



Use of renewable energies in educational institutions: feasibility and environmental benefits

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Abstract. Renewable energy is increasingly viewed as a strategic response to rising energy demand and the urgent need to cut polluting emissions. In educational institutions, shifting toward clean energy sources is especially meaningful because it can reduce operating expenses while also reinforcing environmental awareness among students and the wider community. This study examines the feasibility of adopting renewable energy systems in schools and universities and highlights the environmental gains associated with their use. Through a review of academic literature and documented case experiences, the analysis shows that solar and wind technologies can supply a substantial share of campus energy needs, contributing to measurable reductions in carbon footprint and improved cost performance over the medium term. Overall, the findings indicate that renewable energy adoption in the education sector is technically achievable and financially reasonable, and it also serves as a practical pathway to strengthen sustainability goals and institutional social responsibility.

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1 Introduction

Climate change and the environmental crisis have generated a growing urgency to reduce greenhouse gas emissions, improve energy efficiency, and adopt renewable energy sources. Educational institutions (schools, colleges, universities) are important players because, in addition to their energy consumption, they have an educational role in raising awareness about sustainability among new generations.

In Mexico, a study by the Victoria Faculty of Commerce and Administration (Autonomous University of Tamaulipas) analyzed the feasibility of installing solar panels. It concluded that such an installation has a favorable return on investment and can reduce energy costs, while also being compatible with institutional sustainability goals. A case at UNAM, at the National School of Higher Studies (ENES Juriquilla), shows that by installing a photovoltaic system to cover some of its energy loads, it is possible to save approximately \$12,089 annually and significantly reduce the consumption of fossil fuels thanks to the use of solar energy. In Baja California, an energy efficiency analysis at an educational institution evaluated

measures such as thermal insulation, efficient lighting, etc. Although not all the data focuses exclusively on renewables, this type of study contributes to understanding how profitable and viable it could be to supplement energy with renewable generation

In Ecuador, the project “*Application of Renewable Energies in Rural Schools of Esmeraldas*” reported that introducing renewable sources can noticeably improve everyday learning conditions: classrooms became more comfortable in terms of temperature, lighting quality increased, students experienced less visual strain while reading, and higher levels of attention were observed. The same initiative also strengthened basic services by supporting water treatment systems. In a Chilean university surveyed in 2023, students expressed an overall positive attitude toward decarbonization, suggesting that campuses do not only teach about the energy transition—they also help shape, and are shaped by, broader social views on renewables.

Because climate change is strongly linked to continued dependence on fossil fuels, educational institutions occupy a unique position. They are major energy users, but they are also places where future decision-makers form habits and values. In Mexico, however, clean energy adoption across schools and universities remains limited, which creates a gap between sustainability discourse and daily practice. This research is driven by the idea that education should move beyond theory: institutions can operate as real-world demonstrations of responsible energy use.

Bringing solar or wind power into the educational environment can lower institutional carbon footprints, stabilize or reduce operating costs over time, and encourage a practical ecological culture among students. Recent work, including that of Ramos Aguilar and Hernández Veleros (2023), points to broader co-benefits as well, linking renewable adoption with improvements in human development and economic outcomes. For that reason, this study focuses on examining technical and economic feasibility in educational settings and on describing the long-term advantages that such a transition could deliver. In addition, the research aligns with the Sustainable Development Goals, particularly SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action), by aiming to provide clear, context-based evidence that can inform public policy, campus initiatives, and institutional decision-making toward a cleaner and more equitable energy model.

On the other hand, the transition to renewable energy sources, such as solar, wind, and hydroelectric power, shows a positive impact on economic and human development, in addition to contributing to the reduction of polluting emissions. However, this transition faces challenges related to technical and economic feasibility, as well as the regulatory framework in educational institutions, which limits its large-scale adoption.

Thus, the problem lies in the lack of effective and widespread implementation of renewable energy in schools and universities, which prevents them from reaping the environmental and economic benefits that could improve institutional sustainability and foster an environmental culture in new generations. At the national level, Mexico has set ambitious targets to increase the share of renewable energy in its energy mix, with goals of 35% by 2024 and 50% by 2050. However, dependence on fossil fuels remains high, representing approximately 58% of electricity generation in 2023. This situation reflects a disconnect between national policies and the reality of the energy sector, which also affects educational institutions.

Research objectives

- To estimate the economic viability (cost-benefit, return on investment, payback period) of implementing renewable energy systems (mainly solar photovoltaic) in educational institutions of different levels in Mexico.
- Analyze the technical feasibility (solar resources, available space, electrical load profile, integration with the electrical grid) for this type of installation.
- Quantify the expected environmental benefits, such as reduction of greenhouse gas (GHG) emissions and carbon footprint, derived from the use of renewable energy in schools and universities.
- Evaluate the educational and social effects: how these projects can foster a culture of sustainability, raise awareness among students, teachers and educational communities, and integrate them with the Sustainable Development Goals (SDGs).
- Identify barriers (technical, financial, regulatory) and facilitating factors that condition the effective implementation of renewable energies in the education sector in Mexico.

General objective

To determine the technical, economic, environmental and educational feasibility of incorporating renewable energy sources (especially solar photovoltaic) in Mexican educational institutions to propose recommendations that allow maximizing institutional benefits, reducing operating costs and contributing to the fulfillment of the SDGs, especially SDG 7 (Affordable and clean energy) and SDG 13 (Climate action).

Technological impact

The adoption of renewable energy technologies means that certain pre-existing technical knowledge and technological assets become enablers of innovation in educational institutions. For example, the experience of incorporating photovoltaic modules, monitoring systems, electricity demand management, and distributed generation is based on knowledge of systems design, power electronics, smart grids, and other related fields. This type of implementation tends to render obsolete certain traditional models of centralized generation based on fossil fuels, as well as inefficient passive infrastructures. At the same time, it reduces the likelihood that less efficient technologies will remain unchanged, incentivizing the upgrading, maintenance, and continuous improvement of energy systems. In fact, the literature indicates that one of the key challenges for the expansion of renewable energy in Mexico is precisely technological innovation and the modernization of electrical grids (OECD, 2022). Furthermore, the National Renewable Energy Laboratory (NREL) report for Mexico highlights how the availability of renewable resources and the incorporation of modern technologies could reduce electricity costs and generate new investment opportunities, indicating a clear technological boost. Therefore, in the context of educational institutions, integrating renewable energy recovers and revalues technical knowledge in electrical installations, smart buildings, energy metering, and efficiency, promoting an institutional culture of innovation and sustainability.

Environmental impact

From an environmental perspective, the implementation of renewable energies modifies resource use, reduces certain waste and emissions, and has effects on ecosystems. Installing solar or wind power systems in schools and universities decreases the use of fossil fuels (gas, oil, coal) for electricity generation, which in turn reduces the emission of greenhouse gases (GHG) and other combustion pollutants. For example, the study by Catalán Alonso (2021). For Mexico, the study found that although renewable energy consumption has a marginal long-term impact on emissions (elasticity -0.021), this demonstrates that increasing its share does contribute to mitigation. Regarding waste and emissions, replacing fossil fuels with renewables reduces ash, particulate matter, carbon dioxide, and nitrogen and sulfur oxides that typically accompany thermal power generation. Furthermore, distributed generation in schools requires less extensive infrastructure, which can reduce the impact on soil, fuel transportation, and other factors. On the other hand, the environmental analysis of power plants in Mexico indicated that certain life-cycle impacts (such as manufacturing materials or land use) must be considered, but renewables are still more sustainable. Finally, by fostering a culture of energy efficiency and clean energy generation in educational institutions, the value of ecosystems and biodiversity is restored by reducing the pressure on traditional energy systems. This strengthens the educational role of these institutions as agents of change in raising environmental awareness.

Economic impact

In the economic sphere, the adoption of renewable energy has multiple effects that justify its institutional implementation. First, a reduction in operating costs is expected in schools and universities, as electricity bills decrease and the lifespan of facilities is extended. This frees budgetary resources that can be redirected to other educational purposes (infrastructure, personnel, technology). For example, a general analysis indicates that the reduced costs of solar and wind technologies have significantly improved their competitiveness compared to fossil fuels. Second, the expansion of renewable energy generates investment and employment, which has a multiplier effect on the local and regional economy. In Mexico, it was estimated that renewables could attract up to US\$17 billion in investment, generate thousands of jobs, and improve air quality, which in turn reduces healthcare burdens and improves productivity. Third, diversifying the energy mix contributes to energy security and reduces vulnerability to the volatility of fossil fuel prices, which positively impacts the economic stability of institutions and the country. The renewable energy economy is described as “a low-carbon, resource-efficient, distributed, and socially inclusive economy” (UIIX, 2024). For all these reasons—savings, investment, employment, and security, the

implementation of renewable energy in educational institutions is justified not only as an environmental measure but also as a sustainable economic strategy.

Justification

The transition to renewable energy sources in education not only responds to an environmental imperative, but also entails significant technological, environmental and economic effects that justify its study and implementation in educational institutions.

Project feasibility

- Technical feasibility

The technical feasibility of implementing renewable energy in Mexican educational institutions can be considered high in theoretical terms, especially for photovoltaic solar energy, due to its availability, ease of maintenance, and ability to be integrated into existing infrastructure. Mexico has an average solar potential exceeding 5 kWh/m²/day, placing it among the countries with the highest solar irradiance in the world (National Commission for the Efficient Use of Energy [CONUEE], 2024). This condition allows even medium-sized educational facilities to benefit from grid-connected photovoltaic systems.

The Piedras Negras Technological Institute, as a representative example, has ample roofing areas and favorable solar exposure, which facilitates the installation of modular panels. Furthermore, current photovoltaic technology allows for scalable configurations, so a project can begin with a small number of modules and grow progressively as the investment justifies itself.

According to Radwan, Abu-Hamdeh and Al-Tamimi (2024), Universities and educational centers represent ideal settings for the adoption of clean energy, as they combine constant energy consumption, available space, and an educational function that reinforces environmental awareness. These authors emphasize that even in theoretical projects, university energy modeling serves as an interdisciplinary educational tool, integrating knowledge from engineering, management, and sustainability.

The typical electrical infrastructure of educational facilities in Mexico is also compatible with the integration of renewable energy systems, since the Electrical Installations Regulations and the Official Mexican Standards (NOM-001-SEDE and NOM-013-ENER) provide for the safe connection of photovoltaic systems. This allows for a technical analysis without requiring major structural modifications, thus supporting the project's viability from a planning perspective.

Furthermore, advances in hybrid educational systems that combine solar energy and basic low-cost battery storage show high educational potential. Zambrano-Joya, Rodríguez-Salazar and Rodríguez-Patarroyo (2022). They propose a methodology for designing hybrid systems of a pedagogical nature in schools, demonstrating that even with limited resources it is possible to develop functional models that simulate the generation and distribution of renewable energy.

Therefore, from a technical and educational standpoint, the installation or simulation of solar energy systems is entirely feasible. Its theoretical development allows not only the analysis of production and efficiency parameters, but also the promotion of professional training in sustainability, a central element of the objectives of the National Technological Institute of Mexico (TecNM).

- Economic viability

Economic viability, although theoretical, is analyzed through an overall cost-benefit estimate based on comparative studies and current institutional electricity rates. According to the Federal Electricity Commission (CFE, 2024), Higher education institutions are in the “OM” tariff, with average costs of 3.25 MXN/kWh.

A 30-kW photovoltaic system — capable of covering approximately 50% of the energy consumption of an average academic building — would cost approximately 600,000, according to average prices reported by the International Renewable Energy Agency (IRENA, 2023) and Mexican companies in the sector. If a useful life of 20 years and an estimated annual savings of

90,000 MXN in electricity consumption are considered, the theoretical return on investment (ROI) would be between 6 and 7 years.

Although this projection does not consider actual installation or financing costs, it serves to establish that, under normal conditions, investment in renewable energy is economically feasible in the medium term. In fact, the trend of decreasing costs in solar technology, which has fallen by more than 80% in the last decade (IRENA, 2023), increases its financial attractiveness even for public institutions with limited budgets.

Additionally, there are support and funding programs from government agencies such as the Ministry of Energy (SENER) and the Fund for Energy Transition and Sustainable Energy Use (FOTEASE), which promote educational projects focused on energy efficiency. At the international level, UNESCO (2023) and the International Energy Agency (IEA, 2023). They promote the integration of renewable energies as a cross-cutting strategy for institutional sustainability, which reinforces the economic justification of the project from an academic perspective.

Another important aspect is the indirect impact on the institution's finances. Although this project will not be implemented, it could theoretically reduce operating expenses for electricity and channel those resources toward academic or maintenance activities. It has been observed that schools that adopt energy efficiency programs, even in a theoretical or educational format, improve their financial management and organizational culture by raising awareness of the rational use of resources.

Finally, the economic analysis considers educational and social value. University projects on clean energy have a significant non-monetary return: they strengthen technical skills, increase ties with the productive sector, and consolidate the institution's image as a promoter of sustainability. Therefore, even in the absence of physical implementation, the theoretical development of the project is considered economically viable from an educational cost-benefit perspective.

- Environmental and social viability

The environmental viability of transitioning to renewable energy in educational institutions is widely recognized in literature. The use of clean energy sources in educational spaces directly contributes to the reduction of CO₂ emissions and the improvement of local environmental quality, in addition to functioning as an educational tool for raising awareness.

The average emission factor of the national electricity system in Mexico is around 0.4 kg CO₂/kWh. Therefore, a theoretical annual saving of 30,000 kWh would imply a reduction of approximately 12 tons of CO₂ each year. Although the present project does not include actual measurements, these values allow us to conceptually establish the environmental benefits of the proposal.

Furthermore, renewable energies represent a practical way to achieve the Sustainable Development Goals (SDGs) of the 2030 Agenda, particularly SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). UNESCO (2023) recommends incorporating sustainability into educational programs not only through institutional practices but also through academic projects that analyze the technical and environmental feasibility of clean energies.

In the social sphere, the project's viability is related to the acceptance and participation of the university community. They show that integrating solar energy projects into learning promotes environmental responsibility values and strengthens STEM (science, technology, engineering, and mathematics) skills. Similarly, Colmenares-Quintero, Barbosa-Granados, and Rojas (2022) demonstrated that educational programs focused on renewable energy increase the commitment of teachers and students to sustainability.

In the Mexican context, public institutions also have a social function as role models and environmental leaders. The General Law on Climate Change and the Special Program for Energy Transition (PETE) establish guidelines for universities to develop internal policies for energy efficiency and emissions reduction. Therefore, a theoretical study such as this one, even without practical application, contributes to compliance with these guidelines by generating knowledge and environmental awareness within the academic sphere.

From a cultural perspective, social viability is also linked to the educational process. The inclusion of renewable energy topics in the curriculum and university research strengthens comprehensive environmental education, aligning with the educational model of the National Technological Institute of Mexico, which seeks to train competent, ethical professionals committed to sustainability.

- Institutional and academic viability

Institutional viability is based on the capacity of Mexican universities to develop theoretical or simulated projects within their academic programs. In this case, the project does not require new infrastructure, but only bibliographic resources, access to databases, and faculty guidance.

The Technological Institute of Piedras Negras offers engineering and bachelor's degree programs that include related subjects such as Renewable Energy, Sustainable Development, and Environmental Management, making it easy to integrate the project as an interdisciplinary academic activity. This integration ensures its feasibility from the university planning stage and fosters collaboration among students from different disciplines.

Similarly, the proposed methodology, which is documentary and projective in nature, can be easily reproduced in other institutions of the TecNM system or in state universities, since it is based on accessible sources and non-experimental analysis tools.

In academic terms, this research fulfills the research training criteria that promote critical thinking, scientific communication, and the application of sustainability principles. Therefore, the project is viable not only technically and economically, but also within the university's pedagogical framework.

2 Theoretical framework

The adoption of energy technologies in organizations has been studied using frameworks such as Technology-Organization-Environment (TOE) and the diffusion of innovation theory (Rogers). In educational contexts, these frameworks are adapted to incorporate specific factors: institutional leadership, budget availability, technical maintenance capabilities, and curricular coherence (whether the institution incorporates sustainability into its curricula). Studies on integrated energy systems in schools emphasize that the institutional decision depends not only on economic profitability but also on organizational factors and internal governance (Altassan, 2023). Altassan also proposes a systemic approach that includes behavior and recycling along with renewable generation to maximize both emissions reduction and pedagogical impact (Altassan, 2023).

Contemporary studies on energy transition emphasize the socio-technical nature of innovation: technologies do not appear in isolation, but rather as part of networks of actors (university/school, supplier, local government, community, industry), institutions, and rules. The systems approach to technological innovation helps to identify barriers (financial, regulatory, capacity-based) and levers (public policies, technical training, incentives) for adoption in the educational field (Tan, 2023).^[17] Socio-technical analysis also guides the design of pilot projects in schools that are scalable and replicable.

In addition to the traditional Life Cycle Assessment (LCA) focused on environmental indicators (GHG, energy and material use, emissions), the Solar Cycle Assessment Framework (LCSA)—which integrates LCA, Life Cycle Costing (LCC), and Social LCA (S-LCA)—has gained prominence in recent years for the comprehensive evaluation of solar projects, considering their environmental, economic, and social impacts throughout the system's lifespan (Tan, 2023). This framework is particularly useful for educational institutions because it allows them to quantify not only emissions reductions but also economic benefits (energy costs avoided, module lifespan) and social effects (local job creation, educational opportunities) (Tan, 2023; Smith, 2024).

The installation of photovoltaic or mini-wind turbine systems in schools relies on a well-established base of knowledge and technical resources: photovoltaic system design, power electronics (inverters), interconnection regulations, electrical system

maintenance practices, and energy monitoring tools (SCADA, smart meters). The availability of installation companies, technical manuals, and educational offerings in electrical engineering/renewable energy at many universities facilitates pilot projects and maintenance services (Cayuela et al., 2024).

Distributed generation based on renewable energy reduces the priority given to centralized models highly dependent on fossil fuels. Obsolete infrastructure, such as diesel generators for short-term backup or highly inefficient air conditioning equipment unsuitable for demand management, loses its technical and economic justification when renewables are integrated with energy efficiency measures (Smith, 2024). Likewise, dependence on large transmission lines and associated losses decreases with generation close to the point of consumption.

The transition revalues knowledge in energy efficiency, demand management, bioclimatic building design, and technical maintenance. Furthermore, related technologies (storage batteries, energy management systems, smart controllers) become complementary and generate demand for emerging technical capabilities (Cayuela et al., 2024; Tan, 2023).

Distributed generation in schools helps reduce vulnerability to prolonged local power outages and decreases the need for fossil fuel-powered emergency generators. It also mitigates peak demand during school hours when integrated with energy storage and load management; therefore, it reduces the need for short-term investments in expanding distribution infrastructure (Smith, 2024).

Installing photovoltaic panels in educational institutions replaces, in part, electricity from the grid generated by fossil fuels — which reduces CO₂ emissions and other atmospheric pollutants associated with combustion (NO_x, SO_x, particulate matter). LCA studies applied to solar systems show that, over their lifetime, the carbon footprint of the kWh produced by PV is substantially lower than the average for the fossil fuel-based grid (Smith, 2024; Cayuela et al., 2024).

While PV operations produce very few local emissions, the supply chain and end-of-life management (panels, inverters, batteries) generate material impacts that must be managed: use of silicon, aluminum, glass, and, in batteries, critical materials (lithium, cobalt). Recent technical reports underscore the need for e-waste management plans and circular economy strategies (recycling, materials recovery) to ensure lasting net environmental improvement (Tan, 2023; IEA PVPS, 2021/2022). Proper end-of-life management and extended producer responsibility policies help minimize negative impacts and promote material recovery.

The direct impact of rooftop PV installations on biodiversity is minimal; for ground-level installations, land use can be a factor. In the case of schools, they are usually installed on roofs or rooftops, so the impact on flora and fauna is marginal. However, the reduction in emissions improves air quality and has indirect positive effects on the health of urban and peri-urban ecosystems (Smith, 2024; Cayuela et al., 2024).

Life cycle assessment (LCA) allows for the comparison of the environmental impacts of alternatives (efficiency improvements vs. renewable generation). Recent studies show that, in most contexts, the combination of energy efficiency and PV generation offers the greatest net environmental benefit (Tan, 2023; Smith, 2024). Furthermore, integrating storage and designing for recyclability further enhances the overall sustainability of the project.

Empirical evidence accumulated during 2020–2024 indicates that PV systems for public or educational buildings typically generate a return on investment through savings on electricity bills, although the return depends on several factors: local electricity rates, tax incentives, availability of financing, solar radiation, and system scale. Life Cycle Costing (LCC) assessments show that, with reduced module costs and rising electricity rates, the payback becomes more attractive for medium and large institutions (Smith, 2024; Tan, 2023).

The construction, installation, and maintenance of solar projects generate local employment (technicians, installers, engineers) and can boost the regional supply chain. Furthermore, implementation in educational institutions creates pedagogical opportunities that can lead to student projects, incubators, or micro-enterprises, strengthening human capital in clean energy (Altassan, 2023).

Reducing electricity costs improves the predictability of operating expenses and decreases the institution's exposure to the volatility of fossil fuel prices. This can free up funds for investment in educational infrastructure or academic programs, which has multiplier effects on educational quality (Tan, 2023).

Beyond direct savings, renewables have positive externalities (improved health due to reduced pollution, lower GHG emissions) that translate into savings for the healthcare system and increased social productivity. LCSEA studies combine these externalities with direct economic benefits to offer a more comprehensive view of the value of solar projects in the public sector (Tan, 2023; Smith, 2024).

Limitations and systematic risks of adoption

Although the document shows that solar energy (especially photovoltaics) is a good fit for schools and universities, there are inherent risks that cannot be disguised because they are part of the system. If these risks are not acknowledged from the outset, they can lead to costly surprises or projects that are left unfinished. This is especially important in educational institutions where budgets are rigid and administrative processes tend to be slow.

The first limitation is fundamental: the sun is not constant. Generation changes hourly, seasonally, and, above all, due to cloud cover. This means variations that are felt precisely when energy is most needed (classes, laboratories, air conditioning). In practice, the institution still needs grid backup, and if the aim is to "smooth out" the variation with batteries, then the project becomes more complex, more expensive, and more heavily regulated. In short: solar energy helps a lot, but it doesn't behave like a plant that delivers the same amount of power all the time.

On paper, many proposals look good because they only compare "investment vs. savings." But in daily operation, real costs emerge: cleaning (dust and dirt reduce performance), checking connections, replacing inverters (they don't last as long as the panels), monitoring, insurance, and troubleshooting. In dusty and windy climates, cleaning is essential if you want to maintain performance. Internationally, operating and maintenance (O&M) cost benchmarks vary and depend on the size and type of system; even so, it's an item that should be budgeted on an ongoing basis, not as an "occasional expense."

Panels don't last forever. They typically have a lifespan of decades, and when mass retirements begin, an uncomfortable issue arises: who receives them, how are they dismantled, how much does it cost to recycle them, and what happens to materials like aluminum, and electronic components? Internationally, there are already comprehensive reports on recycling and end-of-life management, and the common thread is that recycling isn't always "the cheapest option" if there isn't a formal, large-scale system to make it profitable.

In Mexico, the challenge is often twofold: on the one hand, the general waste framework exists, but there aren't always specific and standardized rules for photovoltaic panels as a waste stream; on the other hand, specialized recycling infrastructure is still under construction, and this increases the risk that the waste will end up poorly managed or simply "stored" indefinitely.

Here, the risk isn't technical, but rather administrative and regulatory. To connect a photovoltaic system to the grid, certain requirements, contracts, and procedures must be met (it's not simply a matter of "install and you're done"). The regulatory authority defines the framework for distributed generation, and the interconnection process is governed by manuals and formal procedures; furthermore, electrical installations must comply with the applicable Mexican Official Standard (NOM). In institutions, this typically involves: reports, inspections (when applicable), documentation, response times, and coordination with the supplier/distributor.

In practice, these barriers translate into delays (due to administrative burden), additional costs (administrative fees, inspections, modifications), and, in some cases, technical limitations of the local grid (circuit capacity, connection conditions). All of this doesn't mean "it can't be done," but it does mean that the plan must include timelines, responsible parties, and a clear compliance roadmap from the outset.

Educational and social dimension: learning, behavior and governance

Installing solar systems in schools allows for the integration of practical content in science, technology, engineering, and mathematics (STEM) and environmental education. This transforms energy infrastructure into a teaching resource: measuring generation, understanding efficiency concepts, discussing environmental impact, and supporting student research projects (Altassan, 2023).

Projects with student participation in maintenance, monitoring, and outreach generate greater environmental awareness and sustainable practices (conserving, recycling). Evidence suggests that hands-on experience increases the sense of ownership and the likelihood that students will transfer these practices to their homes (Altassan, 2023).

For projects to be sustainable over time, it is key to integrate new responsibilities into institutional governance: budget allocation for maintenance, agreements with suppliers, training of technical staff, and accountability mechanisms. These aspects directly affect the durability and replicability of projects (Tan, 2023).

Barriers and facilitators

Recent studies identify recurring barriers: budgetary limitations for initial investment; lack of access to adequate financing mechanisms for the public/educational sector; deficiencies in technical capacity for design and maintenance; regulatory uncertainty in some countries regarding interconnection and conditions for buying/selling surpluses; gaps in end-of-life management and recycling (Cayuela et al., 2024; Tan, 2023).

Facilitators include financial incentives (subsidies, soft loans); state programs supporting schools (public-private partnerships or savings contract schemes); clear legislation on distributed generation; technical training; and agreements with universities for maintenance and training (Smith, 2024; IEA PVPS, 2021/2022). Success stories (government projects and pilot programs) demonstrate that combining financing and training can overcome initial barriers.

Recommended methodologies for evaluating projects in educational institutions

It is recommended to start with an energy audit (hourly load profile, consumption by use) and a study of the resource (solar irradiance, shading) for appropriate sizing. Simulation tools (PV*Sol, PVSyst) and LCA software allow estimating energy production and environmental footprint throughout the useful life (Smith, 2024; Cayuela et al., 2024).

In addition to calculating the payback period, it is suggested to perform sensitivity analyses (tariff variations, operating costs, incentives) and LCC analyses to compare alternatives (efficiency alone, PV alone, combination). Including risk assessment and scenarios facilitates robust decision-making (Tan, 2023).

Apply LCA to estimate avoided emissions and other environmental impacts; complement with LCC and S-LCA to obtain LCSA (comprehensive sustainability). This is especially useful when comparing financing options or when claiming environmental certifications (Smith, 2024; Tan, 2023).

Educational and social evaluation

Including perception surveys, student participation indicators, and curriculum integration metrics to measure pedagogical impacts. Case studies and participatory evaluation provide evidence on the effectiveness of technology as an educational tool (Altassan, 2023).

The evidence from 2020–2024 converges on the fact that implementing renewable energy in educational institutions is technically feasible and, with appropriate financial and regulatory conditions, also profitable and environmentally beneficial.

However, significant gaps remain: (1) longitudinal studies measuring the medium-term pedagogical impact; (2) comprehensive Local Climate Safety Assessments (LCSAs) applied to school projects of varying scales and climates; (3) replicable financial frameworks for small schools; and (4) circular economy strategies for end-of-life management of components (Tan, 2023; Cayuela et al., 2024; Smith, 2024). Addressing these gaps will allow pilot projects to be transformed into scalable public policies.

Hypothesis

The implementation of renewable energy systems, mainly solar photovoltaic, in Mexican educational institutions is technically, economically and environmentally viable, and contributes significantly to the reduction of operating costs and greenhouse gas emissions, in addition to strengthening the culture of sustainability in the school community.

Installing solar panels in educational institutions generates a favorable return on investment (ROI less than 5 years), due to a decrease of up to 50% in annual energy expenditure (De la Fuente Rodríguez et al., 2024; Aristizábal, 2021).

The use of solar energy in schools and universities significantly reduces the institutional carbon footprint, with an average decrease of more than 30% in CO₂ emissions derived from electricity consumption (Gómez et al., 2025; Perino et al., 2021).

Educational institutions that adopt renewable energy show greater environmental awareness and commitment among their students and teachers than those that do not use it, fostering pro-environmental attitudes and social responsibility (Gallego-Torres et al., 2021; Perino et al., 2021).

The adoption of renewable energy in educational institutions increases when there are public policies, financial incentives and government technical support, which reduce the initial barriers to investment and maintenance (Juárez-Luna & Urdiales, 2024; Puebla State Energy Agency, 2023).

3. Methodology

This work offers something different because it doesn't just focus on whether installing solar panels in a school is profitable or technically feasible. It goes further. The proposal here is to view the project as a complete system where four elements are connected simultaneously: the technical, economic, environmental, and educational aspects. In other words, it doesn't only analyze the cost or savings, but also how the institution's culture changes and what impact it has on student learning.

Another important difference is the approach taken in the study. Instead of a real installation, a theoretical model was developed that is applicable to a specific institution, such as the Technological Institute of Piedras Negras, but can also be adapted to other universities. Recent data, estimates of solar generation in the region, calculations of emissions reductions, and projections of economic savings were combined. All of this was integrated under a comprehensive sustainability vision, considering the impact throughout the system's entire life cycle.

The methodological innovation lies precisely in this integration. Many studies analyze only return on investment or emissions reduction. This study connects both aspects and incorporates educational impact as a central part of the analysis. It proposes that a renewable energy system within a school is not just infrastructure, but a learning tool that can strengthen technical skills, environmental awareness, and social responsibility.

It is also important that the proposed model can be replicated without immediate investment. It serves as a basis for other institutions to assess their own viability before making decisions. This ensures that the study doesn't remain purely theoretical but can become a starting point for real-world projects in the future.

This work employs a mixed-methods approach, combining descriptive and projective methods, primarily based on documentary research and comparative theoretical analysis. Since the aim is not to implement renewable energy systems in

practice, the methodology focuses on reviewing, systematizing, and critically analyzing information from recent academic, regulatory, and technical sources, as well as on the theoretical simulation of application scenarios for higher education institutions.

This type of approach is appropriate for university studies aimed at understanding the conceptual, technical, economic, and environmental feasibility of renewable energies in educational contexts, without requiring fieldwork. According to Hernández-Sampieri et al. (2022), projective research allows for “formulating a proposal based on theoretical and documentary analysis for the resolution or improvement of a specific situation.” Therefore, this research is based on the study and synthesis of previous experiences, evaluation models, and regulatory frameworks applicable to educational institutions in Mexico and around the world.

The study is of a descriptive-projective type, with a non-experimental and cross-sectional design. Descriptive because it seeks to characterize and analyze the main dimensions that influence the incorporation of renewable energies (economic, technical, environmental and social). Projective Because, based on documentary findings and comparative analysis, a theoretical model of viability is proposed for Mexican educational institutions, particularly the Technological Institute of Piedras Negras. Non-experimental, since no variables are manipulated nor is a real intervention carried out. Cross-sectional because the information is collected and analyzed at a single point in time. This type of design has been used in educational energy assessment studies without direct practical application (García-Ferrero et al., 2021); Radwan et al., 2024), since it allows for structuring solid conclusions based on bibliographic review, case comparison, and theoretical modeling.

The research is based on secondary sources selected according to criteria of currency, relevance, and academic credibility. More than thirty documents were consulted, including scientific articles, institutional reports, theses, technical standards, and documents from international organizations (IEA, UN, SEMARNAT, CONUEE, IRENA).

These references support the methods of theoretical analysis, comparison of international cases, and conceptual simulation of environmental and economic benefits.

The study was developed using a theoretical-documentary approach articulated in four strategic phases:

- **Source Curation:** Academic literature (2020-2024) was selected from high-impact databases (Scopus, ScienceDirect, among others). The criteria prioritized sustainability in educational settings, data applicable to the Latin American context, and technical relevance.
- **Comparative Analysis:** Technical-economic feasibility models and energy literacy strategies were synthesized. From this emerged a conceptual model that links infrastructure and training (independent variables) with the benefits and viability of the project (dependent variables).
- **Design of the Projective Model:** A university feasibility proposal was structured based on four dimensions: Technical: Regional solar generation potential. Economic: Tariff savings versus investment costs. Environmental: Mitigation of CO₂ emissions.
- **Educational:** Cultural and formative impact on the community.
- **Validation and Consolidation:** The proposal was validated through triangulation between previous research, Mexican energy policies, and UNESCO guidelines, ensuring academic coherence under APA 7 standards.

Although no field instruments are used, the work uses documentary and content analysis techniques, based on the following strategies:

- **Thematic content analysis:** classification of the reviewed texts into categories such as technical feasibility, cost-benefit, environmental and educational impact.
- **Comparative analysis:** contrast between experiences from different countries (Mexico, Spain, Colombia, Türkiye) and educational levels.
- **Deductive-projective analysis:** derivation of theoretical conclusions for the context of the Technological Institute of Piedras Negras, supported by secondary evidence.
- **Theoretical simulation of benefits:** use of average solar generation and economic savings published in recent literature (Singh & Vaidya, 2024; Radwan et al., 2024).

Scope:

- To offer a methodological and conceptual proposal on the viability of renewable energies in Mexican educational institutions.
- Systematize current knowledge on the environmental, economic and educational benefits of clean energy in the university setting.
- To serve as a theoretical basis for future applied research.

Limitations:

- No actual consumption measurements or photovoltaic installations are carried out.
- The conclusions are derived from documentary analysis and therefore lack empirical validation.
- Economic and technical values are estimated based on averages reported by specialized sources.

The documentary and projective approach is appropriate for university work that seeks to generate theoretical knowledge applied to a local context. According to Brychkov et al. (2023). The systematic study of international experiences allows for the identification of critical success factors in school energy management, even without direct intervention. Similarly, Radwan et al. (2024) emphasize the importance of desk research in guiding university sustainability policies.

For their part, García-Ferrero et al. (2021) and Khodijah et al. (2023) highlight that energy education can be strengthened through academic proposals, simulations and theoretical projects, which coincides with the nature of the present study.

4. Results

What comes through most clearly in the documents is that renewables—especially rooftop solar PV—are not being discussed as a “nice idea” for schools, but as something that can actually work on the ground, with benefits that show up in more than one area: operations, finances, emissions, and learning outcomes.

On the technical side, Mexico is simply a strong place for solar. Multiple sources describe a typical average daily solar irradiation around ~ 5.5 kWh/m²/day, which is high enough to make photovoltaic generation practical across many regions. That matters because it turns PV from a theoretical option into a predictable one. In addition, most campuses already have what PV needs: wide roof surfaces, open areas, and electrical demand that is steady throughout the week. That combination reduces the amount of structural “reinvention” required—systems can often be added in a modular way and expanded as budgets allow, rather than forcing a full redesign from day one.

Financially, the evidence is no longer limited to general optimism. The literature reviewed points to a payback window commonly estimated around 6–7 years for institutions with substantial electricity consumption, which is the kind of timeframe decision-makers can actually plan around. At the same time, the broader economics of solar have shifted sharply over the last decade: global reports show that the cost of utility-scale solar has fallen dramatically since 2010, with major declines in overall installed costs and the levelized cost of electricity. This does not guarantee identical results in every school, but it supports a realistic argument: PV is no longer a premium technology reserved for special projects—it can be a budget strategy, especially when financing programs or public incentives are available to soften the initial investment.

The environmental findings are the most straightforward to interpret. When a school replaces grid electricity produced largely from fossil fuels with on-site renewable generation, the reduction in emissions follows directly. The documented outcomes consistently emphasize lower CO₂ emissions and fewer local pollutants, which translates into a smaller institutional footprint and a clearer alignment with climate and sustainability commitments. This is one of the few areas where the “benefit” is not abstract: the direction of change is reliable, and it is measurable over time through energy-generation and consumption records.

Where the results become more distinctive—and less repetitive—is in the educational impact. The presence of renewable infrastructure on campus is not only an operational improvement; it becomes a teaching asset. Schools that integrate these systems into coursework and projects create a practical bridge between theory and real-world application: students can interpret production data, discuss variability, connect energy topics to climate goals, and develop a more grounded understanding of sustainability. In other words, PV on a roof can function as a daily, visible reminder that sustainability is not just a chapter in a textbook—it is a managed decision with technical and social consequences.

Finally, the results also highlight common barriers that hinder the adoption of these technologies, including a lack of initial funding, slow administrative processes, insufficient institutional support, and limited technical training in some educational settings. However, these barriers are not insurmountable, as they can be overcome through funding plans, strategic partnerships, training programs, and educational policies focused on sustainability.

Taken together, the results indicate that the implementation of renewable energies in educational institutions is not only possible, but highly beneficial, viable at different levels and capable of generating positive impacts that encompass the technical, economic, environmental and educational aspects, thus strengthening the role of schools as agents of transformation and sustainability.

Table 1. dimension, key findings and implications

Dimension	Key findings	Implications (what it means for the institution / the project)
Technique	Documentary evidence indicates solid technical viability for renewable energy (mainly PV) in educational institutions; Mexico presents favorable conditions and the typical infrastructure (large roofs/available areas) facilitates adoption with low complexity of modifications; the technology is described as modular and low maintenance.	Implementation can be planned in stages (scalable), prioritizing buildings with better space and demand; a “modular” design approach is justified to grow without interrupting operations; it is reinforced that technical feasibility is a strong argument for moving from intention to planning.
Economic / Financial	The reviewed studies agree that the initial investment has decreased and that the recovery period is projected to be around 6–7 years, with a favorable return in high-consumption institutions; the savings allow resources to be redirected to educational needs and infrastructure; support programs and financing options are mentioned as facilitators.	For decision-making, the project must be presented as a strategic investment (not just “green spending”), with a financial case that includes payback, risks and continuity; it opens the door to justifying financing schemes, agreements or progressive implementation without compromising the operating budget.
Ambiental	Relevant environmental benefits are reported: reduction of CO ₂ and other pollutants associated with fossil fuels; improvement of air quality and reduction of the ecological footprint; alignment with sustainability goals and climate action.	The environmental outcome serves as support for institutional sustainability policies, social responsibility reports and arguments before the community/authorities; in addition, it allows the project to be translated into communicable indicators (e.g., estimated annual reduction of emissions).
Educational / Social	The presence of renewable technologies generates learning opportunities: integration into academic activities, practical learning, boosting interest in science/technology/engineering and strengthening a culture of environmental responsibility; the institution can become a community benchmark (“model of sustainability”).	Adoption should be treated as a “double” project: infrastructure + training tool; it is justified to include participation components (monitoring, school projects, dissemination) so that the educational benefit is verifiable and does not remain just a declaration.
Barriers to adoption	Recurring obstacles are identified: lack of initial funding, slow administrative processes, insufficient institutional support, and limitations in technical training; however, it is considered that the barriers can be overcome with financing plans, partnerships, training, and educational policies geared towards sustainability.	In implementation, “success” depends on governance: responsible parties, realistic timeline, training, and partnerships; it is recommended to include a management plan (roles, maintenance, support, continuity) from the design stage to prevent the project from remaining in pilot phase or being halted by bureaucratic procedures.

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