

Geographic information systems, practical experiences in higher education

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ABSTRACT

Geographic information systems (GIS) are technological tools for capturing, storing, analyzing, and visualizing geospatial data. This study presents the development and educational implementation of the Sistema de Información Geográfica para el desarrollo Sostenible (SIGDS) or geographic information system for sustainable development, an open-source geoportal integrating renewable energy assessment, smart-grid monitoring, and disaster-risk management at the Technical University of Manabí, Ecuador. A mixed-methods approach was adopted, combining GIS implementation, spatial database development, root mean square error (RMSE)-based validation, and educational evaluation through a structured survey administered to 77 engineering students. Survey reliability was confirmed using Cronbach's alpha ($\alpha=0.84$). GIS validation revealed positional and thematic discrepancies of less than 5%. Results indicate that 85% of users reported improved interdisciplinary understanding, while spatial problem-solving performance increased by approximately 20% compared with conventional instruction. Survey scores revealed strong perceptions of employability enhancement (4.62/5), interdisciplinarity (4.35/5), and acceptable accessibility (3.88/5). The proposed geoportal contributes to higher education by providing a replicable framework for integrating renewable energy planning, disaster resilience, and geospatial analysis into engineering curricula. The platform also supports real-time monitoring and decision-making processes for sustainable territorial development.

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1. INTRODUCTION

Geographic information systems (GIS) are now essential for spatial analysis and interdisciplinary research in higher education, enabling advanced technical skills and sustainable decision-making [1]–[3]. Traditional educational and research institutions usually address energy, environmental, and risk-related fields separately [4], [5].

A critical research gap remains in the literature: previous studies primarily focus on descriptive geospatial mapping and rarely address the integration of real-time smart grid monitoring, renewable energy planning, and natural disaster resilience within a single, open-source educational geoportal, particularly in resource-constrained contexts like Latin America [6].

Although GIS-based educational platforms support geospatial visualization and environmental studies, few integrate renewable energy planning, real-time smart-grid monitoring, disaster-risk assessment, and educational competency development within a single open-source geoportal. This study addresses that gap through an integrated GIS framework for engineering education, renewable-energy planning, and territorial resilience in Latin America, Table 1.

Table 1. Comparison with previous GIS educational studies

Study	GIS education	Renewable energy	Risk analysis	Real-time monitoring	Open source	Educational assessment
[7]	Yes	No	No	No	Partial	Yes
[8]	Yes	No	No	No	No	Yes
[9]	Yes	No	No	No	No	Yes
Sistema de Información Geográfica para el desarrollo Sostenible (SIGDS) or geographic information system for sustainable development (this study)	Yes	Yes	Yes	Yes	Yes	Yes

The main contributions of this study are as follows: in the innovation axis, the implementation of a geoportal for the analysis of clean energy sources, which combines GIS with protocols for monitoring smart networks and energy planning models [10], [11]. Moreover, at the regional level, it serves as a methodological framework for interdisciplinary research and teaching, adjusted to Latin American demands [12].

This is shown in research conducted by the University of Las Tunas and the Center for Research and Electroenergetic Tests of Cuba. In this work, GIS was used for territorial planning in energy development, aiming to achieve adequate spatial planning and the use of endogenous energy resources in territories [13]. In Ecuador, the University of Chimborazo uses GIS in several social science fields, including archaeology and sociology. It is also applied to specific topics such as economics and criminology [14].

At the Technical University of Manabí, an Energy Geoportal provides information on renewable energy potential, hydrological resources, environmental variables, and risk indicators. The platform supports academic and research projects and is available at <https://geoportal.utm.edu.ec/>. The geoportal has supported doctoral and master's research on renewable energy planning, distributed generation, and disaster resilience, demonstrating its value as a multidisciplinary decision-support tool [15]–[17].

GIS promotes technical skill development, spatial reasoning, and multidisciplinary learning while supporting renewable energy assessment and territorial analysis [7], [18]–[21]. Through smart-grid monitoring and geospatial data integration, students acquire competencies that improve employability and decision-making capabilities. Additionally, the geoportal provides a low-cost alternative for universities in developing countries by centralizing open data and eliminating software licensing barriers [22].

The main objectives of this study are: i) to design and deploy a specialized open-source academic geoportal; ii) to implement a structured instructional workflow that links clean energy planning with disaster resilience; and iii) to quantitatively and qualitatively validate the system's impact on spatial reasoning and employability among engineering students. By combining smart grid monitoring with geospatial data management, students develop technical skills bridging academic theory and operational utility demands.

2. METHOD

This study utilizes a mixed-methods approach, combining technical geospatial implementation with a robust empirical assessment of educational outcomes. A spatial data infrastructure was developed using GeoServer (WMS/WFS services), PostgreSQL/PostGIS for spatial storage, and OpenLayers/Leaflet for visualization. Ground-station and remote-sensing datasets were integrated to ensure platform replicability and interoperability.

The survey involved 77 engineering students with prior experience using SIGDS. Participation was voluntary and anonymous, following institutional ethical guidelines. Responses were collected using a five-point Likert scale, and reliability analysis produced a Cronbach's alpha ($\alpha=0.84$), indicating high internal consistency.

The survey had three dimensions. Dimension A measured technical skills and employability to assess skill strengthening for the labor market. Dimension B addressed interdisciplinarity and resilience to evaluate the link between energy and disaster risk. Dimension C focused on usability and accessibility, documenting resource constraints and ease of use. For statistical analysis, we used descriptive and frequency analyses. This helped identify gaps in the learning curve and the instrument's usability.

The research combined a literature review with a mixed-methods case study to evaluate the educational and technical impacts of GIS applications in energy, environmental, and disaster-risk contexts. Data preprocessing involved standardizing input from ground-station sensors and remote-sensing APIs to EPSG:32717 (WGS 84/UTM zone 17S). The geospatial data were classified into four essential axes, Table 2, integrated via ISO 19115 metadata standards. For thematic and positional accuracy, cross-verification using the root mean square error (RMSE) was conducted [23], ensuring that discrepancies between GIS-calculated potentials and field control points did not exceed 5%.

We validated the produced cartographic products through cross-verification. We compared the energy potential layers calculated by GIS with field data collected at control points. For thematic and positional accuracy, we used the RMSE [23], ensuring that discrepancies did not exceed 5% in territorial suitability models. Building on these validation steps, the process moved to developing the GIS.

To develop the GIS, a methodology comprising six interrelated phases was developed to analyze renewable energy sources, in line with their use for sustainable diversification of the territory's energy matrix. These phases included: i) data collection, ii) data preprocessing, iii) criteria selection, iv) GIS modeling, v) validation, and vi) final analysis and mapping. Figure 1 shows the phases of GIS implementation at the Technical University of Manabí.

The GIS workflow supports the analysis of solar, wind, hydrological, biomass, and topographic variables to identify suitable areas for renewable energy deployment. Inputs include infrastructure location, land use, climatological variables, energy demand, and generation data obtained from sensors, smart meters, satellites, drones, and cartographic databases. Integrated spatial analysis facilitates optimal siting, grid integration studies, environmental assessment, and reduction of transmission losses while supporting sustainable energy planning [24], [25].

SIGDS supports geospatial visualization, statistical analysis, and decision-making in energy, environmental, economic, and territorial applications [9], [26]–[32]. Despite its benefits, successful implementation requires adequate infrastructure, faculty training, and curricular integration [8], [33].

Table 2. Essential axes and their integration with ISO 19115 metadata

No	Data category	Information source	Resolution/scale	Key parameters
1	Solar/photovoltaic	Global Solar Atlas/Local stations	1 km	Global horizontal irradiance (GHI), DNI, and temperature
2	Wind	Global Wind Atlas/Anemometric sensors	250 m	Wind speed at 10 m and 50 m
3	Hydrological	National Inventory of Water Resources	1:50,000	Average flows and basin levels
4	Danger maps	Risk Management Entities/GIS models	Variable	Flood and seismic susceptibility

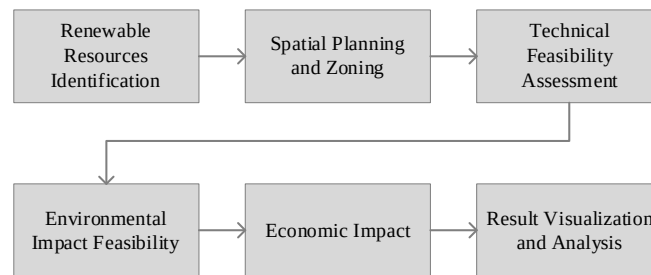


Figure 1. Phases for the implementation of the GIS at the Technical University of Manabí

3. RESULTS

SIGDS supports projects related to renewable energy assessment, environmental management, and disaster-risk analysis [34]. The system also strengthens competencies demanded by the labor market, including engineering, planning, natural resource management, and scientific research [35]–[40]. Table 3 summarizes its interdisciplinary applications. SIGDS is an online geoportal that supports projects related to renewable energy, environmental management, and risk assessment. Authorized users can query solar, wind, and hydropower resources through the platform interface shown in Figure 2.

Access to the geoportal requires authorization. People who work at the Technical University of Manabí can enter using their academic management system password; others who wish to join must do so as a guest or request authorization. Access to the SIGDS allows queries on the potential of solar, wind, and hydroelectric renewable sources.

Table 3. System applications and selection criteria

No	Discipline	Specific application	Study site	Justification
1	Electrical engineering	Monitoring of smart grids	Central University Campus	Critical node for consumption and distributed generation.
2	Renewable energies	Mapping of solar/wind potential	Rural Community	High radiation (>5 kWh/m ² day) and lack of access to stable network.
3	Risk management	Flood modeling	River Basin	History of overflows and recurrent impact on public infrastructure.
4	Education/GIS	Spatial literacy	Students	Need to strengthen technical employability in the region.

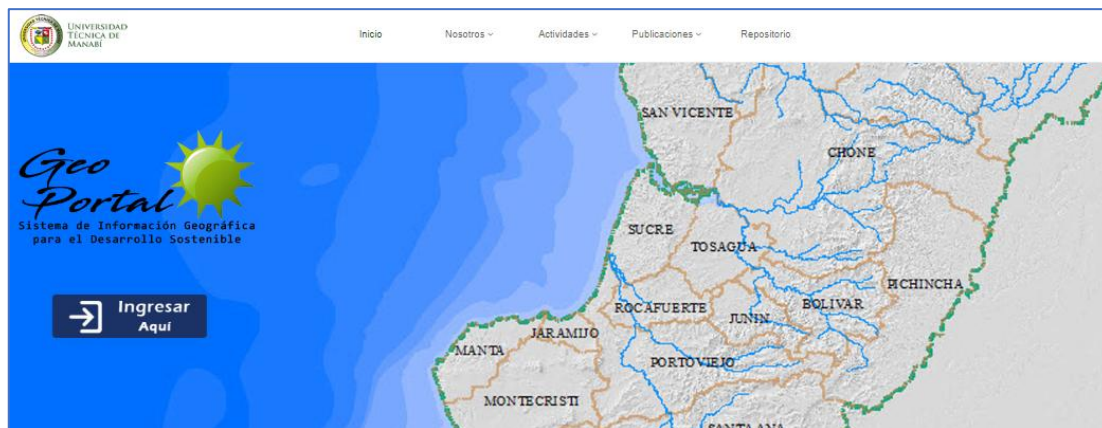


Figure 2. SIGDS cover page

3.1. Geoportal interoperability in energy data management

Figure 3 shows photovoltaic and wind suitability maps in the province of Manabí. On the color scale, it can be observed a strong correlation between areas of higher radiation and wind speed across the territory, which can maximize the viability of distributed energy investments and facilitate their interconnection with the traditional centralized energy system.

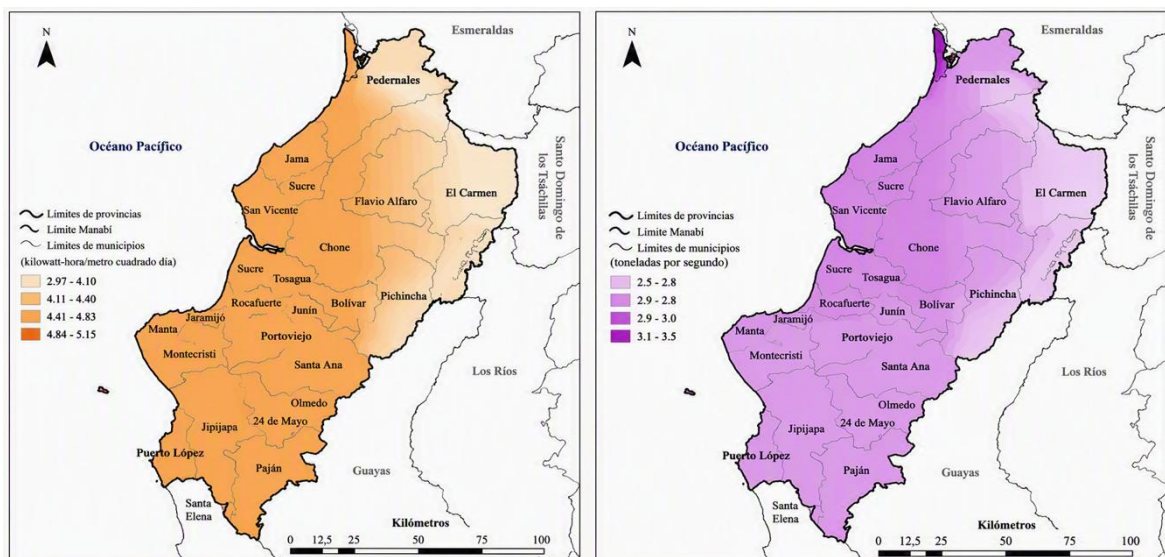


Figure 3. Correlation of areas with the greatest renewable potential in the territory [11], [39] C\$

The SIGDS enables timely spatial queries over the geospatial information stored in the system. For example, we can refer to solar potential, which at any selected point provides information on annual averages in kWh/m²/day, as shown in Figure 4.

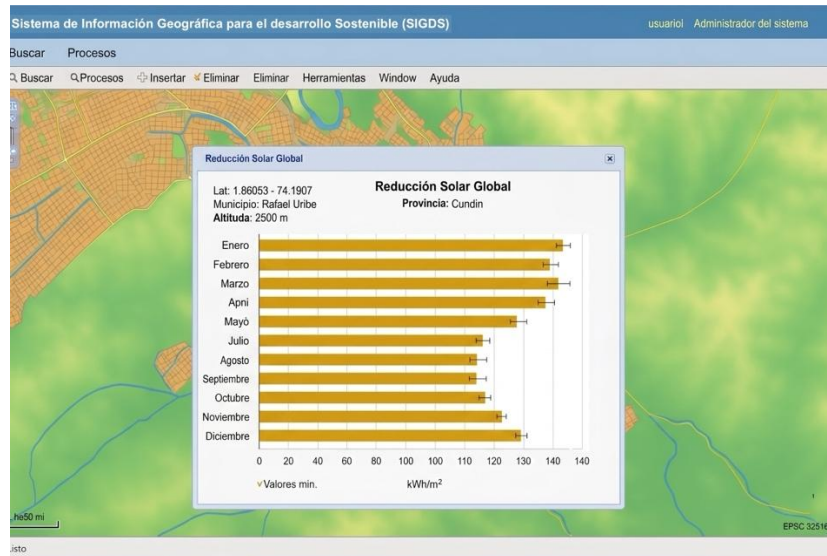


Figure 4. Solar potential point query

In the geoportal, hydropower potential information can be retrieved at any selected point in the province of Manabí. This tool also allows users to visualize the environment around the measured point. By doing so, they can identify elements that may affect the introduction of any type of technology, such as roads, power lines, rivers, towns, slopes, and soil types. Figure 5 shows an example of a specific query of the hydraulic potential in the territory.

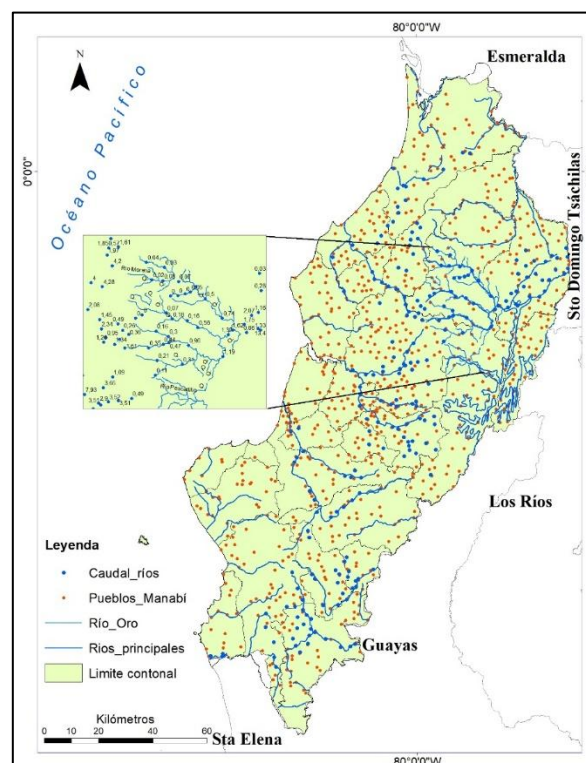


Figure 5. Hydraulic potential

The geoportal allows hydraulic potential assessment at any location in Manabí. Users can visualize surrounding infrastructure, terrain characteristics, settlements, rivers, and electrical networks to support

technology selection and socio-environmental analysis. The system also provides flow, demand, and community data that facilitate sustainable energy planning and resource utilization. Table 4 illustrates hydraulic potential data for the De Oro River.

Table 4. Statistical results of the hydraulic potential in the De Oro River

Location	Electrical service quality	Power demand (kW)	Speed (m/s)	Area (m ²)	Flow rate (m ³ /sg)	Distance (m)	Number of houses	Beneficiaries
Pacho	Good	1456	0.24	1.83	0.44	200	13	91
Bajos de la Viuda	Fair	630	0.21	1.71	0.35	180	7	27
Facundo	Good	1430	0.11	1.51	0.16	100	11	60
Aguas Colorada	Fair	1600	0.12	1.51	0.18	150	16	120
La Letra	Fair	600	0.51	2.65	1.35	100	6	43
Quiñones	Good	7200	0.06	1.95	0.12	200	60	300
La Dicha	Fair	2000	0.23	0.13	0.03	200	20	60
Piche	Fair	2500	0.31	0.14	0.04	200	25	110

The hydraulic assessment reveals considerable spatial variability among communities. “La Letra” exhibits the highest flow rate (1.35 m³/s), suggesting greater feasibility for micro-hydropower applications despite relatively low electricity demand. Conversely, Quiñones presents the largest energy demand (7200 kW) but lower hydraulic potential, indicating the need for hybrid renewable systems. These results demonstrate how GIS-based decision-support tools facilitate matching local energy demand with available renewable resources while supporting sustainable rural electrification strategies.

The employability score (4.62/5) suggests that students perceive GIS competencies as highly relevant for professional practice, particularly in energy planning and territorial management. The interdisciplinarity score (4.35/5) confirms the effectiveness of integrating engineering, environmental sciences, and disaster-risk management within a common geospatial framework. Accessibility obtained the lowest score (3.88/5), primarily due to variability in internet connectivity and hardware availability among users. These findings indicate that while the educational benefits are substantial, infrastructure limitations remain a challenge for broader implementation.

The Geoportal (<https://geoportal.utm.edu.ec/>) shows tables related to the eight rivers studied in the province of Manabí. It also shows different data on communities, the quality of electricity service, energy demand, the number of houses, and beneficiaries. All this information enables teachers, researchers, and students to undertake projects that address existing energy, environmental, and social problems.

3.2. Effectiveness of geographic information systems in flood risk mitigation

Natural hazards in Manabí province include seismic activity, landslides, and floods. Figure 6 shows the territorial multidimensional hazard maps for earthquakes (Figure 6(a)), mass movements (Figure 6(b)), and precipitation in the province of Manabí (Figure 6(c)).

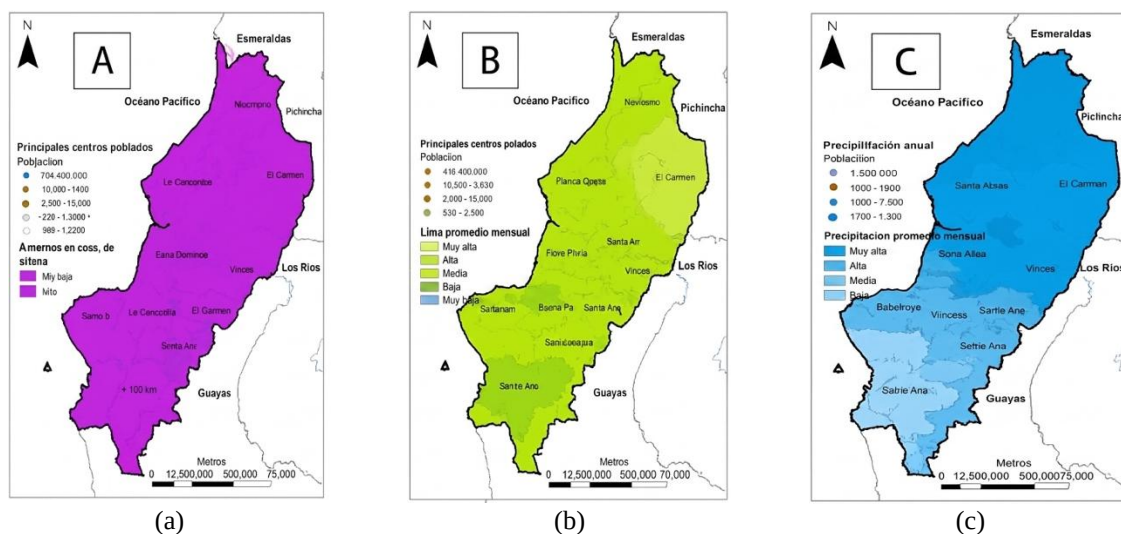


Figure 6. Multidimensional territorial hazard maps for the province of Manabí; (a) the territorial multidimensional hazard for earthquakes, (b) for mass movements, and (c) for precipitation [16]

3.3. Survey results

The survey results indicated that 85% of users reported a significant improvement in their understanding of interdisciplinary concepts (energy-risk). In addition, post-tests showed a 20% increase in the ability to solve complex spatial problems compared to those taught using lecture-based instructional methods. Building on these quantitative findings, the open comments revealed that users highlighted real-time visualization as a major strength, while pointing to the need for more in-depth tutorials for advanced wind data analysis as a weakness. Table 5 presents the overall results of the student and teacher survey.

Table 5. Survey results

No	Dimension	Average (media)	Standard deviation	Interpretation
1	Employability	4.62	0.45	Very high
2	Interdisciplinarity	4.35	0.52	High
3	Accessibility	3.88	0.89	Moderate (network limitation)

Comparative evaluations performed during academic projects indicated that SIGDS reduced site-selection analysis time by approximately 15% relative to conventional manual procedures. Furthermore, for the first time, data from electrical networks and natural disaster risk maps are combined within a single university interface, enabling users to simultaneously access and cross-analyze both datasets, thus enhancing data synergy. As a result, based on academic impact, 85% of users validated the tool as essential for their professional training.

4. DISCUSSION

Integrating GIS with real-time smart-grid monitoring enhances engineering education and reduces renewable-energy site-selection time by approximately 15% in the evaluated case study [16]. To reflect current research trends, the SIGDS is positioned to evolve by integrating emerging technologies. While the current platform relies on IoT sensors for basic smart grid feedback, integrating artificial intelligence (AI) and cloud computing could automate predictive maintenance and dynamic energy dispatching. Furthermore, comparing our problem-based learning (PBL) instructional method with Intelligent Educational Technologies, such as Adaptive Learning Systems or AI-assisted virtual reality (VR) laboratories, reveals that while VR offers deeper immersion, our web-based free and open source software for geographical information systems (FOSSGIS) approach provides higher generalizability and lower deployment costs for developing nations [41], [42].

Figure 7 shows the measurements obtained from the application of sensors on the electrical parameters of the 3.4 kWp photovoltaic power plant installed on the terrace of building 1 of the Faculty of Engineering and Applied Sciences of the Technical University of Manabi. Figure 8 shows measurements of ambient temperature, humidity, ultraviolet radiation, and the photovoltaic module temperature to evaluate hot spots on the solar panels and diagnose the photovoltaic plant's productivity and energy yield [43]–[46]. Measurement values can be obtained at different time intervals, e.g., hourly, daily, monthly, and yearly.

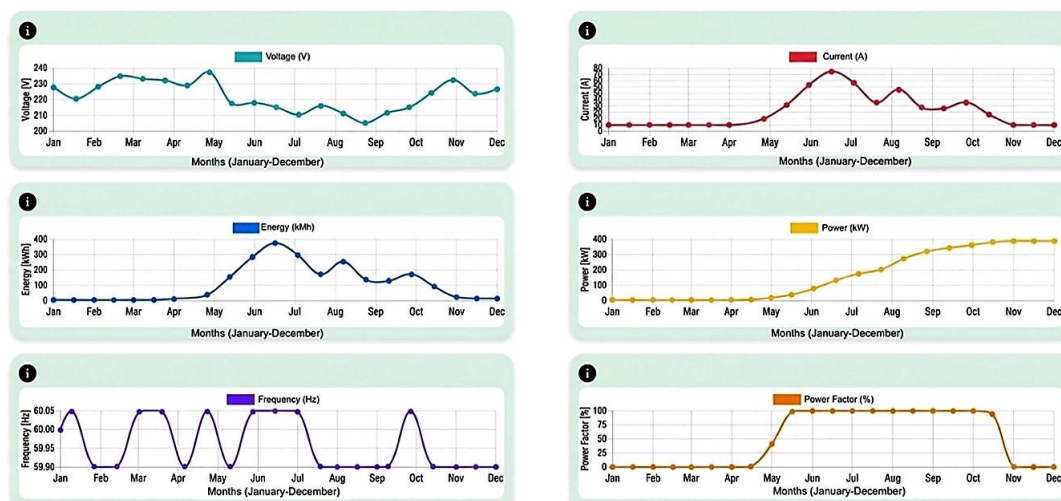


Figure 7. Electrical parameters of the 3.4 kWp photovoltaic power plant

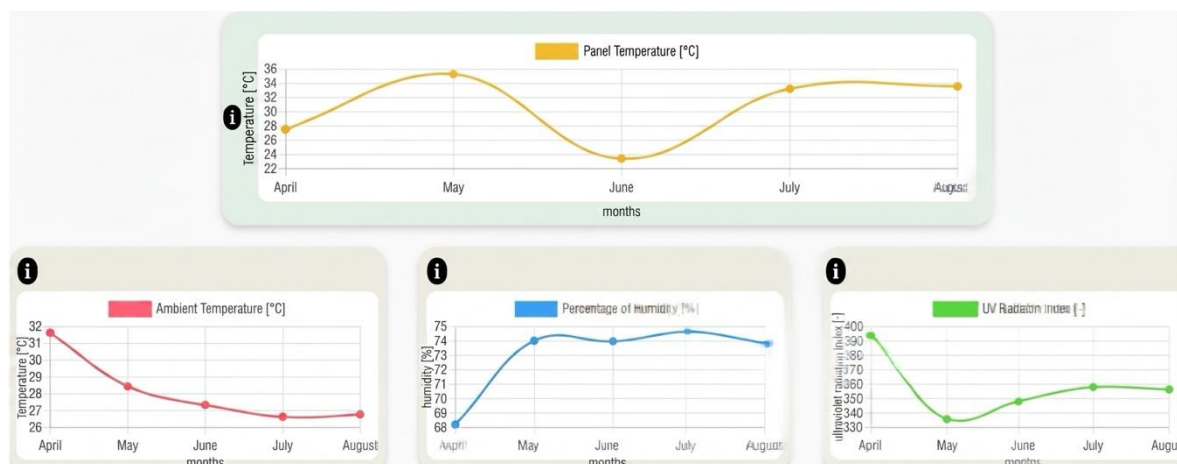


Figure 8. Environmental parameters

GIS-based simulations support the evaluation of renewable-energy integration, grid resilience, energy-flow optimization, and demand variability [47]. Real-time monitoring improves operational efficiency through dynamic management of distributed resources. Beyond academia, the geoportal strengthens community resilience by supporting renewable-energy planning and disaster-risk management [48]. Its integration into Education 4.0 frameworks can enhance spatial reasoning, interdisciplinary learning, and employability through teacher training and open-access digital tools [49], [50].

Digital sustainability principles and open-source technologies reduce operational costs while ensuring database integrity and interoperability [51]–[53]. Furthermore, GIS-based living laboratories can support community planning, microgrid deployment, and disaster-risk reduction in vulnerable regions [54]–[57].

Although validated at a single institution, the use of open-source tools and open geospatial consortium (OGC) standards facilitates replication across universities and engineering programs. Future studies should evaluate broader institutional implementation.

5. CONCLUSION

The implementation of the SIGDS bridges a critical gap in higher education by unifying renewable energy spatial planning, real-time smart grid monitoring, and disaster risk management. Utilizing a purely open-source architecture, the system democratizes access to advanced technological tools for resource-constrained universities.

The research showcases the experiences and contributions from interdisciplinary and multidisciplinary efforts using GIS in engineering and computer science at the Technical University of Manabí, Ecuador. These contributions strengthen the sustainable diversification of the energy matrix, reduce losses, increase efficiency and savings from endogenous resources, and minimize the impact of natural disasters. Thus, they enhance the territory's socio-environmental resilience.

Empirical validation demonstrated statistically significant improvements in spatial reasoning and interdisciplinary problem-solving competencies among engineering students. Survey results showed strong employability perception (4.62/5), interdisciplinary integration (4.35/5), and an overall acceptance rate exceeding 85%. These findings suggest that GIS-based educational environments can effectively bridge academic learning with practical challenges in renewable energy and territorial resilience.

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AUTHOR CONTRIBUTIONS STATEMENT

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- C : **C**onceptualization
M : **M**ethodology
So : **S**oftware
Va : **V**alidation
Fo : **F**ormal analysis
- I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**ding
- Vi : **V**isualization
Su : **S**upervision
P : **P**roject administration
Fu : **F**unding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Authors state no conflict of interest.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article [and/or its supplementary materials].

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