanza de sus sistemas de innovación regionales subyacentes.
Smart cities and the internet: From mode 2 to triple helix accounts of their evolution	[56]	La perspectiva de la neo-evolución de las ciudades que incluye las ciudades inteligentes y el sistema de innovación, más el rol del social media en la cultura. También esta neo-evolución indica un crecimiento que no es de producción espontanea, basada en sectores, o de crecimiento regional, sino como la producción de situaciones sociales, académicas y corporativas. Este modelo primero genera cultura y capital intelectual para luego impactar en la riqueza. Para generar la cultura y el co-diseño de las ciudades se requiere información que proporcionarán las tecnologías electrónicas y de comunicaciones, generando inteligencia colectiva.
How do we understand smart cities? An evolutionary perspective	[57]	Este artículo hace una revisión de modelos conceptuales de ciudades inteligentes y los clasifica en 4 categorías, que se denominan 3RC (Restrictivo, reflexivo, Racionalista y Critico) El modelo Racionalista busca en el sistema de innovación el desarrollo de soluciones y así co-crear tecnologías para la eficiencia de las ciudades. Se centra en las capacidades humanas.
Smart City implementation and discourses: An integrated	[58]	Este artículo presenta una conceptualización al respecto de los modelos tradicionales de ciudades inteligentes, pero la importancia de este radica en la pregunta definitiva ¿Cómo implementar las políticas de

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conceptual model. The case of Vienna	una ciudad inteligente? Y allí surge el como respuesta el sistema de innovación. Para la construcción de la ciudad inteligente de Viena se invitan a los Stakeholders de cada subsistema: Actores de la Política, El conocimiento, lo económico y lo social, quienes priorizaron las dimensiones y proyectos que harán parte de las soluciones de esta ciudad.

Fuente: Elaboración propia.

5 Discusión

5.1 Sistemas Regionales de Innovación: Motor del Desarrollo Urbano

Este concepto ha evolucionado a partir de la noción de Sistema Nacional de Innovación (SIN), para ajustarse a las problemáticas y características de los territorios. De ahí que, diversos autores definen SRI, tomando características del término SNI. De ahí que, los sistemas regionales de innovación (SRI) sean considerados como redes de actores (Empresas, universidades, centros de investigación, gobierno, sociedad civil), instituciones (Marcos regulatorios, políticas públicas, sistemas educativos) y flujos de conocimiento (Transferencia de conocimiento, aprendizaje, colaboración) que interactúan para generar y difundir innovaciones. Estos sistemas desempeñan un papel fundamental en el desarrollo económico y social de las regiones, a través de la existencia de vínculos entre las instituciones centrales y otros factores importantes que interactúan con estas creando sistemas regionales de innovación que funcionan con éxito [24, 25, 27, 59].

Ahora, los actores tienen una alta importancia, y se convierten en impulsores de estos sistemas, por las relaciones generadas entre ellos y sus efectos en la cooperación exitosa, proporcionando la base para los procesos innovación en estos territorios. Así mismo, el análisis de los componentes de SRI se puede enfocar desde diferentes modelos que han sido propuestos para analizar las interacciones y su complejidad, resaltando las propuestas de [60]; el Modelo de Triple Hélice [61, 62] y el Modelo COTEC [63].

5.2 Relación entre ciudades inteligentes y SRI

Las ciudades inteligentes y los SRI se encuentran estrechamente relacionados. Los SRI pueden facilitar la creación y difusión de innovaciones en el contexto urbano, mientras que las ciudades inteligentes pueden servir como motores de innovación regional, representando una oportunidad única para impulsar el desarrollo sostenible y equitativo de las ciudades. Al combinar las ventajas de ambos enfoques, posibilitando crear entornos urbanos más innovadores, eficientes y resilientes, donde los ciudadanos puedan disfrutar de una mejor calidad de vida[64–66]. De acuerdo con lo anterior, esta relación se manifiesta a través de:

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Fig. 2. Relación entre Ciudades Inteligentes y SRI

La **Figura 2.** Permite visualizar La relación entre ciudades inteligentes y SRI. De ahí que, la convergencia entre ambos conceptos represente un paradigma emergente en el desarrollo urbano y regional. Esta sinergia se traduce en un entorno propicio para la generación y difusión de conocimiento, la creación de valor y la mejora de la calidad de vida de los ciudadanos, a través de la co-creación de soluciones, el fortalecimiento de los ecosistemas de innovación y la mejora de la competitividad regional.

5.3 La Interrelación en el Contexto Latinoamericano

La construcción de ciudades inteligentes en América Latina representa una oportunidad única para impulsar el desarrollo sostenible y mejorar la calidad de vida de los ciudadanos. De ahí que, este proceso se encuentra en una etapa inicial, con importantes avances en algunos países y ciudades de la región; evidenciando la existencia desafíos comunes como la brecha digital, la desigualdad social y la falta de inversión en infraestructura tecnológica. Lo que permite identificar la necesidad de adaptación del concepto a las realidades locales, considerando factores como la diversidad cultural, la desigualdad social y las limitaciones presupuestarias, entre otros [25, 67–71].
En conclusión, es fundamental fortalecer los sistemas regionales de innovación para garantizar la sostenibilidad de estos. A través de la colaboración entre los diferentes actores, la inversión en investigación y desarrollo, y la implementación de políticas públicas adecuadas, América Latina puede convertirse en una región líder en la construcción de ciudades inteligentes y resilientes.

6 Conclusiones

El análisis de la literatura efectuado en este artículo permitió observar lo incipiente del tema de ciudad inteligente desde la perspectiva del Sistema Regional de innovación (SRI). Esto evidencia la necesidad de seguir trabajando el tema para lograr comprender la relación de dichos conceptos y sus componentes, así como el rol de sus actores. Otro aspecto, a considerar es la relación entre los conceptos analizados y la importancia de la cooperación de sus actores para lograr mejorar la calidad de vida de sus ciudadanos. Adicional a la divergencia entre estos conceptos entorno al enfoque que le dan los autores y la priorización de la tecnología como principal camino en la construcción de una ciudad inteligente.

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Ahora, los artículos analizados evidencian la posibilidad de visualizar una ciudad inteligente (Smart City) desde el concepto de SRI. Donde los actores de este sistema tienen roles bien definidos que pueden contribuir ampliamente en la construcción de Smart City desde sus actividades cotidianas, siempre que estos interactúen y generen relaciones enfocadas a una misma visión de ciudad. Por otra parte, una ciudad inteligente es constantemente relacionada con el factor tecnológico, que, aunque juega un papel fundamental en la concepción de esta no lo es todo. De ahí que, actores como la universidad, la empresa y el estado que hacen parte del SRI, pueden generar sinergias enfocadas en dar solución a las problemáticas de un territorio, para buscar el mejoramiento de la calidad de vida de sus habitantes y el desarrollo de este.

Por último, los actores del SRI al desarrollar actividades que contienen procesos de investigación, desarrollo e innovación contribuyen a lograr una visión de ciudad inteligente sostenible en el tiempo, haciendo necesario involucrar a los habitantes en el proceso de construcción de ciudad. Acorde a esto, es vital considerar el estado actual de los SRI en Latinoamérica y el fortalecimiento de las relaciones y roles de sus actores en la búsqueda no solo de ciudades sino de territorios inteligentes y sostenibles, que contribuyan activamente al mejoramiento de la calidad de vida de sus habitantes y la disminución de brechas socioeconómicas presentes en nuestros estos territorios.

Agradecimientos. Agradecemos a el ITM por su apoyo para la presentación de esta ponencia.

Divulgación de intereses. Los autores no tienen conflictos de intereses que declarar que sean relevantes para el contenido de este artículo.

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ISBN 978-9930-617-71-7

Technologies for Global Equity: An Approach from Community Groups, using AI, and IoT

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Summary. The paper proposes the use of technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT) to address inequality, focusing on the active elderly population needs. It emphasizes the importance of legally protected rights, such as public safety, health, and territory habitability . These rights are not applied to older adults in many countries, since there is a poor relationship between the State and the citizen´s needs.
Innovation in community groups management is proposed using AIoT technologies as an effective strategy to improve the political, social, and territorial participation of the elderly and, consequently, of the rest of the community.
Successful case studies from several countries are presented, where neighborhood associations have played a crucial role in improving urban quality of life. It can be concluded that integrating these technologies can be effective for fostering participatory and sustainable development in countries with deficient public policies.
In essence, the paper is a descriptive analysis from a qualitative-representative approach, which is supported by a methodological work of case study review, analysis of technological advantages, and the development of proposals and recommendations.

Keywords: Community Groups, AIoT Technologies, Active Elderly

1 Introduction

Social and territorial inequality is a persistent challenge in many countries around the world, particularly affecting the active elderly population. This group faces difficulties in accessing legally protected rights such as public safety, health, and the habitability of the territory. In many countries, the relationship between the state and the private sector is fragile, exacerbating the oppression of basic needs for civil society and devaluing the territory.

One of the focal points of this paper is to reflect on how to preserve the protection of these legally protected rights for the elderly population. The paper approaches this issue from the perspective of fair compensation by the state, in line with the obligation to settle the labor and tax contributions this group has made throughout their lives.

ISBN 978-9930-617-71-7

The paper proposes an innovative solution through the integration of technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT) in the management of community groups. These technologies, collectively referred to as AIoT, can significantly improve citizen participation and informed decision-making, contributing to more efficient and satisfactory community and territorial management.

The proposal focuses on revitalizing community groups, especially in countries with deficient public policies, so that they can serve as effective platforms for political, social, and territorial participation. The implementation of AIoT can transform these organizations into hubs of innovation and well-being, strengthening the social fabric and improving the quality of life for all members, especially the elderly.

In summary, the integration of AI and IoT in community groups offers a promising pathway to address inequality and foster sustainable, participatory development in diverse communities.

2 Historical Context

One of the widely observed initiatives worldwide regarding "economic and value-based development from the territory" is the protection and care of specific neighborhoods by the local community. This communal behavior arises for various reasons, such as the preservation of historic areas, picturesque neighborhoods, traditional product markets, tourist hubs within residential enclaves, or territories designated as World Heritage Sites. Examples of this practice can be found in resort towns like Piriápolis and Punta del Este in Uruguay; the San Telmo and Puerto Madero neighborhoods in Buenos Aires, Argentina; the Raval district in Barcelona, Spain; the neighborhood culture of Morrino in El Morro, Iquique, Chile; and central Paris neighborhoods like Saint-Germain-des-Prés, often referred to as "the chicest neighborhood in Paris."

These "neighborhood" territories maintain a shared culture and lifestyle among residents, which defines how people inhabit these spaces. However, this is not a public policy initiative. Therefore, it should not be confused as a strategy for the economic and value-based development of the territory by the state. What is essential in this paper, however, is that this "neighborhood policy" represents the residents' particular approach to how the territory is configured and lived.

In the same vein of territorial expression, community groups, also known as neighborhood associations, have evolved significantly over time in different regions of the world. These local organizations are formed within neighborhoods, and their main objective is to represent the interests of the residents, as well as to address the issues that affect the community as a whole.

In addition to the above, it is crucial to recognize the value contribution of the active elderly in neighborhood associations. This demographic plays a vital role in the structure of the community and territory, helping to create a reference system that counteracts the disassociation and individualization promoted by social networks—phenomena that particularly affect children, adolescents, and young adults in the context of "surveillance capitalism." The participation of the elderly fosters the creation of a 'neighborhood community' that can mitigate the breakdown of the social fabric and prevent

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the prioritization of image and consumption at the expense of collective well-being and the underdeveloped state, dominated by global corporate interests.

Some experts argue that social media applications impact citizen behavior. For instance, it has been found that "Facebook can influence user behavior and emotions without them being aware of it." In this context, neighborhood associations and the value contributed by active elderly individuals should serve as effective countermeasures to represent the interests of the local territory.

The following Table 1 summarizes the evolution of neighborhood organization, which ultimately sustains the structure and social fabric that form a country and its state. Some countries show a promising future for this type of organization, while others have room for improvement. What is evident in all of these cases is that the influence of Artificial Intelligence (AI) and the Internet of Things (IoT) can significantly strengthen social cohesion and the quality of territorial habitability.

State	Description
Ancient Greece	The concept of neighborhood groups has its roots in Ancient Greece with the **"Athenian Demo"**. This was the basic administrative division in Athens, established around 500 BCE. Its goal was to organize the territory based on neighborhood rather than kinship relationships. This structure was fundamental to the development of democracy, shifting power from the aristocracy to the citizens. [3]
Japan	Neighborhood associations, known as **"Chonaikai"** or **"Chounaikai"**, have a long tradition. They were formalized in 1940 [4], These organizations play a crucial role in community life, from disaster preparedness to the management of public services such as garbage collection. During World War II, the **"Tonarigumi"** (neighborhood associations) were also used for public safety. In Japan, records of neighborhood associations focused on cooperation date back to before the 17th century. More specifically, in the publication **"The Rise of Modern Japan,"** the author states, "Mutual aid neighborhood associations had existed in Japan since before the Edo Period. [5]
Chile	In Chile, neighborhood associations have a history that dates back to the colonial era, when cities were governed by **"Cabildos"** (local councils) [6]. The legal formalization of these organizations came in 1968 during the government of Frei Montalva. Neighborhood associations in Chile focus on citizen participation and local representation, although they face challenges such as bureaucratization and dependence on municipal governments.
Spain	Spain was one of the first countries to legally formalize neighborhood associations. During the Second Republic in the 1930s, movements such as the **Official Association of Neighbors-Tenants of Madrid** emerged. Under Franco's dictatorship, the **1964 Association Law** allowed the creation of neighborhood associations like **"Palomeras Bajas"** in Vallecas, Madrid. These organizations focused on improving living conditions and ensuring the safety of residents. [7]
Singapore	In Singapore, the **Community Development Councils (CDC)** were established in 1997 to strengthen local social infrastructure and promote social resilience. The CDCs organize community programs and provide social assistance with the help of government grants. These councils encourage citizen participation and

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	community development, working closely with citizens, businesses, and organizations. [8]
Dinamarca	Denmark has a long tradition of citizen participation and local democracy through **"beboerforeninger"** or neighborhood assemblies. These organizations play an important role in urban planning and community development. Neighborhood assemblies manage government funds for community projects and promote social cohesion and quality of life in the neighborhood. [9]

Tabla 1. Evolución Histórica y Funcional Agrupación Vecinal en diversos países. Elaboración propia.

Various authors agree on the importance of neighborhood associations in relation to territorial management. In Ramírez [10], They consider that "*the role played by neighborhood associations in improving urban quality of life and as intermediaries between residents and local governments*" is essential for enhancing the quality of life in large cities. Furthermore, the potential value contribution of the active elderly, along with their ability to provide or serve as a reference, helps counterbalance the low value contribution currently observed in regional, municipal, and/or local governments worldwide.

In summary, the evolution of neighborhood associations shows how these organizations have been fundamental for social cohesion and community development in different historical and geographical contexts. From Ancient Greece to modern Denmark and Singapore, neighborhood associations have adapted their roles and functions to respond to the changing needs of their communities, proving to be a valuable tool for citizen participation and territorial management.

3 Methodological Approach of the Study

The analysis presented in the paper explores how technologies such as AI, IoT, and their integration into AIoT could be implemented in community management, such as in neighborhood associations, where they can significantly improve the quality of life for residents, particularly those in the elderly population, and enhance the habitability of the territory.

To develop this, a methodological approach was structured based on research questions such as: What impact does the integration of AI and IoT have on citizen participation in neighborhood communities, especially among older adults? What are the advantages and disadvantages of using emerging technologies like AIoT in the management of neighborhood associations? And how can AIoT technologies improve the quality of life of the elderly population in neighborhood associations?

To address these research questions, a qualitative-descriptive approach was used, based on a literature review and international case studies. The methodology was structured as follows:

- Case Study Review: To illustrate how models of citizen participation in neighborhood associations have been successfully implemented and managed, using a

ISBN 978-9930-617-71-7

descriptive investigation that takes international examples to compare and analyze the local context. The conditions of Denmark, Singapore, and Japan are synthesized to illustrate how citizen participation models work.

- Analysis of Technological Advantages: AI and IoT technologies are recognized as emerging options that can contribute to the lives of older adults and the functioning of neighborhood associations. This approach is more exploratory than experimental in nature.
- Development of Proposals and Recommendations: Proposals and recommendations are presented to improve citizen participation, optimize community resources, and generally foster sustainable development through the use of technologies for neighborhood associations and active older adults. This is a prescriptive approach that suggests actions based on previous analysis of the issues addressed in the paper.

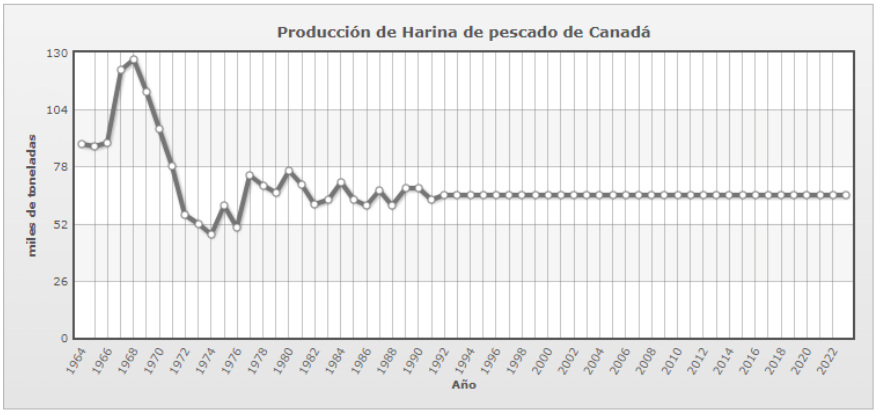
In conclusion, the paper mentions expected outcomes of implementing technologies such as AI and IoT, including improvements in the quality of life for older adults and an increase in community participation.

4 Challenges and Opportunities

4.1 Main Challenges

The Paradox of Natural Resource Preservation

In this regard, a trend can be observed in various sectors around the world, especially in countries that are leaders in the decentralization of the state and in the protection of territory and its habitability. This is the case of Canada. For example, in 1981, Canada decided to stop producing fishmeal. Starting in 1992, Canada ceased fish extraction from its coast for this purpose (see Fig. 1). However, from 1993 to 2023, Canada has continued consuming the same amount of fishmeal. Undoubtedly, this change marks a positive milestone for Canadian territory and its inhabitants, highlighting a commitment to sustainability and the preservation of its natural resources.



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Fig. 1. Fishmeal Production in Canada. Indexmundi, August 22. 2023.

However, the fishmeal that Canada continues to consume must come from other countries, often those with states that intensively overexploit their territories and, consequently, their citizens. The complexity of this situation lies in the fact that it is not an isolated problem, but rather part of a network of global economic groups and countries with more developed economies. These groups seek to interact with fragile states in terms of their society, values, and economic development, ensuring that economic power prevails over the society and state to which the territory belongs.

Territorial Overexploitatio

Overexploitation of territory occurs when natural resources and land are intensively exploited without regard for local communities. This results in environmental degradation, loss of biodiversity, and deterioration in the quality of life for the inhabitants. States that are intensive in territorial overexploitation tend to prioritize short-term economic profits over the long-term welfare of their citizens.

Why is there a demand to promote participatory development in states that are intensive in territorial overexploitation? Because the monetary gain no longer remains in the territory or the country. It is a profit that materializes at the level of global economic groups. The current form of extractivism differs drastically from that of the 20th century. Today's extractivism depletes everything, even the tax base of the state. The extractivism we see today is similar to the business model behind social media. In this case, the neighbor, or community member, becomes part of the monetization cycle of the platform, affecting the tax base of the state. Ultimately, this reduces the sphere of protection that the state can provide to citizens and the territory.

Narcoterritorialization

Narcoterritorialization refers to the control and domination of territories by organized crime and drug trafficking. This phenomenon severely affects the quality of life of the inhabitants, especially the elderly, by generating insecurity and devaluation of the territory’s commercial value. Narcoterritorialization involves activities such as smuggling, money laundering, extortion, and violence, turning these territories into "sacrifice zones."

In the context of the active elderly population, this situation has become an unsolvable problem for these states, which succumb to the rapid penetration of narcoterritorialization and organized crime. These groups exercise control over the territory, establishing their presence and power in specific geographical areas. In these types of states, the situation worsens due to the ineffectiveness of the judicial system and the inefficiency of governmental policies, to the detriment of citizens' needs.

An example of this is the history of Singapore and its period of opium consumption during the 19th and early 20th centuries. Opium use became widespread among the local population and migrant workers, especially Chinese and Malay sailors. The "dens" or "opium dens" were places where people gathered to consume opium and

ISBN 978-9930-617-71-7

socialize. The opium trade was an important source of income for many colonial powers in the Southeast Asian region during the 19th and early 20th centuries.

In modern times, narcoterritorialization is no longer limited to establishments like the old opium dens of Singapore but has evolved into activities such as smuggling, money laundering, extortion, and organized crime in general. Over the last four decades, narcoterritorialization has advanced toward the establishment of drug trafficking routes, corruption of local authorities, co-optation of government institutions, control over the use of violence, and the imposition of their own laws on the territory. Economically, the current form of narcoterritorialization is more profitable; with lower costs, there is a higher monetary return. At the same time, they usurp a territory without paying any taxes.

Fragile States

Social and territorial inequality remains a persistent challenge in many regions around the world, particularly affecting the elderly population. As mentioned, this group faces significant difficulties in accessing fundamental legal rights such as public safety, healthcare, and livable territories. Additionally, fragile states, in general, fail to provide adequate protection for both their territory and citizens, despite the fact that the latter fulfill the tax obligations demanded by the state.

The states of the world's leading economies focus their efforts on generating economic and value-based development from their own territories. A strong state is characterized by its ability to guarantee the well-being of its citizens, maintain political stability, ensure social justice, and foster the economic development of its people.

However, in other countries, some authors point to a precarious relationship between the state and the private sector, which is transforming into an oppression of basic societal needs and promoting territorial devaluation. This is manifested in an intense, yet fleeting, representation of citizen rights and the habitability of their territories.

In this context, the application of technologies such as AIoT (Artificial Intelligence and the Internet of Things) in neighborhood spaces and territories can contribute to several key areas, including:

- **Inclusive and participatory governance**;
- **Economic diversification and autonomy of the neighborhood space**;
- **Redundancy in the public security system**;
- **Conflict control and social cohesion**;
- **Access to high-quality, cost-free services linked to the neighborhood space**; ...among others.

4.2 Opportunitiess

I Integration of AIoT Technologies AIoT

The implementation of technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT), collectively known as AIoT, can offer effective solutions to address

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these challenges. These technologies can enhance territory management and security, as well as promote citizen participation and informed decision-making.

Security and Territory Control:
La AIoT puede proporcionar sistemas de monitoreo en tiempo real para detectar actividades ilícitas y mejorar la seguridad en las comunidades. Sensores y cámaras conectadas pueden alertar a las autoridades y a los vecinos sobre situaciones de riesgo, permitiendo una respuesta rápida y coordinada.

Natural Resource Management:
AIoT can provide real-time monitoring systems to detect illicit activities and improve security within communities. Connected sensors and cameras can alert authorities and residents about potential risks, enabling a quick and coordinated response.

Strengthening of Neighborhood Associations

Neighborhood associations can play a crucial role in mitigating the effects of narcoterritorialization and territorial overexploitation. These organizations can act as intermediaries between residents and authorities, promoting social cohesion and community participation.

Citizen Participation:
Encouraging active participation of residents in decision-making and territorial management can empower communities to address local challenges. Neighborhood associations can organize meetings, workshops, and community activities to engage residents and strengthen the social fabric. By fostering a sense of ownership and responsibility, these initiatives can improve social cohesion and lead to more effective solutions for local issues.

Education and Awareness:
Neighborhood associations can lead education and awareness campaigns on the importance of sustainability and security. Informing residents about the risks of narcoterritorialization and overexploitation practices can mobilize the community to take preventive and corrective actions.

Improvement of the Family Basket:
The integration of AIoT can facilitate electronic payment systems and offer discounts managed directly through local businesses. This approach not only supports the economic activity of neighborhood shops but also enables these businesses to provide discounts specifically to local residents. By leveraging AIoT, local economic development is strengthened, and community cohesion is promoted. This system can create a more efficient, sustainable, and inclusive economic ecosystem that benefits both the businesses and the residents, fostering a mutually supportive relationship within the neighborhood.

Public-Private Collaboration

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Collaboration between the public and private sectors is essential to effectively address these challenges. Public-private partnerships can provide the resources and expertise needed to implement technological solutions and strengthen neighborhood associations. By leveraging the capabilities of both sectors, these partnerships can foster innovative approaches to community development, improve local infrastructure, and enhance public services, all while promoting social inclusion and sustainability.

Investment in Technology:

The private sector can invest in the development and implementation of AIoT technologies within communities, while the public sector can provide the regulatory framework and institutional support needed.

Community Development Programs:

Companies can collaborate with neighborhood associations and local authorities to develop programs that improve the quality of life for residents. These programs can include initiatives focused on security, sustainability, and economic development.

Public Policies and Regulation

It is essential for governments to implement public policies and regulations that protect communities from narcoterritorialization and territorial overexploitation. These policies should focus on safeguarding citizens' rights and preserving the environment.

Regulation of Territory Use:

Establishing clear regulations on land use and natural resources can prevent overexploitation and ensure that economic activities are sustainable and beneficial for local communities.

Strengthening the Neighborhood Regulatory System:

Improving the effectiveness of the judicial system is crucial to combat narcoterritorialization. A robust neighborhood regulatory system can ensure that those responsible for illicit activities are brought to justice and that the rights of citizens in the neighborhood territory are protected.

The violence with which territories are "kidnapped" today, along with the increasing social insecurity experienced by the population in these areas, indicate that the "economic usufruct" of the inhabitants and their territories has already surpassed the definition of the State. This could explain why the elderly population feels the need to gather and support each other as they enter this phase of life. It makes little sense to expect states with fragile pension systems and justice mechanisms to offer a viable option for territorial habitability.

Addressing the challenges of narcoterritorialization and territorial overexploitation requires a comprehensive approach that combines technology, community participation, public-private collaboration, and effective public policies. The integration of AIoT technologies, the strengthening of neighborhood organizations, and the implementation of regulatory policies can transform communities, improving the quality of life of their inhabitants and promoting sustainable and equitable development.

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5 Technological Integration

5.1 Advantages of AI and IoT, Particularly for the Elderly Population

The integration of AI and IoT in neighborhood associations offers a range of key benefits that can significantly improve the quality of life for the population primarily represented by the elderly. Below, Table 2 consolidates relevant advantages of these technologies:

1. Assistance in Daily Life	• Virtual Assistants: Devices like Siri or Alexa can help elderly individuals with everyday tasks, such as setting reminders, answering questions, and controlling home devices. • Home Automation: IoT enables the automation of household tasks like controlling lighting, temperature, and home security, making life more comfortable and secure.
2. Health Monitoring	• Tracking Devices: AI-powered health tracking devices and apps can continuously monitor the elderly's health, detecting potential health issues and allowing for preventive measures. • Medical Alerts: Connected sensors can send automatic alerts to family members or emergency services in case of falls or risky situations, ensuring a quick and appropriate response.
3. Communication and Social Connection	• Video Conferencing and Social Media: AI facilitates communication with family and friends through video calls and social media, helping combat loneliness and isolation. • Virtual Companionship: Virtual assistants can provide companionship and engage in conversations, offering emotional and social support to the elderly.
4. Personalized Healthcare	• Health Recommendations: AI can provide personalized health recommendations, medication reminders, and suggestions for physical activities tailored to individual needs. • Telemedicine: IoT integration enables telemedicine, facilitating remote medical consultations and continuous monitoring of chronic conditions.
5. Home Security	• Security Systems: AI-powered home security systems can detect risk situations, such as falls or intruders, and alert emergency services or family members. • Real-Time Monitoring: Connected sensors and cameras can provide real-time monitoring, improving the safety and peace of mind for the elderly and their families.
6. Access to Information	• Relevant Information: AI can help elderly individuals access relevant information such as news, weather forecasts, and details about local activities. • Education and Entertainment: AI-powered devices can offer entertainment like music and movies, as well as learning opportunities through apps and educational games.

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7. Independence	• Empowerment: AI can empower elderly individuals to live more independently, as they can receive virtual assistance instead of relying solely on caregivers or family members. • Autonomy: The automation of tasks and access to personalized services allow elderly individuals to maintain their autonomy and quality of life.

Tabla 2. AI Assistance in Services Provided by Neighborhood Associations. www.citia.cl / Project rsVecinal. Own compilation.

5.2 Implementation of AIoT in Neighborhood Associations

The implementation of AIoT technologies in neighborhood associations can transform these organizations into hubs of innovation and well-being, strengthening social cohesion and improving the quality of life for all members, especially older adults. Below, Table 3 presents the key management areas for AIoT-type resources:

1. Security and Territorial Contro	• Real-Time Monitoring: Implementation of real-time monitoring systems to detect illicit activities and enhance security within the communities. • Alerts and Rapid Response: Connected sensors and cameras that alert authorities and residents about risky situations, enabling quick and coordinated responses.
2. Health Coordination and Medical Assistance Management	• Health Agenda: Coordination services for the health agendas of senior citizens, individuals with disabilities, and those with special needs. • Telemedicine and Remote Monitoring: Facilitation of remote medical consultations and continuous monitoring of chronic conditions through connected devices.
3. Neighborhood Association Management and Participation	• Transparency and Participation: Management tools for financing and communication channels between association members and residents, promoting active neighborhood participation. • Education and Awareness: Educational campaigns about the importance of sustainability and security, mobilizing the community to take preventive and corrective actions.
4. SNeighbor Assistance Services	• Personalized Assistance: Provision of specific services for neighbors within the territory of the neighborhood association, such as help with household tasks, transportation, and companionship. • Community Support Network: Creation of a community support network that facilitates collaboration and mutual support among neighbors, strengthening social cohesion and community ties.

Table 3. Key Management Areas for Neighborhood Associations. Original Production.

The integration of AIoT technologies in neighborhood associations offers a unique opportunity to improve the quality of life for the senior population. By consolidating the advantages of AI and IoT, effective solutions can be implemented to address challenges in security, health, communication, and autonomy, empowering older adults and

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strengthening communities. The adoption of these technologies not only promotes innovation and well-being but also fosters active participation and social cohesion, creating a safer and more sustainable environment for all.

6 Case Studies

In some regions of the world, experience shows a lack of interest from citizens, in this case, neighbors, in actively participating in their community. The reasons are diverse: "I don't have time," "I work outside the city," "I take care of my parents," among others. However, the underlying question is: Why belong to a neighborhood association if it doesn't offer tangible benefits?

The incorporation of new technologies, especially AIoT, into the management of neighborhood organizations is a unique opportunity to activate citizen participation.

The services and activities that these organizations can offer to the resident community are practically limitless. In addition to the traditional ones such as security, health, and recreation, neighbors themselves can come up with solutions to their problems. For example: Collective transport for people with reduced mobility when public transport does not exist or is deficient.

In some regions of the world, the economic sustainability of neighborhood associations is based on the payment of membership fees. If apathy and lack of incentives, due to the scarcity or absence of free and quality services, conspire against its maintenance, then the incorporation of AIoT to improve the management of the organization becomes an urgent need.

In addition to the points mentioned about the inclusion of AIoT, it is crucial to recognize the potential that the life experience of older adults brings to the community context. From their perspective, the neighborhood association can become a fundamental space for support and the promotion of policies aimed at improving the living conditions of people in their retirement stage. This includes access to health services, recreational activities, social participation, and other benefits that contribute to a dignified and fulfilling old age.

Below, three cases are presented where the State is continuously working to enhance the autonomy of the neighborhood organization as a foundation for building a strong citizen base.

6.1 Denmark: Beboerforeninger and Urban Planning

In Denmark, neighborhood associations, known as beboerforeninger or resident assemblies, have a long tradition of citizen participation and local democracy. These assemblies play a crucial role in community life, representing residents in a specific area and working to improve the quality of life in the neighborhood. A prominent example is their involvement in urban planning and community development.

The neighborhood assemblies contribute to the formulation of policies and projects that are implemented in their neighborhoods, which may include the design of public spaces, parks, and cultural activities. Additionally, they have the prerogative to guide property owners within the same residential complex in securing government contributions to make the properties more attractive to different socioeconomic profiles, thereby

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promoting public policies aimed at "social mixing" to counteract processes of "ghettoization."

6.2 Singapore: Community Development Councils (CDC)

Since 1997, Singapore has implemented a community initiative called the Community Development Councils (CDC), which plays a much greater role than what is generally seen in neighborhood associations in other countries. The CDCs are distributed across the five territorial districts of the nation and represent a government body of the State of Singapore. Their main goal is the organization of grassroots communities and community programs available in each of the territories.

The CDCs strengthen local social infrastructure, create social resilience and social capital, and promote a culture of giving back. Available programs include voucher schemes, community legal clinics, law awareness weeks, family and social integration funds, and skill festivals. This integrated approach has allowed Singapore to maintain a high quality of life and social cohesion within its communities.

6.3 Japan: Chonaikai and Community Resilience

In Japan, neighborhood associations known as Chonaikai (町内会) play a significant role in community life. These voluntary associations, while independent, have an almost governmental status that grants them responsibility and limits their role in the administration and coordination of actions such as neighborhood watch, emergency response, and public space planning. A notable example is their role in disaster prevention and response.

The Chonaikai organize disaster preparedness training events and cleaning activities, and manage household garbage collection services. During World War II, the Japanese government created the Tonarigumi (neighborhood associations), which were also useful for public safety. These associations were officially abolished in 1947 by the Allied forces, but their legacy lives on in the current Chonaikai.

What has been mentioned allows us to infer that, ultimately, the evolution of the neighborhood association as a grassroots civil organization for the citizen and the territory they inhabit depends on the State's recognition of the citizen's status.

It is a fact that in very few places around the world do people live without paying taxes. The most developed states recognize the status of a citizen who contributes taxes, which is reflected in the autonomy granted to the neighborhood association as a base citizen organization. This represents a challenge for a neighborhood association that is unaware of the reality it faces as a civil organization within the type of State in which it is situated. Additionally, it is important to understand that the less tax is paid, the less control there is over the territory one inhabits and how the State manages it.

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7 Conclusions

The present paper, it is an initial approach to a work and project in development, proposes innovation in the grassroots civil organization "neighborhood association" through the use of technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT) as an effective and cost-efficient strategy for political, social, and territorial participation, particularly for the elderly population, especially after their working years.

The adoption of technologies such as AI and IoT is crucial for addressing inequality and improving the quality of life for older adults. These technologies can offer multiple advantages, such as:

Assistance in daily life.	**Health monitoring.**	**Communication and social connection.**	**Personalized healthcare.**
Home security.	**Access to information.**	**Entertainment and learning.**	**Independence.**

The integration of these technologies in neighborhood associations not only improves the management and services that can be provided to the community but also offers significant benefits for the elderly population, promoting their well-being and quality of life.

In regions or municipalities that lack robust public policies to safeguard essential aspects of the communal territory, adopting AI and IoT-based solutions can help compensate for these deficiencies by providing neighborhood associations with the tools they need to better manage their environments and respond proactively to the needs of their members.

Furthermore, fostering participatory development through the integration of these technologies is crucial in states that are intensive in territorial overexploitation. In contexts where natural and territorial resources are exploited without regard for local communities, AIoT technologies can play a key role in preserving quality of life and defending the rights of residents.

Through greater transparency, efficiency, and community participation, these tools can empower communities to manage their own sustainable and equitable development, ensuring that the quality of life in the territory and its residents becomes part of the neighborhood association's self-sustaining model.

In summary, adopting technologies like AI and IoT in neighborhood associations represents a valuable opportunity to improve the quality of life for the elderly population. These technologies not only facilitate resource management and optimization but also promote social integration, security, and the well-being of seniors, contributing to a dignified and fulfilling old age. With proper management through the use of new technologies, it could change the mindset of the apathetic or uninterested neighbor, regardless of their argument: "If I don't belong to my neighborhood association, I'll be left out of multiple social and economic benefits."

A virtuous circle would be created:

- High neighborhood participation (including remote participation);

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- Economic sustainability of the organization;
- Creation of small businesses and services within the sector;
- Public authorities available to collaborate with an organized community;
- Job creation for seniors; Creation and maintenance of public spaces.

All of this and more would derive from increased citizen participation.

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ISBN 978-9930-617-71-7

FREM: Information Extraction System for Generating Phytosanitary Risk Alerts.

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Abstract. Monitoring the internet for pests and/or diseases is a key component of the early warning system, as it locates and extracts documents to generate early information about potential pests that could pose a risk of spreading within the national territory. The National Service for Agrifood Health, Safety, and Quality (SENASICA) is the Mexican government institution responsible for protecting agricultural, aquaculture, and livestock resources from pests and diseases of quarantine importance. A news extractor was developed using web scraping with keywords to download news articles about pests that may represent a risk to Mexico's food sector. Through natural language processing, relevant data from the news documents are selected, such as the title, the country, the pest mentioned in the article, the date of the event, among other details. To assess the success of the extraction, another development presents the information visually with statistics so that SENASICA analysts can evaluate whether the pest data is sufficient and determine if there is a risk of spreading in Mexico's territory, supported by other indicators.

Keywords: Phytosanitary risk, monitoring, pests, web scraping, natural language processing, information retrieval.

1 Introduction

Infectious diseases in animals and pests in the agricultural sector represent one of the main threats to global health security due to their spread and economic impact on affected countries. One of the fundamental objectives of health authorities is to implement early detection systems for high-risk pests to prevent their spread within national borders, relying on reliable information sources such as news websites, social networks, and scientific journals.

In the case of Mexico, there are multiple factors to consider for a pest to spread within the national territory. One important factor is whether the pest is affecting countries with which Mexico maintains commercial and tourism relationships. Geographically close entities are also taken into account.

SENASICA [1] is the government institution responsible for protecting agricultural, aquaculture, and livestock resources from pests and diseases of quarantine importance

ISBN 978-9930-617-71-7

in Mexico. Currently, it does not have an automated early detection and alert system for pests. Information is collected by browsing specific sources daily, such as news sites, websites, scientific journals, social networks, and websites of government entities from other countries dedicated to identifying phytosanitary risks. The filters used to identify useful news include the pest's name, the country of origin, the affected crop, the date the pest was reported, and the identification of keywords suggesting risk.

For SENASICA, having an automated system for detecting high-risk pests could help identify, in less time than the manual process, when a pest may represent a potential threat, allowing authorities to be informed in a timely manner. This would facilitate decision-making to control the pest and prevent its spread within the national territory.

The integration of an automated pest detection system can improve the management of urban agriculture and public health. By leveraging the analysis of large volumes of data and real-time data verification from various sources, smart cities can create a strong network for early pest detection. This integration allows for timely information sharing with urban planners, agricultural managers, and health authorities, promoting coordinated and efficient responses. As a result, resilience and sustainability in urban environments are strengthened, aligning with the objectives of smart city initiatives to create safer and more responsive urban ecosystems.

Currently, there are some tools that retrieve relevant news, but for SENASICA, this would involve providing confidential information, which is why there is interest in developing a tool exclusively for the government institution. Moreover, such tools extract information about various countries and pests in general, not specifically about pests and news of interest to Mexico

1.1 Current Method

Currently, at SENASICA, the search for phytosanitary news is carried out as follows: a group of analysts daily reviews specific sources in search of relevant news. When a headline that mentions a pest is identified, the full article is read. If it is determined that the news represents a phytosanitary risk, the competent authorities are informed, and a report is generated. This current method requires a lot of manual work and time, and there is a possibility that some relevant news may go unnoticed due to the large volume of news, and some articles may not be accessed because of time constraints that exceed the analytical capacity of those responsible for these tasks. Additionally, no sources are reviewed over the weekends, which increases the workload for analysts at the start of the week.

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2 Proposed Solution

The proposed solution is to create software called “FREM” that automates the search for pest-related news. Using web scraping [2], the software will download news articles related to pests of interest. The extracted information will include the title, URL, content, and the name of the pest mentioned in the article, among other details. Afterward, the obtained information will be cleaned. Subsequently, through the use of natural language processing (NLP), the context [3] in which the pest is reported will be analyzed, evaluating whether it is likely to spread within the national territory or if it is in its early stages of propagation. The software will generate a report with key data from the article, such as the title, the mentioned pest, the date of the news, the country of origin, and a summary of the content. Additionally, the extracted information will be displayed visually to better visualize the obtained results.

3 State of the Art

3.1 Current Tools

3.1.1 Importance of Monitoring Diseases and Crops

Wang, Chen, and Dong [4] emphasize the importance of early warning technology for diseases and pests in crops for national food security, highlighting the current reliance on manual methods and field visits that affect accuracy. The study investigates the current state of this technology in agriculture, comparing and analyzing predominant technologies and algorithms, and proposes an improved solution based on the Internet of Things (IoT), big data, and cloud computing. It employs principles of biology, ecology, and mathematics to analyze historical and current factors, predicting future trends by applying algorithms such as Back Propagation neural networks and rough set theory to build early warning models. IoT technology enables the real-time acquisition of environmental data, improving the accuracy and timeliness of forecasts. The study concludes that the combination of IoT, communication technology, cloud computing, and big data can enhance agricultural disaster prevention, although the technology is still under development. The work was supported by national science and technology projects in China.

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3.1.2 PetsLens

PestLens [5] is a web-based system that utilizes an online platform to collect, assess, and disseminate information about exotic plant pests. It allows analysts to monitor information in real-time, consolidate it, and present it to decision-makers through email notifications and a web interface. The system employs Google Alerts to receive results from automated queries directly via email, typically sourced from media outlets, blogs, and non-specific websites. It sends weekly email notifications with summarized articles on new pest information and includes a repository of all published articles that can be searched by pest name, pest type, event category, keyword, and/or date range.

3.1.3 PADI - web

The French Animal Health Epidemiological Intelligence System (Veille Sanitaire Internationale, VSI) and its web monitoring component PADI-web [6] detect signals of diseases from online news sources through automatic collection, processing, and extraction of epidemiological information. It collects news in English via customized Google News RSS feeds, using specific search terms related to disease names, clinical signs, and hosts. The team relies on formal notifications from sources such as the World Organisation for Animal Health (OIE) and the European Commission (EC) for the indicator-based component, while also consulting general news and animal health websites, along with biosurveillance systems. It processes these news items by verifying their relevance using keywords in titles and headlines. Finally, it employs an information extraction (IE) method that combines rule-based systems and data mining techniques to identify and verify epidemiological entities (diseases, locations, dates, hosts, and number of cases) mentioned in the news, using frequent itemset discovery algorithms and support vector machine (SVM) classification.

3.1.4 Identifier Using ResNet

An identification model for pests was created based on the deep learning algorithm ResNet V2 [7], which processes images to identify pests, significantly improving detection accuracy compared to traditional methods. Additionally, a method was developed to issue warnings about pest outbreaks based on pattern identification and the density of detected insects. This method enables farmers and agricultural managers to take preventive and control measures in a timely manner. Overall, the system is an advanced software that utilizes deep learning technology to process images of insects and issue alerts.

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3.2 Advantages and Disadvantages

Table 1. Advantages and Disadvantages of Current Tools.

Advantages	Disadvantages
They allow for the timely detection of new exotic pests, enabling a rapid response to mitigate their impact	Limited to Government Users
They combine human expertise with advanced technological tools to monitor and consolidate information about pests in real-time	Most of the sources used are scientific articles, which can delay real-time detection, as scientific publications tend to be slower in dissemination compared to other media
Weekly reports are available for free to anyone who requests them	The news, in general, does not specifically include information about pests of interest to Mexico, particularly for SENASICA
	Some data collection exercises developed in them had news dates that were outside the desired range of recent dates concerning the search date

4 Method and Results

Web scraping is a technique used to automatically extract information from websites [8-10]. It involves sending requests to a web page, obtaining its content (HTML), and extracting relevant data such as text, images, or links. The main techniques include using regular expressions to search for specific patterns, DOM parsing with tools like BeautifulSoup to navigate and extract data from HTML elements, and navigation with headless browsers like Selenium, which allow interaction with dynamic sites. Popular libraries for web scraping include BeautifulSoup (easy to use for static HTML), Selenium (for dynamic sites that load content with JavaScript), Scrapy (more advanced and optimal for large projects), and Requests (for making HTTP requests) [11]. For news pages, the combination of Requests and BeautifulSoup is usually the most effective and efficient if the content is static. If the page relies heavily on JavaScript, Selenium is more suitable [12,13].

Natural language processing (NLP) allows computers to understand, interpret, and generate human language by applying various techniques such as tokenization, stopword removal [14], stemming, and lemmatization [15]. These techniques improve accuracy in tasks such as sentiment analysis and text classification. Since it is necessary to analyze the context of the news content, these processing techniques need to be applied to the downloaded information.

ISBN 978-9930-617-71-7

An extractor was developed in Python using web scraping and libraries like BeautifulSoup to extract information from the sources consulted daily by SENASICA. The extracted parameters included the publication date of the news, the title of the news, the country of origin, the news URL, and its content. To avoid duplicate news storage during extraction, it checks that the news URL is not already stored. News extraction occurs every minute. Additionally, the name of the pest or the name of the crop mentioned in the news title was extracted.

Since extracting the content of the news also retrieves information that is not of interest (such as advertising messages, social media from the page, etc.), the extracted content was cleaned using regex [16] to detect junk data such as phone numbers, emails, addresses, among others.

Subsequently, natural language processing techniques were applied to the obtained information, such as removing special characters and punctuation, tokenization, stopword removal, and lemmatization.

Over a period of 2 weeks, approximately 1,000 news articles were extracted from 12 sources (websites) that discussed pests or crops of interest.

Table 2. Example of Extracted Information.

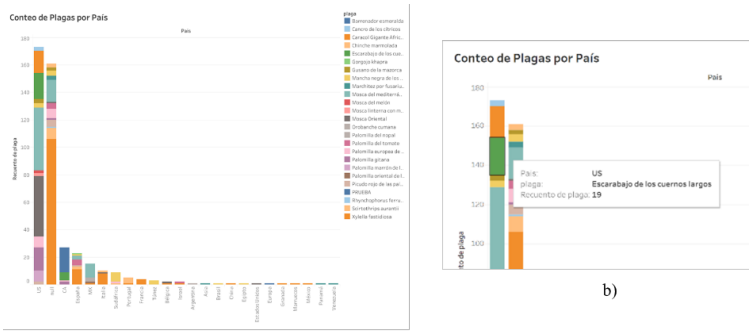
Title	Publication Date	URL	Content	Country	Pest
Anastrepha ludens (Mexican Fruit Fly): APHIS Establishes, Amends, and Removes Quarantine Areas in Texas	Aug. 22, 2024	https://www.pestalerts.org/nappo/official-pest-reports/1110/	Phytosanitary Alert System Anastrepha ludens (Mexican Fruit Fly): APHIS Establishes, Amends, and Removes Quarantine …	United States	Anastrepha ludens

To display relevant information about the pests found and the countries in which they were located, a webpage was created [17], which shows the frequency of news by pest name (see Fig. 1) and the pests that have been found by country (see Fig. 2). Additionally, a count of the pests found by month is shown (see Fig. 3).

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Fig 1. World map showing the countries from which the most news has been extracted. The larger the area of the circle, the greater the number of news articles downloaded.



a) b)

Fig 2. a) Pest Count by Country. The pests found are shown according to the country mentioned in the news. The larger the shaded area, the greater the number of news articles discussing a specific pest. b) Example of the pest "Longhorn Beetle" located in the United States, with a total of 19 news articles.

ISBN 978-9930-617-71-7

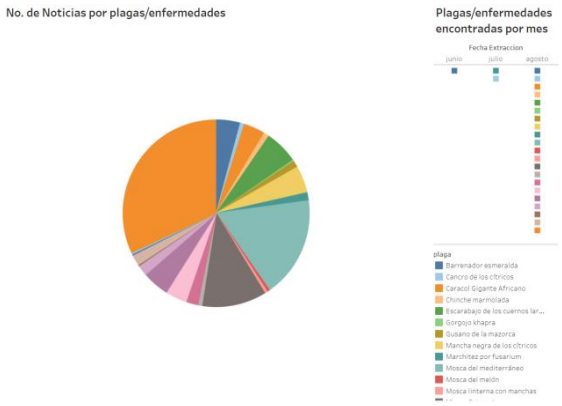


Fig 3. Pests Found by Month.

5 Related Results

Daily, SENASICA reports news related to pests of interest in monitors found on its website https://www.gob.mx/senasica. The monitors contain about 2 to 3 news articles, and each reported article includes the title, a summary, and the website from which the information was extracted. It has been found that the news downloaded by the extractor matches the information reported by SENASICA daily. Below is an example.

Example 1

Information Reported by SENASICA

Monitor reported by SENASICA: *https://dj.senasica.gob.mx/Contenido/files/2024/septiembre/MonitorFitosanitario02092024_3f1bf529-2eac-40eb-82f6-049597323d51.pdf*

News: Argentina: Implementa acciones de vigilancia para prevenir el ingreso de Orobanche cumana, desde Bolivia.

URL: https://www.argentina.gob.ar/noticias/se-iniciaron-acciones-para-la-prevencion-de-la-maleza-orobanche-cumana.

Information Found by the Extractor

ISBN 978-9930-617-71-7

Found URL: https://www.argentina.gob.ar/noticias/se-iniciaron-acciones-para-la-prevencion-de-la-maleza-orobanche-cumana

Found Title: Se iniciaron acciones para la prevención de la maleza Orobanche cumana.

Found Pest: Orobanche cumana.

6 Statistics of Obtained Results

Over a period of two weeks, the following results were obtained from an average of 17 news pages visited daily. The consulted pages correspond to news sites and government agency websites from countries dedicated to the protection of phytosanitary risks.

A total of 1,559 news articles were found (see Fig. 4), of which 1,124 contained the scientific name of a pest and 435 mentioned the name of a crop (beans, corn, bananas, etc.).

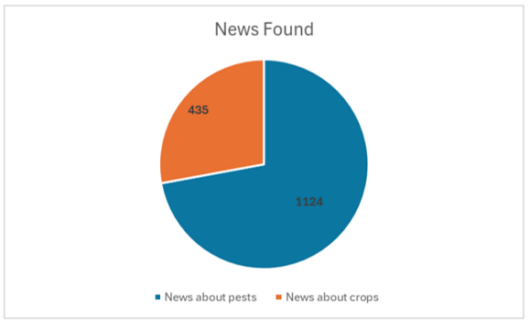


Fig 4. News Found About Pests or Crops.

The number of news articles extracted per day is also shown. It is important to mention that at the beginning of the extractions, the number of downloaded news articles was high since news was being downloaded for the first time and new search pages were being added to the extractor. However, as days went by, only recent news articles were downloaded (see Fig. 5).

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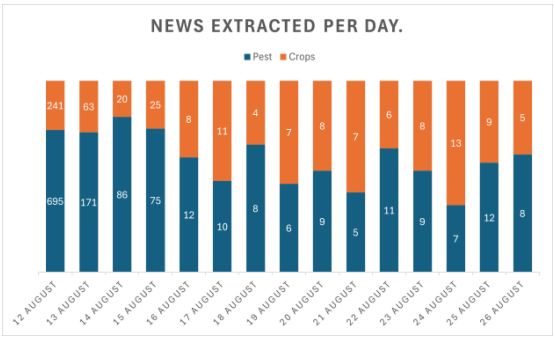


Fig 5. News Extracted Per Day.

The names of the pests that appeared most frequently in the downloaded news were Mediterranean Fruit Fly, Oriental Fruit Fly, and Xylella Fastidiosa, which coincide with the pests currently being monitored by SENASICA.

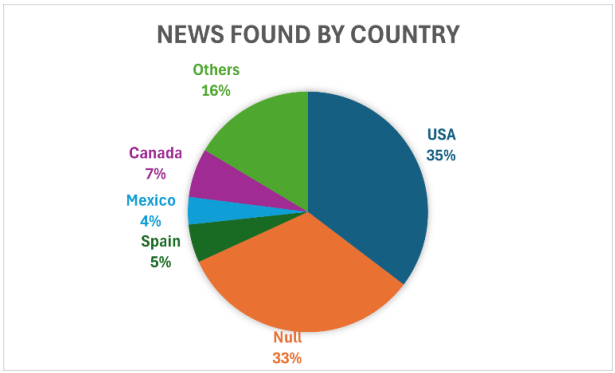


Fig 6. News Found by Country.

Of all the extracted news articles (see Fig. 6), 35% originate from the United States, 7% from Canada, and 5% from Spain, countries that are close to Mexico. Additionally, 4% of the news corresponds to events occurring within the national territory. However, 33% of the news articles do not mention the country where the pest is manifesting. This issue is intended to be addressed by analyzing the content of the news more deeply to determine the country in question, which would modify the percentages of the found news articles.

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It is expected that as more search sources are added to the extractor, the number of news articles found daily will increase, leading to more matches with what is published by SENASICA.

7 Discussion

The web scraping technique is useful for extracting information from the web. However, most of the time, this information contains junk data (such as advertisements and social media), making it necessary to apply data cleaning techniques once the data has been extracted. By using filters that require news titles or subtitles to include names of pests or crops, it ensures that the extracted news will have relevant information for SENASICA. One of the current issues is that experts at SENASICA need to visit many sources (websites) in a very short time, and searches are not conducted on weekends. However, by establishing that the extractor automatically performs searches across all sources every minute, it ensures that early information will be available to take necessary actions, preventing the possible spread of any pest.

In relation to the scalability of the project, several relevant aspects have been identified. One of the main challenges is that some websites detect and block access through web scraping techniques. Although longer intervals between requests have been implemented to mitigate this issue, these sites are currently not included in the extraction process. However, strategies to overcome this limitation are still being explored.

Currently, the system runs on a computer with 32 GB of RAM, which has managed the workflow without significant difficulties. The average volume of data downloaded is approximately 20 news articles per day. As the data volume grows, migration to cloud storage services is projected to optimize database management and scalability.

Additionally, a thorough analysis of infrastructure costs — including storage, servers, and bandwidth — is underway, and further performance tests are being conducted to ensure the system can support sustained database growth without affecting operational efficiency.

The visualization of pests by country provides accurate information on pests that could reach Mexico if they are in nearby countries or countries with which there are trade and tourism relations.

Unlike pre-existing systems, FREM is specifically designed to search for news relevant to Mexico, filtering downloaded news based on pest names that are of particular interest to the Mexican territory. These news articles are obtained exclusively from reliable sources previously selected by SENASICA. Additionally, FREM performs continuous monitoring, operating every minute to detect the publication of new articles in real time,

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which represents a significant advantage for the institution by facilitating timely surveillance of pest outbreaks.

The FREM extraction tool, in its first version, already generates clear information that aligns with SENASICA's reports. Future work will include developing new versions of FREM with enhanced capabilities for more extensive extraction (searching in other types of documents, as well as identifying new pests to look for) and reliability (indicating documents that streamline decision-making, allowing analysts to review fewer documents to confirm whether it is a pest or not).

8 Conclusions

In this work, a software tool has been presented to automate the monitoring of high-risk pests, aiming to prevent the spread of pests at the national level. Most of the extractions performed show useful and relevant information for SENASICA, finding similarities with what is reported regarding what the extractor has found. However, it is necessary to broaden the search range to obtain a greater number of news articles and have even more similarities with the information they consider important. For Mexico and other countries, having a search tool like this means obtaining key information to prevent a pest from affecting the phytosanitary sector, which could have repercussions not only on the food supply of the population if it affects crops that are part of the daily diet of Mexicans (such as corn and beans) but also on their economy if these are products exported to other countries (for example, avocado), thus highlighting the importance of this project being developed.

9 Future Work

As a continuation, it is planned to extract information from all the sources that SENASICA consults daily, incorporating search terms that include the plural forms of the pests of interest, as well as expanding the search for news to social media platforms like X (formerly Twitter), Facebook, among others. Additionally, through the use of natural language processing techniques, the aim is to analyze the content of the news and identify or deduce other relevant data, such as the country, province, or municipality of origin, the type of activity that relates it to Mexico, and the precise date of the event, among other data that may not be mentioned in the news text, as well as gaining more context from the downloaded news that would be useful to SENASICA analysts. Following the continuous download of news, part of other project work will involve evaluating whether these correspond to an alert or notice and obtaining summaries of the developed extractions. Finally, additional versions of the web development will be completed, where relevant and useful information for SENASICA authorities will be presented.

ISBN 978-9930-617-71-7

Acknowledgments

Instituto Politecnico Nacional SIP 20242048.

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ISBN 978-9930-617-71-7

Assessing Smart Cities in Developing Countries: Multidimensional Approaches

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Abstract. This paper explores the multidimensional approaches to evaluating smart cities in the context of developing countries. While traditional evaluation frameworks—such as classification, maturity, data-driven management, and innovation ecosystems—have offered valuable insights into the technological and institutional dimensions of smart cities, they often neglect crucial social and cultural aspects. To address this gap, we introduce the Conscious and Inclusive Communities approach, emphasizing the active participation of local communities in all stages of smart city development. This new framework ensures that smart city initiatives are not only technologically advanced but also socially equitable and culturally aware, particularly in regions where inequality and exclusion present significant barriers to sustainable urban growth. By conducting a systematic literature review, this paper synthesizes existing approaches while highlighting the necessity of integrating social inclusion and community engagement into smart city evaluations. The findings offer a comprehensive framework for policymakers and urban planners, guiding the development of smart cities that are both innovative and inclusive.

Keywords: Smart Cities, Developing Countries, Evaluation Frameworks, Community Inclusion, Sustainable Urban Growth.

1 Introduction

In recent years, the concept of smart cities has gained significant traction worldwide, particularly as urban areas face increasing pressures from rapid population growth, resource management, and infrastructure challenges. Smart cities have been promoted as potential solutions for improving the efficiency, sustainability, and inclusiveness of urban systems [1]. In developing countries, where infrastructure gaps, governance complexities, and socio-economic inequalities are prominent, the promise of smart cities has been met with both optimism and caution [1]. While these cities offer innovative solutions through the use of digital technologies like the Internet of Things (IoT) and big data analytics, they also face significant challenges, such as high financial costs, large informal economies, and the need for stronger governance frameworks. However, the adoption of smart cities in developing nations presents unique challenges due to infrastructure gaps, socio-economic inequalities, and varying levels

ISBN 978-9930-617-71-7

of technological readiness. Thus, the evaluation of smart cities in these contexts becomes critical to ensure that they deliver on their promise of inclusive and sustainable development [2].

Evaluating smart cities involves understanding how well they integrate technology, governance, innovation ecosystems, data management, and, crucially, social inclusion. Existing frameworks for smart city evaluation typically focus on four key approaches: classification, maturity, data-driven management, and innovation ecosystems [1,2]. While these approaches provide valuable insights into the technological and institutional dimensions of smart city development, they often overlook the importance of community engagement and inclusivity, which are vital in ensuring that the benefits of smart cities are equitably distributed. To address this gap, this paper introduces a fifth approach: Conscious and Inclusive Communities. This new framework emphasizes the active participation of local communities in the design, implementation, and governance of smart city projects, ensuring that urban transformation is not only technologically advanced but also socially equitable.

As a methodological approach, this paper will conduct a literature review to systematically examine the existing frameworks for evaluating smart cities in developing countries [1]. The goal is to identify and synthesize the most relevant evaluation approaches and explore how they can be adapted to the unique socio-economic and technological realities of these countries. This review will not only incorporate the four widely recognized approaches but also propose a fifth, more socially inclusive approach that addresses the gaps identified in the current literature.

1.1 Evaluation of smart cities in developing countries

The evaluation of smart cities has become a growing field of study, particularly as cities worldwide face increasing pressures to address issues such as rapid urbanization, resource scarcity, and social inequality. In recent years, several approaches have been proposed to assess the development and impact of smart cities. These include ranking models, which compare cities based on specific performance indicators; maturity models, which assess the stage of technological and institutional development; and data-driven management models, which focus on the real-time use of big data and analytics for urban governance. Additionally, innovation ecosystem frameworks have emerged, emphasizing the role of collaboration between governments, industries, academia, and citizens in fostering smart city solutions.

Despite the progress made in evaluating smart cities, much of the existing literature focuses on developed nations, where infrastructure, governance, and technological resources are more readily available. In contrast, developing countries face distinct challenges, such as inadequate infrastructure, socio-economic disparities, and limited access to advanced technologies. As a result, the evaluation frameworks commonly used in developed countries may not fully capture the realities and needs of cities in developing regions.

ISBN 978-9930-617-71-7

Furthermore, while the four traditional approaches (classification, maturity, data-driven management, and innovation ecosystems) provide valuable insights into technological and institutional dimensions, they often fall short in addressing social inclusion and community engagement. In the context of developing countries, where urban inequality is more pronounced, it is crucial to evaluate how smart city projects are impacting not only economic efficiency and technological advancement but also the well-being of marginalized communities.

This paper, therefore, seeks to fill this gap by exploring the question:
"What are the main approaches used to evaluate smart cities in developing countries, and what key aspects are considered in these evaluations?"

In addition to the existing four approaches, this study proposes a fifth approach—*Conscious and Inclusive Communities*—which emphasizes the active participation and inclusion of local communities in the smart city development process. This approach is crucial to ensure that smart city initiatives are equitable and meet the diverse needs of all citizens, particularly in regions where inequality is a significant barrier to sustainable development.
To address the unique challenges and opportunities presented by smart cities in developing countries, this paper adopts a comprehensive approach that combines established evaluation frameworks with a new socially inclusive perspective. The following sections are organized as follows: Section 2 provides an in-depth literature review on the four main approaches to assessing smart cities—classification, maturity, data-driven management, and innovation ecosystems—while introducing the Conscious and Inclusive Communities approach. Section 3 discusses key findings, highlighting the practical and theoretical implications for urban planners and policymakers. Finally, the conclusion offers recommendations for implementing these multidimensional frameworks to support more inclusive, resilient, and sustainable urban development in diverse contexts.

2 Methodology

This research employs a Systematic Literature Review (SLR) methodology to examine the various approaches used to evaluate smart cities in developing countries. The SLR focuses on multidimensional evaluation frameworks, incorporating dimensions such as classification, maturity, data-driven management, innovation ecosystems, and social inclusion. The objective is to identify the key evaluation strategies in smart city initiatives and propose a comprehensive framework that integrates these diverse approaches to better suit the context of developing nations.

The methodology for the review follows the standards outlined by [3], combined with the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) guidelines [38]. A detailed review protocol was designed during the initial phase, which set forth the study objectives, research questions, and systematic process for se-

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lecting and reviewing the literature. This protocol includes the specification of databases, keywords, and inclusion/exclusion criteria for the articles reviewed, guided by the central research question.

The selection criteria for this SLR include peer-reviewed academic articles, written in English, and accessible online. Only studies published between 2014 and 2024 were included, as the smart city development agenda has gained significant traction in most developing countries over the last decade. These articles must specifically discuss the evaluation frameworks, challenges, and outcomes of smart city projects. Only studies that addressed the technological, social, governance, and innovation dimensions of smart city evaluation were included. Two widely recognized academic databases, Scopus and Web of Science, which are extensively used for retrieving literature in the social sciences, were employed for gathering evidence. One comprehensive search string focused on relevant keywords related to smart cities and for developing countries was combined using the search process (Table 1).

Table 1. Keywords included in the research string.

Query	String
Smart cities in developing countries	(TITLE-ABS-KEY(“smart cities” OR “smart city” OR “Sustainable city” OR “Sustainable cities” OR “Digital city” OR “Digital cities” OR “Resilient cities” OR “Intelligent cities” OR “Liveable City” OR “developing countries” OR “developing country” OR “developing society” OR “developing societies” OR “middle income countries” OR “middle income country” OR “low income countries” OR “low income country” OR “lower middle income countries” OR “underdeveloped countries” OR “emerging market” OR “emerging economy” OR emerging “economies” OR “less industrialized”))

The initial search yielded 55 sources, which were reduced to 48 after duplicate entries were removed. A preliminary screening of titles and abstracts was conducted to assess relevance, leaving 36 articles that met the inclusion criteria. Many sources were excluded due to their narrow focus on specific smart city technologies that did not directly address the evaluation approaches outlined in the research questions. Full-text reviews of the remaining articles led to a refined list of 25 papers aligned with the study's objectives. After removing two brief papers, a final selection of 23 articles was made. Additionally, relevant references from related studies on smart city evaluation frameworks were included, bringing the total to 26 articles. These selected publications were analyzed for relevant evidence using NVivo 14, a qualitative data analysis software.

3 Smart Cities Assessment: Key Approaches

In the context of developing countries, the assessment of smart cities has gained significant importance as cities increasingly adopt digital technologies to tackle critical challenges such as rapid urbanization, socio-economic inequalities, and sustainability.

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The implementation of smart technologies in these regions holds the potential to substantially enhance the quality of life and the efficiency of urban services, although it also faces unique challenges related to infrastructure and governance. According to Esashika [2], the evaluation of smart cities can be approached through several key frameworks. One such approach focuses on ranking, comparing the performance of different cities using standardized indicators, while another looks at the maturity of smart cities, evaluating their level of technological implementation and public policy development. Additionally, the data-driven management approach emphasizes real-time management through the use of big data, and the innovation ecosystem approach highlights collaboration between governments, academia, industry, and civil society to foster urban innovation.

These approaches, widely applied in global contexts, provide a robust foundation for assessing the progress of smart cities. However, in developing countries, where social inequalities are more pronounced and resources are limited, it becomes essential to complement these perspectives with an additional approach: Conscious and Inclusive Communities. This framework ensures that urban development is not only technologically advanced but also equitable and participatory, placing the needs and realities of local communities at the heart of the transformation process. Table 2 summarizes the generalities of each approach.

Table 2. Smart Cities Assessment.

Key Approach	Generalities
Ranking Approach	Based on rankings which compare the performance of cities based on standardized indicators such as mobility, governance, sustainability, and quality of life.
Maturity Approach	It classifies cities into stages, from early technology implementation to advanced integration of smart solutions.
Data-driven Management Approach	Leverages technologies such as big data, IoT, and sensors to collect and analyze real-time data, optimizing urban services like mobility, waste management, and energy consumption.
Innovation Ecosystem Approach	Emphasizes collaboration between government, industry, and academia to drive urban innovation.
Conscious and Inclusive Communities Approach	Focused on ensuring that smart city development does not exacerbate social inequalities but instead promotes inclusion and equity.

The following section presents these five key approaches, adapted to the assessment of smart cities in developing countries, each offering a critical lens for understanding and improving the process of urban transformation in these regions.

3.1 Ranking Approach

The classification approach to smart city evaluation relies on the use of rankings, which compare the performance of cities based on standardized indicators such as mobility,

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governance, sustainability, and quality of life [17]. These rankings provide a quantitative snapshot of how cities perform in key areas of urban development, offering governments, policymakers, and stakeholders a clear view of where their cities stand in comparison to others. By identifying strengths and weaknesses in urban systems, this approach helps to pinpoint specific areas that require improvement, fostering more targeted policy interventions [1].

Several contemporary rankings evaluate smart cities, each with specific regional focuses and criteria. In Europe, the European Smart Cities Ranking by Giffinger et al. [31] continues to be influential, alongside the CITYkeys initiative, which prioritizes sustainability and innovation metrics [32]. Globally, the IMD Smart City Index (2023) and the Networked Society City Index by Ericsson [33] focus on holistic smart city metrics, including connectivity and citizen engagement. Other indices, such as the Smart City Index [34] and the IESE Cities in Motion Index 2023 [35], assess a city's performance across dimensions like mobility, governance, and quality of life, offering a comprehensive view of urban development.

In the context of developing countries, where cities often face significant disparities in infrastructure, technological capabilities, and governance, the classification approach serves as a particularly useful tool for benchmarking progress [1,15]. It allows cities to set clear, measurable goals and track their development over time relative to international standards. This is important for cities striving to enhance their global competitiveness while addressing critical challenges such as poverty, transportation inefficiencies, and energy shortages. Rankings also provide a means to promote transparency and accountability, as they allow citizens and stakeholders to assess the effectiveness of local governance based on visible, standardized criteria.

However, while the classification approach offers substantial benefits, it is not without challenges. In developing countries, there is often a lack of reliable and consistent data, which can undermine the accuracy and usefulness of rankings. Cities in these regions may struggle to collect the high-quality data necessary to measure performance across various indicators due to financial constraints, technical limitations, or insufficient administrative capacity. This data gap can lead to skewed or incomplete evaluations, potentially misrepresenting a city's actual progress or needs. Furthermore, the focus on measurable indicators can sometimes overlook critical qualitative aspects of urban life, such as social inclusion and community engagement, which are harder to quantify but equally essential to the success of smart city initiatives [16].

Despite these challenges, the classification approach remains a powerful tool for urban development in developing countries. It provides a structured, comparative framework that enables cities to benchmark their progress and set ambitious yet achievable targets. For governments, these rankings offer a roadmap to prioritize investments and reforms in areas where cities are lagging behind. Additionally, rankings serve as an important motivational tool, encouraging cities to improve their standing by implementing new policies, technologies, and governance strategies that address their specific shortcomings. The competitive nature of rankings can drive innovation, as cities seek to enhance their performance and visibility on a global stage [18].

In summary, the classification approach is highly valuable in promoting smart city development, especially in developing countries where the need for clear, actionable metrics is crucial. However, it must be adapted to the local context, with efforts made

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to improve data collection processes and account for qualitative dimensions of urban life. Despite its limitations, the visibility and accountability that rankings provide make them an indispensable tool for cities aiming to enhance their sustainability, governance, and overall quality of life.

3.2 Maturity Approach

The maturity approach evaluates a smart city's development by examining factors such as technological infrastructure, the adoption of public policies, and social engagement [19,22]. It classifies cities into stages, from early technology implementation to advanced integration of smart solutions. In developing countries, this approach helps cities identify strategic priorities, focusing on infrastructure and regulatory frameworks to advance towards higher levels of smart city development [16,20]. By assessing a city's technological readiness and governance capacity, the maturity approach provides a roadmap for policy and infrastructure improvements. Early-stage cities might prioritize basic infrastructure such as internet access and urban sensors, while more advanced cities could focus on smart transportation systems and real-time data analytics [21].

This approach is particularly valuable for developing countries, as it highlights developmental gaps and enables cities to set incremental goals aligned with their current capabilities. Policymakers can use this framework to understand which policies or interventions are needed to transition from one stage to the next, such as strengthening governance structures or enhancing public-private partnerships.

Despite its benefits, the maturity approach faces challenges, particularly in developing regions, where financial and resource constraints, along with political instability, can slow progress. For this reason, the approach advocates a phased, long-term strategy, ensuring cities gradually build the foundations for a more advanced smart city ecosystem.

Ultimately, the maturity approach remains an essential tool for guiding sustainable and inclusive urban growth. By understanding where a city stands in its development cycle, urban managers can make more informed decisions, allowing for targeted interventions and tailored strategies that address both technological and social needs.

3.3 Data-driven Management Approach

The data-driven management approach leverages technologies such as big data, IoT, and sensors to collect and analyze real-time data, optimizing urban services like mobility, waste management, and energy consumption [23]. This approach enables cities to make informed and efficient decisions, adjusting operations dynamically to improve both service delivery and urban quality of life. In developing countries, data-driven systems present significant opportunities to enhance efficiency and transparency, addressing challenges such as congestion, pollution, and resource management [25].

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By integrating real-time technologies, cities can optimize systems like traffic flow and energy use, becoming more responsive and adaptable [24]. This approach allows cities to bypass traditional urban management methods, streamlining processes and reducing inefficiencies. For example, real-time data on waste collection can optimize routes, lowering fuel costs, while smart meters can help reduce energy waste.

Despite its potential, technological infrastructure remains a key challenge in developing countries. The installation of sensors and data platforms requires substantial investment, and even where infrastructure exists, data processing capacity and skills gaps may limit effectiveness. Data privacy and security concerns also arise, particularly in regions with weak regulations, where there is a risk of data misuse or dependency on large technology firms.

Nevertheless, the benefits of data-driven management for improving urban efficiency, cost savings, and citizen engagement are substantial. It offers cities the ability to monitor and adjust their operations in real-time, fostering sustainable urban growth and better meeting the needs of the population [26]. While challenges remain, data-driven approaches represent a crucial step toward smarter, more responsive cities, especially in developing countries.

3.4 Innovation Ecosystem Approach

The innovation ecosystem approach, based on the Triple Helix model, emphasizes collaboration between government, industry, and academia to drive urban innovation. Over time, this model evolved into the Quadruple Helix, adding civil society as a crucial pillar, recognizing the role that citizens play in shaping city development [27]. By involving a broad spectrum of stakeholders, the model ensures that smart city solutions are not only technologically advanced but also aligned with the needs of the local population [29].

In developing countries, where technological and socio-economic barriers often exist, this approach is particularly important. Collaboration between sectors helps cities overcome challenges related to infrastructure, governance, and economic development. Governments provide regulatory support, industries offer technologies, academia supplies research, and civil society ensures inclusivity. Urban Living Labs (ULLs) exemplify this approach by engaging stakeholders—including citizens—in the testing and implementation of smart technologies, ensuring that innovations benefit all segments of the population, particularly the marginalized [28].

The innovation ecosystem approach operates on the principle that no single sector can address urban challenges alone. By fostering collaboration, it offers a holistic framework where each actor contributes unique capabilities to create sustainable and innovative solutions [30]. It also promotes the democratization of innovation, ensuring that citizens actively participate in the development of technologies that shape their cities.

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However, the approach's success depends on effective coordination among stakeholders, which can be hindered by institutional silos, misaligned incentives, or a lack of trust. Cities must therefore promote inclusive governance frameworks that encourage open communication and shared accountability.

This approach is justified by its ability to create locally relevant and adaptable solutions, ensuring that smart city initiatives in developing countries become catalysts for broader transformation, not isolated experiments. The emphasis on collaborative learning ensures that smart city technologies are not only cutting-edge but also socially relevant and scalable to diverse urban contexts.

The innovation ecosystem approach is vital for developing smart cities, particularly in developing regions where challenges demand a collective effort. By fostering cooperation between government, industry, academia, and civil society, cities can co-create solutions that are inclusive, innovative, and sustainable, ensuring that technologies address the real needs of the communities they serve.

3.5 Conscious and Inclusive Communities Approach

The Conscious and Inclusive Communities approach, proposed as an original contribution of this study, focuses on ensuring that smart city development does not exacerbate social inequalities but instead promotes inclusion and equity [3,5,6]. This approach emphasizes the importance of involving local communities in all phases of smart city projects, from planning and implementation to governance. In developing countries, where inequalities are often deeper, this approach ensures that smart technologies address the real needs of marginalized populations, fostering urban development that is inclusive, culturally aware, and socially sustainable [5,6,8].

While other approaches prioritize technology, innovation, and institutional maturity, the Conscious and Inclusive Communities framework centers on people and communities as the core of the urban development process. The premise is that technology alone cannot solve urban problems unless the needs, active participation, and inclusion of citizens are considered [7,9]. The approach aims to mitigate urban inequalities, particularly in developing contexts, where smart city solutions, if not designed inclusively, risk worsening social divides. This approach ensures that the benefits of smart development reach all sectors of the population, especially the most vulnerable communities, which are often ignored in urban transformation processes [4,7].

The Conscious and Inclusive Communities framework promotes equitable and participatory development by fostering platforms where citizens are not only recipients of technology but co-creators of solutions [6]. Conscious inclusion ensures that residents

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can express their needs, participate in decision-making, and ensure that urban development respects their interests, identities, and cultures [7,11]. Moreover, cities that empower their communities through active and conscious participation are more resilient to challenges such as social, economic, or environmental crises. This approach highlights the importance of aligning urban development with local realities, drawing on the knowledge and adaptability of communities to create solutions that truly reflect their needs [6,11].

The justification for this approach is grounded in the need to overcome criticisms of traditional smart cities, which often prioritize technological infrastructure and economic efficiency over social contexts or the needs of the population [10]. As noted by scholars, one of the key criticisms of traditional smart city projects is their tendency to focus on technology without addressing the human element of urban life [10]. The Conscious and Inclusive Communities approach responds to these critiques by ensuring that technological solutions promote equitable and participatory development, rather than exacerbating social inequalities.

In developing countries, where inclusion and equity are not optional but essential for the success of any smart city project [1], this approach ensures that smart cities improve the quality of life not just for the wealthiest or most connected sectors, but for all citizens. This is particularly important for the disadvantaged communities, which are often the most affected by technological changes if they are not involved in the process from the start. By embedding inclusion and equity as central pillars of smart city development, the Conscious and Inclusive Communities framework ensures that cities become more just and resilient.

Furthermore, this approach complements the other evaluation frameworks—Classification, Maturity, Data-Driven Management, and Innovation Ecosystems—by ensuring that smart city assessments also measure their social impact and their capacity to include all citizens, regardless of socio-economic status. While the other approaches offer useful models for measuring and managing smart cities, they do not explicitly address the critical issues of social equity and participation. The Conscious and Inclusive Communities framework fills this gap, providing a more holistic view of urban development that goes beyond technological innovation to focus on social well-being.

Finally, the Conscious and Inclusive Communities approach promotes a broader vision of smart cities. True urban intelligence does not only lie in technological efficiency but in a city's ability to create a just, inclusive, and resilient society. The success of a smart city should not be measured solely by its ability to innovate, but by its capacity to improve the lives of all its citizens, ensuring that no one is left behind. This approach calls for a more inclusive evaluation of smart city initiatives, where success is defined not just by innovation metrics but by the social, economic, and cultural progress of the entire population.

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4 Discussion: Addressing the Research Gap through Conscious and Inclusive Communities

The introduction of the Conscious and Inclusive Communities approach as part of the evaluation framework for smart cities addresses a significant research gap that has been overlooked in traditional models of smart city development. While existing approaches prioritize technological advancement and economic growth, they often fail to adequately consider the social and cultural needs of local communities, particularly in developing countries [1,3,4,12]. This omission has sparked criticism from scholars such as Esashika [2], who argue that the focus on technology and economic metrics without sufficient attention to local social contexts can lead to disconnects between smart city projects and the very citizens they are designed to serve. Examples such as Masdar City and Songdo reveal how smart city initiatives that neglect community expectations create urban environments that, while technologically advanced, lack the engagement and social inclusivity needed to be truly successful [13,14].

In the context of developing countries, where social inequalities are more pronounced, the Conscious and Inclusive Communities approach becomes particularly critical. Ignoring the needs of marginalized populations in these regions can not only exacerbate existing disparities but also lead to the creation of smart cities that primarily benefit urban elites, leaving large segments of the population further behind [6,11]. Smart city projects that do not integrate inclusive decision-making processes risk perpetuating the very social and economic inequalities they seek to mitigate. This approach ensures that technological solutions are not only designed with the most vulnerable communities in mind but also implemented in ways that respect local cultural identities and needs. By placing communities at the heart of the decision-making process, this approach promotes social equity and ensures that all residents have a voice in the transformation of their urban environments.

One way to enhance this community-driven innovation is through the concept of ULLs, as outlined in the Quadruple Helix model. This model includes civil society as a core actor in the co-creation of smart city solutions, alongside government, academia, and industry [5,7]. However, the Conscious and Inclusive Communities approach goes beyond merely involving citizens in innovation; it advocates for their empowerment in problem definition and solution implementation. Rather than being passive participants, citizens become active co-creators, influencing the direction of urban development in ways that are conscious of cultural diversity and local realities. This approach acknowledges that solutions developed in isolation from community input are unlikely to address the most pressing needs of the population.

Moreover, this approach contributes to the broader goals of social sustainability and urban resilience. For a smart city to be truly sustainable, it must extend beyond technological and environmental dimensions to integrate social sustainability. This means creating urban environments where citizens are not just recipients of technology but

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active participants in shaping the future of their cities. By embedding communities in the decision-making process, cities can become more resilient, with greater capacity to adapt to social, economic, and environmental crises [4,9]. Community participation in decision-making fosters a sense of ownership and responsibility, which enhances the ability of cities to respond to challenges such as climate change or social unrest. Therefore, the Conscious and Inclusive Communities approach reinforces both sustainability and resilience, ensuring that urban transformations are not only driven by technology but also by the needs and aspirations of the people.

From a theoretical and methodological perspective, the Conscious and Inclusive Communities approach represents an evolution of traditional smart city evaluation models, which have historically focused on infrastructure, technology, and data [6,8]. While these models provide valuable insights into the maturity and innovation capacity of smart cities, they fail to explicitly address critical issues related to social inclusion, participation, and equity. The introduction of the Conscious and Inclusive Communities framework expands these existing models by incorporating indicators that measure a city's capacity to engage and include all residents in the development process. These indicators are essential for evaluating not only the technological sophistication of smart cities but also their ability to create inclusive, equitable, and participatory urban spaces.

Furthermore, this approach contributes to a more holistic understanding of what it means for a city to be "smart." While technology and innovation are important components of smart city development, they are not the only measures of success. A truly intelligent city is one that can create a just, inclusive, and resilient society. The Conscious and Inclusive Communities approach shifts the focus from purely technological metrics to a more comprehensive evaluation that considers the social well-being of all citizens. In this way, the success of a smart city is not only measured by its ability to innovate but also by its capacity to improve the lives of its most vulnerable populations and ensure that no one is left behind.

In conclusion, the Conscious and Inclusive Communities approach addresses a critical gap in the evaluation of smart cities by ensuring that social equity and inclusion are at the forefront of urban development. It challenges the traditional focus on technology and economic growth by advocating for a more people-centered approach that empowers communities, promotes social sustainability, and builds urban resilience [3,4,11]. This contribution provides a necessary complement to existing frameworks, offering a more inclusive lens through which to evaluate and develop smart cities, particularly in developing countries.

Conclusions

This paper contributes to the existing literature on smart city evaluations by proposing a more holistic and inclusive framework, particularly relevant for developing countries. While traditional approaches such as classification, maturity, data-driven management, and innovation ecosystems provide valuable insights into the technological and governance aspects of smart cities, they often fall short in addressing the social

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and cultural dimensions that are critical for sustainable urban transformation. The proposed Conscious and Inclusive Communities approach fills this gap by ensuring that smart city initiatives are equitable, participatory, and responsive to the real needs of local populations, particularly marginalized communities.

The Conscious and Inclusive Communities approach challenges the conventional focus on technology and economic growth by placing people and communities at the center of smart city development. It advocates for the active involvement of citizens in every stage of the urban transformation process, from planning to implementation and governance. This framework not only promotes social equity but also enhances urban resilience, as communities that are engaged and empowered are better equipped to adapt to social, economic, and environmental challenges.

Additionally, the integration of this approach with existing evaluation frameworks strengthens the overall assessment of smart cities. By incorporating indicators of social inclusion, participation, and equity, urban planners and policymakers can better measure the success of smart city projects in terms of their impact on society rather than just their technological advancements.

For policymakers and urban planners in developing countries, the recommendations outlined in this paper offer a roadmap for creating more inclusive and sustainable urban environments. By adopting a multidimensional approach that combines technological innovation with social responsibility, cities can ensure that smart city initiatives truly benefit all citizens, fostering a more just and resilient urban future.

In conclusion, the framework proposed in this paper provides a comprehensive tool for assessing smart cities in developing regions, ensuring that the pursuit of innovation does not leave any community behind. Future research and policy should continue to explore how inclusive practices can be integrated into the development of smart cities, particularly in regions where inequality and social exclusion are significant barriers to sustainable urban growth.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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ISBN 978-9930-617-71-7

Electric systems and real-world experiences for smart cities

Monitoring electrical parameters inside of PV inverters

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Abstract. The vast majority of inverters installed today are not monitored, or the monitoring is carried out in the AC part with sensors external to the inverter. The inverters that can be purchased on the market have an interface to extract the data with which it works. These interfaces usually work with the Modbus protocol, in their TCP/IP or RS485 bus versions. Access to this data allows access to both DC and AC parameters, as well as additional parameters such as operating temperature. Wireless technologies make it possible to send data over long distances without the installation of additional cables. This research designs a device that accesses investor data and transmits it wirelessly to the cloud.

Keywords: LPWAN, LoRa, Smart Monitoring PV Inverters.

1 Introduction

Nowadays, it is of vital importance to have real-time data from electrical installations. This becomes even more interesting in generation facilities such as PV plants or smaller scale generation in homes. Most installations are not monitored, or if they are, it is only on the AC side. It is quite difficult to find installations that have access to the DC side.

Inverters are usually monitored via applications provided by the manufacturers. These applications do not provide all the data that inverters have available. Another added problem is the rate at which the data is taken, which is usually no less than 5 minutes, which is insufficient for quality monitoring. Moreover, the data cannot be downloaded and are the property of the manufacturers, without users having access to this information.

To access all inverter data, the ModBus protocol can be used, which allows access to all stored variables. It can be accessed via RS485 or TCP/IP interface, and the data

ISBN 978-9930-617-71-7

is then uploaded to the cloud where it can be accessed for viewing, downloading, analysis, etc. The data rate can also be reduced to better adapt it to the monitoring needs of each installation.

Inverters are often installed in locations where it is necessary to use large amounts of cable to access the inverters or where wireless coverage does not reach them. This is where LPWAN (Low-Power Wide Area Net-wrok) technologies are used, which have a long range and low power consumption. Of particular interest is the LoRa (Long-Range) network, which has a range of 5-10 km, sufficient for most domestic installations and large PV plants.

2 Related work

Before starting with the development of the equipment, it is necessary to review the state of the art in the monitoring of electrical installations, with emphasis on those that use IoT (Internet of Things) access and wireless communications.

The most widely used technology in IoT devices for monitoring electrical installations is Wi-Fi (Wireless-Fidelity), and there are several articles that describe devices that send information using this technology. Sánchez-Sutil et al. [1] developed a low-cost, open-source home meter for homes with PV installations. Medeiros et al. [2] implemented a three-phase metering device using Wi-Fi and low cost, to be installed in homes and industrial environments. Hernández et al. [3] studied the influence of data sampling frequency in electrical installations, with case studies in Spain, using Smart Meters with Wi-Fi technology. Hlaing et al. [4] built a Smart Meter with Wi-Fi and IoT connection for single-phase installations. Cano-Ortega et al. [5] developed a platform to analyse large amounts of data in the cloud from measurements in homes, PV plants and electric vehicle chargers. Salor et al. [6] implemented a mobile power quality meter for transmission facilities. Benavides et al. [7] developed a model to remotely control a microgrid based on demand-side power control.

Cano-Ortega et al. [8] realized a device to monitor the efficiency and operating conditions of induction motors in industrial environments using LoRa technology. Abete et al. [9] implemented a low-cost IoT connected meter based on the ADE7913 measurement chip. Sánchez-Sutil et al. [10] developed a control and measurement system for public lighting networks based on a LoRa network. Sánchez-Sutil et al. [11] built an energy efficiency system for public lighting under a LoRa LPWAN network. Francisco Sánchez-Sutil et al. [12] designed and tested a control and data reading device for power quality analyzers using ModBus and RS485 communication, eliminating wiring and using a wireless LoRa LPWAN network. Sánchez-Sutil et al. [13] implemented a Smart plug to monitor and control electrical devices in homes with LoRa communication. Sánchez-Sutil et al. [14] developed an energy efficiency system for irrigation systems using LoRaWAN. Sánchez-Sutil et al. [15] designed and implemented a real-time smart meter with LoRa communication. Cano-Ortega et al. [16] built a smart meter for residential environments with application of TLBO algorithm and LoRaWAN networks. Sánchez-Sutil et al. [17] developed a power quality analyzer for monitoring public lighting networks with LoRa wireless communication system.

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3 Hardware design

The hardware design has sought to make a PCB (Printed Control Board) board with the smallest possible dimensions in order to facilitate installation near the inverters. The board has been designed with dual Wi-Fi and LoRa wireless communication. The design could be made with one or the other network, or both at the same time. It is also possible to make boards with only one of the two types of communication depending on the needs.

The microcontroller chosen is the Arduino Nano (AN) [18] because of its size and power, as well as its ability to work with different components. Access to Wi-Fi, and therefore to IoT via Google's Firebase [19] service, is guaranteed by a Wemos d1 mini (Wd1m) microcontroller [20]. This microcontroller is connected to a Deek-Robot datalogger model id8122 from which the measurement time is taken; as an option, the datalogger incorporates a microSD memory slot that would allow the measurements to be recorded. The LoRa network communication has been realised with a Dragino LA66 LoRaWAN Shield (LA66S) card [21]. The design is completed by a W5100 mini-Ethernet card, as the inverter chosen for the tests, model Sunny boy 3000 TL-21 from SMA, has implemented the ModBus protocol via TCP/IP.

Access to Firebase from the LoRa network is not direct, but requires the node network service as a gateway. LA66S sends the data to the PG1302 hub [22]. This hub sends the data to TTN (The Things Network) via a wired or Wi-Fi Internet connection, which is already installed on a Raspberry Pi 4 [23]. TTN has implemented a server with MQTT protocol (Message Queuing Telemetry Transport) [24] for each project, this server is connected to Node-Red, which in turn sends it to Firebase. The applications for mobile devices are enhanced with MIT App Inventor [25]. Fig. 1 shows the block diagram of the device.

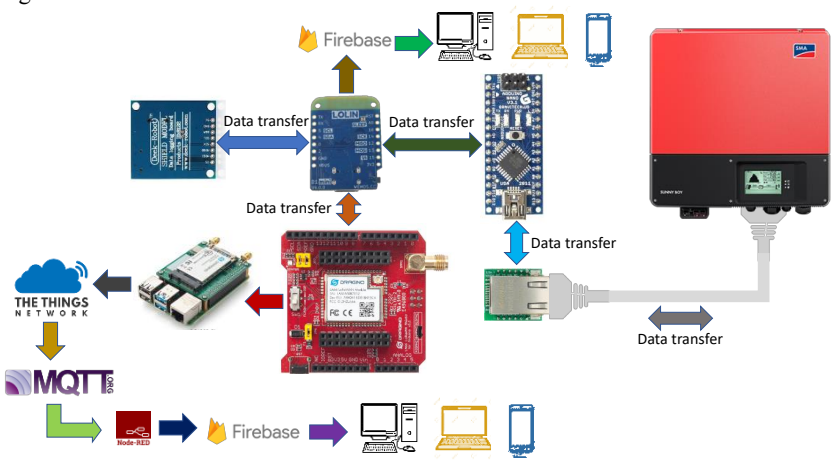


Fig. 1. Device block diagram.

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The connection diagram of the device is shown in Fig. 2. The connection between the inverter and the W5100 Ethernet card is made via network cable with RJ45 connection. W5100 is connected to AN for information exchange. AN sends measurement command to W5100, once received the data is sent to Wd1m via the serial port. Wd1m reads the measurement time and uploads it to Firebase. In turn, it sends the information to LA66S to send it to the PG1302 concentrator, which uploads the data to TTN, with the MQTT server it is received by Node-Red and sent to Firebase. Fig. 3 shows the PCB board mounted and sending data.

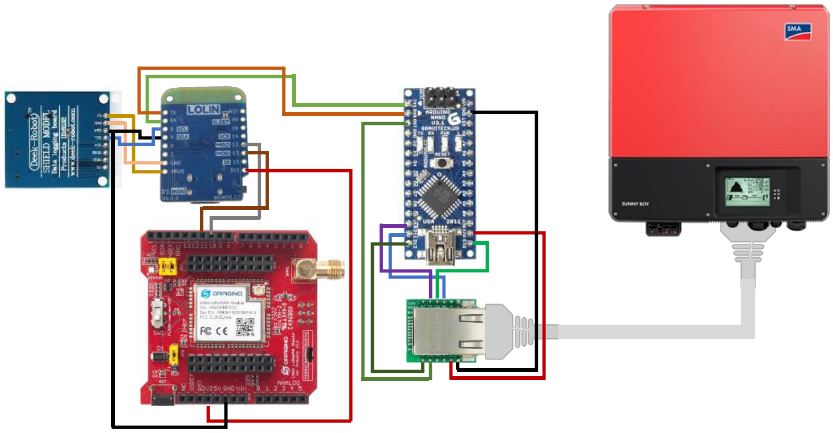


Fig. 2. Connection diagram of the inverter data extraction circuit and sending to the cloud via Wi-Fi and/or LoRa.

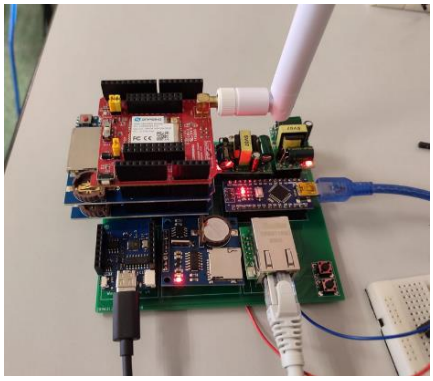


Fig. 3. Assembled PCB board of the inverter access device.

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4 Software design

4.1 Arduino Nano programming

AN deals with ModBus communication with the inverter, in this case under TCP/IP protocol, which is the one chosen by the manufacturer. To start the program, it must start (i) the ModBus system; (ii) the W5100 network card; (iii) the serial port. Subsequently, the work it does is to read the serial port, if it receives a measurement command from Wd1m, it sends the command to the inverter, waits for the inverter's response and sends the measurement data to W1dm. Fig. 4 shows the flow diagram for AN.

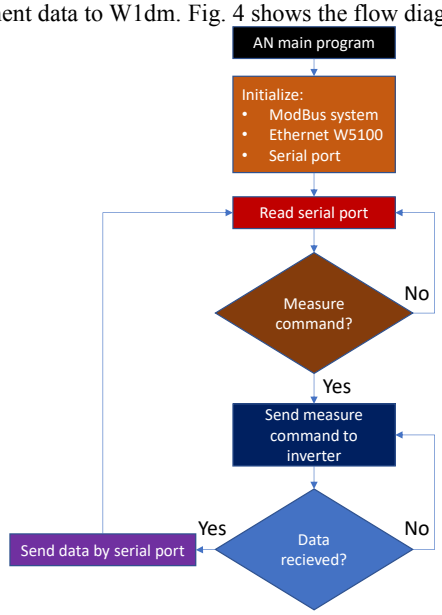


Fig. 4. AN main flow chart.

4.2 W1dm programming

W1dm is the center of the measurement device. First, W1dm must perform initialization, preparing (i) the real-time clock; (ii) the serial port for communication with AN; (iii) start the virtual serial port for communication with LA66S; (iv) start the Wi-Fi adapter. Subsequently, W1dm must take care of sending measurement command to AN, receiving data from AN, taking the measurement time, sending the measurement data to Firebase and sending the measurement data to LA66S. Fig. 5 shows the flowchart of W1dm.

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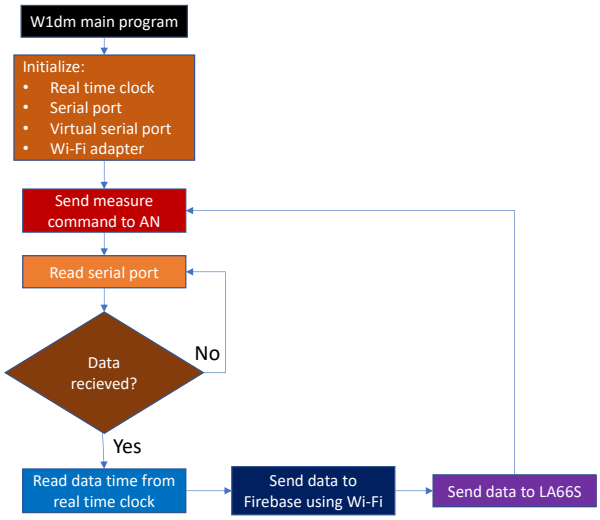


Fig. 5. W1dm main flow chart.

4.3 Programming Node-Network

The LoRa network cannot connect directly to Firebase to have the data in the cloud, but it is sent directly to TTN which implements an MQTT server for each device. To connect TTN with Firebase, Node-Red is used as a gateway. For this purpose Node-Network waits for an event from TTN, collects and converts the necessary data and sends it to Firebase. In addition to the electrical data, the LoRa network parameters are also collected for communication statistics and to improve the network. Fig. 6 shows part of the Node-Red program, corresponding to the LoRa system variables.

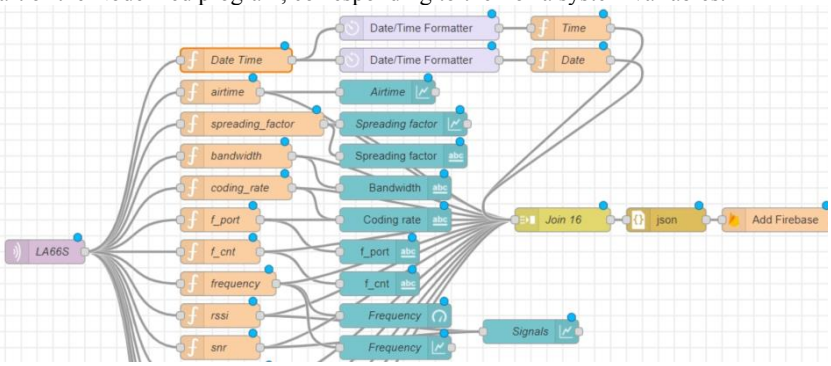


Fig. 6. Node-Red program.

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4.4 Programming for data download

The data is downloaded and deleted from Firebase on a daily basis, so as not to take up the free Firebase quota for each project, which amounts to 1 GB of information. To do this, a Python program has been implemented that accesses each project, downloads the information in json format, which is how Firebase offers it, converts it to csv and deletes it from Firebase. The program runs at 2am each day to download the previous day's data, using the Windows task scheduler. If for some reason a day is not downloaded, it searches for previous days and downloads and deletes all the data. Fig. 7 shows the flow diagram

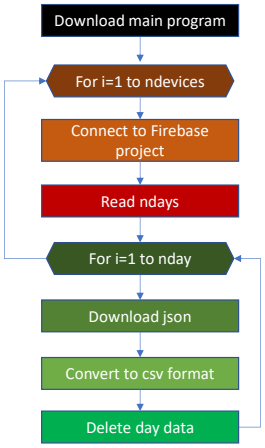


Fig. 7. Download data program.

5 Results

5.1 Test equipment

To perform the tests, the PV installation of the Department of Electrical Engineering of the University of Jaén has been used. The installation is located on the terrace of the A3 building of the Campus de las Lagunillas in Jaén. The installation consists of 10 Axitec model AC-270P/156-60 panels providing 2.97 kWp, connected to a grid-connected SMA Sunny boy 3000 TL-21 inverter, located in the A3-265 laboratory. Fig. 8Fig. 8 shows the installation for carrying out the tests.

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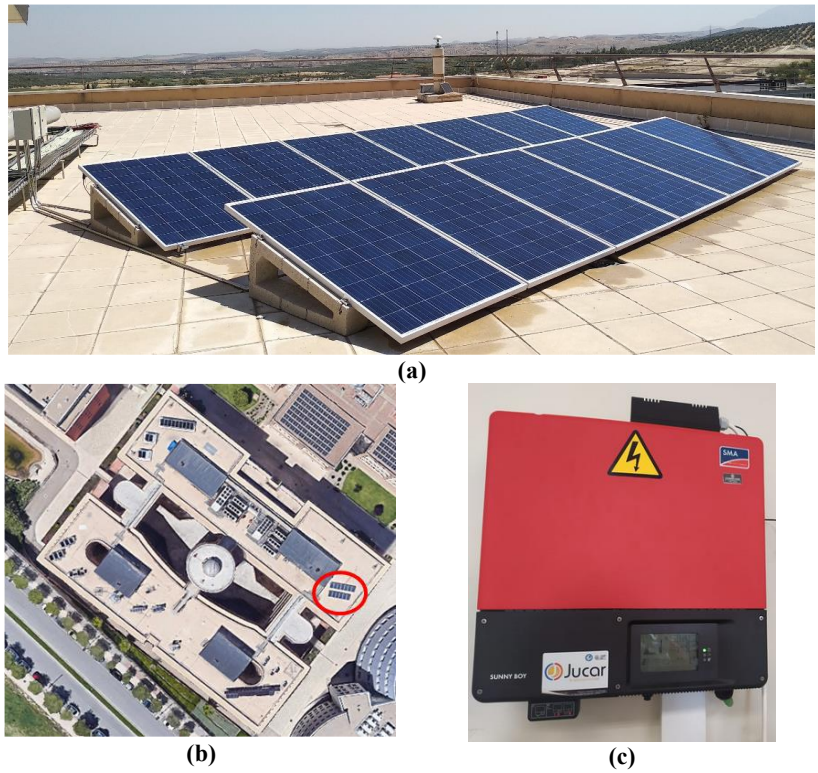


Fig. 8. (a) Arrangement of the solar panels; (b) location of the installation in the A3 building; (c) inverter installed in the A3-265 laboratory.

5.2 Data obtained

The information obtained can be represented and analyzed to improve the monitored system and improve equipment monitoring. This information is downloaded daily at 2 am and saved in csv format.

Fig. 9 shows the data measured on 11 July 2024. Part (a) shows the DC voltage which is maintained at a value of 70 VDC while the generator is not generating, then the voltage rises to around 300 VAC, the AC voltage remains constant at around 240 VAC which is the reference voltage of the grid to which the inverter is connected. The currents are shown in part (b), where it can clearly be seen that the AC output current is higher than the DC input current. The DC power is higher than the AC power, as shown in part (c). On the other hand, the efficiency is lower in the DC part than in the AC part as can be seen in part (d). Finally, the operating temperature of the inverter is shown in part (e) which, as can be seen, coincides in shape with the daily generation

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curve, with the temperature increasing with the increase in power handled by the inverter.

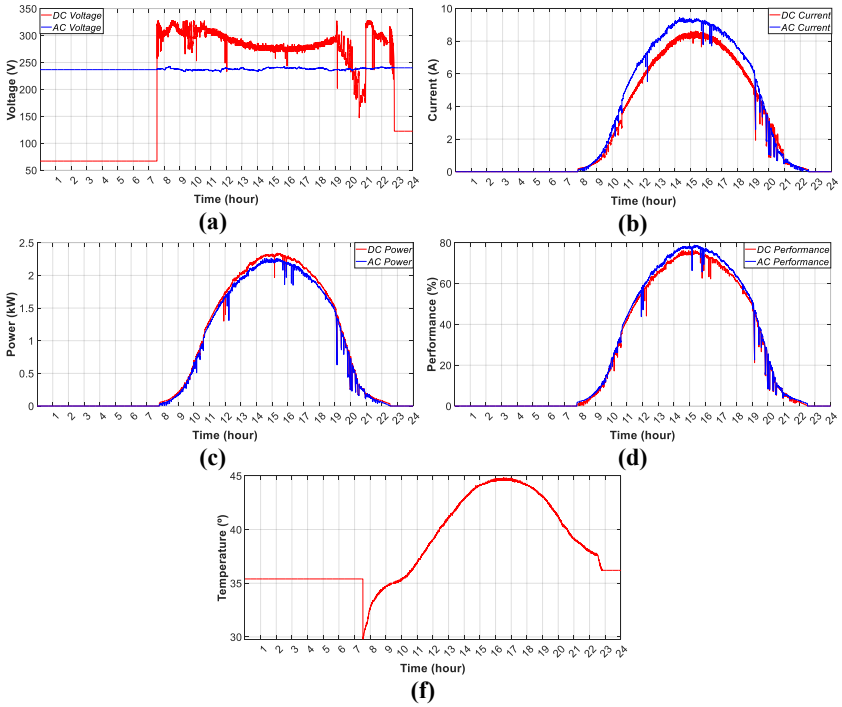


Fig. 9. Data measured on 2024/07/11. (a) voltage; (b) current; (c) power; (d) performance; (e) inverter temperature.

5.3 Data visualization

A Dashboard has been created to monitor the inverter data as well as the LoRa grid parameters. The data is refreshed every 10 seconds and the display range is 1 day. The dashboard has been realized in Node-Red. Fig. 10 shows the inverter dashboard and Fig. 11 the LoRa network dashboard.

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Fig. 10. Inverter Dashboard created in Node-Red.

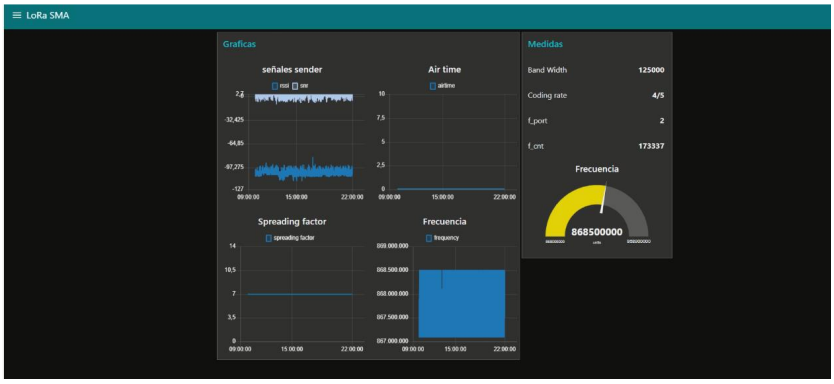


Fig. 11. Dashboard for LoRa network data created in Node-Red.

On the other hand, an app for mobile devices has also been developed for real-time visualisation of the data generated. The application is made in MIT App Inventor for the Android operating system. Fig. 12 shows a screenshot of the application.

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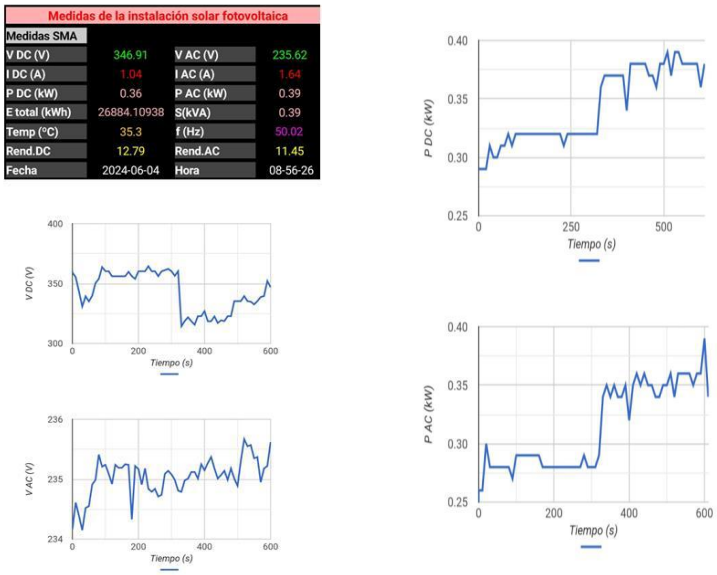


Fig. 12. App for display on Android devices.

Acknowledgments. The authors acknowledge the support provided by the Thematic Network 723RT0150 ‘‘Red para la integración a gran escala de energías renovables en sistemas eléctricos (RIBIERSE-CYTED)’’ financed by the call for Thematic Networks of the CYTED (Ibero-American Program of Science and Technology for Development) for 2022.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article. This research was funded by the Council of Andalucía (Junta de Andalucía. Consejería de Transformación Económica, Industria, Conocimiento y Universidades. Secretaría General de Universidades, Investigación y Tecnología) through project ProyExcel 00381.

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ISBN 978-9930-617-71-7

Design and implementation of DC meter for PV plants

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Abstract. Due to the growth of photovoltaic plants both in Spain and the rest of the world, it causes a technological development in the normal operation of these plants. In this sense, the authors have developed a DC meter for use in PV plants based on current regulations. The hardware implementation of the meter is based on sensors that allow the measurement of electrical variables such as voltage, current and power. And the software design allows the different electrical variables to be measured in real time. The calibration process of the equipment is carried out according to IEC standards. Furthermore, the measurement and processing of the data obtained is carried out by means of a microcontroller.

Keywords: Photovoltaic, Data acquisition; IEC standards; low-cost; open source; Smart Direct Current in Real-Time

1 Introduction

The consumption of electricity is increasing every year and this leads to an increase in new photovoltaic (PV) plants and their integration into the electricity grids. This makes the electricity system more and more reliable and sustainable. Therefore, PV plants must perform optimally during their operation time.

The evaluation of PV requires the measurement of electrical variables in small time intervals. This causes problems due to the large amount of data and equipment that must be reliable and accurate. In the case of large-scale plants, this approach is technically and economically challenging, as it requires extending measurements down to the module level across a very large field [1]. The need for sensors to measure variables in each module, as well as the cost of the integrated monitoring system, increases proportionally with the size of the PV plant [2,3]. The current standard for PV plant monitoring based on UNE-EN IEC 61724-1 [4] entitled PV system performance. Part 1: Monitoring. The standard indicates the recording of the electrical variables defined in point 11 of this standard.

Furthermore, data management requires a large storage space and post-processing, it is complex especially in large plants. In addition, communication problems may arise from each individual unit to the central unit.

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The monitoring equipment must include the electrical variables that allow the plant operation to be evaluated in real time. From the electrical point of view, direct current (DC), voltage and power must be measured [2].

The hardware design must distinguish several monitoring levels (i) plant level; (ii) inverter level; (iii) DC module string grouping; (iv) DC PV module string; (v) DC PV module.

The PV plant measurement equipment on the DC side of the inverter shall be equipped with voltage and current sensors, which allow power and energy assessment. The equipment for PV module strings and conjunction of these strings will contain voltage and current (DC) sensors. Finally, module level equipment will implement DC voltage and current sensors.

Some authors have designed plant (AC) measurement equipment with installed voltage, current and frequency sensors, which allow to obtain RMS, harmonics, power and energy values [12,13,14]. The software design methodology must integrate the measurement [15] and sending of data at a minimum rate of electrical variables [11].

The performance evaluation will be based on current plant operating data and reference values. To manage the information obtained and operate accordingly, a server is designed in the plant that brings together all the data generated, so that it is available for monitoring the plant. Additionally, the data will be uploaded to the cloud at the recording interval and will be accessible for external consultation.

2 Design FV

2.1. Hardware

2.1.1. Microcontroller

The DC measurement device designed and developed in this article requires a powerful and fast microcontroller, as measurements need to be taken at very small-time intervals. Another important factor is memory, since a large number of voltage and current measurements must be made and stored. Therefore, in addition to having a large memory capacity, it is essential that the microcontroller can quickly access the stored data to perform the necessary calculations.

An open development platform is used that can accommodate other peripherals that complement the functions of the microcontroller. Examples could be storage on a memory card or a real-time clock that provides the date and time of each measurement. The Arduino family is therefore particularly interesting to use. They are low-cost devices for this type of application. Finally, it is important that the size of the microcontroller is small.

An added feature of Teensy 4.1 [16] is that it includes a device for microSD cards up to 32 GB, which does not require additional storage hardware, and because it is included on the board, it has a higher speed. In terms of size, the smallest model is the Teensy 4.1. Therefore, taking into account the microprocessor, available RAM, size, price and additional options, the Teensy 4.1 microcontroller has been chosen for the DC measurement.

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2.1.2. Voltage measurement circuit

The first stage of the signal conditioning circuit for the voltage circuit consists of five 1000 kΩ, 1/4 W resistors in series, which form a voltage divider together with another 10 kΩ resistor, the value of which has been determined according to the specifications in the component datasheet. The voltage divider is designed to cause a voltage drop of 2 V across the 10 kΩ resistor when the input voltage is 1000 V.

The next component is a high-precision optically isolated voltage sensor, specifically the ACPL-C87A [17] from Broad-com. Its function is to provide optical isolation to electrically separate the input and output signals, providing safety and protection against electrical interference. This feature also has a positive influence on the reliability of the measurement, since the voltage to be measured is referenced to the negative pole, whose voltage may not be zero, while the amplifier output signal is referenced to an isolated ground which it shares with the other components of the circuit.

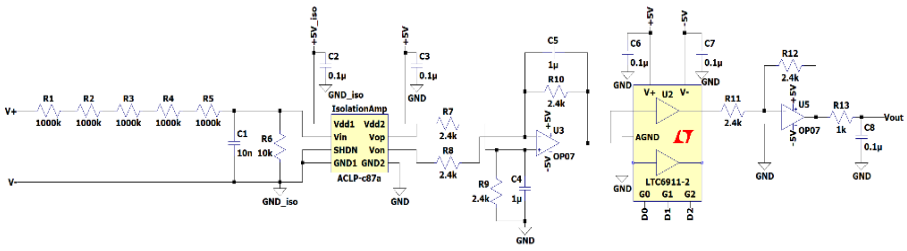


Fig. 1. Signal conditioning for the voltage measurement circuit

The ACLP-C87A has a nominal input range of 0 to 2 V with a very high input impedance (Rin = 1 GΩ), in the case where (R1+R2+R3+R4+R5) >> R2, the component error can be estimated as:

$$e(\%) = \frac{R2}{Rin} \cdot 100 = \frac{10 \cdot 10^3}{1 \cdot 10^9} \cdot 100 = 0.001\% \quad (1)$$

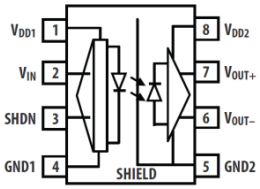


Fig. 2. ACLP-C87A internal circuit scheme

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To power this component, two 5 V supplies are required, one of which is isolated and whose neutral is connected as a reference to the input signal GND1, while the other is connected with respect to the output signal ground GND2.

The next component is an operational amplifier OP07CPZ [18] acting as a subtractor, since the input voltage to the ACLP is equivalent to the voltage difference between Vout+ and Vout- at the output of the component.

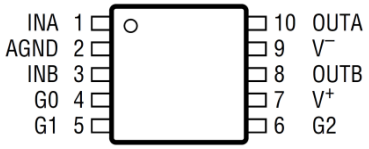


Fig. 3. LTC6911-2 amplifier pins scheme

Once the signal has been subtracted, it is amplified using the LTC6911-2 [19], a programmable gain amplifier, which allows the voltage signal to be adjusted to approximate the full scale of the ADC. In this way, the relative accuracy of the measurement can be increased for the same resolution. The amplifier has two channels A and B, which are capable of providing up to 5 V each, although in this case only channel A has been used, as the maximum output voltage will be 3.3 V (input voltage to the Teensy).

The component is dual-powered at ± 5 V, and its digital pins G0, G1 and G2 are activated by the Teensy 4.1, being a logic one when they take the 5 V value. However, the microcontroller's digital pins provide a 3.3 V output when they are on, so a voltage converter is needed to boost this voltage to the 5 V required by the LTC6911-2 to make the gain adjustment.

Next, because passing through the LTC6911-2 inverts the signal to be measured, an operational amplifier acts as an inverter. Finally, to reduce noise, a first-order RC low-pass filter is placed at the end of the circuit.

2.1.3. Current measurement circuit

The HSTS016L sensor [20], which provides a voltage signal that increases proportionally with the current passing through the conductor, is used for current measurements. One of its main characteristics is that it is non-invasive, due to its split core, that allows the conductor to be wrapped around it without requiring any modifications to the circuit being measured. It has a measuring range from -30 A to 30 A, with an output value of 2.5 V when there is no current flowing through the conductor; this voltage is the reference voltage and remains constant at the sensor's Vref output. Since the objectives do not include measuring negative current, the conditioning circuit has been designed so that a 0 V output corresponds to 0 A in the conductor. For this reason, the reference signal Vref has been subtracted from the Vout clamp's output signal using an operational amplifier configured as a subtractor. The sensor is powered by 5 V.

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The next part of the circuit is the same as the voltage circuit explained above: the signal is amplified by the LTC6911-2, inverted, and filtered before reaching the analogue pin of the microcontroller.

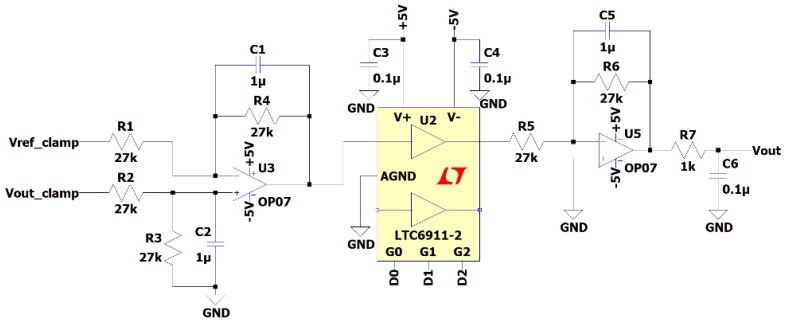


Fig. 4. Signal conditioning for the current measurement circuit

2.1.4. Power supply circuit

Once the characteristics of the meter, the communications, and the components that are part of the voltage and current modules have been defined, it becomes possible to determine and calculate the voltages and power required from the sources that make up the equipment's power supply module.

The power supply circuit includes an AC-DC source (PSK-15D-9) [21] that converts the mains voltage into a continuous 9V signal, from which the voltages required by the components of the designed circuits are derived. This source has an efficiency of 84% and a power rating of 15 W, which exceeds the demand of the equipment. The circuit is equipped with a 3.15 A fuse and a 350 V varistor to protect it from over-voltage. Additionally, two capacitors are mounted at the source's output: a 1 µF ceramic capacitor with 50V insulation and a 100 µF electrolytic capacitor with at least 25V insulation, to reduce output voltage ripple. The characteristics required for both capacitors are specified in the component's datasheet.

A DC-DC converter was used for the isolated 5 V supply needed to power the isolation amplifier of the voltage circuit, as it provides an independent ground and 5 V signal at its input, with 1 W of power. The selected component is the IHA0109S05 [22], to which a 470 µF capacitor has been added at its input, as specified in its datasheet.

The 5 V supply is provided by an LDO LD1085V50 [23] regulator, with 10 µF electrolytic capacitors installed at both the input and output to ensure stability. The regulator can deliver up to 7.5 W of power.

Finally, for the -5 V supply, an isolated TEC 2-0911 DC-DC converter [24] was used, which is supplied with 9 V at the input and provides a 5 V output, whose polarity can be reversed due to its isolation from the main source. In this case, the positive output is connected to ground, and the negative output is connected to the -5 V supply of the components. It is capable of delivering up to 5.4 W of power with an efficiency of 81%.

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The Table 1 shows the power consumption of the elements that make up the string-level electricity meter, while Table 2 presents the output power and efficiency of the selected sources.

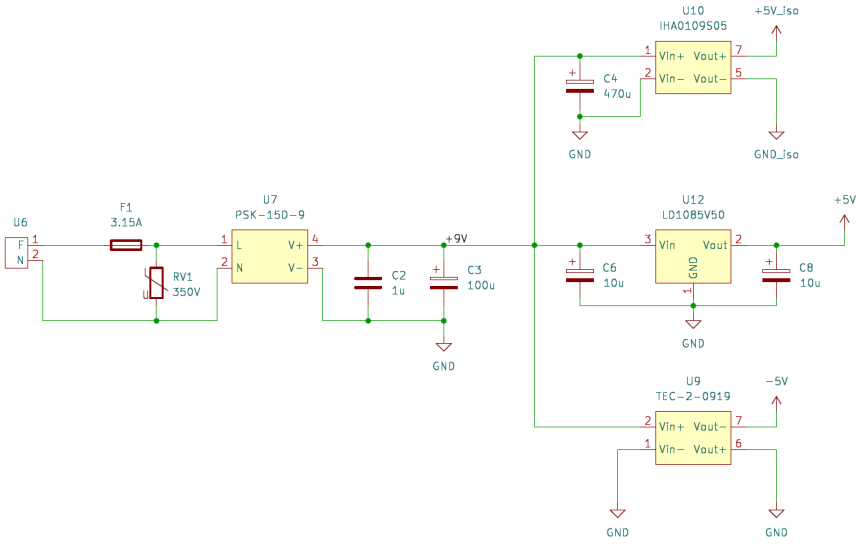


Fig. 5. Power supply circuit

Table 1. Maximum power demanded by the equipment.

Amount	Component	Voltage			
		5 V	-5 V	5 V isolated	3,3 V
1	Voltage measurement circuit	186.5 mW	121.5 mW	60 mW	5 mW
3	Current measurement circuit	129.6 mW	64.6 mW		5 mW
1	Teensy 4.1	500 mW			
1	LoRa	25 mW			
1	ESP32 S2 Mini	2500 mW			
Total		3600.3 mW	315.3 mW	60 mW	20 mW

Table 2. Efficiency and output power of each source.

Component	Maximum output power (mW)	Efficiency (%)	Real power consumption (mW)
LD1085V50 (5 V)	7,500 mW	55.55	6481.19 mW
TEC 2-0911 (-5 V)	2,000 mW	81	389.26 mW
IHA0109S05 (5 V iso)	1,000 mW	77	77.92 mW

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PSK-15D-9-DIN (9 V)	15,000 mW	84	8271.7 mW

2.2. Software design

2.2.1. Main program

The program running on the Teensy 4.1 microcontroller is responsible for taking measurements of the electrical parameters. The program can be divided into the following routines:

- Start-up routine: The program starts with the configuration of analogue (measurement) and digital (control) pins with their respective ADCs, it also defines the variables and initialises the SD reader, as well as any hardware necessary for the operation of the equipment.
- Measurement routine: The voltage and current values of each string are read synchronously. It compares the received signal with the maximum input voltage values of the analogue pin, and if the threshold is exceeded, the LTC gain is adjusted downwards to protect the meter. The gain is then progressively increased until the optimum accuracy for the detected voltage and current level is reached. Finally, the constant assigned to the gain set in each case is applied.
- Data sending routine: The data sending routine creates a CSV file (if it does not already exist) to store the measured data in the SD card's memory. Finally, it waits 500 ms before returning to the start of the measurement routine.

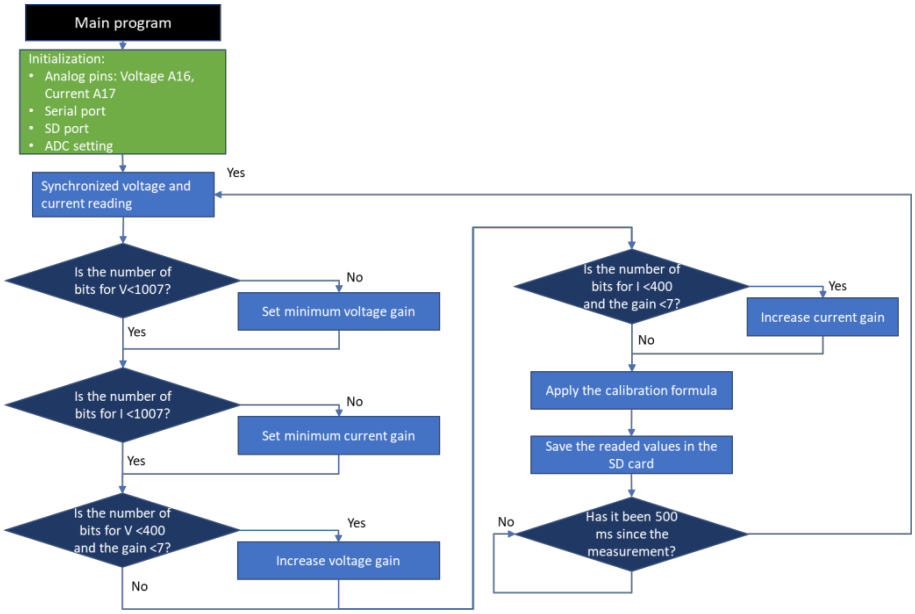


Fig. 6. Flowchart of the microcontroller Teensy 4.1 code

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3 Results

In the results section, different tests have been carried out at both the theoretical and experimental levels. Firstly, the voltage and current circuits have been calibrated, which makes it possible to analyse the tendency of the sensors for different voltage and current levels of the circuits designed. Subsequently, ramp tests were carried out to study the operation of the circuits.

3.1. Calibration of Measurement Circuits.

3.1.1. Voltage circuit

To perform the calibration of the voltage circuit, first of all, theoretical calculations of the calibration constants corresponding to each gain of the circuit were carried out. In this way, the optimum measured voltage level at which the gain change is to be made can be found. Then, using the PQ-Box 300 [25] network analyser as a reference, the circuit calibration was performed, yielding the equation that relates the number of bits read to the voltage in the circuit for the different ranges in which each gain operates.

The experimental calibration test was conducted for a DC voltage of up to 560 V, due to the limitations of the standard equipment. However, given the linear behaviour of the equipment, the calibration performed will allow accurate measurements up to 830 V.

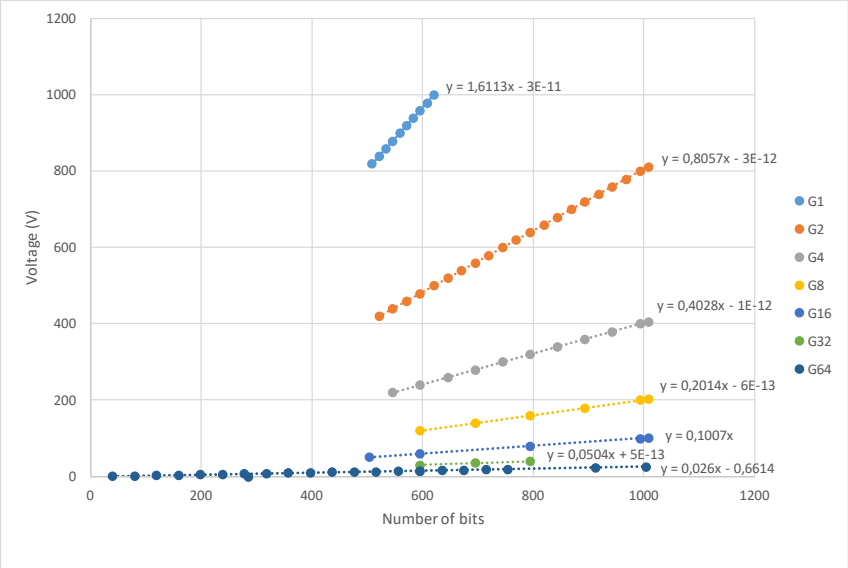


Fig. 7. Theoretical calibration constants for the voltage metering circuit

Figure 7 shows the theoretical calibration constants up to 1000 V values. And figure 8 shows the experimental calibration constants up to values of 830 V.

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As we can see, the slope obtained in the theoretical calculations and in the experimental test is very similar; however, differences can be observed in some decimals and in the offset, which was unknown when carrying out the theoretical calculations.

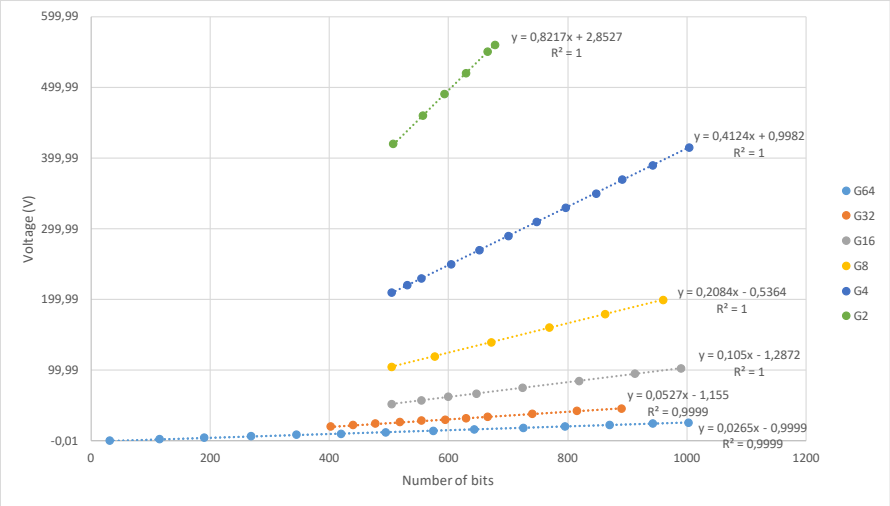


Fig. 8. Experimental calibration constants for the voltage metering circuit

3.1.2. Current circuit.

In the case of the current circuit, we proceeded in a similar way to the voltage circuit, in this case using the Siglent CP4050 clamp ammeter [26], as the analyser previously used does not have sensors capable of measuring direct current. In this case, the experimental calibration test was carried out up to a continuous current of 10.5 A, due to the 11 A limitation of the equipment acting as a load. As it is a linear sensor, it is able to take current measurements accurately up to 18.5A.

Figure 9 shows the theoretical calibration constants up to a value of 30 A.

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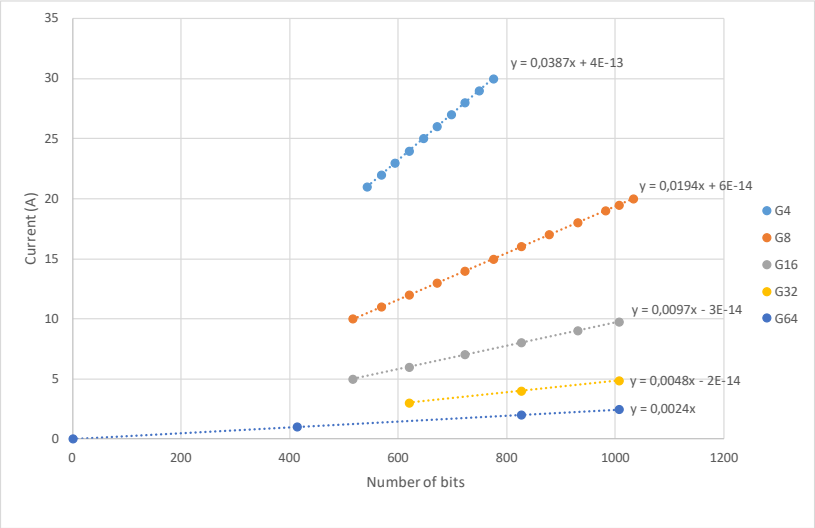


Fig. 9. Theoretical calibration constants for the current metering circuit

Figure 10 shows the experimental calibration constants up to a value of 18.5A.

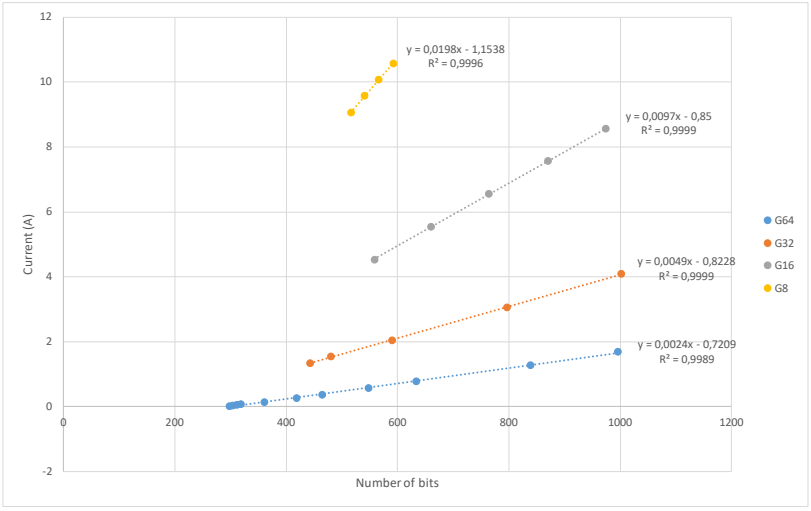


Fig. 10. Experimental calibration constants for the current metering circuit

As with the voltage circuit, the calibration constants obtained vary very little from the theoretical values. Once again, the experimental data show an offset voltage specific

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to the conditioning circuit which was not taken into account in the theoretical calculations.

3.2. Performance tests

3.2.1. Voltage circuit

In order to check the measurement accuracy of the designed voltage circuit, a voltage slope test was carried out, which consisted of taking measurements of a signal that increases progressively from 0 to 560 V. The test was carried out for the standard unit and the designed unit simultaneously, and the data obtained were plotted together in Fig. 11. The test was carried out simultaneously for the standard unit and the designed unit, and the data obtained were plotted together in the graph in Fig. 11.

In Fig. 11, several points outside the expected values can be seen, these are located at the voltages at which the circuit performs the gain change. These points appear because the software is designed to protect the circuit in case of overvoltage, therefore, when the input voltage to the microcontroller exceeds 3.25 V the gain is set to 1, using its respective constant, and increases progressively until it reaches the most appropriate value. These points with abnormal values can be removed from the registers by the software, so they are not a problem.

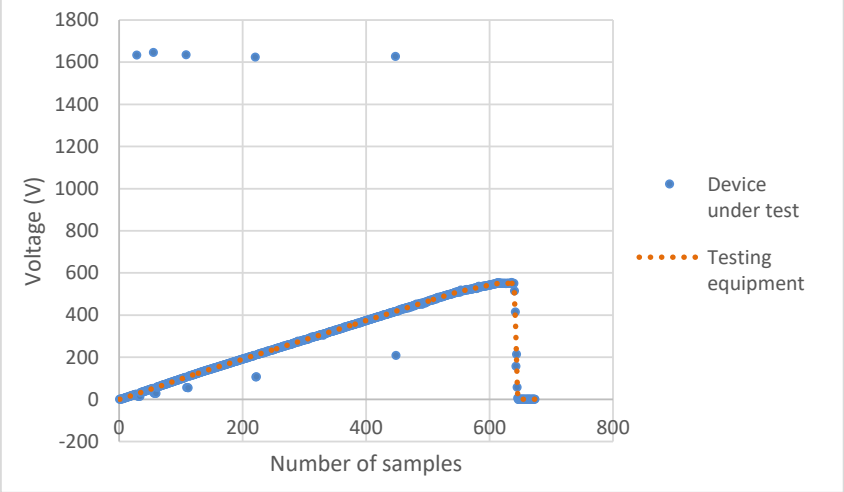


Fig. 11. Increasing voltage test for the voltage metering circuit

3.2.2. Current circuit

For the current circuit, we have proceeded in a similar way to the previous section, taking measurements with the designed circuit, applying an increasing current from 0 to 10.5 A, and then decreasing from the maximum value to zero with the same slope.

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Again, some values outside the expected range can be seen, as in the voltage circuit, these values indicate the change in gain and can be eliminated by software.

In this case, the number of samples taken in the ramp is significantly small, this is due to the fact that the source with which the test was carried out is not capable of generating a current ramp with a lower slope.

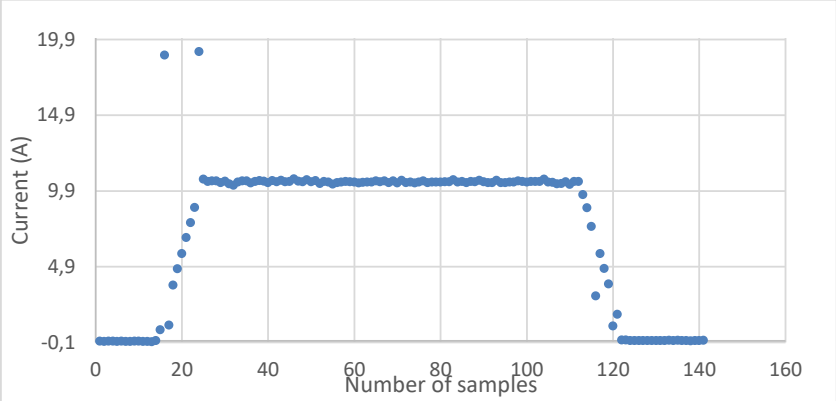


Fig. 12. Increasing current test for the voltage metering circuit

4. Conclusions

In this research, the authors develop and implement a low-cost prototype PV meter for measuring photovoltaic electrical installations in domestic and industrial environments. The core of the prototype is the Teensy 4.1 microcontroller, compatible with the open-source Arduino platform.

The advantages are many. These include obtaining the basic variables, current and voltage in accordance with the IEC 61724-1 standard. To perform the stationary analysis, measurements every 500 ms are used, which conforms to the specific standard. The sampling and calculation of the measured signal is possible due to the processing capacity of the microprocessor, which is another of the advantages of great interest offered by the equipment for use in Smart grids.

To validate the operation of the prototype and check that it is valid for use in Smart grids, it has been validated in a network emulator together with an electronic load that allows voltage and current ramps to be simulated with the desired slope and characteristics.

In addition, the prototype design includes readily available hardware and open-source software. This means that it is freely accessible to researchers and general users for their own design in a non-intrusive way.

Acknowledgments. The authors acknowledge the support provided by the Thematic Network 723RT0150 ‘‘Red para la integración a gran escala de energías renovables en sistemas eléctricos (RIBIERSE-CYTED)’’ financed by the call for Thematic Networks

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of the CYTED (Ibero-American Program of Science and Technology for Development) for 2022.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article. This research was funded by the Council of Andalucía (Junta de Andalucía. Consejería de Transformación Económica, Industria, Conocimiento y Universidades. Secretaría General de Universidades, Investigación y Tecnología) through project ProyExcel 00381.

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ISBN 978-9930-617-71-7

Controlling electrical measurement devices with cloud integration

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Abstract. In industries, generating plants with renewable energies, etc., there are a multitude of electrical variable measurement equipment with communication capabilities through different buses such as TCP/IP and RS485 that support the communication protocol with Modbus equipment. For both existing and newly implemented installations, having real-time measurement data in the cloud to be viewed or processed is essential in today's electrical installations. The use of wired technologies would increase the cost of this implementation. Wireless technologies make it easy, reduce the cost, and are ideal for these types of tasks. This research aims to develop equipment that connects to meters, extracts the information and sends it to the cloud in real time.

Keywords: LPWAN, LoRa, Cloud Computing.

1 Introduction

A multitude of metering devices are installed to monitor installations that only provide data locally. The same is often true for new installations. On the other hand, most of the new installations are not monitored either. The vast majority of these devices have Mo-dBus interfaces, under RS485 or TCP/IP protocol, which enables access to data and programming of the devices.

Access to the devices is wired, which would imply a large outlay for both new and existing installations, with the installation of a large amount of wiring, which would make this installation unfeasible.

Measuring devices are also often far away from the control areas, or are installed in areas that are difficult to access, or in environments that are harmful to people. This is where wireless technologies find their niche application.

Traditional Bluetooth technology does not make much sense in these installations, as its range of action is small, and it would not change much from a traditional inspection by looking directly at the reading of the device. Wi-Fi (Wireless-Fidelity) technology is very applicable in this type of application, but has several drawbacks. The first

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of these is its radius of action, which although it is greater than Bluetooth requires routers or signal repeaters to increase coverage in large areas such as industrial areas. Secondly, it is vulnerable to external attacks that could hack into the system.

This is where LPWAN (Low-Power Wide Area Wireless Network) technologies have their application. In this research, the LoRa (Long-Range) network has been chosen with coverage ratios of 5-10 km and more than 1000 devices per concentrator that make them sufficient for industrial installations from small to large.

Cloud computing is fundamental nowadays, that is why the devices created in this research send information in real time to the cloud so that the data can be visualized and analysed in real time.

2 Related Work

Before starting with the development of the equipment, it is necessary to review the state of the art in the monitoring of electrical installations, with emphasis on those that use IoT (Internet of Things) access and wireless communications.

Cano-Ortega et al. [1] realized a device to monitor the efficiency and operating conditions of induction motors in industrial environments using LoRa technology. Abete et al. [2] implemented a low-cost IoT connected meter based on the ADE7913 measurement chip. Sánchez-Sutil et al. [3] developed a control and measurement system for public lighting networks based on a LoRa network. Sánchez-Sutil et al. [4] built an energy efficiency system for public lighting un-der a LoRa LPWAN network. Francisco Sánchez-Sutil et al. [5] designed and tested a control and data reading device for power quality analyzers using ModBus and RS485 communication, eliminating wiring and using a wireless LoRa LPWAN network. Sánchez-Sutil et al. [6] implemented a Smart plug to monitor and control electrical devices in homes with LoRa communication. Sánchez-Sutil et al. [7] developed an energy efficiency system for irrigation systems using LoRaWAN. Sánchez-Sutil et al. [8] designed and implemented a real-time smart meter with LoRa communication. Cano-Ortega et al. [9] built a smart meter for residential environments with application of TLBO algorithm and LoRaWAN networks. Sánchez-Sutil et al. [10] developed a power quality analyzer for monitoring public lighting networks with LoRa wireless communication system.

The most widely used technology in IoT devices for monitoring electrical installations is Wi-Fi (Wireless-Fidelity), and there are several articles that describe devices that send information using this technology. Sánchez-Sutil et al. [11] developed a low-cost, open-source home meter for homes with PV installations. Medeiros et al. [12] implemented a three-phase metering device using Wi-Fi and low cost, to be installed in homes and industrial environments. Hernández et al. [13] studied the influence of data sampling frequency in electrical installations, with case studies in Spain, using Smart Meters with Wi-Fi technology. Hlaing et al. [14] built a Smart Meter with Wi-Fi and IoT connection for single-phase installations. Cano-Ortega et al. [15] developed a platform to analyze large amounts of data in the cloud from measurements in homes, PV

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plants and electric vehicle chargers. Salor et al. [16] implemented a mobile power quality meter for transmission facilities. Benavides et al. [17] developed a model to remotely control a microgrid based on demand-side power control.

3 Hardware design

Measuring equipment is usually installed in electrical panels where there is not much space for the placement of the device designed in this research. It is therefore necessary to design a PCB (Printed Control Board) as small as possible. For this purpose, components of reduced dimensions have been chosen. The device has been designed to work with Wi-Fi and/or LoRa at the same time. However, it is possible to design smaller boards with only one of the two wireless networks.

One of the small, versatile and powerful microcontrollers available on the market is the Arduino Nano (AN) [18], which is why it has been chosen for this research. Following the criteria of miniaturization, the Wemos d1 mini (Wd1m) [19] microcontroller with Wi-Fi network access has been chosen, which works with an ESP8266 compatible chip. W1dm allows access to the cloud using Google's Firebase service [20]. W1dm has a Deek-Robot ID8122 datalogger connected to it to time the measurements in real time, it also has a microSD card slot available which could optionally save the data locally. For the LoRa network, a Dragino LA66 LoRaWAN shield [21] (LA66S) chip has been chosen. The test devices are five Carlo Gavazzi EM24DINAV93XISX [22] devices for monitoring the AC side of the inverter and the public grid, one VMUM4AS1T2XT [23] device, one VMUSAV30XSXX [24] device and one VMUP2TIWXSX [25] device. VMUM4AS1T2XT interfaces to the ModBus network for VMUSAV30XSXX and a VMUP2TIWXSX device. Therefore, there are three devices connected to the ModBus network.

Access to Firebase from the LoRa network is not direct, but requires the node network service as a gateway. LA66S sends the data to the PG1302 hub [26]. This hub sends the data to TTN (The Things Network) via a wired or Wi-Fi Internet connection, which is already installed on a Raspberry Pi 4 [27]. TTN has implemented a server with MQTT protocol (Message Queuing Telemetry Transport) [28] for each project, this server is connected to Node-Red, which in turn sends it to Firebase. The applications for mobile devices are enhanced with MIT App Inventor [29]. Fig. 1 shows the block diagram of the device.

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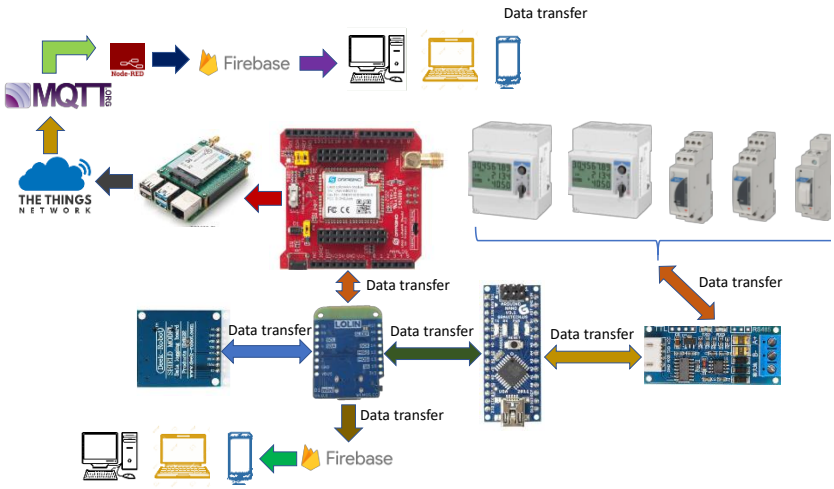


Fig. 1. Device block diagram.

The connection between the measurement equipment and AN is made with an XY-R485 module, which connects the AB terminals of the module with those of the measurement devices. W1dm sends a measurement order to AN which, through XY-R485, once it has received the measurement data, sends it back to W1dm which uploads it to Firebase taking the measurement time from ID8122. It also sends the data to LA66S to upload it to TTN through PG1302, which sends it to MQTT and from there to Node-Red which acts as a gateway sending the information to Firebase. Fig. 2 shows the connection diagram between the devices and Fig. 3 shows the device with the PCB board mounted and in operation.

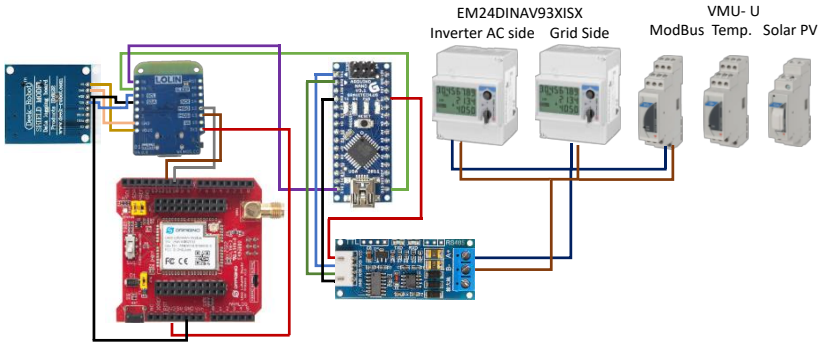


Fig. 2. Connection diagram of the inverter data extraction circuit and sending to the cloud via Wi-Fi and/or LoRa.

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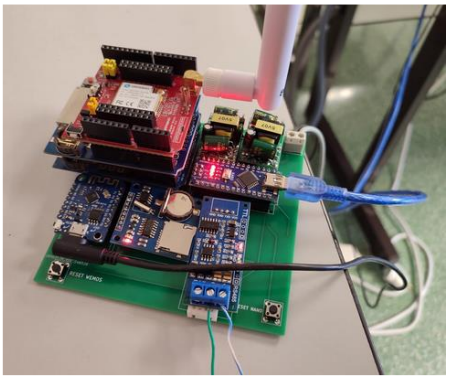


Fig. 3. Assembled PCB board of the control access to measurement devices.

4 Software design

4.1 AN Nano programming

AN performs the data acquisition process by connecting via RS485 and ModBus with the measurement devices, implemented by the manufacturer of these devices. The program must initialize (i) the serial communications port to connect to XY-R485; (ii) the virtual serial port to communicate with W1dm; (iii) the XY-R485 module. Once the initialization is done, it must continuously read the virtual serial port, if a measurement command arrives, send the measurement order to XY-R485 through the serial port, and once the data is received, send it through the virtual serial port to W1dm. Fig. 4 shows the AN flow diagram.

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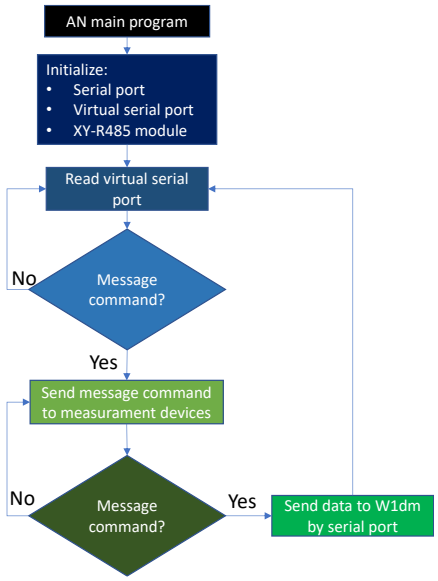


Fig. 4. AN main flow chart.

4.2 W1dm programming

W1dm is responsible for the operation of the device. It must first start (i) the real-time clock; (ii) the serial port for communication with AN; (iii) the virtual serial port for communication with LA66S; (iv) the Wi-Fi adapter. Continuously, W1dm should send measurement commands to AN, once the measurement data is received take the real-time clock time, upload the data to Firebase using the Wi-Fi connection and send the data to LA66S for uploading to the LoRa network. Fig. 5 shows the flowchart of W1dm

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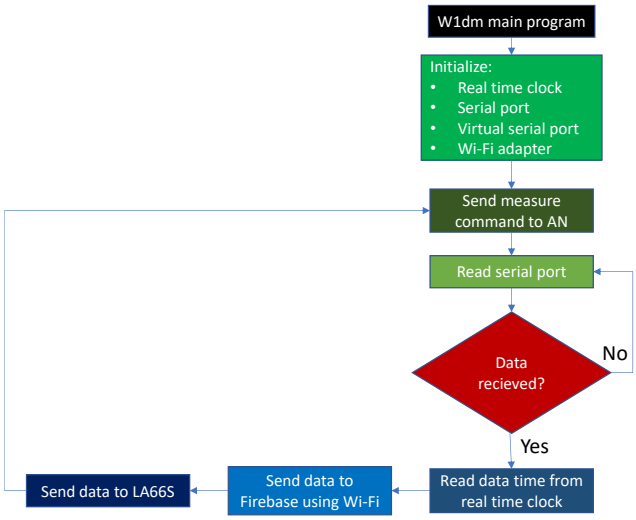


Fig. 5. W1dm main flow chart.

4.3 Programming Node-Network

The LoRa network cannot connect directly to Firebase to have the data in the cloud, but it is sent directly to TTN which implements an MQTT server for each device. To connect TTN with Firebase, Node-Red is used as a gateway. For this purpose Node-Network waits for an event from TTN, collects and converts the necessary data and sends it to Firebase. In addition to the electrical data, the LoRa network parameters are also collected for communication statistics and to improve the network. Fig. 6 shows part of the Node-Red program, corresponding to the LoRa system variables.

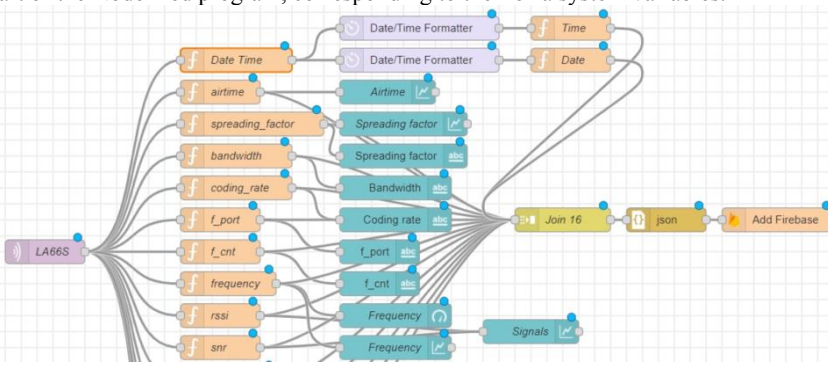


Fig. 6. Node-Red program.

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4.4 Programming for data download

Firebase can store up to 1 GB free of charge. Therefore, the information is downloaded daily and saved for historical purposes. In this sense, a Python program has been created that connects to each Firebase project, unloads the information that exists up to the day before the current one and deletes the information once it has been downloaded. To do this, the program has been included in the Windows task manager so that it runs at 2 am daily. Fig. 7 show the flowchart.

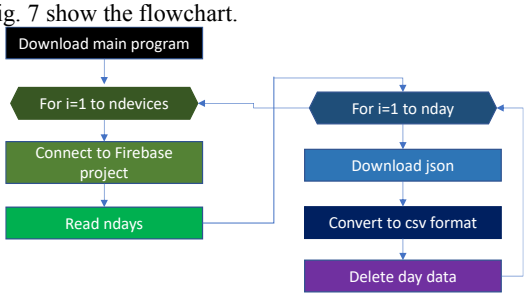


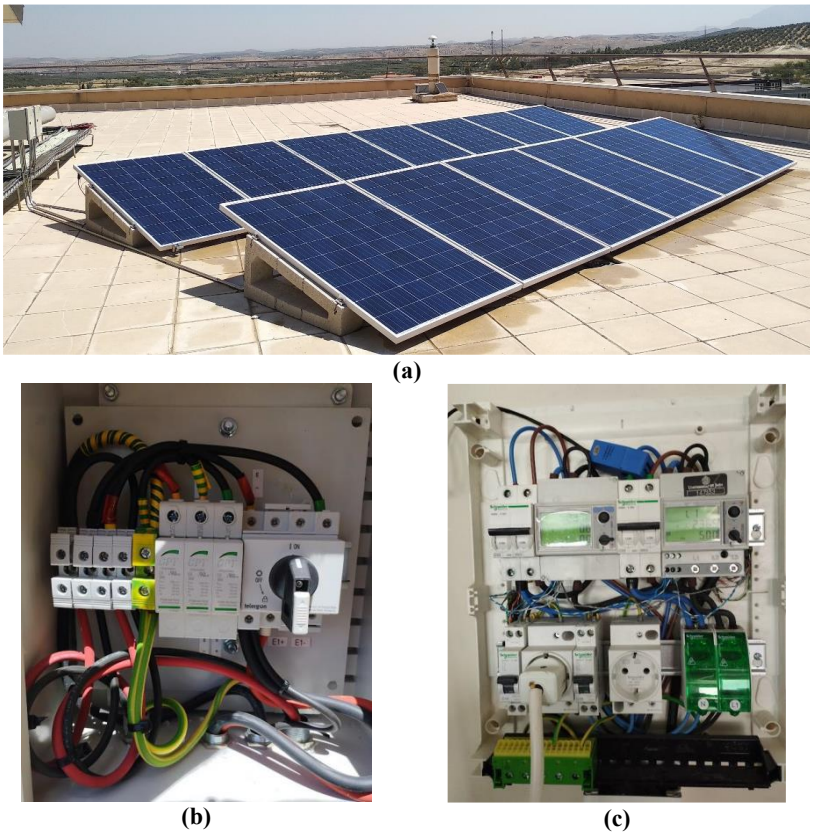
Fig. 7. Download data flow chart.

5 Results

5.1 Test equipment

To perform the tests, the PV installation of the Department of Electrical Engineering of the University of Jaén has been used. The installation is located on the terrace of the A3 building of the Campus de las Lagunillas in Jaén. The installation consists of 10 Axitec model AC-270P/156-60 panels providing 2.97 kWp, connected to a grid-connected SMA Sunny boy 3000 TL-21 inverter, located in the A3-265 laboratory. On the terrace together with the PV panels are installed the modules VMUM4AS1T2XT, VMUSAV30XSXX and VMUP2TIWXSX In the laboratory, next to the inverter there are 2 modules EM24DINAV93XISX to monitor the AC side of the inverter and the public grid. Fig. 8 shows the installation for carrying out the tests.

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(a) **(b)** **(c)**

Fig. 8. (a) Arrangement of the solar panels; (b) (b) switchboard located on the terrace of building A3; (c) switchboard located in the laboratory A3-265.

5.2 Data obtained

The information generated can be used for analysis and representation, which can be used to make improvements to the installation. The data is downloaded daily at 2 am and saved in csv format,

The data shown in Fig. 9 for the DC side and Fig. 10 for the AC side were recorded on 7 July 2024. Part (a) shows the voltage decaying to 0 VDC when there is no sun, and remaining around 300 VDC during generation hours. As for the DC currents they are shown in part (b) which have a maximum at around 8.5 ADC. In consonance with the current, the DC power is shown in part (c), which has a maximum value of around 2.5 kW. Part (c) shows the irradiance, with a maximum of around 1,000 W/m2. Finally, part (e) shows the outside temperature and the module temperature. The measurements of the AC part are similar to those of DC, showing in part (a) the voltages, with values

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around 240 VAC, in part (b) the current with values close to 9 AAC, with lower values on the grid side, and part (c) the AC power, also with lower values on the grid side.

The information generated can be used for analysis and representation, which can be used to make improvements to the installation. The information is downloaded daily at 2 am and saved in csv format,

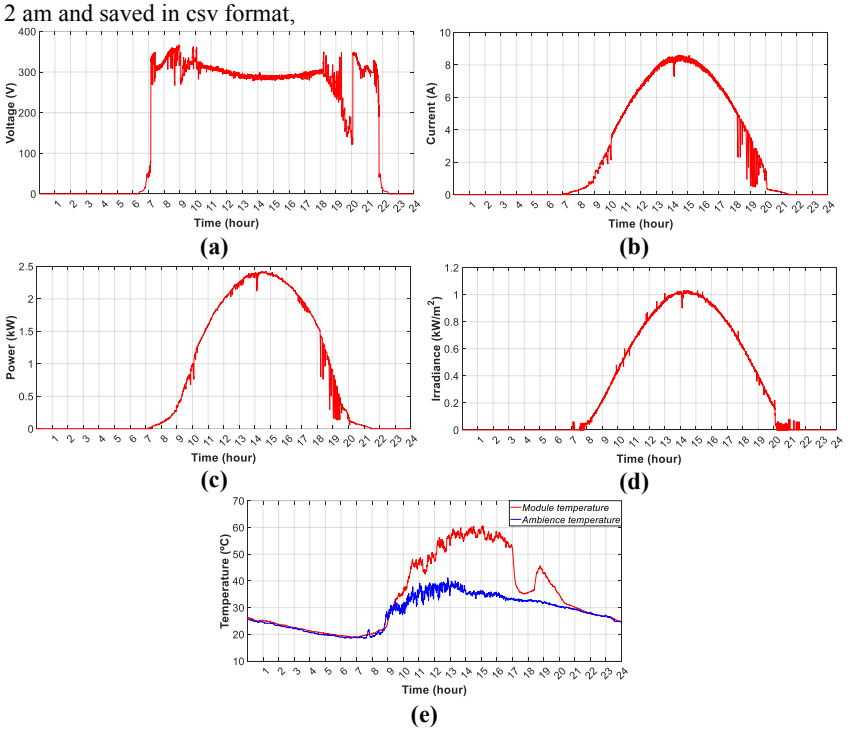
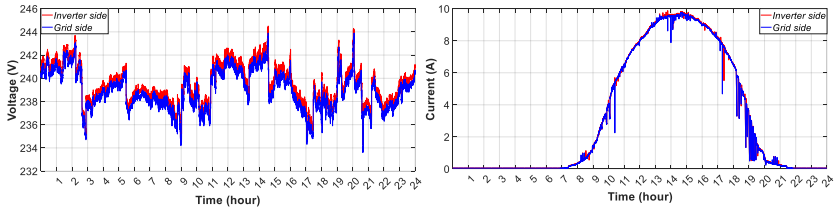


Fig. 9. DC data measured on 2024/07/07. (a) voltage; (b) current; (c) power; (d) irradiance; (e) temperatures.



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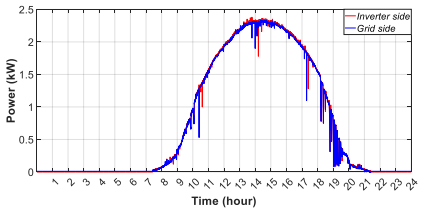


Fig. 10. AC data measured on 2024/07/07. (a) voltage; (b) current; (c) power.

5.3 Data visualization

A Dashboard has been created to monitor the inverter data as well as the LoRa grid parameters. The data is refreshed every 10 seconds and the display range is 1 day. The dashboard has been realized in Node-Red. Fig. 11 shows the inverter dashboard and Fig. 12 the LoRa network dashboard.

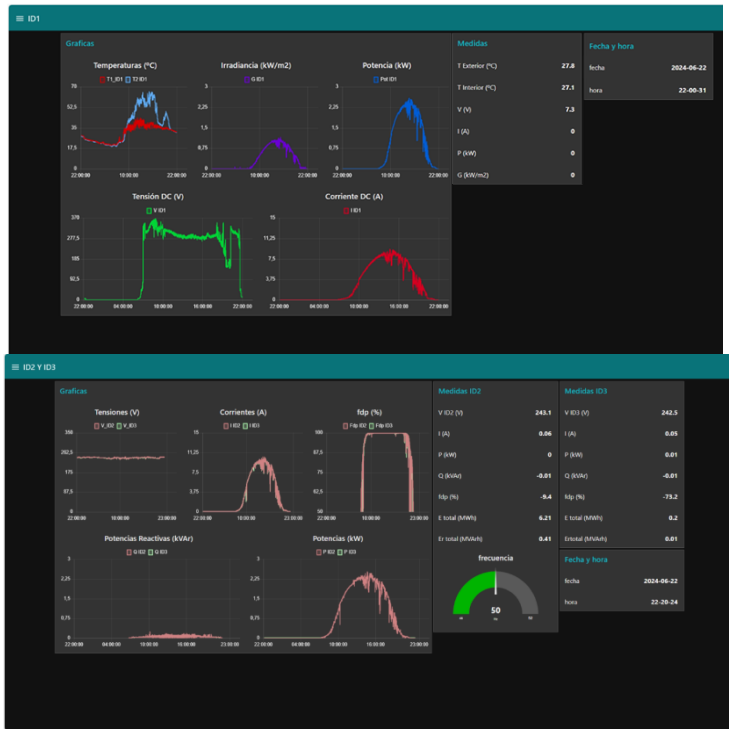


Fig. 11. Measurement devices Dashboard created in Node-Red.

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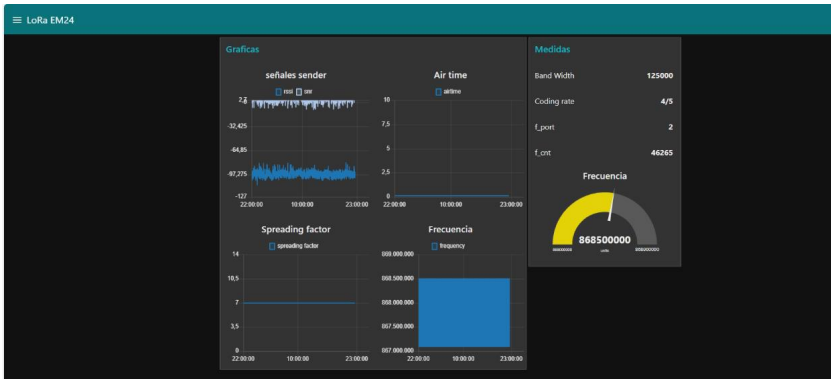


Fig. 12. Dashboard for LoRa network data created in Node-Red.

On the other hand, an app for mobile devices has also been developed for real-time visualisation of the data generated. The application is made in MIT App Inventor for the Android operating system. Fig. 13 shows a screenshot of the application.

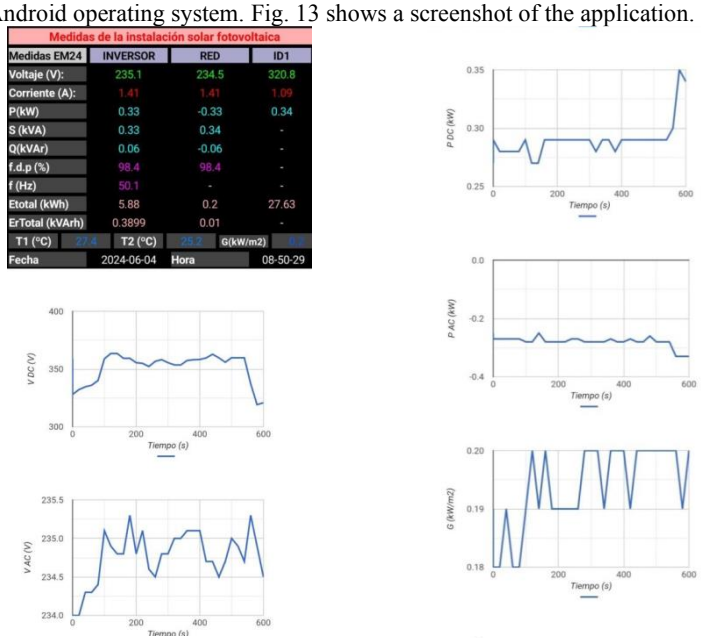


Fig. 13. App for display on Android devices.

Acknowledgments. The authors acknowledge the support provided by the Thematic Network 723RT0150 ‘‘Red para la integración a gran escala de energías renovables en sistemas eléctricos (RIBIERSE-CYTED)’’ financed by the call for Thematic Networks of the CYTED (Ibero-American Program of Science and Technology for Development) for 2022.

ISBN 978-9930-617-71-7

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article. This research was funded by the Council of Andalucía (Junta de Andalucía. Consejería de Transformación Económica, Industria, Conocimiento y Universidades. Secretaría General de Universidades, Investigación y Tecnología) through project ProyExcel 00381.

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ISBN 978-9930-617-71-7

Analysing the Performance of Electricity Generation through PV Rooftop Systems in Food Industry Facilities

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Abstract.
In recent years, photovoltaic (PV) systems show remarkable growth, contributing significantly to the global energy mix. This expansion encompasses diverse installations, from small residential to large industrial facilities, presenting challenges for efficient operation and maintenance (O&M). Despite the growing awareness of O&M's importance, there remains a misconception about its scope. This study emphasizes real-world application challenges of rooftop PV systems within the food industry. Parameters such as irradiance, module temperature, and power input and outputs of the inverters are monitored and analyzed to assess system performance. The study addresses different aspects for improvement in standard metrics and provides practical considerations. Focusing on three industries in the south of Spain, each equipped with rooftop PV self-consumption systems on their rooftops with nominal PV system powers ranging from 13.95 kW to 44.1 kW, the results show different operational scenarios with performance ratios (PRs) have ranged from 0.38 to 0.92. The findings underline the importance of considering user-defined requirements, grid distributor influences, and continuous advancements for analysing and evaluating PV system performance.

Keywords: System Performance, Rooftop Solar Photovoltaic systems.

1 Introduction and objectives

In recent years, the generation of electricity through photovoltaic (PV) systems has experienced significant expansion, making a noteworthy contribution to the energy mix in countries such as Spain, the United States, Germany, and China. Globally, installed PV capacity has experienced exponential growth, surging from 104 GW in 2012 to

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1581 GW in 2023 [1,2]. This increase in capacity has occurred not only in large facilities but also in small installations, potentially with a capacity of less than 100 kW. In Spain, the representative residential PV facility in 2023 is a 4.7 kW installation without storage [3]. Over one hundred and ten thousand PV rooftop systems were installed, equivalent to 527 MW. Concerning rooftop PV in industrial facilities, the average nominal power was 91 kW, surpassing fifteen thousand rooftop PV systems to reach 1400 MW [3]. It is crucial to highlight that, while the average power figure may be illustrative of the national reality in residential self-consumption, industrial installations exhibit wide dispersion, ranging from small installations of 15 kW to several-megawatt installations [4]. This type of installation presents a current and future challenge for operation and maintenance (O&M) to ensure optimal electricity generation [5].

Managing PV system requires crucial implementation of O&M strategies to ensure reliability, energy efficiency, and secure plant operation throughout its lifecycle [6]. Despite the growing awareness of O&M's importance, many investors and end-users are unfamiliar with relevant concepts and best practices. This misconception often arises from the belief that O&M is limited to tasks like module cleaning and checking the plant status on manufacturer-provided monitoring portals. In reality, O&M involves daily activities such as preventive fault diagnosis, equipment response analysis, and the formulation of strategies based on real operational data, contributing significantly to long-term performance [7,8]. Moreover, some users and investors, lacking awareness of the importance of O&M, are not inclined to invest time in it, including monitoring systems and data collection, due to the belief that these entail a low additional cost with minimal economic returns for the plant. Assessing performance is not a trivial task, involving various factors where multiple requirements and uncertain conditions must be simultaneously considered. Consequently, managers of PV power plants require monitoring methodologies to assess the operation's quality throughout its lifecycle in terms of daily, monthly, or annual performance [9].

In line with this objective, the IEC 61724 standard [10] plays a crucial role, aiming to establish definitions and terms for addressing the monitoring and analysis of PV systems. It additionally defines a categorization for monitoring systems, taking into account their complexity and technical specifications. This standard defines the parameters to be measured (e.g., irradiance, temperature), as well as the sensors (type, precision, etc.), their installation (location, placement, etc.), recalibration requirements, maintenance, etc. The methodology for measurements, data processing, and the parameters to be calculated are also outlined. The primary goal of monitoring PV systems is to evaluate the performance of each system and detect potential faults. Therefore, a comprehensive analysis of the system is required, involving subsystem analyses, to determine performance parameters and metrics such as yields or efficiencies, loss factors, performance ratios, and indices [11].

The main objective of this study is to apply current regulations to various PV rooftop systems in food industry facilities. While recognizing the importance of metrics proposed by the standard, the goal is to address their limitations by acknowledging potential omissions of factors that may influence energy production.

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2 Description of PV Rooftop Systems in Food Industry Facilities

Table 1. Facilities used in the study, along with the technical specifications of the PV modules and inverters for the Rooftop PV systems.

		Technical specifications	
01# Location Andalusia, Spain		P_0	13.95 kW
		No. PV modules	31
		Nominal PV module power	450
		No. Inverters	1
		Inverter model	3P3-15KW-4G
		Inverter brand	Solis
02# Location Andalusia, Spain		P_0	44.10 kW
		No. PV modules	90
		Nominal PV module power	490
		No. Inverters	1
		Inverter model	40 KTL-M3
		Inverter brand	Huawei
03# Location Andalusia, Spain		P_0	37.24 kW
		No. PV modules	76
		Nominal PV module power	490
		No. Inverters	1
		Inverter model	36 KTL-M3
		Inverter brand	Huawei

Three industries in southern Spain have PV self-consumption systems on their rooftops, with nominal PV array powers (P_0) of 13.95 kW (01#), 44.1 kW (02#), and 37.24 kW (03#). Plant 01# is composed of 31 modules, which are faced south-east (Azimuth -20º) and 12º tilt angle. Meanwhile, plant 02# consists of 90 modules, which are divided into two groups of sub generators with different orientations. The modules have an east-west configuration (Azimuth -90º,90º) and tilt angle of 10º. Therefore, half of the modules are oriented to the east, while the other half are oriented to the west. Finally plant 03# has 76 modules that faces south-east (Azimuth -20°) and tilt angle of 5º. Table 1 shows these Rooftop PV systems. The table also provides key technical specifications related to modules, generators, and inverters.

In plant 01#, ABB Power Analyzer M4M 20 Rogowski is used for accurate monitoring of electrical parameters and power quality analysis, while, Energy Meter EM340DIN, serves as a three-phase energy meter for active energy measurement in industrial applications. Three phase inverter Solis-3P15K-4G is used for this plant. Meanwhile, in Plants 02# and 03#, Janitza Energy Analyzer UMG 103-CBM is used for measuring electrical parameters, Huawei SUN2000 inverters with three-phase current, are used in both systems. These inverters feature an efficiency of 98.4%, with power ratings of 40 kW (02# P2) and 36 kW (03# P3). Each inverter has 8 available string inputs, distributed in pairs for the 4 Maximum Power Point Trackers (MPPTs). These MPPTs can operate within a voltage range of 200V to 1000V.

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Environmental parameters and module temperature in all plants are monitored through the Datasol MET Cell. This device allows acquisition of solar radiation, module temperature, and ambient temperature. The MET radiation measurement includes temperature compensation for the module and has a range from 0 to 1400 W/m^2.

All data obtained from system components are visualized and stored through a web server, enabling easy downloading for analysis or real-time monitoring.

3 Data and Methodology

The Rooftop PV Systems in the Food Industry Facilities have been monitored for months.

The electrical and environmental parameters of Plant 01# were monitored in both September 2022 and November 2023. Apart from the temporal difference between these two months, there is also a different inverter configuration in November 2023. During this month, the inverter is set up to prevent energy injection into the electrical grid at the connection point between the industry and the public distribution grid. This configuration aims to ensure that the power at the grid connection point remains in a consumer balance, provided there is internal consumption exceeding the tolerance of the measurement system. This tolerance is calculated as the sum of the power measurement equipment's accuracy classes and the transformer or current measurement probe class. In contrast, in September 2022, the inverter is not configured to prevent energy injection into the electrical grid.

Regarding Plant 02#, the electrical and environmental parameters were monitored in both September 2023 and November 2023. In these months, there is no different inverter configuration, and the setup to prevent energy injection into the electrical grid is not active. Moreover, there is a difference in the distribution of PV modules between the arrays connected to the different MPPT of the inverter. In September 2023, there was a different number of modules in series for each MPPT. The inverter consists of 4 MPPTs with two inputs each. The number of modules in each MPPT in September was as follows: [18-18], [9-0], [18-0], [13-13]. For example, MPPT1 consists of two strings of 18 modules each, and so on. In November 2023, all arrays of the inverter had the same number of modules in series. The number of modules in each MPPT in November is as follows: [15-15], [15-0], [15-0], [15-15].

For Plant 03#, the electrical and environmental parameters were monitored in September 2023 and November 2023. In this installation, the configuration to prevent energy injection into the electrical grid is not active, and it has the same number of modules in series in all input branches of the inverter.

In these installations, both the electrical parameters of the direct current (DC) and alternating current (AC) parts, as well as the environmental parameters, have been monitored and recorded. The measured parameters are in-plane irradiance, G_{i}, PV module temperature, T_{mod}, DC array voltage, V_{A}, DC array current, I_A, DC array power, P_A, AC output voltage, V_{out}, AC output current, I_{out}, and AC output power, P_{out}. They have been measured by devices with specifications recommended by the IEC 61724 standard. The considered recording interval has been five minutes, which may be suitable for this type

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of installations. This study focus on the calculation of parameters outlined in the international standard IEC 61724 [10].

The first step involves processing and validating data in accordance with the standard recommendations. Subsequently, calculated parameters and metrics are obtained as outlined by the standard for the PV system. The ensuing formulations, characterized by summations, integrate the temporal aspect, where τ_k signifies the duration of the kth recording interval within a given reporting period, τ. The symbol Σ_k represents the sum across all recording intervals within the reporting period. For example, τ can be a day, a month, or a year, and k can be 1, 15, or 60 minutes. It is essential to note that in formulas featuring the product of power quantities and the recording interval τ_k, the power should be stated in kilowatts (kW), and the recording interval in hours for the resulting energy to be expressed in kilowatt-hours (kWh).

The in-plane irradiation, denoted as H_i and measured in [W/m^2] is determined by multiplying the summation of in-plane irradiance values G_k by the recording interval τ_k:

$$H_i = \sum_k G_k \times \tau_k \quad (1)$$

Where G_k represent the irradiance incident upon the front side of the inclined surface parallel to the plane of the modules in the PV array, also known as plane-of-array (POA) irradiance.

The energy output of the PV generator, represented as the DC output energy from the PV array, and expressed in [kWh], is calculated as follows:

$$E_A = \sum_k P_{A,k} \times \tau_k \quad (2)$$

The cumulative AC output energy [kWh] of the PV system at the inverter's output, denoted as E_{out}, is calculated based on the inverter's output power, P_{out}, considering the recording interval τ_k:

$$E_{out} = \sum_k P_{out,k} \times \tau_k \quad (3)$$

Yields represent the ratio between an energy quantity and the array power rating (P_0), serving as an indicator of the actual operational efficiency relative to the rated capacity. They are expressed in units of kWh·kW^{-1}, where kWh in the numerator denotes energy production and kW in the denominator means the system power rating. Inherently, the ratio, being commensurate with hours, conveys the temporal proportionality required for the array to operate at P_0, thereby generating the designated energy quantity observed throughout the reporting period.

The PV array energy yield (Y_A) is defined as the energy output per rated kilowatt of the installed PV array:

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$$Y_A = {}^{E_A}/_{P_0} \quad (4)$$

Where:

P_0: is the sum of the DC power outputs derived from all installed PV modules under standard test conditions (STC) at the power rating reference condition.

The final system yield denoted as Y_f, is the net energy output of the entire PV system per rated kilowatt of the installed PV array:

$$Y_f = {}^{E_{out}}/_{P_0} \quad (5)$$

The reference yield (Y_r) for a PV system is calculated by dividing the total in-plane irradiation by the module's reference in-plane irradiance:

$$Y_r = {}^{H_i}\Big/_{G_{i,ref}} \quad (6)$$

Where the reference in-plane irradiance, represented as $G_{i,ref}$ (kW·m^{-2}) is the irradiance at which P_0 is defined, typically specified under STC.

The reference yield denotes the hours required for solar radiation to match the incident solar energy observed during the reporting period, assuming reference irradiance levels under STC. If the reporting period spans one day, Y_r effectively represents the equivalent number of sun hours at the reference irradiance per day.

Yield losses are determined by deducting yields. They are expressed in units of kWh·kW^{-1} (or h), they represent the duration for which the array would need to operate at its P_0 to compensate for the corresponding losses observed throughout the reporting period.

The array capture loss, denoted as L_c, encompasses losses attributed to the operational aspects of the array, such as losses in wiring and junction boxes before DC measurement, array temperature effects, soiling, etc. It is formally defined as:

$$L_c = Y_r - Y_A \quad (7)$$

The balance of systems (BOS) loss, denoted as L_{BOS}, quantifies the losses within the BOS components, encompassing the inverter, as well as all wiring and junction boxes not accounted for in the array capture loss. It is defined as:

$$L_{BOS} = Y_A - Y_f \quad (8)$$

The efficiency of the rated array is expressed as:

$$\eta_{A,0} = {}^{P_0}\Big/_{(G_{i,ref} \times A_a)} \quad (9)$$

In this context, the total array area (A_a) is calculated as the sum of the frontal surface areas of the PV modules, delineated by their outer boundaries.

The mean system efficiency throughout the reporting period is formally characterized by:

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$$\eta_f = {E_{out}}/{(H_i \times A_a)} \quad (10)$$

The parameter η_{BOS}, representing the BOS efficiency throughout the reporting period, is a dimensionless value and is defined as:

$$\eta_{BOS} = {E_{out}}/{E_A} \quad (11)$$

The performance metrics defined in the standard are not mandatory, and their use may depend on the system design and user requirements. The most suitable metric for a specific application may vary. In this document, the performance ratio will be employed.

The Performance Ratio (PR) is defined as the coefficient between the Y_f and Y_r. It serves to quantify the comprehensive impact of output losses within the system, arising from factors such as array temperature, inefficiencies, and failures in system components. This includes considerations for system component balancing.:

$$PR = {Y_f}/{Y_r} \quad (12)$$

4 Results and Discussion

Figure 1 illustrates the normalized parameters of the Rooftop PV systems in the Food Industry Facilities. The left y-axis represents the DC power generated by the PV array (input to the inverter), $P_{A,k}$, and the AC power output, $P_{out,k}$, both parameters are normalized with P_0. Meanwhile, the right y-axis represents the in plane irradiance, G_k, and it is normalized to $G_{i,ref}$.

The four subplots in Figure 1 correspond to Plant 01#, with subplots (a) and (b) representing parameters on September 4 2022, and November 1 2023, respectively. The difference between these plots is due to the inverter configuration, with (b) set to prevent energy injection into the grid. Plot (b) demonstrates a limitation in electricity generation as the PV system's energy output only meets the industry's electrical demands. Even on a clear day, the photovoltaic generator hardly surpasses 15% of its nominal capacity throughout the day. On the other hand, on September 4, 2022, another clear day, the PV system operated at almost full capacity. Both operating scenarios may be considered suitable as they align with user-defined requirements, and the inverter configuration may be influenced by the requirements of the grid distributor.

Additionally, Figure 1 includes plots (c) and (d) representing parameters of PV system 02# on September 24, 2023 and November 7, 2023, respectively. Between these dates, there was a change in the distribution of modules in series among arrays connected to different MPPTs of the inverter. While this change should not pose a problem within voltage design ranges, some MPPTs experience suboptimal operation due to module voltage ranges not aligning with optimal MPP window. This situation may be providing a non-optimal performance.

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Table 2 and Figure 2 display the results for various parameters and metrics across the three installations over different months. Columns and figures (a) and (b) correspond to PV system 01# for the months of September 2022 and November 2023, respectively. Columns and figures (c) and (d) pertain to PV system 02# for the months of September 2023 and November 2023, respectively. Finally, columns and figures (e) and (f) relate to PV system 03# for the months of September 2023 and November 2023, respectively.

In Table 2, columns (a) and (b), despite being the same system, show a difference of more than 55% in the Performance Ratio. This discrepancy, in addition to occurring in different months (September and November), is primarily attributed to the behaviour of the inverter. In September, as previously indicated, the inverter attempts to track the maximum power point. In November, however, the inverter's goal is solely to meet the industrial load demand and prevent the injection of electrical energy into the grid. Since the capacity of the photovoltaic generator exceeds the industrial load demand in this installation, the inverter operates most of the time outside the maximum power point, resulting in higher capture losses and reducing the efficiency of the rated array by half. A 14% reduction in the balance-of-system efficiency is also observed when comparing September and November. Overall, there is a decrease in the n_f. Although this is not the most suitable from an energy criterion, it is a desired behavior by the system user and it may be a requirement from the electric utility due to potential transformer or distribution network congestion.

PV system 01# and PV system 03# have identical orientations and very similar inclinations, but they are situated in different locations of southern Spain. As shown in Table 2, H_i columns (b) and (e) is almost identical for the same month. However, since $n_{A,0}$ in PV system 01# is less than half, even though the inverters and modules are not exactly the same, it may be mainly attributed to the inverter configuration. Both Table 2 and Figure 2 indicate that for PV system 03#, the efficiencies and PR are relatively similar and high between both months. In this system, the PR values are always above 0.75.

On the other hand, the analysis results for PV system 02# show that configuring arrays with different numbers of modules in series, even in different Maximum Power Point Trackers of the same inverter, can reduce the system efficiency and PR. A better system performance was observed in November, following the reconfiguration, with an increase in PR from 0.7 to 0.85. Conversely, this behaviour is not observed in PV system 03#, where the PR remains nearly constant between the two months. While this behaviour could be influenced by other factors such as a reduction in the average module temperature or possible dirt accumulation, the primary cause is likely the reconfiguration of the modules.

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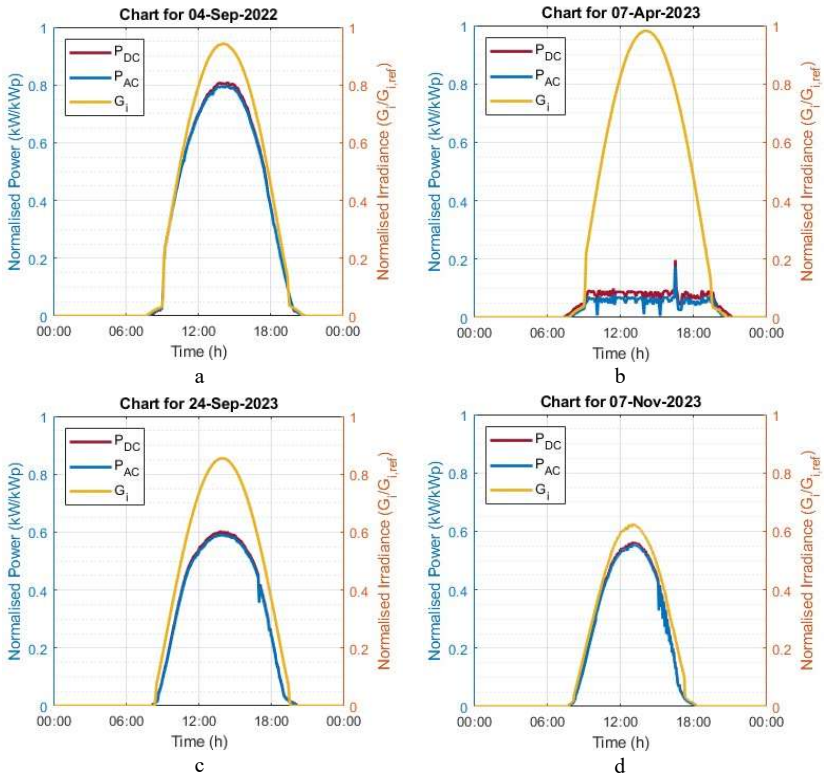


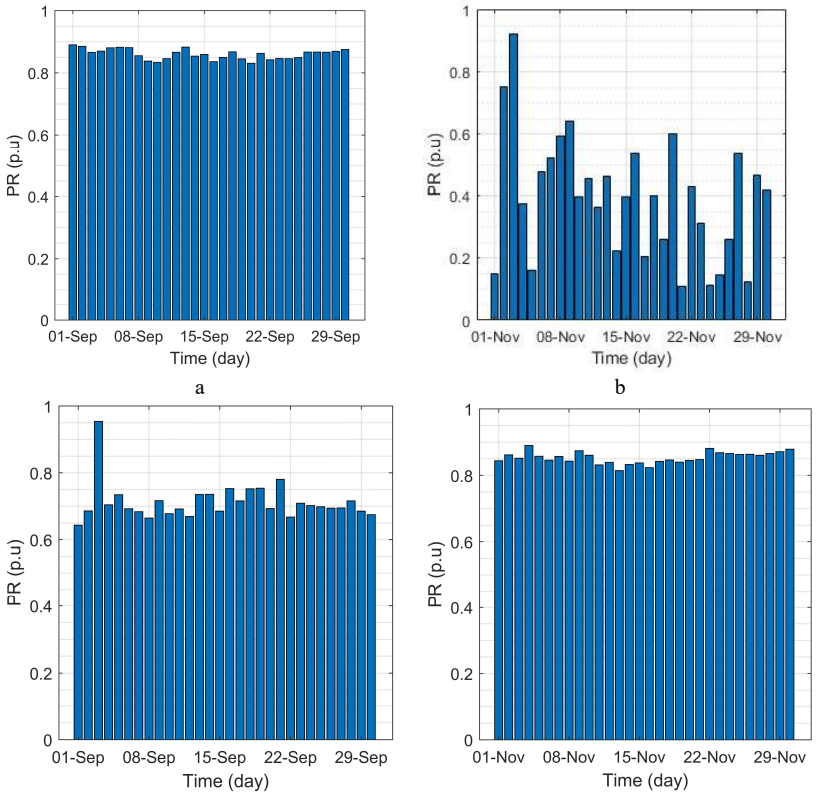
Fig. 1. DC power generated by the photovoltaic array, the AC power at the output of the inverter, and the radiation in the incident plane a) PV system 01#; b) PV system 01#; c) PV system 02#; d) PV system 02#;

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Table 2. Monthly calculated parameters and Metrics for the Installations.

Parameters	a PV system 01 September 2022	b PV system 01 November 2023	c PV system 02 September 2023	d PV system 02 November 2023	e PV system 03 September 2023	f PV system 03 November 2023
H_i (kWh/m^2)	173.94	94.44	168.22	80.69	165.34	94.43
E_A (kWh)	2096.60	584.90	5320.30	3088.40	5320.32	3297.40
E_{out}(kWh)	2086.80	499.12	5219.90	3028.20	5219.98	3238.30
Y_A kWh· kW^{-1} (or h)	150.29	41.93	120.64	70.03	142.87	88.54
Y_f kWh· kW^{-1} (or h)	149.59	35.78	118.37	68.67	140.17	86.96
Y_r kWh· kW^{-1} (or h)	173.94	94.44	168.22	80.69	165.34	94.43
L_c kWh· kW^{-1} (or h)	23.64	52.51	47.58	10.65	25.36	5.89
L_{BOS} kWh· kW^{-1} (or h)	0.71	6.15	2.28	1.36	2.69	1.59
$\eta_{A,0}$ (p.u)	0.18	0.09	0.15	0.18	0.18	0.19
η_f (p.u)	0.18	0.08	0.15	0.18	0.17	0.19
η_{BOS} (p.u)	0.99	0.85	0.98	0.98	0.98	0.98
PR (p.u)	0.86	0.38	0.70	0.85	0.83	0.92



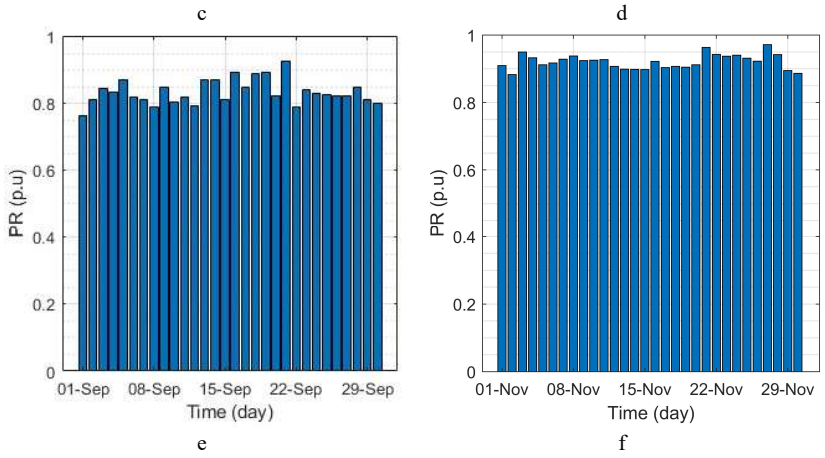


Fig. 2. Daily PR. a) PV system 01#; b) PV system 01#; c) PV system 02#; d) PV system 02#; e) PV system 03#; f) PV system 03#

5 Conclusion

The study underscores the significance of adapting standard metrics to real-world operational complexities in PV systems. The influence of inverter configurations and module distributions on system performance is evident, impacting energy generation and efficiency.

Performance indices based on ratings are relatively straightforward to calculate; however, these indices may overlook known factors that cause the system's energy production to deviate from expectations solely based on manufacturer-provided information. In the analysed installations, different PRs were found for different causes. The analysed monthly PR values vary from 0.38 to 0.92. It is worth mentioning that in PV system 01, due to a change in the inverter configuration, the system went from a PR of 0.86 in September 2022 to 0.38 in September 2023. On the other hand, in PV system 02, the PR improved from 0.7 to 0.85 from September to November by changing the distribution of the modules to ensure the maximum energy extraction range of the inverter. The findings emphasize the need for a determinate approach in assessing PV system performance, considering user preferences and grid distributor requirements. Additionally, the study highlights the importance of addressing these intricacies in monitoring and maintenance strategies.

The study contributes to bridging the gap between standards and practical challenges, providing insights for industry. Future research directions may explore advanced monitoring methodologies and adaptive strategies to enhance the overall reliability and performance of PV rooftop systems in industrial settings. As well as, extending the monitoring period to a full year or more to better capture seasonal variations and long-term performance trends. In addition, the focus will be broadened to include

ISBN 978-9930-617-71-7

a wider range of industries and to analyse grid dependency in both grid-connected and off-grid scenarios.

Acknowledgments

The work was supported by "*Centro para el Desarrollo Tecnológico Industrial (CDTI)*" and "*Corporación Tecnológica de Andalucía (CTA)*" under the project: "*SolAGRO+. Análisis funcional avanzado predictivo para la mejora de la gestión del mantenimiento de sistemas de autoconsumo solar fotovoltaico en sector de la industria agroalimentaria"*. With additional support from the projects oriented towards the ecological transition and the digital transition. (Grant No. TED2021-131137B-I00 *("Aportación a la Transición Ecológica en el sector Industrial a través del Autoconsumo Fotovoltaico"*) and the authors also acknowledge the support provided by the Thematic Network 723RT0150 "Red para la integración a gran escala de energías renovables en sistemas electricos (RIBIERSE-CYTED)" financed by the call for Thematic Networks of the CYTED (Ibero-American Program of Science and Technology for Development) for 2022. The authors would like to thank the University of Jaén for its support by the programme: "*Acción 2. Doctorados en entidades externas comprendida en la Línea de Actuación: Fomento y divulgación de la transferencia, enmarcada en el Objetivo 1: Apoyo a las actividades de trasferencia del conocimiento, del Plan de Apoyo a la Transferencia del Conocimiento, el Emprendimiento y la Empleabilidad año 2023, para la contratación de doctorandos industriales*".

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ISBN 978-9930-617-71-7

Voltage stability in the WSCC power system for large-scale integration of renewable energy

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Abstract. The integration of renewable energy sources (RES) introduces significant challenges to the stability of the electrical grid, particularly in maintaining voltage stability, due to the unpredictable nature of these sources. This unpredictability can impact the overall security and reliability of the system. Flexible AC Transmission Systems (FACTS) enhance this stability by managing the flow of active and reactive power, which is crucial in systems such as the WSCC. The widely studied 9-bus system serves as scenario for the contingency analysis, loadability analysis and sensitivity analysis. All these are made with the objective to assess the improvements of large-scale RES integration into the grid.

Keywords: renewable energy, RES, FACTS, voltage stability.

1 Introduction

The integration of renewable energy sources (RES) into the electrical grid presents significant stability challenges, particularly concerning voltage stability. This is primarily due to their unpredictable and intermittent nature, which can greatly affect the overall security and reliability of the power system [1]. As these renewable sources, such as wind and solar power, depend on climatic conditions, their variability introduces uncertainty in power generation, making grid management more complex.

To address these challenges, Flexible AC Transmission Systems (FACTS) play a vital role in enhancing grid stability [2]. FACTS devices help control and manage the flow of active and reactive power within the grid, thus maintaining a balanced and stable system. This capability is crucial for ensuring that power can be efficiently distributed and consumed, especially in complex grid systems like the Western System Coordinating Council (WSCC).

The WSCC, a prominent system referenced in many studies, includes a well-known 9-bus model that serves as a common scenario for conducting various types of analyses. In this context, contingency analysis is used to assess the system's response to unexpected failures or changes, loadability analysis examines the maximum load the system

ISBN 978-9930-617-71-7

can handle before becoming unstable, and sensitivity analysis helps identify how changes in system parameters can affect system behavior. Together, these analyses provide a comprehensive understanding of the system's dynamics and resilience.

This work analyses the injection of large-scale renewable energy into the WSCC system to demonstrate it can improve the voltage stability of the system in different scenarios. Specifically, a wind farm comprised of doubly fed induction generators (DFIG). These are type 3 wind turbines (WT), according to the classification of the international electrotechnical commission (IEC).

2 Methodology

The methodology chosen for assessing voltage stability in the WSCC system begins with conducting a standard power flow analysis under normal conditions using the Electrical Transient and Analysis Program (ETAP). The results obtained from ETAP are then compared with those found in authoritative textbooks to ensure accuracy and consistency [3]. For added validation, the power flow analysis is also executed using the PSAT toolbox [4], showing results that align closely with those reported in the literature. It's important to note that these validation processes underscore the reliability of the software tools used in the analysis. In Fig. 1 the object of study is presented.

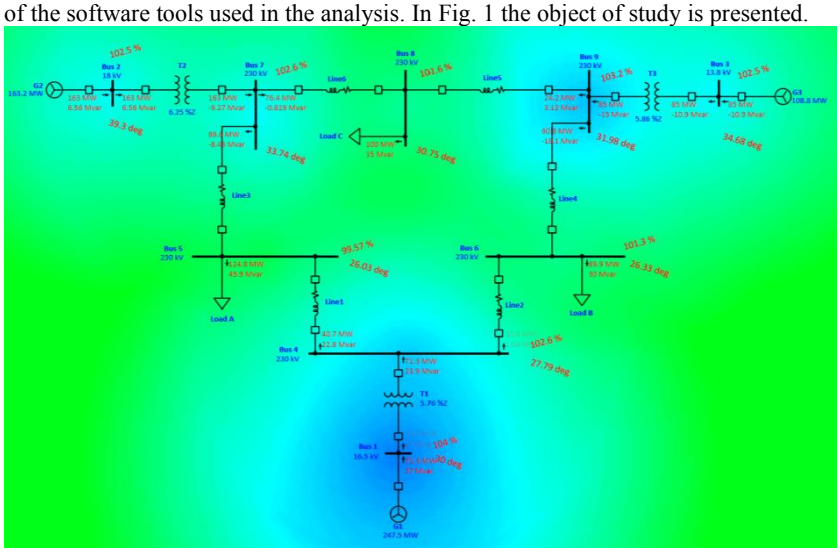


Fig. 1. The WSCC 9 bus 3 generator system in ETAP. Notice the voltages and phase angles calculated very similar to those published in [3].

A notable aspect of this analysis is the difference in how each software program inputs the system parameters. For instance, ETAP requires system impedance input in ohms per kilometer, whereas PSAT uses the per unit (p.u.) total to define transmission line impedances. These discrepancies necessitate careful unit conversion and parameter

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adjustment, which inherently contribute to the small variations observed in numerical results from the power flow analysis.

Following the initial power flow analysis, the WSCC system undergoes contingency analysis. This involves systematically disconnecting each transmission line and analyzing the resulting power flow scenarios to identify the bus with the lowest voltage, if it is bellow 90% of the nominal voltage for more than one minute, this is known as an undervoltage condition. Each scenario derived from the contingency analysis is then further examined through active power versus voltage (P-V) curves, reactive power versus voltage (Q-V) curves, and voltage versus reactive power (V-Q) sensitivity analyses to understand the system's robustness and identify potential vulnerabilities.

In contingency scenarios—with transmission lines being selectively removed—the power flow calculations reveal which bus bar experiences the lowest voltage. This assessment helps simulate an incident where existing loads must be supplied through alternative pathways within the system. Along with the normal operation scenario of the WSCC system (with no contingencies), these seven scenarios are analyzed using P-V curves, also referred to as Nose-curves. P-V curves are instrumental in evaluating the loadability of each bus bar, providing insights into how much more load each bus bar can handle before reaching instability [5].

Additionally, Q-V curve analyses are conducted for each scenario, focusing on the sensitivity of bus voltages to changes in reactive power injection. Q-V curves are crucial for utilities as they gauge proximity to voltage collapse, enabling operators to make informed decisions to maintain system stability. These analyses illustrate the maximum reactive power that can be supported by the most vulnerable bus before voltage levels drop to critical limits, thus averting potential instability [6].

The V-Q sensitivity analysis, specifically within the ETAP software, ranks each bus by assessing voltage sensitivity as adjustments are made to reactive power in the system. This ranking provides valuable insight into which buses are most susceptible to voltage changes, allowing operators and planners to implement strategies that maintain optimal system performance and avert possible disruptions in the event of power fluctuations or unexpected contingencies [7].

These analyses are also done for the seven contingency scenarios but with the inclusion of large-scale renewable energy with the aim of improving the voltage stability in the most vulnerable bus bar. As mentioned in the introduction the equivalent/aggregate model [8] of the wind farm is one DFIG WT of 70 MW nominal power with a static VAR compensator (SVC) at the wind farm common bus before the step-up transformer. The windfarm is modeled with an aggregated model as in [9] and [10].

3 Results and discussions

In Fig. 2 and Fig. 3, the numerical results from the power flow for each scenario are presented. The lowest bus voltage and the largest phase angle are highlighted with a yellow background for each scenario. The lowest bus voltage of all scenarios is shown in red, while the second lowest is shown in orange.

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Note the similarities in the original scenario for both software programs. This, combined with the results presented in [3], confirms the accuracy and consistency of the calculations in both software programs. However, PSAT calculates an even worse undervoltage condition for the scenario without the transmission line between bus 4 and bus 5, marked in red.

ETAP														
Removal of the transmission line between the bus bars x-y	5-7		6-9		7-8		8-9		4-6		4-5		Original	
	Voltage (pu)	Phase (deg)	Voltage (pu)	Phase (deg)	Voltage (pu)	Phase (deg)	Voltage (pu)	Phase (deg)	Voltage (pu)	Phase (deg)	Voltage (pu)	Phase (deg)	Voltage (pu)	Phase (deg)
Bus 1	1.04	0	1.04	0	1.04	0	1.04	0	1.04	0	1.04	0	1.04	0
Bus 2	1.025	31.67	1.025	18.83	1.025	20.55	1.025	7.36	1.025	6.59	1.025	6.05	1.025	9.3
Bus 3	1.025	18.5	1.025	20.14	1.025	-5.4	1.025	8.42	1.025	-0.125	1.025	2.94	1.025	4.68
Bus 4	0.9999	-1.91	1.007	-1.92	1.017	-2	1.023	-1.98	1.028	-1.93	1.038	-1.5	1.026	-2.21
Bus 5	0.9497	-7.51	0.9716	-0.514	0.9765	-0.01	0.9906	-4.53	0.9981	-4.72	0.9021	-9.23	0.9957	-3.97
Bus 6	0.9794	1.39	0.9712	-6.18	1.03	-7.08	1.009	-2.21	0.9602	-10.67	1.02	-3.84	1.013	-3.67
Bus 7	1.018	26.06	1.017	13.22	1.02	14.96	1.012	1.73	1.024	1.02	1.004	0.37	1.026	3.74
Bus 8	1.002	19.51	1.007	12.72	0.9777	-13.38	0.9831	-2.03	1.01	-2.85	1.002	-1.94	1.016	0.747
Bus 9	1.02	15.77	1.024	17.42	1.016	-8.14	1.034	5.72	1.021	-2.85	1.029	0.238	1.032	1.98

Fig. 2. Results from the Power Flow analysis in ETAP for each of the seven scenarios.

PSAT														
Removal of the transmission line between the bus bars x-y	5-7		6-9		7-8		8-9		4-6		4-5		Original	
	Voltage (pu)	Phase (deg)	Voltage (pu)	Phase (deg)	Voltage (pu)	Phase (deg)	Voltage (pu)	Phase (deg)	Voltage (pu)	Phase (deg)	Voltage (pu)	Phase (deg)	Voltage (pu)	Phase (deg)
Bus 1	1.04	0	1.04	0	1.04	0	1.04	0	1.04	0	1.04	0	1.04	0
Bus 2	1.025	30.2256	1.025	17.8218	1.025	19.8879	1.025	6.1479	1.025	4.7212	1.025	-1.4531	1.025	9.28
Bus 3	1.025	17.1931	1.025	19.0452	1.025	-7.1631	1.025	8.1165	1.025	-3.0209	1.025	-1.9869	1.025	4.6648
Bus 4	0.99559	-2.5574	1.0047	-2.4166	1.0159	-2.4713	1.0225	-2.2462	1.0282	-2.2578	1.0388	-2.3397	1.0258	-2.2168
Bus 5	0.93801	-8.8294	0.96779	-1.3923	0.97363	-0.71008	0.98969	-5.1713	0.99881	-5.5664	0.83875	-20.394	0.99563	-3.9888
Bus 6	0.97481	0.30975	0.96387	-7.0928	0.99938	-8.077	1.0087	-2.5078	0.94182	-14.621	1.0203	-6.0661	1.0127	-3.6874
Bus 7	1.017	24.6174	1.0157	12.2059	1.0192	14.2915	1.01	0.5004	1.0223	-0.85828	0.98772	-7.2283	1.0258	3.7197
Bus 8	1.001	18.0586	1.0054	11.6249	0.96904	-15.6343	0.97828	-3.5408	1.0063	-5.1948	0.98948	-8.5309	1.0159	0.72753
Bus 9	1.0189	14.4594	1.0234	16.3236	1.0126	-9.9139	1.0338	5.4223	1.0167	-5.7605	1.0244	-4.7059	1.0324	1.9667

Fig. 3. Results from the Power Flow analysis in PSAT for each of the seven scenarios.

It is safe to say that the contingency involving the transmission line between bus 4 and bus 5 represents the worst scenario for undervoltage at busbar number 5. In Fig. 4, the P-V curve for the three buses with loads in the WSCC system under a contingency between bus 4 and bus 5 is shown. The loadability of bus 5 is compromised since the nominal load of the bus 5 is 125 MW according to [3]. This indicates a deficit of active power, meaning that additional sources should be added to overcome the undervoltage.

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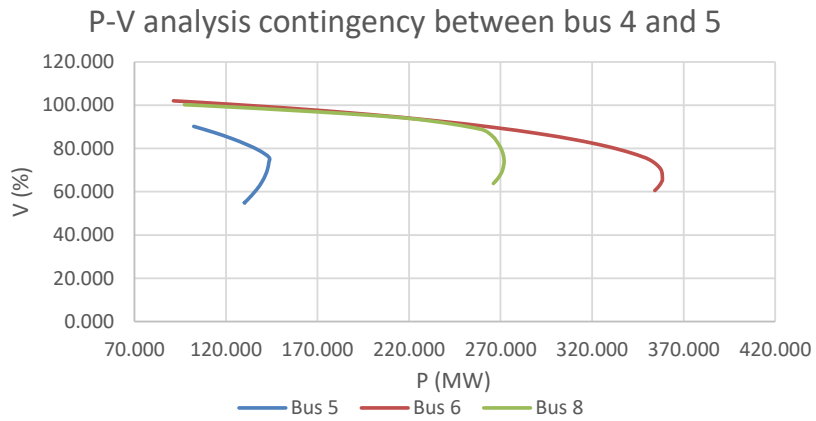


Fig. 4. P-V curves for the three buses with loads in the WSCC without the transmission line between bus 4 and 5.

In Fig. 5 the Q-V curve for the three buses with loads in WSCC system under a contingency between bus 4 and 5. From Fig. 5 is evident the high sensitivity of bus 5.

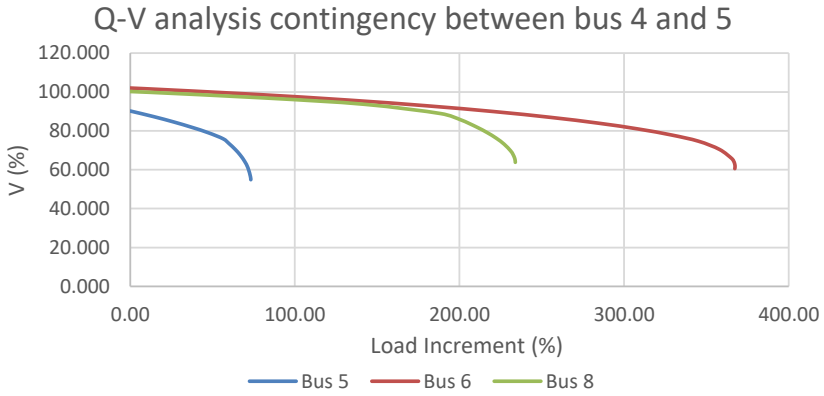


Fig. 5. Q-V curves for the three buses with loads in the WSCC without the transmission line between bus 4 and 5.

In Fig. 6, the sensitivity analysis of the worst contingency scenario is presented. Here, the sensitivity of bus 5 to changes in reactive power is much higher than that of any other bus once the transmission line between bus 4 and bus 5 is removed. Please bear in mind that this study concerns a sustained interruption, meaning one that lasts longer than one minute according to standards (e.g., IEEE-1159, ANSI-C84.1). The goal of any grid operator should be to prevent voltage collapse due to possible load variations. Since the load at bus 5 can vary throughout the day, a sufficient loadability

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margin should be maintained for active and reactive power demand at bus 5, even when the transmission line is absent, to prevent voltage collapse. This situation strongly supports the argument for adding RES at bus 5.

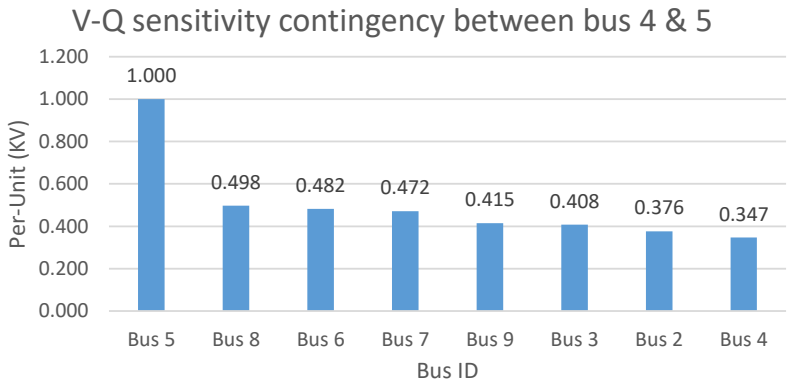


Fig. 6. V-Q sensitivity analysis without the transmission line between bus 4 and 5.

3.1 The addition of RES

This section examines the analysis of bus 5 with the injection of RES. Here the RES is a 70 MW Type 3 wind farm equipped with a Static Var Compensator (SVC) as detailed in the introduction. The SVC can provide a 45 MVAr injection at bus 5. Figure 7 illustrates the WSCC system with the RES injection at bus 5. Notably, the SVC is connected to the common coupling bus of the wind farm, positioned before the step-up transformer.

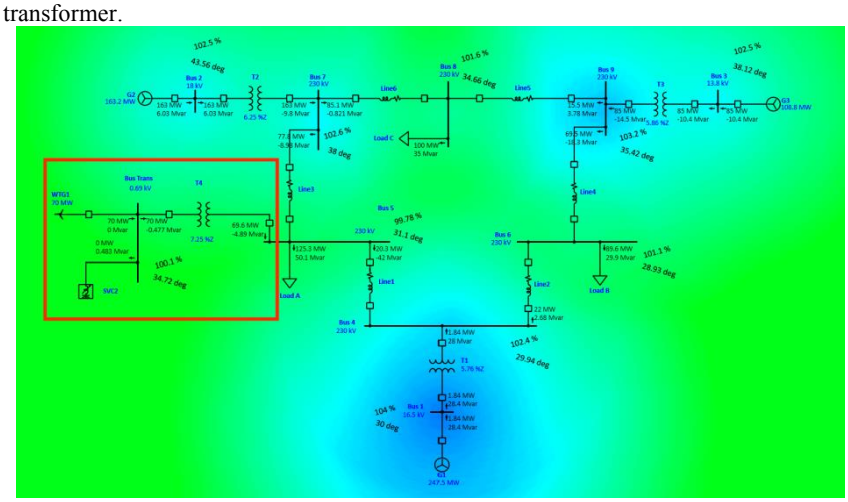


Fig. 7. The WSCC 9 bus system with the addition of RES in bus 5 (red rectangle).

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3.2 Improvements in voltage stability

Figure 8 illustrates the analysis of the worst contingency scenario now incorporating RES. Notably, the bus voltage remains stable, not dropping below 5%, primarily due to the integration of the wind farm. Additionally, the overall system voltage shows improvement with the addition of RES. Figure 9 presents the P-V curves for the three buses with loads in the WSCC, including RES at bus 5. Here, one can observe the enhanced loadability of the bus and the avoidance of an undervoltage condition at bus 5. This demonstrates that, even during the contingency, the loads at bus 5 can be adequately supplied without resorting to extreme measures such as undervoltage load shedding. It is noteworthy that the load at bus 5 is 125 MW, which, as shown in Fig. 9, is well above the 5% lower voltage threshold, with ample margin from the point of voltage collapse (PoVC) on the nose curve.

Figure 10 displays the Q-V curves for the buses with loads in the WSCC system, factoring in RES and the contingency between bus 4 and bus 5. In comparison to Fig. 5, the Q-V curve in Fig. 10 for bus 5 shows significant improvement. This indicates that, even under contingency conditions, the reactive power consumption at bus 5 can be increased by more than 50% without reducing the bus voltage below 95% of its nominal value.

These analyses clearly indicate an improvement in both loadability and reactive power sensitivity at the bus experiencing the lowest voltage during the studied contingencies. It is essential to highlight that, although the wind farm is modeled as an aggregated entity, the ETAP software incorporates wind turbine models that remain effective even under transient conditions. This insight underscores the capabilities of the simulation software to model and optimize the performance of renewable energy systems in dynamic grid situations, enhancing overall grid resilience and stability.

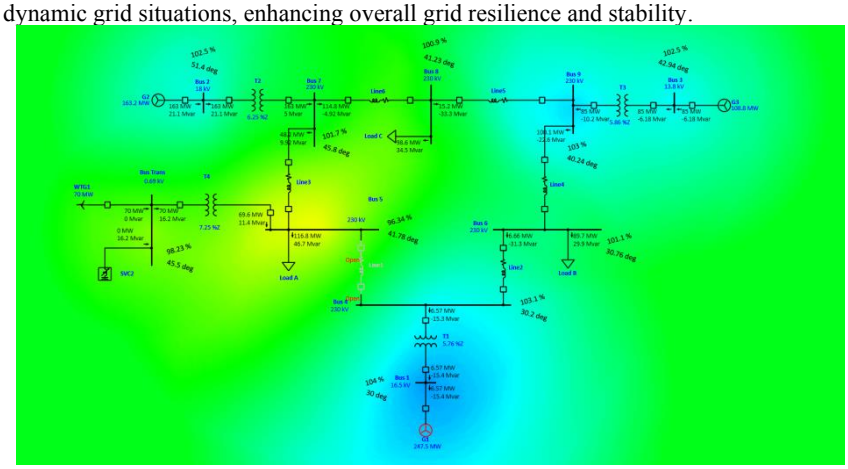


Fig. 8. The WSCC 9 bus system with RES at bus 5 during the contingency between bus 4 and 5.

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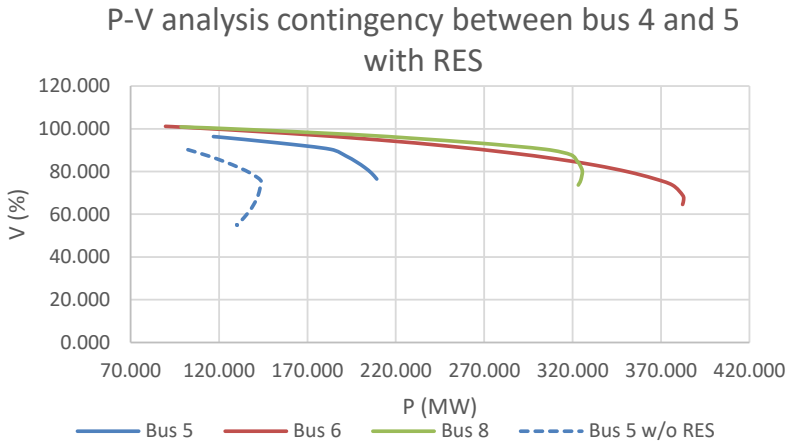


Fig. 9. P-V curves for the three buses with loads in the WSCC without the transmission line between bus 4 and 5 and with 70 MW of RES addition in bus 5. Dotted line is without RES.

Another important detail of the wind farm model is the inclusion of the SVC. This is a common arrangement in onshore wind farms as reported in previous literature[11, 12].

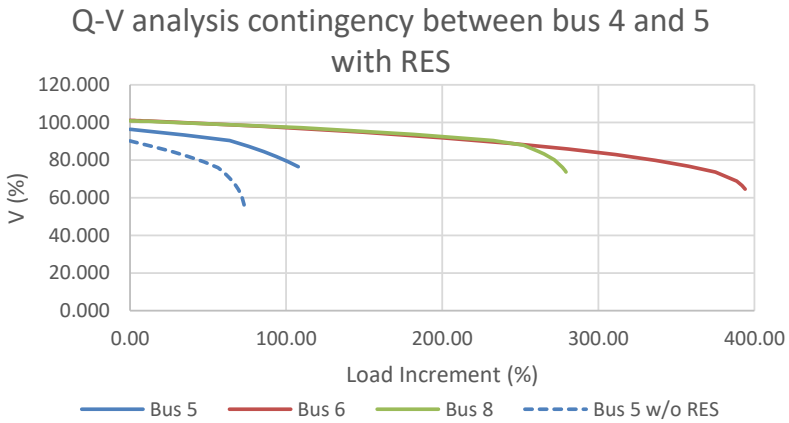


Fig. 10. Q-V curves for the three buses with loads in the WSCC without the transmission line between bus 4 and 5. Dotted line is without RES.

In Fig. 11 the contingency between bus 5 and 4 is shown for the scenario where the wind farm is connected to the bus 6 instead of the bus 5. Here is visible that the undervoltage condition in bus 5 occurs even though the injection of RES. It is important to mention that this study was carried out for the RES in bus 8 with similar results, see Fig. 12. In Fig. 11 and Fig.12 the red rectangle indicates the 70 MW type 3 wind farm.

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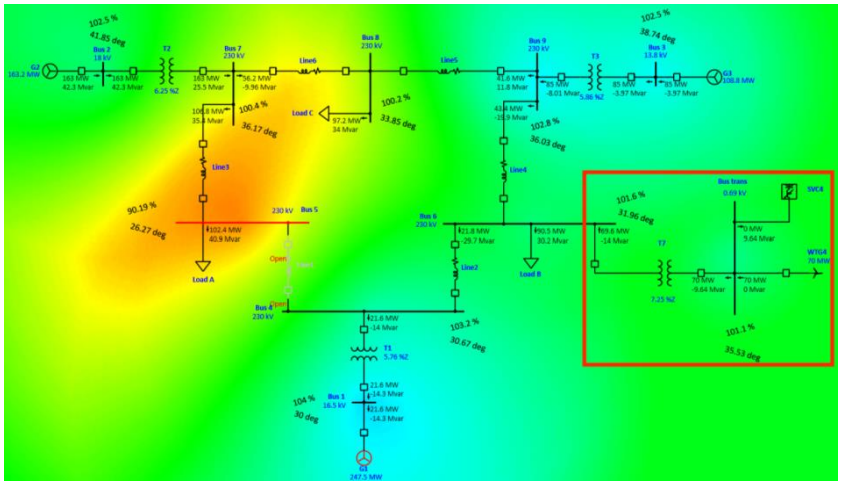


Fig. 11. WSCC with RES in bus 6 during the contingency in between bus 5 and 4.

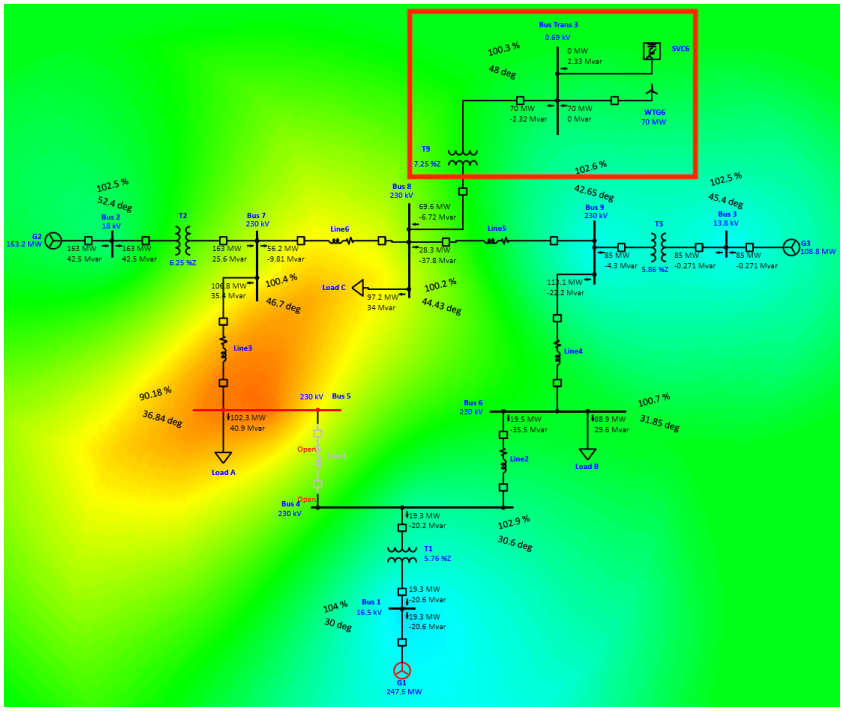


Fig. 12. WSCC with RES in bus 6 during the contingency in between bus 5 and 4.

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4 Conclusions

From the analyses presented in the last section, some important conclusions can be drawn. First, the contingency analysis shows that the worst-case scenario is the removal of the transmission line between buses 4 and 5. This contingency causes an undervoltage condition on bus 5, which could lead to a voltage collapse of the grid, as the bus P-V curve during the contingency demonstrates reduced loadability and increased sensitivity in the Q-V curve.

Second, the addition of renewable energy sources (RES) at the bus with the lowest voltage during the contingency alleviates the undervoltage condition and improves loadability and reactive power supply. This improvement is contingent upon the wind farm being adequately equipped with a Static Var Compensator (SVC), as is common with many modern wind farms.

Third, the point of coupling for the RES in the power system should be carefully studied to enhance voltage stability. Not every location for RES injection can effectively alleviate the undervoltage condition during a contingency. Therefore, studies like the one presented here should be conducted and considered during the planning of grid growth and expansion.

Acknowledgments. The authors acknowledge the support provided by the Thematic Network 723RT0150 ‘‘Red para la integración a gran escala de energías renovables en sistemas eléctricos (RIBIERSE-CYTED)’’ financed by the call for Thematic Networks of the CYTED (Ibero-American Program of Science and Technology for Development) for 2022.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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ISBN 978-9930-617-71-7

Operación inteligente de sistemas de generación fotovoltaicos en microrredes eléctricas aisladas de corriente alterna para reducción de costos y mejora de condiciones operativas

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Abstract. Este documento aborda los desafíos asociados a la optimización de la operación diaria de generadores distribuidos de energía fotovoltaica (GDFV) en microrredes eléctricas aisladas. Para lo cual se propone una metodología maestro-esclavo con el objetivo de reducir los costos de producción de energía y mantenimiento de los sistemas fotovoltaicos, y mejorar las condiciones operativas de la red. En la etapa maestra se resuelve el problema de inyección inteligente de potencia activa de los generadores fotovoltaicos mediante las versiones continuas de dos métodos de optimización: el Algoritmo genético de Chu & Beasley (GA) y el Algoritmo genético poblacional (PGA). Mientras que la etapa esclava, se encarga de evaluar las soluciones propuestas por la etapa maestra resolviendo un flujo de potencia horario basado en el método de aproximaciones sucesivas. Las metodologías de solución propuestas, se validan en el escenarios de prueba de 27 nodos reportados en la literatura, con el objetivo de seleccionar la metodología con mejor rendimiento. Lo anterior para validar la capacidad de optimizar la operación de generadores distribuidos de energía fotovoltaica en microrredes aisladas, considerando las variaciones en la generación y demanda de energía real. El estudio resalta la importancia de consideraciones financieras para una gestión efectiva y económicamente viable de sistemas fotovoltaicos, ofreciendo una contribución valiosa a la implementación efectiva de Energías Renovables No Convencionales (ERNC) en microrredes eléctricas aisladas.

ISBN 978-9930-617-71-7

Keywords: Generación distribuida · Optimización · Metodología maestro-esclavo · microrredes eléctricas aisladas.

1 Introducción

La dependencia mundial de combustibles fósiles para la generación de energía plantea desafíos significativos debido a sus costos elevados, falta de sostenibilidad y consecuencias ambientales negativas. La transición hacia fuentes de energía renovables y bajas en carbono, se presenta como una necesidad apremiante en los sistemas eléctricos tradicionales [1]. En este contexto global, el impulso por integrar energías alternativas alineadas con los requisitos de sostenibilidad, eficiencia económica y compatibilidad ambiental se convierte en un imperativo, representando uno de los principales retos para las nuevas generaciones en términos energéticos [2].

Las microrredes eléctricas asiladas surgen como respuesta a la necesidad de llevar la energía a regiones sin conexión a la red eléctrica. Tradicionalmente, estos sistemas emplean generadores diésel como fuente de alimentación principal, aumentando costos operativos y afectando el medio ambiente con las emisiones de gases contaminantes [3]. En un esfuerzo por seguir la hoja de ruta de eficiencia energética y aprovechar el potencial solar de diversas regiones a nivel mundial, se ha integrado generación distribuida en los sistemas eléctricos de distribución, principalmente a base de generación fotovoltaica. Sin embargo, la operación actual de estos sistemas carece de un análisis inteligente y eficiente, operando frecuentemente en el máximo punto de potencia, lo cual en escenarios de baja demanda y alta generación causa efectos negativos en el sistema asociados a los perfiles de tensión, pérdidas de energía y capacidades de corrientes en los dispositivos que componen la red [4]. Abordar estos desafíos requiere modelos matemáticos que representen el problema de operación para la reducción de costos operativos, y estrategias de solución eficientes para controlar la generación y demanda energética.

En este sentido, diferentes investigaciones relacionadas con la operación inteligente de dispositivos de generación solar en microrredes eléctricas aisladas han sido reportadas en la literatura especializada en la última década. Siendo este un problema actual de alto interés a nivel internacional. Entre las principales publicaciones, se destaca el trabajo reportado en [5], el cual aborda la optimización diaria del despacho de generadores distribuidos fotovoltaicos en redes de distribución, considerando aspectos económicos, técnicos y ambientales como funciones objetivo. Los autores presentan una metodología maestro-esclavo que emplea el optimizador Hormiga León. Dos escenarios de prueba basados en redes urbanas y rurales en Colombia son empleados para validar la metodología propuesta. Los resultados muestran soluciones de buena calidad y repetibilidad, con tiempos de procesamiento cortos.

La investigación reportada en [6], tiene como objetivo explorar la aplicación de una versión paralelizada del método de optimización de Montecarlo, para la asignación y operación óptima de DG en redes eléctricas aisladas, para mini-

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mizar las pérdidas de energía durante la operación diaria de la red. Los autores usan MATLAB y OpenDSS cono herramientas de simulación. Los autores informaron tiempos cortos de procesamiento con niveles adecuados de reducción en las pérdidas de energía. Sin embargo, dentro de este trabajo no se tuvo en cuenta el impacto sobre las condiciones económicas de la red. Además, no se consideraron condiciones variables de demanda y generación de energía que permitieran representar de manera más realista la operación de los sistemas eléctricos de distribución analizados.

Guzmán et al. [7] abordan la planificación de la ubicación y dimensionamiento de generadores fotovoltaicos en redes de distribución radial. El trabajo tiene como objetivo minimizar los costos operativos anuales durante 20 años, para lo cual, considera costos de compra de energía, inversión en generadores fotovoltaicos y costos de operación. Para determinar ubicaciones óptimas usan el algoritmo de senos y cosenos, mientras que en el software GAMS se resuelve el MINLP asociado a la operación de los generadores localizados y dimensionados por la metodología de optimizacón antes mencionada. Es importante destacar que el estudio no tiene en cuenta las características telescópicas del sistema analizado, lo cual impacta aspectos operativos y restringe la corriente a través de las líneas.

Otros autores han propuesto modelos de optimización utilizando metodologías maestro-esclavo. Un ejemplo de ello son los autores de [8], quienes emplean una versión paralelizada del algoritmo PSO que opera en una estrategia maestro-esclavo con un método de flujo de potencia multiperiodo basado en aproximaciones sucesivas. Su objetivo es optimizar la operación de sistemas de almacenamiento de energía (BSS) en redes de corriente eléctricas con alta penetración de generadores distribuidos. Otro caso destacado es el trabajo presentado en [9], que propone una estrategia de optimización basada en una versión Paralela Discreta-Continua del Algoritmo de Optimización de Cúmulo de Partículas (DCPPSO). Este enfoque busca ubicar y dimensionar eficientemente generadores fotovoltaicos. Asimismo, se destaca el trabajo en [10], que utiliza un algoritmo de búsqueda de cuervo continuo discreto (DCCSA) para resolver el problema.

Los trabajos revisados, comparten el uso de sistemas de prueba reportados en la literatura para validar la eficacia de las metodologías propuestas y horizontes de evaluación de un día típico de operación. Sin embargo, todos ellos no tienen en cuenta la variación de la demanda y generación de energía durante intervalos de operación en los que puede cambiar la disponibilidad del recurso renovable. Lo cual se identifica como una oportunidad de investigación en este documento.

Este trabajo propone una metodología de optimización maestro-esclavo para la operación inteligente multiperido de generadores de energía solar distribuidos (PV DG) en microrredes eléctricas aisladas. Por medio de esta metodología se busca reducir los costos de operación asociados a la producción de energía en los generadores convencionales a base de combustibles fósiles (Diesel) y el costo de mantenimiento de los PV DG. Mejorando al mismo tiempo las condiciones operativas de la red relacionadas con el balance de potencia, perfiles de tensión y cargabilidades en las líneas de distribución de energía. La etapa maestra, es

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la encargada de proponer las configuraciones de despacho de potencia de los PV DG instalados dentro de la red aislada en periodos de una hora en un horizonte de 24 horas, para lo cual, se proponen dos métodos de optimización, Los cuales corresponden al algoritmo genético de Chu-Beasley (CBGA) y el algoritmo genético basado en población (PGA). La etapa esclava es la encargada de evaluar cada una de las configuraciones de inyección de potencia entregada por la etapa maestra, para lo cual, se realiza un análisis del flujo de potencia horario basado en el método de aproximaciones sucesivas [11]. Para validar la metodología propuesta, se emplea el escenario de 27 nodos, junto con las curvas de generación y demanda reportadas en la literatura.

Las principales contribuciones de este artículo se describen a continuación:

- Un modelo matemático para la gestión inteligente de generadores PV en microrredes eléctricas aisladas, el cual considera costos de generación, operación y mantenimiento, además de las restricciones técnicas que presentan los sistemas de generación PV en microrredes aisladas.
- La implementación de dos técnicas de optimización metaheurísticas, cada una de ellas empleadas en la etapa maestra para la generación de configuraciones de inyección de potencia por parte de los generadores PV bajo un escenario de generación y demanda variable. Las cuales, permiten reducir los costos operativos y mejorar las condiciones de la red eléctrica.
- La selección del método PGA, como el más eficiente en términos de calidad y repetibilidad de la solución aplicado al problema de gestión de la operación de PV DG en microrredes aisladas, en el cual se consideran restricciones técnicas y de mantenimiento, de tal manera que se minimizan los cotos operativos totales bajo entornos de generación y demanda de potencia variables.

1.1 Estructura del artículo

El contenido de este artículo se estructura en seis secciones. En la Sección 2 se presenta la formulación matemática que describe el problema de operación inteligente de generadores PV en microrredes eléctricas aisladas AC. La Sección 3 contiene la metodología propuesta, en la cual se describe la función de adaptación, la codificación del problema, y cada una de las técnicas de optimización empleadas en la etapa maestra y el método de flujo de potencia utilizado en la etapa esclava. La Sección 4 describe el sistema de prueba empleado para la validación de la metodología propuesta. El análisis numérico y gráfico de los resultados se discute en la Sección 5. Finalmente, el conjunto de conclusiones y trabajos futuros se presenta en la Sección 6.

2 Formulación matemática

En esta sección se presenta el modelo matemático utilizado para resolver el problema de operación inteligente de PV DG en microrredes eléctricas aisladas para la reducción de costos de operación y mejora de las condiciones operativas [12].

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2.1 Función objetivo

La función objetivo planteada en este documento, busca la minimización de los costos de operación de la red, los cuales están asociados a la producción de energía por parte de los generadores diésel y el mantenimiento de los PV GD. Esta función considera que los PV DG son de propiedad del operador de red o del propietario de la microrred. Es importante resaltar que solo se considera la gestión de energía activa dentro de la formulación planteada, dado que es el escenario de mayor análisis dentro de la literatura especializada. La ecuación (1) representa la función objetivo del sistema.

$$\min E_{\cos t} = C_{kWh}\left(\sum_{h\in\mathcal{H}}\sum_{i\in\mathcal{N}} P_{i,h}^{gc}\Delta h\right) + C_{O\&M}\left(\sum_{h\in\mathcal{H}}\sum_{i\in\mathcal{N}} P_{i,h}^{pv}\Delta h\right) \quad (1)$$

Donde $p_{i,h}^{gc}$ corresponden a la potencia activa entregada por cada generador convencional y $p_{i,h}^{pv}$ es la potencia activa inyectada por cada PV DG conectado al nodo i en el período de tiempo h. El término $\mathcal{N}$ representa el conjunto de nodos que componen la red y $\mathcal{H}$ hace referencia todos los periodos contenidos en el horizonte de tiempo analizado. El término Δh está asociado a la duración de cada periodo de tiempo. En este documento se define que los periodos serán de una hora. Finalmente, se tiene que los términos C_{kWh} y $C_{O\&M}$ son los parámetros de costo de energía por kWh y el costo de operación y mantenimiento de cada PV DG respectivamente. En donde el valor de $C_{O\&M}$ es de 0.0019 USD y se encuentra reportado en [13]. Mientras que el valor de C_{kWh} depende del sistema eléctrico. Para el sistema de prueba utilizado en este trabajo, C_{kWh} es de 0.2913 USD, valor que se encuentra reportado en [14].

2.2 Conjunto de restricciones

Las restricciones operativas hacen referencia a las ecuaciones, límites y parámetros que modelan el comportamiento del sistema. En primer lugar, se establecen las ecuaciones de balance de potencia suministrada y consumida en la red. La ecuación (2) expresa el balance de potencia activa, en donde $P_{i,h}^{gc}$ es la potencia activa suministrada por el generador convencional, $P_{i,h}^{d}$ la potencia activa demandada por las cargas, y $P_{i,h}^{pv}$ la potencia activa suministrada por los PV GD en el nodo i para cada periodo h. Mientras que, la ecuación (3) muestra el balance de potencia reactiva, en donde $Q_{i,h}^{gc}$ es la potencia reactiva suministrada por el generador convencional y $Q_{i,h}^{d}$ es la potencia reactiva demandada en el nodo i para cada periodo h.

$$p_{i,h}^{gc} + p_{i,h}^{pv} - P_{i,h}^{d} = v_{i,h}\sum_{j\in\mathcal{N}} Y_{ij}v_{j,h}\cos\left(\theta_{i,h} - \theta_{j,h} - \varphi_{ij}\right), \left\{\forall i \in \mathcal{N}, \forall h \in \mathcal{H}\right\}, \quad (2)$$

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$$q_{i,h}^{gc} - Q_{i,h}^{d} = v_{i,h} \sum_{j \in \mathcal{N}} Y_{ij} v_{j,h} \sin\left(\theta_{i,h} - \theta_{j,h} - \varphi_{ij}\right), \left\{\forall i \in \mathcal{N}, \forall h \in \mathcal{H}\right\}, \quad (3)$$

Los límites operativos que aseguran el funcionamiento seguro y eficiente del generador convencional se expresan mediante las siguientes ecuaciones:

$$P_i^{gc,\min} \leq P_{i,h}^{gc} \leq P_i^{gc,\max}, \left\{\forall i \in \mathcal{N}, \forall h \in \mathcal{H}\right\}, \quad (4)$$

$$Q_i^{gc,\min} \leq Q_{i,h}^{gc} \leq Q_i^{gc,\max}, \left\{\forall i \in \mathcal{N}, \forall h \in \mathcal{H}\right\}, \quad (5)$$

La ecuación (4) expresa los límites de potencia activa del generador convencional (G), donde $P_i^{gc,\min}$ y $P_i^{gc,\max}$ son las potencias mínimas y máximas suministradas por el generador convencional. Luego la ecuación (5) se refiere a los límites de potencia reactiva, donde $Q_i^{gc,\min}$ y $Q_i^{gc,\max}$ son las potencias mínimas y máximas suministradas.

Las siguientes ecuaciones modelan el comportamiento del panel y consideran las restricciones de potencia de este:

$$P_i^{pv,\min} \leq P_i^{pv} \leq P_i^{pv,\max}, \left\{\forall k \in \mathcal{N}\right\}, \quad (6)$$

$$P_i^{pv,\min} \leq P_{i,h}^{pv} \leq P_i^{pv} G_h^{pv}, \left\{\forall i \in \mathcal{N}, \forall h \in \mathcal{H}\right\}, \quad (7)$$

La ecuación (6) presenta el rango de potencia activa que puede suministrar el panel, donde $P_i^{pv,\min}$ y $P_i^{pv,\max}$ son los límites mínimos y máximos de potencia. El límite máximo se obtiene cuando los PV GD se encuentran operando en el punto máximo de potencia durante un día promedio de operación. La ecuación (7) indica que la potencia máxima que puede entregar el panel está dada por la curva de generación típica de la región donde se encuentre ubicado dado que está en función de la radiación, temperatura y tipo de tecnología, lo cual se simboliza con el término G_h^{pv}. Finalmente, en la ecuación (8) se presentan los límites mínimos $V_i^{\min}$ y límites máximos $V_i^{\max}$ de variación de tensión permitidos en cada nodo del sistema. Mientras que, la ecuación (9) presenta que la corriente de línea que se da entre los nodos i y j en cada periodo h, $I_{ij,h}$, debe ser menor o igual a la corriente máxima $I_{ij}^{\max}$ que soporta cada tramo de red .

$$V_i^{\min} \leq V_{i,h} \leq V_i^{\max}, \left\{\forall i \in \mathcal{N}, \forall h \in \mathcal{H}\right\}, \quad (8)$$

$$|I_{ij,h}| \leq I_{ij}^{\max}, \left\{\forall i, j \in \mathcal{N}, \forall h \in \mathcal{H}\right\}, \quad (9)$$

3 Metodología de solución

La metodología usada presenta un enfoque maestro esclavo, por medio de la cual, se divide el problema en dos etapas; la primera etapa (maestra) utiliza un método de optimización para determinar el nivel de inyección de potencia de los generadores fotovoltaicos. La segunda etapa (esclava) utiliza un método numérico para evaluar las soluciones obtenidas en la etapa maestra acorde a una función de aptitud definida.

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3.1 Función de adaptación

La función de adaptación hace referencia al valor de función objetivo del problema más un valor de penalización, el cual se aplica en respuesta a posibles violaciones de las restricciones operativas del sistema. Estas restricciones abarcan las infracciones de regulación de tensión (± 8%) y cargabilidad de cada línea (superior al 100%). La función de adaptación empleada en este documento se presenta en la ecuación (10).

$$fadap = FO + \alpha Pen_V + \beta Pen_I \tag{10}$$

$$Pen_V = \sum_{i\in\mathcal{N}}\sum_{h\in\mathcal{H}} \max(0, V_{i,h} - V_i^{\max}) - \min(0, V_{i,h} - V_i^{\min}) \tag{11}$$

$$Pen_I = \sum_{i\in\mathcal{N}}\sum_{j\in\mathcal{N}}\sum_{h\in\mathcal{H}} \max(0, I_{ij,h} - I_{ij,h}^{\max}) \tag{12}$$

En donde, FO representa la función objetivo presentada en la ecuación (1). Pen_V y Pen_I corresponden a las penalizaciones por infracción en regulación de tensión y cargabilidad de línea. Mientras que α y β son los factores de penalización. Estos factores son escogidos heurísticamente con un valor de 1000. Para el calculo de Pen_V se suman las violaciones de tensión obtenidas en todos los nodos durante las 24 horas de operación empleando la Ecuación (11). Mientras que, para incluir las penalizaciones por violación en las cargabilidades en las lineas se emplea la Ecuación (12).

3.2 Codificación

Para representar el problema bajo estudio, se utiliza una codificación vectorial de tamaño $[1, H \times |PVDG|]$. Donde H describe el número de periodos contenidos en el horizonte de tiempo analizado. $|PVDG|$ denota el número de PV DG que existen dentro de la red. Como se puede apreciar en la Figura 1, para cada generador se propone un nivel de potencia a despachar en cada periodo de tiempo. Siendo este valor limitado por los valores máximos y mínimos obtenidos al representar la curva de potencia de cada generador operando en el máximo punto de potencia.



Fig. 1. Codificación para la operación de generadores fotovoltaicos distribuidos.

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3.3 Etapa maestra

En esta etapa se proponen diferentes configuraciones de despacho de los PV DG, lo cual permite explorar el espacio de solución, seleccionando la mejor solución al problema mediante la aplicación de criterios de evolución basados en algoritmos poblacionales. Este trabajo se utilizan dos técnicas de optimización para la etapa maestra: una versión continua del Algoritmo genético de Chu & Beasley y una versión continua del Algoritmo genético basada en poblaciones.

Algoritmo genético de Chu & Beasley El GA se inspira en el mecanismo de selección natural, un proceso biológico en el que los individuos más fuertes son probablemente los ganadores en un entorno competitivo [15]. El método se basa en 3 procesos esenciales: generación de la población inicial, implementación de operadores genéticos para la obtención de un único descendiente (selección, recombinación y mutación), y evaluación de los criterios de convergencia o detención del algoritmo [16]. A continuación, se describen los criterios de selección, recombinación y mutación que controlan la exploración del CBGA [17].

- **Selección**: la población descendiente comienza a seleccionar los cromosomas más aptos de la población actual para ser los padres de la siguiente generación. La selección se realiza escogiendo aleatoriamente 4 padres, realizando un torneo donde se comparan respecto al valor de su función de adaptación. La pareja de padres con la menor función de aptitud es seleccionada para crear un hijo.
- **Recombinación**: este proceso altera la población descendiente aplicando un operador para combinar las características de diferentes cromosomas y generar nuevas soluciones. Dado que este problema opera con variables continuas, en este documento se promedian los valores contenidos dentro de los dos individuos seleccionados como padres para generar el descendiente.
- **Mutación**: en este paso se realiza la mutación aleatoria de algunos genes de los cromosomas seleccionados. Esto produce variabilidad en la población e induce a que se amplíe el espacio de soluciones evaluadas, evitando converger prematuramente a una solución subóptima. En el caso particular de este documento, al descendiente se le mutan algunas características dentro de los valores mínimos y máximos de potencia fijados para cada periodo de tiempo.

Algoritmo genético poblacional El método de optimización PGA se utiliza para resolver problemas de optimización complejos. Se diferencian con el método anterior principalmente en la forma en que se maneja la población. Mientras que el CBGA modifica un individuo en cada iteración, en el PGA se modifica la población en su totalidad, lo que permite una mayor diversidad y exploración del espacio de soluciones. La característica poblacional de este algoritmo define un número N de hijos para conformar la nueva población y podrían reemplazar a la generación de padres o mezclarse con ellos en la siguiente generación, inspirándose en la evolución biológica en dónde prevalece el organismo "más fuerte".

Este método utiliza los mismos principios de selección, recombinación y mutación que el CBGA.

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3.4 Etapa esclava

Para evaluar el impacto en los costos de producción de energía de los generadores, así como las restricciones técnicas respecto a la cargabilidad en las líneas y regulación de tensión en los nodos, es necesario determinar el flujo de potencia para los diferentes periodos de tiempo establecidos. El método de aproximaciones sucesivas utilizado para resolver el flujo de potencia en este trabajo, fue introducido por primera vez en [18]. El método determina las tensiones nodales para cada hora de operación en los nodos de demanda (d), dado que en los nodos de generación (Slack) es conocida. Para esto se calcula hora a hora el flujo de potencia mediante la siguiente ecuación recursiva:

$$V_{d,h}^{t+1} = -Y_{dd}^{-1}[diag^{-1}(V_{d,h}^{t,*})(S_{d,h}^{t,*} - S_{pv,h}^{*}) + Y_{ds}V_{s,h}] \tag{13}$$

donde t es el contador de iteraciones. $V_{d,h}$ denota el vector que contiene la tensión en los nodos de demanda para cada periodo de tiempo h. Y_{ds} es el componente de la matriz de admitancia que asocia el nodo slack con los nodos de demanda, mientras que Y_{dd} denota el componente de la matriz de admitancia que relaciona los nodos de demanda entre sí. $S_{d,h}$ representa el vector en el dominio complejo que contiene la potencia activa y reactiva demandada en los nodos de carga para cada periodo de tiempo h. $S_{pv,h}$ es el vector en el dominio complejo que contiene la potencia activa producida por cada PV DG para cada período de tiempo h. $V_{s,h}$ denota el vector que contiene la tensión en los terminales del nodo de la subestación para cada período de tiempo h, el cual, es un parámetro conocido en la solución del flujo de potencia.

La ecuación (13) se soluciona de manera iterativa hasta cumplir con el criterio de convergencia. La ecuación (14) presenta el criterio de convergencia, en donde ϵ es el parámetro de error definido en este documento con un valor de $1 \cdot 10^{-10}$. Se emplea como punto de inicio un voltaje plano en todos los nodos del sistema (1 p.u.).

$$\left| V_{d,h}^{t+1} - V_{d,h}^{t} \right| \leq \epsilon \tag{14}$$

Con los niveles de tensión asociados a cada hora de operación se evalúa la función de adaptación para cada hora, junto a las penalizaciones ligadas a las restricciones de cargabilidad y regulación de tensión empleando la Ecuación (10). Posterior al calculo de la función adaptación en cada hora de operación, se suman los resultados obtenidos en todas las horas y se retornan a la etapa maestra.

4 Sistemas de prueba

Esta sección describe el sistemas de prueba 27 nodos reportados en la literatura especializada, el cual ha sido ampliamente usado para validar estrategias de planeamiento y gestión de la energía [10, 14]. Este sistema se analiza en la región de Colombia, donde por las condiciones geográficas se mantienen una condición de generación y demanda promedio alrededor del año de operación.

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Se adaptan las curvas de generación y demanda rural reportadas en la literatura para la región de Capurganá-Colombia [14]. Para caracterizar dichas curvas, se emplearon los datos de radiación solar y temperatura ambiente proporcionados por la base de datos de la Administración Nacional de Aeronáutica y del Espacio (NASA) [19]. La Figura 2 representa la curva de generación esperada en p.u para la ciudad de Capurganá, Colombia. La cual representa la generación de potencia en p.u de un panel de silicio policristalino instalado en la región bajo análisis.

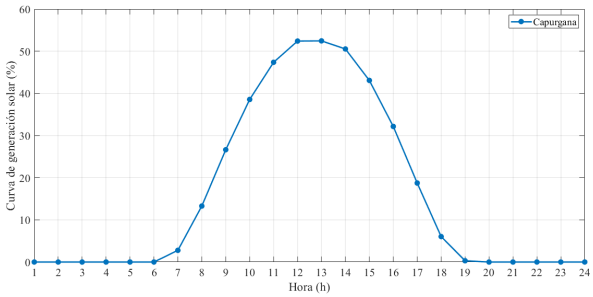


Fig. 2. Perfil de generación esperado en Capurganá, Colombia [14].

Las curvas de demanda energética en la red eléctrica aislada de Capurgána, se obtuvo por medio de la información de consumo proporcionada por los datos históricos del IPSE [20], entidad encargada de la supervisión y monitoréo de los sectores eléctricos no interconectados de Colombia. En la Figura 3 se presenta la curva de demanda energética de la red aislada de Capurganá. La cual corresponde a un día promedio de operación.

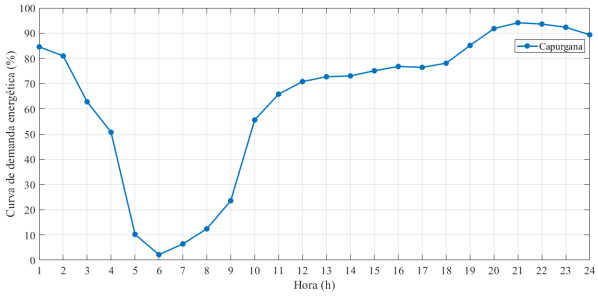


Fig. 3. Perfil de consumo energético esperado en Capurganá, Colombia [14].

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4.1 Sistema de prueba de 27 nodos

En la Figura 4 se presenta la configuración de la red de 27 nodos. Este sistema de distribución radial está compuesto de 27 nodos y 26 líneas que opera a una potencia y voltaje base de 100 [kVA] y 23 [kV], respectivamente. Cabe destacar que este sistema presenta 3 generadores fotovoltaicos ubicados en los nodos 5, 9 y 19. Cada generador tiene una potencia nominal de 2400 [kW] [14].

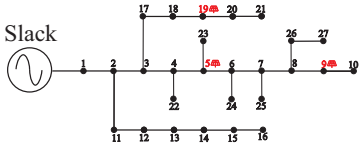


Fig. 4. Topología radial de 27 nodos.

En este sistema de prueba se considera la característica telescópica de las líneas de distribución. Los parámetros de línea del sistema se encuentran reportados en [14].

5 Resultados de simulación

En esta sección se presentan y analizan los resultados de simulación asociados a la implementación de las metodologías de solución propuestas para la operación inteligente PV DG.

Los parámetros de sintonización de las dos técnicas empleadas son presentados en la Tabla 1. Estos parámetros fueron hallados de manera heurística.

Table 1. Parámetros de optimización

Método	Parámetro	Valor
GA	N° individuos	40
	N° iteraciones máx	4000
	N° mutaciones	20
PGA	N° individuos	100
	N° iteraciones máx	2000
	N° mutaciones	20
	N° de hijos (N)	80

En la Tabla 2, se presenta los resultados de simulación obtenidos al evaluar las metodologías de solución propuestas. Esta tabla presenta de izquierda a derecha el método de optimización empleado, la mejor solución (reducción máxima),

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la solución promedio, la desviación estándar promedio, la diferencia entre la mejor solución y la solución promedio, y el tiempo de procesamiento promedio requerido al ejecutar la metodología 100 veces.

Table 2. Resultados de simulación sistema de 27 nodos

Método	**Solución minima [USD]**	**Solución promedio [USD]**	**Desv standar promedio [%]**	**Diferencia entre soluciones[%]**	**Tiempo[s]**
GA	13.159,5540	13.375,4074	0,5096	1,6138	9,0854
PGA	12.577,0017	12.676,6478	0,2658	0,7861	534,9691
Caso Base	18.544	- - -	- - -	- - -	- - -

La Figura 5 presenta las reducciones obtenidas por las metodologías de solución con respecto al caso base, el cual tiene un costo de total de energía de 18.543 dólares en un día promedio de operación en un escenario ausente de generación fotovoltaica. Lo cual equivale en un año de operación a 6.768.560 dólares en costos de compra de energía. La subfigura (a) muestra las reducciones máximas con respecto al caso base, que presentan en promedio una reducción de un 30,6062% para las dos metodologías, mientras que en el caso de la subfigura (b) que muestra las reducciones promedio se obtiene una reducción del 29,7555% en promedio. Además, se observa que las dos metodologías logran minimizar notablemente los costos de compra de energía. En términos económicos, en un día promedio de operación las metodologías logran reducir 5.675 dólares en promedio, lo cual equivale analizando un año promedio de operación a 2.071.375 de dólares. Siendo importante destacar que la mejor solución en relación con la función objetivo fue el PGA. Este método obtiene una reducción mínima diaria de 5.966 dólares y anual de 2.177.590 de dólares.

Con el objetivo de identificar la repetibilidad y tiempos de procesamiento requeridos por las metodologías se analiza la Figura 6. En términos de la desviación estándar al ejecutar cada algoritmo 100 veces, en la figura 6(a) se observa que se obtiene como valor máximo 1,6138% y en promedio 1,1999%. Lo cual demuestra que se obtuvieron respuestas adecuadas en las dos metodologías. En la subfigura (b) se muestran los tiempos de procesamiento requeridos. Donde el más eficiente es el GA con una diferencia de 525 segundos por iteración comparado con el PGA, sin embargo el PGA logró obtener los mejores resultados para la función objetivo y la desviación estándar. Por lo tanto, se considera que para el sistema de 27 nodos el método con mejor eficiencia en términos de solución y repetibilidad es es el PGA.

6 Conclusiones

Para el sistema de 27 nodos, las dos metodologías son eficientes desde el punto de vista de la solución obtenida y la repetibilidad de dichas soluciones. El menor tiempo de procesamiento se logra con el GA. Sin embargo, el PGA logra muy buenos resultados, considerando que el horizonte del periodo de análisis es de 24

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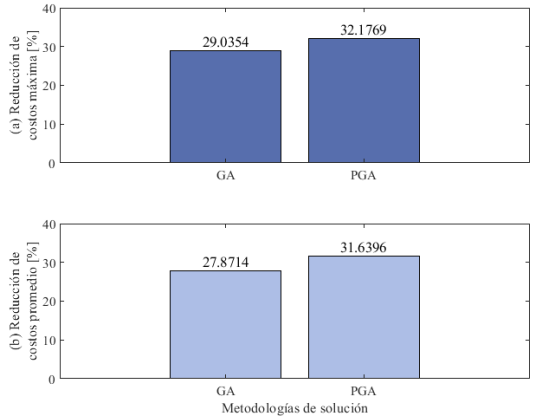


Fig. 5. Reducciones en costos de producción de energía máximas y promedio en el sistema de 27 nodos

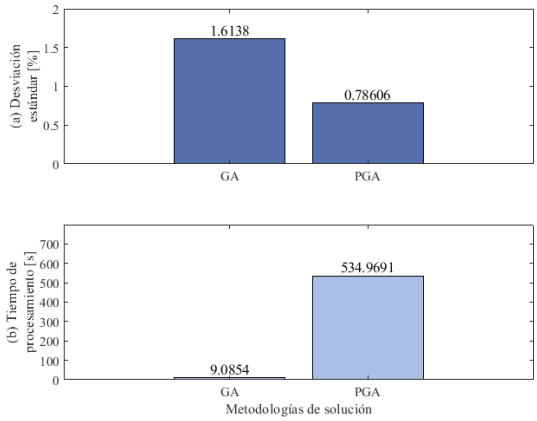


Fig. 6. Resultados de simulación para el sistema de 27 nodos en términos de desviación estándar con respecto a la mejor solución y tiempos de procesamiento

horas (86.400 segundos), la diferencia de ejecución de 525 no es representativa comparada con las mejoras económicas logradas por el PGA. Razón por la cual, en este documento se establece que el PGA es la metodología más adecuada entre los métodos de solución empleados en este trabajo para resolver el problema de operación inteligente de FV GD en microrredes eléctricas aisladas, considerando la variación en la generación y demanda de energía

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Finalmente, como trabajo futuros de esta investigación se puede considerar la implementación y desarrollo de nuevas metodologías de optimización que permitan mejorar los resultados obtenidos por las metodologías propuestas. Adicionalmente, se puede considerar dentro de la microrred la operación de otras tecnologías de generación renovables como la generación eólica, así como también la operación de sistemas de almacenamiento de energía. Habiendo solucionado el problema de operación de múltiples recursos energéticos distribuidos, se puede plantear la posibilidad de estudiar la relocalización de estos dentro de la red para mejorar los aspectos técnicos, económicos y ambientales de la misma. Todo lo anterior respetando las limitaciones técnicas, topográficas y climáticas de la región donde se encuentra localizada la red eléctrica aislada.

Agradecimientos Los autores agradecen la financiación otorgada por ANID/ FONDECyT bajo el proyecto 11240006: *"Smart energy management methods for improving the economic, technical, and environmental indexes of the alternating current microgrids including variable generation and demand profiles"*, de la facultad de ingeniería de la Universidad de Talca, Campus Curicó, Chile. Este trabajo también es soportado por el programa Iberoamericano de Ciencia y Tecnología para el Desarrollo (CYTED) a través de la Red Temática 723RT0150 *"Red para la integración a gran escala de energías renovables en sistemas eléctricos"* (RIBIERSE-CYTED).

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ISBN 978-9930-617-71-7

IMPLEMENTACIÓN DE MICRORREDES CON COMPONENTES SOLARES Y DE BATERÍAS EN ZONAS RURALES EN GUATEMALA

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Abstract. La electrificación rural es clave para mejorar la calidad de vida en comunidades remotas de Guatemala, donde los índices de pobreza y falta de acceso a la energía son altos. Un ejemplo exitoso es el programa de Sistemas Aislados con Paneles Solares implementado en Tzalamilá, Senahú, Alta Verapaz, que ha beneficiado a 650 hogares y mejorado las condiciones de vida de más de 3,900 personas. Este proyecto destaca por utilizar microrredes solares que, junto con baterías, proporcionan un servicio confiable y sostenible, reduciendo la dependencia de combustibles fósiles.

Este programa demuestra la efectividad de las microrredes para llevar energía a comunidades aisladas, pero también resalta la necesidad de superar desafíos financieros, institucionales y técnicos. La inversión inicial en tecnología, la falta de personal capacitado y la limitada infraestructura en zonas rurales son obstáculos que deben ser abordados. La participación activa de las comunidades, como en el caso de Tzalamilá, ha sido fundamental para garantizar el buen funcionamiento y mantenimiento de los sistemas solares, lo que asegura su sostenibilidad a largo plazo.

Para replicar y expandir estos esfuerzos, se recomiendan varias medidas, como el financiamiento gubernamental para proyectos de energía renovable, la diversificación económica de las comunidades y la formación técnica. Las alianzas público-privadas pueden asegurar que los equipos sean de alta calidad y a precios accesibles, mientras que la educación y el entrenamiento continuo en tecnología renovable son esenciales para el éxito de estos proyectos.

Keywords: Microrredes, paneles solares, electrificación rural y energías renovables.

ISBN 978-9930-617-71-7

1 INTRODUCCIÓN

La electrificación rural es una herramienta crucial para mejorar la calidad de vida en comunidades remotas, particularmente en Guatemala, donde los índices de pobreza y la falta de acceso a la energía son elevados. La electricidad es un motor de desarrollo económico y social, pues facilita el acceso a servicios básicos como la salud, la educación y la seguridad alimentaria [1]. La ausencia de electricidad en estas áreas limita las oportunidades de crecimiento y perpetúa la pobreza energética [2]. Según la Agencia Internacional de Energía (AIE), más del 55% de las nuevas conexiones eléctricas necesarias para cubrir las áreas no electrificadas dependerán de sistemas descentralizados como microrredes y otras tecnologías basadas en energía renovable.

Un caso exitoso es el programa de Sistemas Aislados con Paneles Solares implementado en la comunidad de Tzalamilá, Senahú, Alta Verapaz, que ha beneficiado a 650 hogares y mejorado las condiciones de vida de más de 3,900 personas. Este proyecto ha demostrado la viabilidad de las microrredes solares, que, al estar integradas con sistemas de almacenamiento mediante baterías, garantizan un servicio energético confiable y sostenible, reduciendo significativamente la dependencia de combustibles fósiles.

Otro ejemplo relevante es el caso de las mujeres indígenas guatemaltecas capacitadas en India. Como parte del programa global de Barefoot College, varias mujeres de comunidades rurales de Huehuetenango y Quiché recibieron capacitación técnica en la instalación y mantenimiento de sistemas solares en India. A su regreso, llevaron luz a más de 500 hogares guatemaltecos, logrando no solo mejorar el acceso a energía en sus comunidades, sino también empoderarse a nivel social y económico.

Este programa muestra cómo la capacitación y participación activa de la comunidad son fundamentales para el éxito de las microrredes en zonas rurales.

Además de estos esfuerzos, el programa liderado por la Dra. Susana Arrechea, New Sun Road Guatemala, también ha tenido un impacto significativo. Este proyecto, incubado en la Universidad de California en Berkeley, busca proporcionar energía solar, conectividad a internet y capacitación digital en comunidades rurales sin acceso a electricidad. Con un enfoque en la inclusión de mujeres indígenas, el programa ha logrado empoderar a mujeres locales para que gestionen centros comunitarios, asegurando la sostenibilidad de los proyectos de energía solar y fomentando la equidad de género Emisoras Unidas.

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2 Antecedentes y Teorías Relevantes

Las microrredes se han consolidado como una solución ideal para la electrificación de zonas rurales, debido a su capacidad de operar tanto conectadas a la red como de manera autónoma (off-grid). Se componen de generadores renovables, como paneles solares, combinados con tecnologías de almacenamiento y controladores inteligentes.

La implementación de estas redes ha sido ampliamente documentada en estudios globales. Por ejemplo, Schnitzer et al. (2014) realizaron una revisión de siete casos exitosos de microrredes en áreas rurales, destacando que, cuando las comunidades están involucradas en la operación y el mantenimiento, la sostenibilidad de los proyectos mejora significativamente.

En el contexto guatemalteco, los sistemas basados en energía solar fotovoltaica han sido especialmente exitosos debido a la alta radiación solar de la región y la caída en los costos de los equipos solares en los últimos años. De acuerdo con estudios recientes, las microrredes basadas en energía solar, acompañadas de almacenamiento en baterías, se han convertido en una solución rentable y viable para comunidades aisladas.

2.1 Desafíos y Sostenibilidad

A pesar de los éxitos obtenidos, la implementación de microrredes en áreas rurales no está exenta de desafíos. Estos incluyen obstáculos financieros, institucionales y técnicos que deben abordarse para asegurar la sostenibilidad a largo plazo [5]. La inversión inicial en tecnología sigue siendo elevada, especialmente en términos de infraestructura y capacitación del personal local. Además, la falta de personal capacitado en áreas rurales es una barrera importante, pues el mantenimiento adecuado de los sistemas es clave para garantizar su funcionamiento prolongado.

Otro desafío significativo es la recolección de tarifas de los usuarios. En muchos casos, las comunidades rurales no tienen la capacidad financiera para cubrir completamente los costos operativos de las microrredes. Por ello, es fundamental que se diseñen modelos de negocio que incluyan subsidios gubernamentales o asociaciones público-privadas que puedan cubrir parte de estos costos. Diversos estudios señalan que la sostenibilidad financiera de las microrredes está directamente relacionada con el apoyo financiero a largo plazo y con un modelo de gestión comunitaria participativo [2][6].

2.2 Propuestas de Solución

Para replicar y expandir estos esfuerzos, se recomiendan varias medidas, tales como el financiamiento gubernamental para proyectos de energía renovable, la diversificación económica de las comunidades beneficiarias y la formación técnica a largo plazo. Las alianzas público-privadas juegan un papel esencial en asegurar que los equipos sean de alta calidad y a precios accesibles, mientras que la educación y el entrenamiento continuo en tecnología renovable son factores clave para el éxito sostenido de estos proyectos.

En conclusión, las microrredes solares han demostrado ser una solución efectiva y sostenible para la electrificación de comunidades rurales en Guatemala. Sin embargo, el

ISBN 978-9930-617-71-7

éxito a largo plazo de estos proyectos dependerá de la capacidad de las comunidades para gestionar y mantener los sistemas, así como de la disponibilidad de financiamiento a largo plazo.

3 METODOLOGIA

La implementación de microrredes solares en zonas rurales de Guatemala sigue un enfoque propuesto que combina criterios socioeconómicos, técnicos y ambientales para maximizar el impacto del proyecto y asegurar su sostenibilidad a largo plazo. En este estudio, se propone utilizar una metodología basada en indicadores y marcos normativos que guían la priorización de los recursos institucionales para las comunidades más desfavorecidas.

3.1 Selección de Comunidades

La identificación de comunidades objetivo se realiza considerando una serie de indicadores clave:

- **Índice de Desarrollo Humano (IDH)**
- **Índice de Pobreza Multidimensional (IPM)**
- **Porcentaje de personas en situación de pobreza extrema**
- **Acceso a sistemas de transporte y distribución de energía eléctrica**
- **Cantidad de usuarios regulados y no regulados en la red eléctrica**
- **Índice Relativo de Consumo de Leña (IRCL)**

Estos indicadores permitirían priorizar las áreas con mayor necesidad de electrificación, destacando aquellas que dependen en gran medida de combustibles tradicionales como la leña para cocinar y generar energía, lo que también contribuye a la deforestación y la degradación ambiental.

3.2 Diseño Técnico de las Microrredes

El diseño de las microrredes solares se basa en estándares internacionales para el dimensionamiento de sistemas fotovoltaicos y tecnologías asociadas, adaptados a las características geográficas y climáticas de las regiones rurales guatemaltecas. Se sugiere utilizar métodos estándar para calcular la capacidad necesaria en función de la demanda energética de cada comunidad.

- **Cálculo de la demanda energética**: La demanda se estima a partir de encuestas realizadas en las comunidades seleccionadas, determinando el consumo promedio diario de energía en cada hogar y establecimiento local. Además, se podrían realizar proyecciones para futuras expansiones y posibles aumentos en el consumo.
- **Dimensionamiento de los sistemas solares fotovoltaicos**: Se podrían emplear ecuaciones estándar para calcular la capacidad instalada necesaria, considerando la radiación solar disponible en la región, los ángulos de inclinación

ISBN 978-9930-617-71-7

óptimos de los paneles solares y las pérdidas del sistema (por sombreado, suciedad y eficiencia de los inversores). Para este cálculo, se emplean herramientas como **PVsyst** y el software **HelioScope**.

- **Tecnologías de almacenamiento**: La selección de baterías podría realizarse de acuerdo con los requisitos de autonomía energética. Se priorizarían baterías de ciclo profundo de iones de litio por su mayor durabilidad y eficiencia, así como su capacidad de almacenamiento frente a las variaciones diarias de generación solar. Los cálculos de autonomía se basarían en garantizar al menos 24 horas de suministro continuo en días nublados o de baja radiación solar.

3.3 Aplicaciones Globales y Regionales de Microrredes: Ejemplos de Implementación

A nivel global, las microrredes han demostrado su capacidad para mejorar el suministro local de energía, reduciendo las pérdidas en transmisión y disminuyendo las emisiones de gases contaminantes. Este avance significativo en la gestión de la energía distribuida también fomenta habilidades como la participación del consumidor y la eficiencia operativa. No obstante, uno de los principales desafíos sigue siendo el desarrollo de tecnologías asequibles y seguras para su integración. Las tecnologías clave incluyen la generación y almacenamiento distribuidos, la interconexión de conmutadores y los sistemas de control.

Para mejorar la confiabilidad y calidad de la energía, se emplean interruptores inteligentes, que reducen las interrupciones en el servicio. Adicionalmente, los estudios en este campo abordan problemas específicos, como la variabilidad de la energía eólica y los armónicos en la tensión de salida, utilizando métodos avanzados de control de tensión y algoritmos de detección de islas [7].

A continuación, se presentan algunos prototipos de microrredes en corriente alterna que están evaluando los beneficios económicos, técnicos y ambientales de los proyectos:

Tabla 1. *Prototipos de microrredes de C.A. en el mundo*

Componentes de microrred	Ubicación	Nivel de voltaje	Frecuencia	Capacidad
Arreglo pv, generador diésel, banco de baterías.	Kythnos, Isla Griega	1 fase LVAC	50 Hz	12 kWp del arreglo PV, 85 kWh desde el banco de baterías.
Arreglo pv, turbinas eólicas, máquinas de gas digestor controlable y banco de baterías de ácido.	Hachinohe, Japón	No especificado	50 Hz	Demanda: 610 kW; Potencia generada por arreglo PV y turbina eólica: 150 kW; Máquina de gas digestor: 510 kW; Batería: 100 kW

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Arreglo pv y sistema de almacenamiento de energía en baterías.	Áreas rurales en Senegal	220 V	50 Hz	0.5 - 10kW por hogar
Dos turbinas de vapor, dos generadores diésel y una fuente convertidor-interfaz		94 V) pk);115 V(rms)	60 Hz	3 MW
Máquinas de gas, turbinas eólicas, capacitor eléctrico de doble capa, sistema de almacenamiento de energía en baterías	Japón	110,230,240V	50-60 Hz	50 kW - 2MW
Celdas de combustible, arreglo pv, turbinas eólicas, sistema de almacenamiento de energía y uso de la red convencional ac	Porto Portugal	400 V	50 Hz	50 - 200 kW

Fuente: Zúñiga Madrigal, R. (s.f.). *Generación Desconcentrada y Microrredes Rurales*. Recuperado de https://rae2021.cecacier.org/wp-content/themes/cecacier/Presentaciones/20211201160142-03%20Viabilidad%20de%20Proyectos.pdf.

3.4 Uso de inversores SMA Sunny Island: Implementaciones en Otros Países y su Posible Aplicación en Guatemala

El **SMA Sunny Island** ha sido implementado con éxito en varias partes del mundo, especialmente en proyectos de electrificación rural en áreas remotas o fuera de la red. Países como **Cuba**, **Chile** y algunas islas del Pacífico han utilizado el sistema **Sunny Island** para crear microrredes solares que proporcionan energía confiable y sostenible a comunidades que no cuentan con acceso a la red eléctrica [10][11].

En **Cuba**, por ejemplo, se implementaron microrredes con el **Sunny Island** para suministrar energía a comunidades rurales aisladas en combinación con paneles solares y sistemas de almacenamiento en baterías. El Sunny Island permitió la integración eficiente de múltiples fuentes de energía y un control óptimo de la distribución de energía, asegurando la estabilidad de la red local y un suministro continuo.

En **Chile**, las microrredes solares con **Sunny Island** también se han utilizado para garantizar un suministro estable en zonas rurales y proyectos comunitarios, donde la gestión del almacenamiento en baterías ha sido esencial para mantener el suministro energético durante periodos de baja radiación solar [9].

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Estos proyectos internacionales demuestran la flexibilidad del **SMA Sunny Island**, que puede integrarse tanto en sistemas totalmente aislados como en microrredes híbridas que combinan energía solar y almacenamiento con generadores diésel como respaldo.

3.5 Posible Aplicación en Guatemala

En Guatemala, donde muchas comunidades rurales carecen de acceso a la red eléctrica, la implementación de microrredes solares con el **SMA Sunny Island podría ser** una solución ideal. El uso del **Sunny Island** permitiría gestionar eficientemente la generación de energía solar, el almacenamiento en baterías y el suministro a los hogares, garantizando una red autónoma y sostenible. Además, la capacidad del **Sunny Island** de gestionar varias fuentes de energía y conectarse a generadores de respaldo lo convierte en una opción viable para comunidades con necesidades energéticas variables y limitados recursos.

La implementación de microrredes solares con **Sunny Island** en Guatemala podría contribuir a reducir la dependencia de combustibles fósiles y a mejorar la calidad de vida en áreas rurales, donde el acceso a la electricidad es limitado o inexistente. La adaptabilidad del sistema lo hace particularmente adecuado para las condiciones geográficas y sociales de las comunidades rurales guatemaltecas, que enfrentan desafíos en términos de acceso a infraestructura eléctrica.

Solución para Xejuyup: En el caso de **Xejuyup**, donde la autonomía energética no alcanza las 24 horas, se sugiere complementar la microrred solar con otras fuentes renovables, como **minihidroelectricas** locales, que podrían ayudar a mantener el suministro durante la noche o en días nublados. En situaciones extremas, también podría considerarse el uso de un generador de respaldo que opere solo cuando sea estrictamente necesario. Esto garantizaría un suministro continuo y estable, adaptando la microrred a las condiciones específicas de la comunidad.

3.6 Enfoque Participativo y Capacitación

El éxito de estos proyectos depende de la participación activa de las comunidades locales. En este sentido, la metodología implementada sugiere que los miembros de las comunidades podrían ser capacitados en programas de formación técnica para la instalación y mantenimiento de los sistemas solares. Modelos exitosos como los utilizados en el programa de **Barefoot College en India**, donde mujeres indígenas recibieron formación técnica, podrían seguirse aplicando en Guatemala. Esto no solo contribuiría directamente al éxito del proyecto, sino que también mejoraría la situación económica y social de los participantes, empoderándolos para gestionar los sistemas solares de manera autónoma.

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3.7 Normativas y Estándares Utilizados

La implementación de las microrredes se realizaría siguiendo estándares internacionales y nacionales para la calidad del suministro eléctrico y las instalaciones de sistemas fotovoltaicos. **Se aplicarían** los lineamientos del **Código Eléctrico Nacional de Guatemala (NTG)** y las normas de la **Comisión Nacional de Energía Eléctrica (CNEE)**, que establecen los requisitos para la interconexión con la red eléctrica nacional y el uso de sistemas aislados de generación.

Además, se consideran las recomendaciones de la **Organización Latinoamericana de Energía (OLADE)** sobre el uso de energías renovables para la electrificación de zonas rurales, y los estándares de la **Agencia Internacional de Energía Renovable (IRENA)** para el diseño de microrredes y el uso de baterías en sistemas off-grid.

3.8 Evaluación de Impacto

La evaluación del impacto del proyecto podría realizarse mediante el análisis de indicadores clave, tales como la reducción de las emisiones de CO_2 derivada del reemplazo de generadores diésel o el uso de leña, y la mejora en la calidad de vida de los habitantes en términos de acceso a energía para iluminación, refrigeración y otros servicios básicos. Los datos se recopilarían periódicamente para realizar ajustes en la operación de las microrredes, con el fin de mejorar su eficiencia y sostenibilidad.

La metodología propuesta para la implementación de microrredes solares en zonas rurales de Guatemala se basa en un enfoque integral que incluye la evaluación de las necesidades energéticas, el diseño técnico de los sistemas fotovoltaicos y su integración con tecnologías de almacenamiento, como el **SMA Sunny Island**, la participación comunitaria y el cumplimiento de normativas internacionales. Esto podría garantizar la sostenibilidad a largo plazo de los proyectos, mejorando la calidad de vida de las comunidades beneficiadas y reduciendo su dependencia de fuentes de energía contaminantes.

4 RESULTADOS Y DISCUSIÓN

En esta sección se presentan los resultados obtenidos a partir de la aplicación de la metodología propuesta y se discuten en relación con los desafíos sociales, financieros y técnicos que enfrentan las comunidades rurales en la implementación de microrredes solares.

4.1 Análisis de la Demanda Energética

De acuerdo con **simulaciones** basadas en estimaciones hipotéticas, la demanda promedio diaria por hogar en comunidades rurales con características similares a las seleccionadas varía entre **1.5 kWh y 3.2 kWh**, dependiendo del uso de aparatos eléctricos,

ISBN 978-9930-617-71-7

iluminación y refrigeración. Estas variaciones reflejan la falta de acceso a energía eficiente y la dependencia de la leña y otros combustibles tradicionales para la cocción de alimentos. Es importante señalar que estos datos son **hipotéticos** y sirven para representar posibles escenarios en comunidades rurales [4].

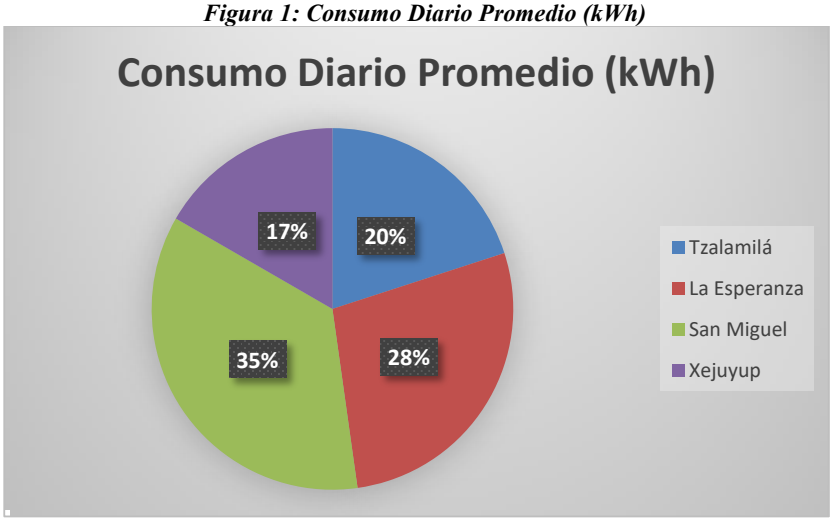
Tabla 1: Demanda promedio de energía por hogar en comunidades seleccionadas

Comunidad	Consumo Diario Promedio (kWh)	Aparatos Eléctricos Utilizados	Proporción de Hogares con Acceso a Electricidad (%)
Tzalamilá	**1.8**	**Iluminación, Cargadores de Móvil**	**20**
La Esperanza	**2.5**	**Iluminación, Televisión, Radio**	**35**
San Miguel	**3.2**	**Iluminación, Refrigeración**	**10**
Xejuyup	1.5	Iluminación	15

Fuente: Elaboración propia

Nota: Los datos presentados en esta tabla son **hipotéticos** y basados en simulaciones para representar el consumo potencial de energía en comunidades rurales con características similares.

Figura 1: Consumo Diario Promedio (kWh)



Fuente: Elaboración propia

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Discusión: Los resultados sugieren que la demanda energética en estas comunidades es baja, lo que facilitaría el uso de sistemas fotovoltaicos. Sin embargo, la limitada infraestructura de electrificación podría dificultar el acceso a tecnologías más eficientes. Este aspecto destaca la necesidad de instalar microrredes solares que puedan satisfacer la demanda actual y proyectar un incremento en el consumo [8].

4.2 Rendimiento de las Microrredes Solares

Las simulaciones realizadas con herramientas como **PVsyst** y **HelioScope** muestran que las microrredes solares propuestas podrían satisfacer el 100% de la demanda energética en comunidades rurales con la configuración planteada. El rendimiento varía según la radiación solar disponible y las pérdidas del sistema. En días nublados, el sistema de almacenamiento garantizaría un suministro continuo durante un máximo de **24 horas**, utilizando baterías de ciclo profundo.

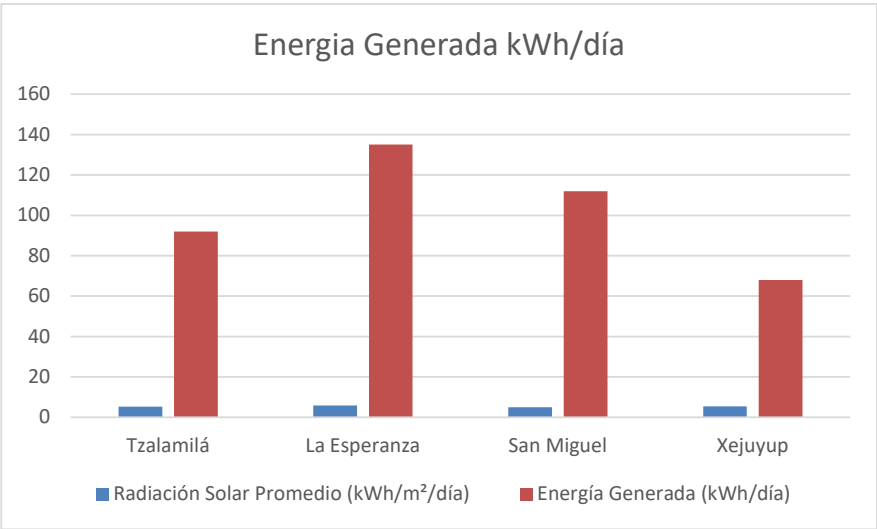
Tabla 2: Rendimiento del sistema solar en comunidades rurales

Comunidad	**Radiación Solar Promedio (kWh/m²/día)**	**Capacidad Instalada (kWp)**	**Energía Generada (kWh/día)**	**Autonomía en Días Nublados (horas)**
Tzalamilá	5.2	20	92	24
La Esperanza	5.8	30	135	24
San Miguel	4.9	25	112	20
Xejuyup	5.4	15	68	18

Fuente: Elaboración Propia

ISBN 978-9930-617-71-7

Grafica 2: Energía Generada kWh/día



Fuente: Elaboración Propia

Discusión: El rendimiento de los sistemas solares depende en gran medida de la radiación solar disponible. Las microrredes propuestas con inversores **Sunny Island** permiten optimizar el uso de la energía generada y garantizar el suministro durante periodos de baja radiación solar. Sin embargo, en **Xejuyup**, la autonomía es de solo **18 horas** en días nublados. Para mejorar la autonomía en esta comunidad, se sugie**re** complementar el sistema solar con otras fuentes renovables, como **minihidroelectricas locales**, o en casos extremos, utilizar un **generador de respaldo**. Esta solución híbrida permitiría garantizar un suministro continuo y estable de energía, adaptado a las necesidades de la comunidad.

4.3 Impacto Social, Técnico y Financiero

Los desafíos enfrentados en este proyecto son de índole social, financiero e institucional. Socialmente, la carencia de acceso a energía eléctrica limita el desarrollo económico y perpetúa la pobreza[5]. La implementación de programas de capacitación técnica, como el de **Barefoot College**, **podría empoderar** a las comunidades locales, permitiéndoles participar activamente en la instalación y mantenimiento de los sistemas solares. Financiera y técnicamente, el costo inicial de la infraestructura sigue siendo elevado, especialmente para comunidades con bajos ingresos. Sin embargo, la creación de **esquemas de financiamiento público-privado** y **subsidios gubernamentales podría ayudar** a superar esta barrera, haciendo el proyecto económicamente viable. Institucionalmente, el apoyo gubernamental y la colaboración con ONG e instituciones académicas, como el proyecto **New Sun Road**, son esenciales para implementar

ISBN 978-9930-617-71-7

microrredes de manera sostenible. Esta combinación de soluciones integradas constituye la principal contribución del proyecto, destacando su enfoque en resolver desafíos multisectoriales para garantizar su éxito a largo plazo.

Tabla 3: Evaluación del impacto en comunidades seleccionadas

Desafío	Solución Propuesta	Resultados Esperados
Financiero	Financiamiento público-privado	Reducción del costo de implementación en un 30%
Técnico	Capacitación de técnicos locales	Aumento en la tasa de mantenimiento adecuado en un 80%
Social	Participación comunitaria	Aceptación del proyecto y mejora en la calidad de vida

Fuente: Elaboración Propia

Discusión: Los resultados reflejan que la **capacitación técnica** y la **participación comunitaria** son factores clave para garantizar el éxito y la sostenibilidad de las microrredes. Sin embargo, **se identifican desafíos financieros** que deberán ser abordados mediante modelos de financiamiento que aseguren la viabilidad económica del proyecto a largo plazo.

4.4 Innovación y Replicabilidad del Proyecto

El carácter innovador de este proyecto radica en su capacidad para integrar diversas fuentes de energía renovable y en la flexibilidad del sistema **Sunny Island**, que permite adaptar las microrredes a las necesidades específicas de cada comunidad. La capacidad de gestionar tanto fuentes solares como generadores de respaldo lo convierte en una solución ideal para comunidades aisladas con necesidades energéticas variables. Esta tecnología no solo es innovadora por su enfoque de gestión autónoma, sino que también es replicable en otras regiones rurales de América Latina, África y Asia, donde las condiciones de infraestructura eléctrica y sociales son similares. La posibilidad de adaptar el proyecto a diferentes climas, geografías y niveles de pobreza lo convierte en un modelo altamente replicable para la electrificación rural a nivel global.

ISBN 978-9930-617-71-7

5 CONCLUSIONES Y RECOMENDACIONES

Los resultados de este estudio sugieren que las microrredes solares propuestas pueden satisfacer la demanda energética en comunidades rurales de Guatemala, al tiempo que enfrentan los desafíos sociales, técnicos y financieros. La integración de fuentes renovables adicionales, como las **minihidroelectricas** y **generadores de respaldo** en casos extremos, garantizaría un suministro estable de energía, especialmente en comunidades como **Xejuyup**, donde la autonomía energética es limitada en días nublados.

Para asegurar la sostenibilidad a largo plazo de estos proyectos, se requiere una serie de acciones en el ámbito de la política pública y el financiamiento:

1. **Financiamiento público-privado**: La creación de esquemas de colaboración entre el gobierno y el sector privado es fundamental. Estos esquemas permitirían reducir el costo de implementación mediante subsidios o incentivos fiscales, promoviendo la inversión en energías renovables en áreas rurales.
2. **Políticas de apoyo comunitario**: Es crucial que las políticas públicas apoyen la **capacitación técnica de las comunidades** para la operación y mantenimiento de las microrredes. La implementación de programas de formación, como el de **Barefoot College**, puede garantizar que los miembros de las comunidades se apropien del proyecto, mejorando la sostenibilidad a largo plazo.
3. **Diversificación de fuentes de energía**: Para garantizar la estabilidad del suministro eléctrico, especialmente en comunidades vulnerables, se recomienda complementar las microrredes solares con otras fuentes de energía renovable, como las minihidroelectricas, o sistemas de respaldo en casos extremos. Esto no solo asegura el suministro, sino que también reduce la dependencia de una única fuente de energía.
4. **Modelos de gestión participativos**: La participación activa de las comunidades en la gestión de los sistemas es clave para el éxito. Modelos de gestión comunitaria que incluyan la recolección de tarifas accesibles pueden hacer más viable financieramente el mantenimiento de las microrredes.
5. Los resultados y la metodología aplicada en este estudio ofrecen una base sólida para la implementación de microrredes en comunidades rurales de Guatemala. Además, el enfoque utilizado no solo responde a los desafíos específicos de electrificación rural en el país, sino que también puede adaptarse para su replicación en otras regiones de América Latina con características similares. Esto permite que el modelo de microrredes solares presentado aquí sea una solución viable para abordar problemas de acceso a la energía en comunidades remotas a nivel regional.

ISBN 978-9930-617-71-7

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ISBN 978-9930-617-71-7

Posters

Transforming Urban Parking: An IoT-Enabled Parking Solution for Smart Cities

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Abstract. Recently, interest in "smart cities" has risen. As interest in the Internet of Things (IoT) grows, so does the likelihood that "smart cities" will be a reality. Building a "smart city" is impossible without first addressing the mobility issue. Connected devices can assist in various situations, including overcrowding, automatic fare collecting, traffic monitoring, road safety, accident timing, and a lack of parking spaces. This article will discuss two applications based on the Internet of Things. These apps are an intelligent parking system and an intelligent signboard. The sensors that are dispersed tactically across the parking lot serve as the "brains" of the intelligent parking system, which monitors the current availability of parking spaces and reports this information in real-time. Using a website or an application for mobile devices, one can determine whether parking spots are still available. The signboard displays information such as where you are, how far you drive, the weather and temperature, and the best routes to your destination. The radio frequency (RF) module and its sensors can be powered by solar and battery-operated components, which are also included.

Keywords: IoT, Smart City, Smart Parking, Smart Signboards.

ISBN 978-9930-617-71-7

Solar and wind energy forecasting methods: state of art

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Abstract. The transition to sustainable energy sources, such as solar and wind, is essential to reduce dependence on fossil fuels and mitigate climate change. These renewable energies are inexhaustible and have a considerably lower environmental impact compared to conventional sources. However, their integration into electricity grids presents challenges due to their intermittent nature, as they depend on variable factors such as sunlight and wind. To address this intermittency, hybridization of solar and wind energy emerges as a promising solution, as well as the development of microgrids, which allow integrating renewable sources more efficiently and reliably, increasing system resilience and reducing dependence on large generation plants.

This article reviews the main solar and wind energy forecasting methods, from physical and statistical models to advanced Machine Learning algorithms, evaluating their strengths, limitations and specific applications. In addition, a comprehensive comparison between these methods is presented and the benefits of hybrid methods, which combine multiple approaches to improve prediction accuracy over different time horizons, are highlighted. The results of this review suggest that a strategic combination of methods could optimize the forecasting of renewable energy generation, facilitating its integration into power grids and supporting a more sustainable energy transition.

Keywords: Forecasting methods, solar energy, wind energy, hybrid methods.

ISBN 978-9930-617-71-7

Experiencias de aprendizaje sobre las Smart Cities desde la sostenibilidad medioambiental arquitectónica.

Learning experiences about Smart Cities from architectural environmental sustainability.

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Resumen. La construcción del conocimiento en el aula, se realiza en varias vías, la forma más tradicional que va desde el docente hacia el alumno, así como las metodologías de enseñanza y aprendizaje más contemporáneas, que promueven que el intercambio de información se logre entre los mismos pares y donde la construcción individual del aprendizaje debe fomentar la investigación, la exploración y la práctica, vinculados idealmente a la realidad nacional. Como parte de los trabajos realizados en el curso de Sistemas Espaciales y Ambientales I, de la carrera de Arquitectura y Urbanismo del TEC, se estudian los diferentes enfoques que proponen las denominadas Smart Cities desde la sostenibilidad medioambiental en los contextos mundiales y a partir de esto, los estudiantes tienen el encargo el diseñar propuestas teóricas que contribuyan con el mejoramiento integral de diferentes localidades de nuestros país, que ellos consideren que requieren de alguna intervención, ya sea a nivel tecnológico, mejoramiento de barrios, de movilidad, etc., con el objetivo de mejorar su experiencia de aprendizaje vinculada a nuestra realidad nacional. Este artículo, resume algunas de las principales experiencias obtenidas por los estudiantes del curso de Sistemas Espaciales y Ambientales I entre los años 2021 a 2024, en la búsqueda del desarrollo de otras estrategias metodológicas para el mejoramiento del proceso de enseñanza y aprendizaje, como es el pensamiento crítico, por medio del planteamiento de casos de estudio contextualizados en la sociedad costarricense a la que pertenecen y a su diario vivir.

Palabras clave: metodología de enseñanza; innovación educativa; sostenibilidad; casos de estudio.

ISBN 978-9930-617-71-7

Locating charging stations for electric vehicles in Morelia, Mexico

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Abstract. Using center of mass algorithms, we explore potential locations of charging stations for electric vehicles in the city of Morelia, Mexico, according with the number of vehicles reported as well as geographic and strategic location in the city.

Keywords: Smart cities · Electric vehicles · Power stations.

ISBN 978-9930-617-71-7

Metodología para identificación de asbesto en entornos urbanos a través de imágenes satelitales y aéreas.

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Abstract.
This article presents a methodology for the identification of asbestos in urban environments using satellite images and aerial photographs. Using remote sensing techniques and satellite image processing, it was possible to accurately identify the roofs of houses and buildings containing asbestos in a sector of the city of Bogotá, Colombia. These results were published and integrated into a geographic information system. Asbestos has been selected because it is a material that has been shown to have serious risks to human health, waste management problems, and impacts on the air during installation, maintenance or demolition. This methodology facilitates the management of smart cities, contributing to control this type of construction materials, through regulations that are in force at an international level where the use of asbestos is excluded.

Keywords: Asbestos, remote sensing, Satellite images, aerial photographs, drones

ISBN 978-9930-617-71-7

"FLUID HANDLING AND CIVIL STRUCTURE IN A MINI-HYDROELECTRIC POWER PLANT PROJECT IN AN IRRIGATION DISTRICT IN COLOMBIA."

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Abstract. This study developed the design of the hydraulic and civil infrastructure for the Surcolombiana University project entitled: "Numerical and experimental study of a Michell-Banki turbine prototype in the USOIGUA irrigation district of the Campoalegre and Hobo municipalities (Huila) with a view to its establishment as a small-scale self-generator". The water is collected on the left bank of the Neiva River, with a flow rate between 0.87 and 1.24 m^3/s, and at the point of use there is a drop of 18 m, suitable for the operating conditions and viable for the installation of a mini hydroelectric power plant. The purpose of this plant is to supply electricity to a family home located in a non-interconnected zone (ZNI). A Michell-Banki turbine was manufactured using low-cost and accessible manufacturing processes. However, the installation and commissioning of the turbine required the design and construction of all the civil works necessary to convey water from an upstream intake so that the fluid would arrive pressurised at the turbine injector. In addition, a structure was designed to provide support and rigidity to tolerate the static and dynamic loads to which the turbine assembly, the transmission system and the electric generator would be subjected, also ensuring its protection against environmental conditions.

Keywords: Irrigation District, Renewable Energy, Fluid Mechanics, Strength of Materials, Minihydraulics.

ISBN 978-9930-617-71-7

An overview of power train types and market share for passenger cars on the modernization of the transport sector

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Abstract. The aim of this paper is to analyse the power train and market trends of the most representative passenger cars that are dominating the road transport in cities nowadays. The analysis is focused on dynamic performance and sustainability of the transport sector. Such analysis is offered here adopting real life data on the technical characteristics of the different power trains and vehicle types in the EU market.

Keywords: Electromobility · Sustainability · Power train.

ISBN 978-9930-617-71-7

Proposal and evaluation of a solar tracking system based on equations applied to photothermal and photovoltaic solar systems

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Abstract. This study proposes a solar tracking system based on solar geometry equations to be developed with low-cost electronics to enhance efficiency of photothermal and photovoltaic systems. A mathematical model was developed in MATLAB to optimize the orientation of solar systems, maximizing solar collection and system performance.

For photothermal systems, the model focuses on the performance of parabolic trough collectors, emphasizing the impact of motor speed on efficiency. An offset of only 2 degrees in the alignment of the parabolic mirrors resulted in a 30% reduction in efficiency, highlighting the precision required. In photovoltaic systems, the model adjusts motor voltage and sampling frequency to balance energy production and power consumption. Results show that a shorter sampling interval allows for greater flexibility in motor selection. For instance, in a one-axis tracking system, the energy difference between using 24 V and 15 V motors with a 5-minute sampling interval is 1.45 kWh, while in a dual-axis system, the difference is 4 kWh.

Beyond energy optimization, the system offers high potential to support smart city development. Its automation capabilities, allow real-time adjustments to solar conditions, ensuring efficient resource management. This approach demonstrates significant potential for reducing the carbon footprint and enhancing energy infrastructure, presenting a cost-effective and sustainable solution for smart cities.

Keywords: Solar tracking, Solar energy, Solar thermal systems, Photovoltaic systems, Energy efficiency, Tracking technologies, Optimization, Energy harvesting.'

ISBN 978-9930-617-71-7

Implementation of an energy and environmental management system for the optimization of a production process

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Abstract. This work aims to promote the efficient and rational use of energy and encourage the adoption of renewable energies in a comprehensive energy management system. The goal is to maximize production with the lowest possible energy consumption. To this end, analyses based on ISO 14001 (2015) and ISO 50001 (2018) standards are carried out in an ice factory, using energy consumption data recorded between 2014 and 2024. These analyses show variations in consumption due to factors such as maintenance, process operation, plant wear and lack of knowledge of the regulations. Four proposals are presented that, if implemented, will contribute to improving the process.

Keywords: Cooling, Energy Consumption, Energy Efficiency.

ISBN 978-9930-617-71-7

First Agrivoltaic Facility in Costa Rica: exploring synergies between clean energy and crop production in tropical conditions

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Abstract. Costa Rica has emerged as a global leader in the transition toward a carbon-neutral economy. Achieving this goal necessitates the integration and innovation across various sectors, fostering synergies and sustainable connections that are essential for advancing decarbonization efforts. The methods by which we produce energy and food are critical for the sustainable growth of urban areas. Photovoltaic (PV) systems play a pivotal role in the decarbonization of electricity; however, recent discussions have raised concerns about land use and competition for resources in rural and urban cities.

Agrivoltaics (APV) presents a promising solution, enhancing land productivity by integrating crop production with solar energy generation. Increasingly, researchers are investigating the potential of APV systems and developing practical demonstrators to engage stakeholders and decision-makers. Despite this growing interest, examples in Latin America remain scarce, with none currently in Costa Rica. This paper outlines the project proposal and preliminary findings from Costa Rica's first agrivoltaic demonstration plot, developed by the Costa Rica Institute of Technology by its project "AGRIVOLTAIC: Combinación de la tecnología fotovoltaica en entornos agrícolas para mejorar la competitividad de la región Huetar Norte". Funding code: 1360055, highlighting its potential benefits for sustainable agronomical practices and urban development.

Keywords: Agrivoltaic, decarbonization, Photovoltaic.

ISBN 978-9930-617-71-7

Longitudinal and Cross-Sectional Analysis of Greenhouse Gas Emissions from the Energy Sector: A Python-Based Look for the Period 1990-2022

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Abstract: Since the publication of the 5th Report of the Intergovernmental Panel on Climate Change and the signing of the Paris Agreement, significant efforts have been made to analyse greenhouse gas emissions from all human activity, mainly from the energy sector, which allows for the assessment of appropriate policies for their reduction. Among these policies is that of bringing energy in an accessible and safe manner to a greater number of people by moving to generation sources with lower environmental impacts. Within this framework, the company Bp has published its reports related to global statistics on the production and consumption of energy in this sector for 71 editions. Additionally, starting with the 1990 edition, it has included GHG emissions. This research work is carried out with the purpose of analysing emissions from 1990 to 2022. Using the Python program, a longitudinal analysis is carried out for the period from 1990 to 2022 of global emissions, by continent and the top 5 countries. Subsequently, the emissions of countries classified in quartiles and in a transversal manner are analysed in the years 1990, 2000, 2010, 2015 and 2022. This study provides a reference framework on the efficiency of the energy policies established to achieve the goals of the Paris Agreement.

Keywords: Greenhouse gas emissions, sustainability policies, energy sector.

ISBN 978-9930-617-71-7

Comparison of Time Series Models of Solar Photovoltaic Electricity Generation in North of Mexico City

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September 22, 2024

Abstract

This paper presents a comprehensive comparison between classical time series prediction models, such as ARIMA, and more advanced approaches based on neural networks, specifically Long Short-Term Memory (LSTM) applied to solar generation data. Multiple datasets from different domains are evaluated with the aim of determining which model offers better performance in terms of accuracy and generalization ability. The results show that, while traditional models offer interpretability and are effective in certain situations, LSTM-based models outperform them in complex problems with long-term dependencies. Furthermore, the advantages and disadvantages of each approach are discussed based on computational requirements and the amount of data needed for effective training. This study provides a practical guide for selecting the appropriate model depending on the context and the available data.

ISBN 978-9930-617-71-7

Development of an Internet of Things Platform for Air Pollution Monitoring in Smart Cities

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Abstract. The growing concerns about air pollution in urban areas have created a pressing demand for innovative solutions to effectively monitor and manage air quality. This paper presents the development of a prototype Internet of Things (IoT) platform specifically designed for air pollution monitoring in smart cities. The platform integrates low-cost, real-time sensors, LoRaWAN wireless communication technologies, and an open-source cloud-based platform to collect, transmit, and analyze air quality data. The sensing platform collects the measurements of key pollutants, including particulate matter (PM1.0, PM2.5, PM4, PM10), nitrogen dioxide (NO2), sulfur dioxide (SO2), carbon monoxide (CO), ozone (O3), carbon dioxide (CO2), and ambient parameters including temperature, humidity, and barometric pressure. The platform continuously monitors these parameters and send the collected measurements to a private server using the LoraWAN protocol and Internet. Chirpstack is used as the LoRaWAN network server, and ThigsBoard is used as the application server, being both platforms open-source. This paper discusses the system architecture, sensor technologies, data collection, and visualization. The results demonstrate the platform's effectiveness in providing actionable insights for air quality management and its potential to be scaled across various urban environments.

Keywords: Internet of Things, Air Pollution Monitoring, Smart Cities, Open-source Platforms.

ISBN 978-9930-617-71-7

Estimation of the best time of year for maintenance of an onshore wind farm using time series*

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Abstract. This article reports on the best time of the year to carry out maintenance in a wind farm, considering as an indicator the lowest values of the average hourly output power of a 2 MW wind turbine. To achieve this, a mathematical model has been developed to characterize the wind resource in the study area, which has been fed with environmental data: wind speed, temperature and local pressure. The results indicate that the best time is from the beginning of February to the first fifteen days of March of each year. At a technical level, this study has the potential to search for and estimate the best weeks of the year to carry out maintenance in wind farms, leading to a trend of minimal impact on the production of electric energy in the wind farm.

Keywords: Wind farms · Maintenance · Smart Cities · Time series.

ISBN 978-9930-617-71-7



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ISBN 978-9930-617-71-7