

Minds running on Direct Current

Challenges of Electrification
in Latin America and
the Caribbean

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Infrastructure of
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Youth, Education, and
Continuing Training in
the Regional Electricity
Transition

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Energy Alone Is Not
Enough: We Need
Flexibility

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Credits

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Foreword

Electrification lies at the heart of the energy transformation in Latin America and the Caribbean. Growing demand, the accelerated integration of renewable sources, the modernization and expansion of grids, energy storage, digitalization, and the need to ensure more resilient systems pose challenges that extend well beyond the strictly technological dimension. Electrifying the region also means addressing issues of access, affordability, planning, regulation, investment, sustainability, and equity.

Latin America and the Caribbean are particularly well positioned to advance this process. The region's diverse energy resources, its renewable energy potential, and the technical capabilities developed over recent decades provide a solid foundation for deepening the transformation of its electricity systems. However, the regional landscape also reveals significant gaps across countries and territories. Communities still lack adequate access to modern energy services, infrastructure requires further investment, and systems are increasingly exposed to extreme weather events, even as new demands emerge from the electrification of transport, industry, and other end uses of energy.

At the Latin American Energy Organization (OLACDE), we recognize that responding to these challenges requires stronger regional cooperation, the promotion of knowledge exchange, and the creation of spaces that bring technical expertise closer to decision-making. It also requires broadening the range of voices involved in shaping our region's energy future.

It is in this context that *Direct Current Minds: Challenges of Electrification in Latin America and the Caribbean* was created—a publication that brings together reflections from women specialists involved in project implementation, research, regulation, planning, and other strategic areas of the region's energy sector.

This publication seeks to highlight their knowledge and professional experience, not only in recognition of their careers, but also as a tangible contribution to the regional technical debate. Broadening the voices involved in energy discussions enriches the analysis, brings new perspectives to familiar challenges, and strengthens a professional community capable of responding to the present and future challenges of electrification.

Across these pages, the publication addresses issues spanning the full transformation of the electricity sector: from access and electricity demand to generation, grids, and



infrastructure; from flexibility and storage to resilience, innovation, and planning; and from regulatory frameworks and public policies to electrification experiences developed directly in local communities.

The contributions combine technical expertise with an implementation-oriented perspective. This is especially relevant in a region where energy solutions can rarely be transferred uniformly from one country to another. Geography, climate conditions, economic structures, available resources, and social needs create distinct realities that require context-specific responses, while also offering extraordinary opportunities for regional learning and cooperation.

For this reason, the publication aspires to be more than a collection of articles. It seeks to become a meeting point between knowledge and decision-making, technical experience and public policy, and the current challenges and future possibilities of our energy systems.

The electrification of Latin America and the Caribbean will be decisive in achieving more sustainable, secure, resilient, and inclusive energy systems. Building that future will require infrastructure, innovation, and financing, but also knowledge, cooperation, and new forms of leadership capable of turning the region's opportunities into concrete solutions.

The voices brought together in this volume are part of that collective endeavor and invite us to view regional electrification not only in terms of what remains to be resolved, but also through the capabilities, experiences, and ideas that Latin America and the Caribbean already possess to shape their own energy future.

Gloria Alvarenga

Director of Energy Integration, Access and Security
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The Invisible Infrastructure of Regional Electrification

The expansion of electricity grids explains only part of the energy transition. Invisible infrastructure—comprising governance, innovation, human capital, strategic planning, and institutional strength—determines Latin America and the Caribbean’s capacity to accelerate resilient, inclusive, and sustainable electrification.

Introduction

Latin America and the Caribbean (“LAC” hereafter) possess some of the world’s most favorable conditions for leading the energy transition. The region has abundant renewable resources, one of the cleanest electricity mixes on the planet, and strategic reserves of critical minerals for the energy transition. Yet the pace of electrification remains uneven across countries and even within individual territories. In this context, we must ask: why do countries and territories with similar conditions advance at such different speeds?

Several international organizations agree that the energy transition depends on a combination of infrastructure, innovation, governance, and institutional capabilities (IEA, 2023; IRENA, 2023; WEF, 2023). However, empirical evidence specific to the region shows that regulatory autonomy has the greatest explanatory weight (De Halleux, Estache, and Serebrisky, 2020). By contrast, Maravall (2022) argues that transforming the energy sector requires strategic, regulatory, and organizational changes that go beyond technological replacement. Traditionally, these differences have been explained by the availability of natural resources, the expansion of electricity grids, or the incorpora-

tion of new technologies. International experience demonstrates, however, that although these factors are indispensable, they are insufficient to explain why some countries accelerate their energy transitions while others advance more slowly. Physical infrastructure is the visible expression of the electricity system, but behind it lies a set of capabilities that shape its planning, financing, implementation, and sustainability.

In this article, we propose understanding these differences through the concept of the invisible infrastructure of electrification: the institutional, regulatory, financial, technological, and human capabilities that enable the development of visible infrastructure. This is not a new category of physical infrastructure, but a conceptual framework that brings together strong institutions, stable rules, specialized talent, innovation, financing mechanisms, and cooperation among stakeholders. These capabilities neither generate electricity nor build grids, but they determine how quickly a country can plan, implement, and sustain its electrification process. Far from being an abstract concept, invisible infrastructure provides a framework for understanding why similar investments produce different outcomes depending on the capabilities that support them.

Accordingly, we develop this argument in two sections. Section 1 summarizes the literature around four dimensions of regulatory governance. Section 2 then explains why governance and the regulatory framework lie at the core of this invisible infrastructure, in contrast with visible infrastructure, and presents the analytical framework.



Literature Review

The literature on electrification in LAC is organized around four dimensions: regulatory governance; the political economy of reforms; institutional heterogeneity; and regional cooperation and integration.

I. Regulatory Governance

De Halleux, Estache, and Serebrisky (2020) construct governance reform indices across four dimensions—market structure, private participation, regulatory autonomy, and operational organization—for the region’s electricity sector. They find that governance reforms, taken together, are statistically significantly associated with higher technical and process quality, but not with improvements in social or service outcomes. Considered separately, regulatory autonomy has the strongest correlation with desirable outcomes, while private participation is not significantly associated with any outcome.

Balza et al. (2020), in an IDB study covering 18 countries over five decades, find that private investment and the quality of regulatory governance are positively associated with better electricity-sector performance.

Andrés, Guasch, and Azumendi (2008) position their work at the intersection of two strands of literature that had previously developed separately: one examining the impact of private participation on sector performance, and another measuring the governance of regulatory agencies. Drawing on

two original databases on electricity distribution in the region, the authors construct a regulatory governance index and show that regulation and its governance influence sector performance, thereby linking two research traditions that had previously evolved in parallel.

II. Political Economy of Reforms

Jordana and Levi-Faur (2005) document the expansion of autonomous regulatory agencies in the region. They analyze the creation and reform of regulatory agencies in nineteen countries and twelve sectors between 1979 and 2002, distinguishing national diffusion patterns—where the number of pre-existing agencies in a country increases the probability that new agencies will be created—from sectoral patterns, where diffusion occurs across countries within the same sector. This finding frames the creation of regulatory institutions as a political diffusion process rather than an automatic technical response to market needs.

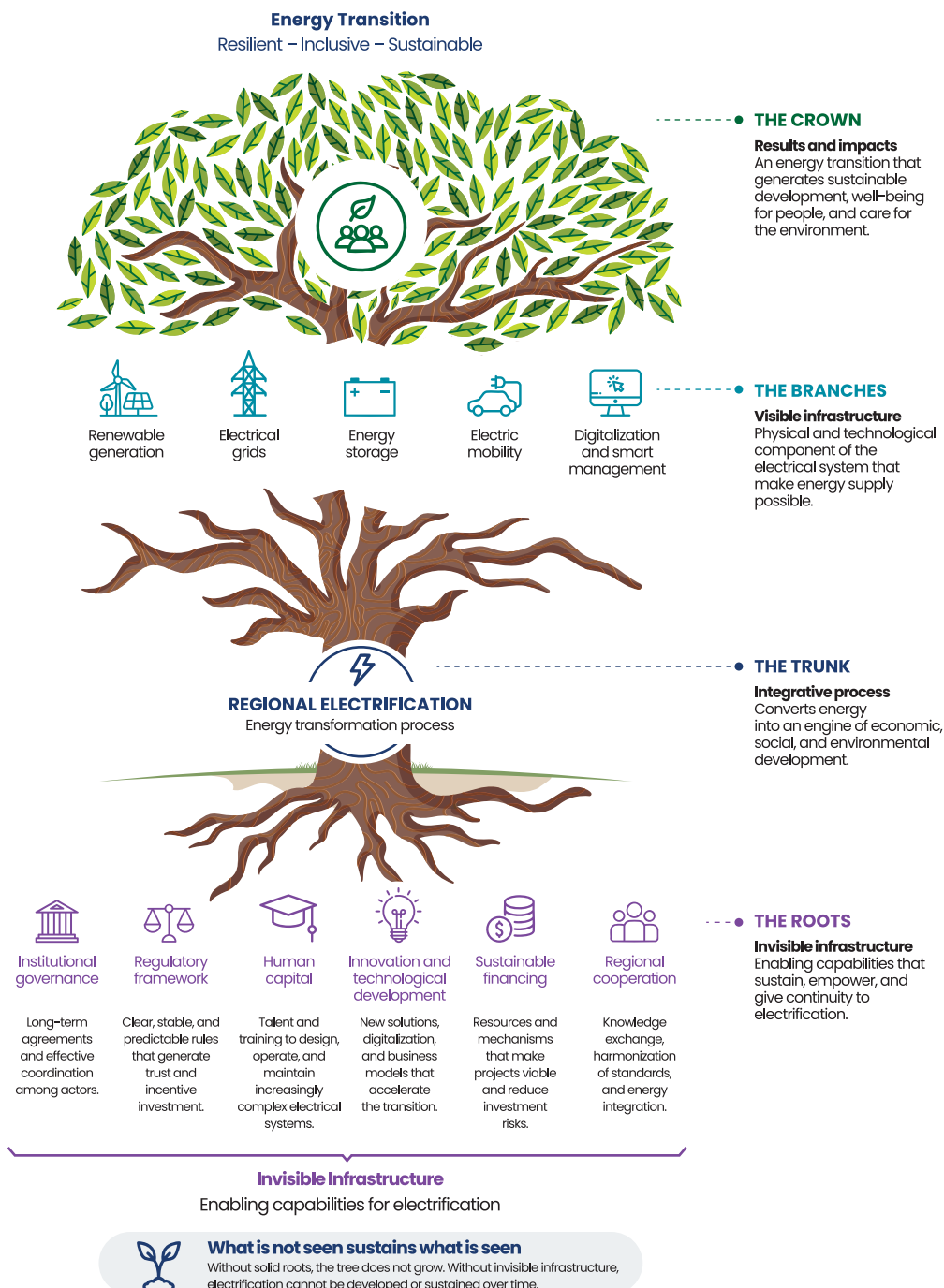
III. Institutional Heterogeneity and Regional Cooperation

An additional challenge is institutional and regulatory heterogeneity. Cerra et al. (2016) identify differing levels of development in planning and regulatory frameworks across LAC countries. Using the International Monetary Fund’s public investment management assessment, they show that the implementation of good practices in infrastructure planning, allocation, and execution is uneven throughout the region.

Figure 1.

Conceptual model of the invisible infrastructure of electrification.

Source: Authors' own elaboration.



This heterogeneity is also evident at the sectoral level. Georgoulas et al. (2018) assess the institutional capacity of six countries in the region to plan and procure sustainable infrastructure in the energy, transport, and water sectors. They find that interministerial coordination and the integration of sustainability criteria into planning and procurement remain limited, even in countries with more consolidated regulatory frameworks. Institutional fragility is therefore identified as a constraint on the capacity to design robust policies and develop long-term scenarios (ECLAC, 2025).

Analytical Framework: Invisible Infrastructure

Invisible infrastructure has a core and four capabilities mediated by that core. Governance and the regulatory framework occupy the center: they are the conditions that make it possible to build consensus, sustain long-term policies, and provide predictability for investment (De Halleux, Estache, and Serebrisky, 2020). Financing, human capital, and innovation depend on this regulatory core to operate effectively: access to credit, retention of technical talent, and adoption of new technologies respond to the stability of the rules of the game rather than functioning as autonomous capabilities (Balza et al., 2020). Regional cooperation operates at a different, supranational scale, facilitating knowledge exchange and the harmonization of standards across countries.

Analyzing electrification through these capabili-

ties clarifies that visible and invisible infrastructure do not compete with one another; they reinforce each other. Every investment in generation, transmission, or distribution achieves its greatest impact when developed on the foundation of institutions capable of sustaining public policy, training professionals, attracting investment, and building trust. In this sense, invisible infrastructure does not replace physical infrastructure; it strengthens it. It acts as a multiplier of physical infrastructure: the more robust the enabling capabilities for electrification, the greater the impact of investments aimed at transforming the energy system.

This perspective is particularly relevant to Latin America and the Caribbean. The region has sufficient resources to play a leading role in the global energy transition, but it faces challenges related to regulatory stability, access to financing, the development of specialized talent, and coordination across levels of government. In a context of pronounced territorial asymmetries and limited resources, strengthening these capabilities can generate an impact comparable to that of a new investment in physical infrastructure.

The twenty-first-century energy transition will depend not only on the number of megawatts installed or the kilometers of grid built. It will also depend on countries' ability to strengthen the conditions that make those investments possible. Visible infrastructure enables electricity to reach people; invisible infrastructure enables that electricity to become development, resilience, and well-being.

Investing in both dimensions is not an either-or choice, but a necessary condition for Latin America and the Caribbean to turn their extraordinary energy potential into a genuine opportunity for sustainable development.

Conclusions

This paper proposed understanding differences in the pace of electrification across Latin America and the Caribbean through the concept of invisible infrastructure: the institutional and regulatory capabilities that support the electricity system's physical infrastructure. The evidence reviewed shows that regulatory autonomy and the quality of governance explain a substantial share of this

variation, beyond the availability of natural resources or capital (De Halleux, Estache, and Serebrisky, 2020; Balza et al., 2020; Andrés, Guasch, and Azumendi, 2008). The creation of regulatory institutions also follows a logic of political diffusion (Jordana and Levi-Faur, 2005), while marked heterogeneity persists across countries in planning capacity (Cerra et al., 2016; Georgoulas et al., 2018; ECLAC, 2025).

Countries with similar conditions achieve different outcomes depending on the strength of these enabling capabilities. Strengthening governance and the regulatory framework is therefore a central condition for the region to turn its energy potential into resilient, inclusive, and sustainable electrification.

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Youth, Education, and Continuing Training in the Regional Electricity Transition

A perspective on generational renewal, gender equity, and the demand for technical training to strengthen energy resilience in Latin America and the Caribbean.

The Structural Mismatch Between Tomorrow's Infrastructure and Today's Training

Discussions of the energy transition in Latin America and the Caribbean often focus on major infrastructure projects: wind farms, grid digitalization, or large-scale battery storage. Yet no infrastructure can sustain its autonomy if the human factor behind every kilowatt generated is neglected. More than a technological shift, regional electrification requires the thorough development of the skills of those who operate—and will operate—the system. From this perspective, incorporating the experience of traditional energy sectors such as hydrocarbons strengthens the electricity grid in the face of decarbonization challenges. Ultimately, the resilience of the future model will depend on mobilizing all available regional talent, linking existing knowledge with the creation of genuine leadership opportunities for young people.

Despite this aspiration, a clear timing mismatch remains: universities are rarely able to keep pace with the technological innovation demanded by industry. As the electricity mix shifts toward clean and decentralized models, rigid curricula hinder the inclusion of critical fields such as the circular economy, operational flexibility, and new regulatory frameworks. This dis-

ce between the classroom and the productive sector—which, according to ECLAC (2025), confines the region to isolated pilot initiatives—deepens external technical dependence. A contradictory labor-market phenomenon is thus taking shape: despite high levels of informality, energy companies cannot find qualified personnel, and more than 30% of the workforce is underqualified (ECLAC, 2025).

Under these circumstances, educating and training new generations extends beyond academia and becomes a pillar of energy security. Designing sustainable infrastructure requires equitable talent development and immediate attention to gender disparities in the sector. Although women account for 44% of participation in general sciences in the region, the figure falls to 28% among engineering graduates and to 22% in fields associated with the Fourth Industrial Revolution—a severe gap that affects STEMI enrollment (UN Women, 2022; UNESCO, 2024).

Dynamic Skills, Workforce Reskilling, and the New Youth Profile

The centralized fossil-fuel-based paradigm is shifting toward a model built on operational flexibility, variable renewable energy sources², and new energy carriers³. Managing this architecture requires young people to approach the transition from a systems perspective. Designing and assessing future energy markets requires mastery of digitalization, predictive analytics, and large-scale data management (IRENA, 2023)—skills that



complement and extend beyond the scope of traditional static mass and energy balances.

However, training people to decarbonize the energy mix does not mean eliminating conventional industry or discarding inherited knowledge. The literature on a just transition indicates that operational and engineering skills from the hydrocarbon sector provide an invaluable technical foundation for deploying solutions in the electricity sector, including the integration of complex grids and green hydrogen (Maissa et al., 2025; Philp & O’Neil, 2026). Continuing education therefore becomes an indispensable workforce-reskilling tool for professionals in the early and middle stages of their careers.

At the same time, this technical reconfiguration is insufficient unless accompanied by leadership and policy-influence capabilities (OLACDE & UNR, 2026). For new generations—and particularly women working in STEM—to break through the barriers to advancement described by the “leaky pipeline” phenomenon, technical training must be complemented by negotiation, project-management, and strategic-networking skills (UNESCO, 2024).

Regional Empirical Evidence on Youth Interest in Technical Training

To examine how these theoretical dynamics operate in practice, it is useful to analyze how young audiences respond to continuing-training initiatives in the region. Given the slow pace of curriculum reform, open virtual spaces serve as agile

indicators of the sector’s concerns.

In this context, the Global Academy for Energy Transition (Youth4energy) organized two complementary virtual activities in 2026: Webinar 1 (March 2026), entitled “Young Voices in the Energy Transition: Experiences from International Arenas”, focused on leadership, generational renewal, and participation in global networks; and Webinar 2 (June 2026), entitled “The End of Hydrocarbons? The Role of Sector Professionals in Energy Continuity”, focused on process engineering, technical analysis, and operational feasibility.

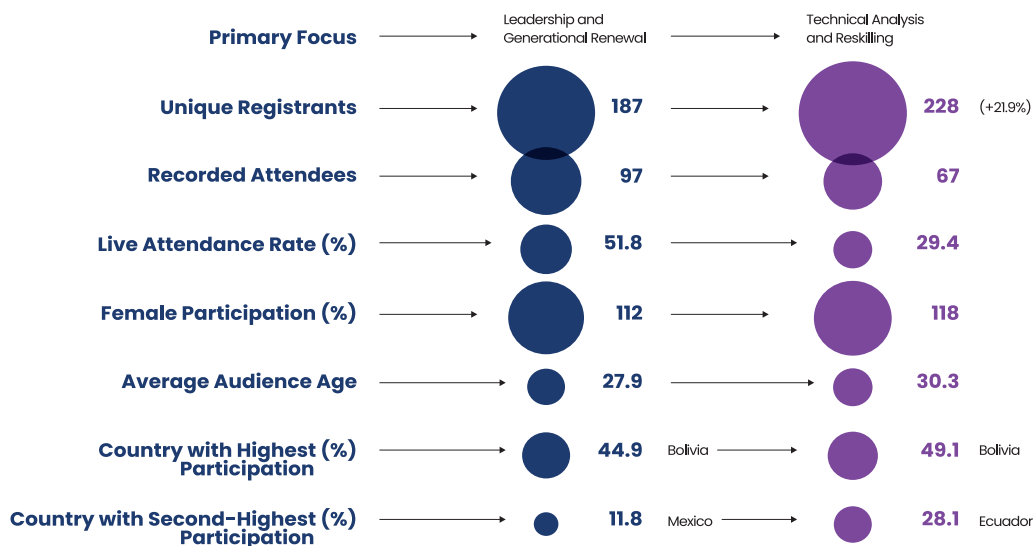
Table 1

The live attendance rate represents the proportion of registrants who attended the session in real time.

Although both events had regional reach, the audience ultimately became concentrated in specific countries. This characteristic prevents the metrics from being extrapolated to Latin America and the Caribbean as a whole. Nevertheless, analysis of the records provides useful elements for discussion:

- Concern about technical reskilling. Although the leadership event was more successful at retaining live attendees (51.8%), the event on hydrocarbons attracted 21.9% more registrants. This difference suggests that, beyond the general discourse surrounding the transition, there is concrete demand for understanding the operational transformations affecting professional practice.

Table 1

Comparison of youth participation in continuing-training activities

Note. Authors' own elaboration based on internal registration and attendance records for webinars organized by Youth4energy's Global Academy for Energy Transition (2026).

● Webinar 1 (March 2026) ● Webinar 2 (June 2026)

- Women's participation in engineering debates. Despite addressing a traditionally male-dominated field such as hydrocarbons, women represented 51.7% of registrations for the second webinar. This figure does not in itself indicate a reversal of structural gaps in STEM disciplines (UNESCO, 2024), but it does show that open virtual environments provide accessible spaces for technical exchange.

- Academic networks and social capital. The high proportion of participants from Bolivia (44.9% to 49.1%) and Ecuador (28.1%) reflects direct engagement with local contact networks, professionals, and engineers. Viewed through the lens of social capital (Coleman, 1988; Giacobelli, 2022), this suggests that direct outreach through trusted channels—such as academic community groups and direct messaging—may be more effective at mobilizing young audiences than broad, impersonal digital dissemination.

Toward Educational Governance Through Territorial Networks

Modernizing the energy mix of Latin America and the Caribbean requires more than financing infrastructure or importing technology. The critical factor to address is the speed at which local capabilities are developed to operate, maintain, and lead these new systems. If university offerings and public training policies remain disconnected from labor-market demands, the skills gap will compromise the region's technical autonomy.

In response to this challenge, academic institutions, the private sector, and regional organizations need to coordinate more flexible and decentralized training strategies (CAF et al., 2025). Exploratory evidence indicates that these initiatives become more effective when they rely on territorial networks and on the mediation of local educators and professionals who

act as connectors of social capital within their communities.

Likewise, advancing gender equity in STEM fields and creating effective decision-making spaces for young talent are key pillars of sustainable human capital (UNESCO, 2024). In this process, conti-

nuing education, professional reskilling, and the development of new regional leadership are indispensable for connecting conventional industry with the transition. Without a coordinated commitment to education and the effective inclusion of new generations, any decarbonization roadmap will risk losing its viability.

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Energy Transition *in Chile:* Achievements and Challenges of a System in Transformation

The Figures Behind the Transformation

Chile aspires to position itself as a leader in Latin America's energy transition, in line with its National Energy Policy¹, which establishes the goal of obtaining 100% of electricity generation from clean sources by 2050.

The figures suggest that the country is moving decisively toward this goal. As of July 2026, national installed capacity exceeded 40 GW: more than 50% corresponded to non-conventional renewable energy (NCRE)², 18.5% to hydropower plants, and 31% to thermal plants, against peak demand of 13.1 GW³. In 2025, NCRE supplied 44% of National Electricity System (SEN) generation⁴, and on May 10, 2026, it reached a record 88.4% of hourly generation, demonstrating the feasibility—albeit not without difficulties—of predominantly renewable operation.

This progress reflects sustained investment⁶, supported by lower wind and photovoltaic technology costs and by reduced barriers in contract markets and transmission. Investment in renewables reached nearly USD 3.695 billion in 2025 and could rise to USD 5.5 billion annually over the next five years⁷.

The expansion of NCRE has occurred in parallel with the gradual retirement of coal-fired power plants. To date, 2,674 MW of fossil-fuel capacity has been disconnected, with commitments to phase out most of the fleet by 2040 or earlier. In the face of this accelerated decarbonization, stora-

ge is the key enabling technology.

In this area, Chile has 2.6 GW of storage in operation, 3.1 GW under testing, and 4.2 GW under construction⁸, concentrated in the hybridization of solar projects to inject daytime surpluses into high-cost nighttime blocks.

These figures confirm a technological disruption rather than a simple evolution. They also reveal its strategic dimension: Chile imports 98% of the fossil fuels it consumes⁹, exposing it to volatility in international prices and availability. Consequently, local energy resources strengthen energy independence while supporting the reduction of greenhouse gas emissions.

However, electricity represents only 23% of national energy consumption, and fossil fuels remain the primary source used (65% of the 2024 energy mix¹⁰). One of the key actions for achieving carbon neutrality by 2050 is therefore to electrify end uses, yet growth in electricity demand has been modest. In 2025 it increased by only 0.4% relative to 2024, and weighted growth of approximately 3.2% is projected for the SEN.

The challenge of electrification will therefore be met only if we adopt certain public-policy decisions and ensure a secure, high-quality supply at reasonable prices.

Critical Bottlenecks in the Process

Technological transformation creates operational and market-design challenges. Several regulatory, governance, and operational shortcomings must



now be addressed without losing sight of costs for end users or the security and quality of supply.

a) Impact on System Security

The replacement of synchronous generation¹¹ by inverter-based variable renewable energy (VRE)¹² has reduced the electricity system's frequency robustness (inertia) and voltage robustness (short-circuit strength), weakening its ability to withstand disturbances. As a result, various studies^{13,14} recommend improving these resources to reduce the risks arising from unstable system behavior.

The blackout of February 25, 2025¹⁵, which left the country without electricity for more than seven hours, and the tight supply conditions preceding recent rainy seasons show that supply security is no longer merely a technical matter: it is a strategic requirement for decarbonization.

Storage and other technologies are therefore essential to mitigating these risks. However, the large-scale incorporation of storage with grid-forming¹⁶ capability and the design of an appropriate ancillary-services market¹⁷ remain under development. Progress is constrained by the lack of long-term operational data and by regulation based predominantly on administratively calculated costs set by the system operator rather than on a competitive price-discovery mechanism.

b) Storage and the Short-Term Market

Storage is expanding, driven by arbitrage opportunities, renewable-energy curtailment, and capacity payments guaranteed through

2034.

Nevertheless, storage scheduling, dispatch, and opportunity-cost calculation generate uncertainty and gaps between owners' expectations and the National Electricity Coordinator's (CEN) scheduling and dispatch decisions¹⁸. The task is complex: 9 GW of storage is expected to be scheduled and assigned opportunity costs by 2027, without comparable benchmarks or experience.

With a power mix of these characteristics, the "audited-cost" dispatch model is becoming increasingly difficult to administer. A transition to a competitive offer-based market is therefore urgent. Another challenge is reducing or eliminating inefficiencies that translate into system costs or side payments¹⁹, which have grown significantly and affect prices for unregulated customers²⁰ and, soon, tariffs for regulated customers.

c) Infrastructure Development and Tariff Distortions

Another bottleneck is the lag in transmission development and uncertainty regarding the optimal level of grid expansion. Among other factors, insufficient transmission infrastructure led to the curtailment of 6.084 TWh of clean energy in 2025, equivalent to 7.1% of annual generation and 16.2% of NCRE generation²¹. Critical projects such as the Kimal-Lo Aguirre line are indispensable, but their development presents challenges for both owners and public authorities.

According to CEN figures²², 52% of transmission expansion works²³ currently under

execution show some degree of delay. This figure has improved relative to previous years because Law No. 21,721 and other measures addressed certain obstacles affecting the development of these projects.

Meanwhile, the distribution regulatory framework—substantively dating from 1982—was designed for a one-way grid and passive customers. The segment must now be modernized to incorporate active bidirectional grids capable of integrating distributed generation and local storage, while also implementing flexible tariffs and promoting grid digitalization.

The final tariffs paid by Chileans also reflect complex past measures—such as the tariff freeze introduced in response to the 2019 social unrest and the pandemic—which created a USD 6.5 billion debt to suppliers serving regulated customers. This is compounded by delays in transmission and distribution tariff-setting processes, which result in costly retroactive adjustments.

Tariff normalization in 2024 led to significant increases for users, whose effects will continue until 2035. The experience has yielded an important lesson: price freezes create enormous distortions and appear to be more costly in the medium and long term. Together with ineffective tariff-setting processes, they increase public distrust, reduce transparency in electricity bills, and raise doubts about the benefits of the transition.

Toward Flexible and Continuously Adaptive Regulation

Chile can lead the region's energy transition as a model of cost-efficient decarbonization. The transition will be determined in the operational, regulatory, and institutional arenas.

It is essential to provide the National Energy Commission (CNE)²⁴ with greater autonomy and stronger technical capabilities, transforming it into an institution independent of political cycles. Regulatory processes must also be made more flexible, with *ex ante* and *ex post* evaluations, and oversight should shift from a punitive approach to one focused on compliance.

For the system operator, governance, predictive models, and the traceability of operational decisions should be improved. It is also urgent to minimize fragmentation in strategic planning²⁵ and adopt a single instrument that ensures continuity in public and private efforts and accountability for the goals the country has set.

At the regulatory level, grid adaptation must become more efficient; tariff signals should transfer the benefits of NCRE to users; the wholesale market should move from audited costs to offers; and the capacity market should be critically reviewed to ensure that it effectively remunerates the adequacy required by the system. As for security, minimum standards alone will not be sufficient: new services will likely be needed and should be allocated through market mechanisms that ensure efficiency.

Chile is not alone in facing the challenges described in this article; all countries, to a greater or lesser extent, are experiencing or will experience this process. Technological transformation is irreversible. The task is therefore to respond as ro-

bustly as possible, and doing so requires stronger spaces for collaboration that promote joint learning and the exchange of information and experience across the many dimensions of this complex yet fascinating process.

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Anexo Técnico de Exigencias Mínimas de Instalaciones Basadas en Convertidores que se coenctan al Sistema Eléctrico Nacional, de la Norma Técnica de Seguridad y Calidad de Servicio

Energy Alone *Is Not* Enough: We Need Flexibility

Latin America and the Caribbean are moving toward an increasingly renewable electricity mix, overcoming major challenges that technology is resolving step by step. Yet generating clean energy is no longer enough. The new challenge is to manage it intelligently and more efficiently over time by integrating storage, flexibility, and demand to build resilient electricity systems.

A Transition That Raises a New Question

For years, the conversation about a just energy transition focused primarily on one question: how can we generate more energy from renewable sources?

That question remains important. Indeed, diversified generation is becoming increasingly relevant across Latin American countries and receiving greater attention from public authorities—but it is no longer sufficient.

Latin America and the Caribbean have exceptional conditions for renewable generation and have made substantial progress in deploying it. In December 2025, approximately 65% of regional electricity generation came from renewable sources. During the same period, however, natural gas accounted for 22.8% of generation and continued to play an important backup role because of its operational flexibility.

This reality creates an energy-transition paradox: abundant renewable resources can coexist with a continued need for other sources to guarantee

that energy is available exactly when the system requires it.

We must no longer ask only how much clean energy we can generate, but also how capable we are of managing it intelligently and more efficiently over time. That is where the discussion of flexibility begins.

A flexible electricity system can respond to variations in generation and demand while maintaining balance, reliability, and security. This capability becomes increasingly important as the share of variable sources such as photovoltaic solar and wind power grows.

IRENA estimates that, by 2030, the global electricity system will require approximately three times the daily flexibility it needed in 2019 to efficiently manage variability in demand and in solar and wind generation.

This means that installing more renewable generation is only part of the challenge. The energy transition also requires stronger grids, storage, interconnections, intelligent demand management, digitalization, and new forms of user participation.

From Backup to Energy Management

For many years, discussing batteries in electricity systems meant discussing backup. The usual question was simple: how many hours can a facility continue operating if the grid fails?



That perspective is changing. Batteries remain an exceptional backup tool, but their true potential within the energy transition is far greater. Today they can store renewable surpluses, shift energy across different hours of the day, reduce demand peaks, facilitate self-consumption, provide stability services, and strengthen the resilience of critical facilities. In other words, they are becoming a fundamental component of intelligent and more efficient energy-resource management.

The International Energy Agency notes that battery storage is particularly well suited to providing flexibility over continuous periods of one to eight hours. Its response speed also allows it to contribute to electricity-grid stability within seconds.

A battery does not generate energy; it creates something that will become increasingly valuable for our electricity systems: control over timing. It allows us to decide when to use energy that has already been produced. That capability profoundly changes the energy paradigm.

Historically, electricity-system flexibility has been built primarily around large power plants capable of increasing or reducing output according to grid needs. The expansion of distributed generation, storage, smart grids, and the electrification of new end uses now makes it possible to build flexibility on the user side as well.

A home with photovoltaic generation and storage; a company capable of shifting certain loads; a business that manages its demand peaks; a microgrid; or a fleet of electric vehicles whose char-

ging responds to time-based signals can cease to operate solely as passive loads.

In 2025, OLACDE estimated regional storage capacity at approximately 2.5 GW, including about 1.5 GW of battery energy storage systems (BESS) and 1 GW of pumped-hydro storage. Chile, Brazil, and Mexico are among the countries advancing its deployment, while other economies still face regulatory and financial barriers.

The diversity of our electricity systems makes one-size-fits-all solutions inappropriate. The flexibility needed by a large interconnected system will not necessarily be identical to that required by a small grid, such as an island, a rural community, an industrial facility, or a Central American electricity system. Although the region faces similar needs, each country must tailor its solution to its own energy priorities, demand growth, economic and operational dynamics, and stage of national development. Precisely for this reason, distributed generation and storage create an opportunity to decentralize part of the electricity system's response capability as well.

Storing Energy to Close the Loop

This transformation becomes even more relevant when we consider the progress of electrification. Electrifying transport, industrial processes, heating and cooling, and other uses traditionally dependent on fossil fuels will increase electricity demand. Yet truly sustainable electrification also requires us to ask where that new electricity comes from and when it is consumed.

The electric vehicle provides a useful example. Electrifying transport reduces its direct dependence on fossil fuels, but the environmental and energy benefits can be strengthened if charging is coordinated with renewable generation and energy-management mechanisms.

This gives rise to the concept of Closing the Sustainable Charging Loop: generating renewable electricity in a distributed manner, storing it when necessary, and using it later to serve new electrical loads, including mobility.

Solar energy produced during peak irradiation hours need not be consumed at that same moment. Storage creates a temporal bridge between generation and demand. The principle seems simple, but it transforms the logic of the system. Users no longer assess only how much energy they generate; they begin to evaluate when they generate, consume, and store it, and when it is most advantageous to use it. In this way, the system becomes more efficient and strengthens the development of the sustainable ecosystem as a whole.

The Challenge Is Not Merely Technological

The technologies needed to advance already exist and continue to evolve. The real regional challenge is to create conditions for using them efficiently and in an economically sustainable manner. The International Energy Agency estimates that, to support the global goal of tripling renewable capacity by 2030 while maintaining

electricity security, global storage capacity would need to increase sixfold to approximately 1,500 GW.

However, simply installing energy-storage systems is not enough to solve this challenge. The process requires rigorous planning, precise identification of needs, and technical-economic analysis to support investments in each application sector.

Economic signals that recognize the value of flexibility are equally essential. In El Salvador, these solutions have been increasingly integrated in recent years, driven both by the need for backup during outages and by the search for more efficient energy management.

In this context, countries across the region must consolidate regulatory frameworks that define the conditions under which storage and distributed energy resources can participate in electricity markets. As a priority, local technical capabilities should be developed by strengthening the personnel responsible for project implementation and training decision-makers, provi-





ding them with the theoretical foundations needed to deploy effective solutions. Finally, this energy-transition process must be organized around an equitable

approach that does not deepen existing inequality.

Flexibility should not become a privilege available only to those who can purchase technology. It should be progressively incorporated into energy planning as a tool for improving resilience, security, competitiveness, and access. This point is especially important in Latin America and the Caribbean, where large electricity systems coexist with isolated territories, vulnerable communities, highly energy-intensive industries, and countries at very different stages of regulatory development.

The regional energy transition will require technology, but also institutions capable of evolving at the same speed as that technology.

During the first stage of the energy transition, we learned to produce renewable electricity with increasing competitiveness. The next stage—which is already under way—is learning to manage it intelligently and more efficiently.

Energy storage is one of the most important tools for doing so, but it must be understood as part of a broader flexibility ecosystem that includes distributed generation, demand management, digitalization, smart grids, interconnections, and electrification.

The objective should not be to install batteries simply because the technology is available. It should be to build electricity systems capable of responding intelligently to a far more dynamic, decentralized, and electrified energy reality.

For Latin America and the Caribbean, this represents an extraordinary opportunity. Our renewable wealth can become an even greater advantage if we can manage not only how much we generate, but also when we use that energy and what we use it for.

The energy future of our region will not depend only on how many renewable megawatts we install. It will depend on our ability to turn those megawatts into energy available at the right time, in the right place, and for those who need it most.

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"We are driving the energy of the future by **advancing electrification and fostering equity across the sector**—commitments that we at OLACDE champion to transform our region."

Photovoltaic-Powered *Irrigation to Improve* Subsistence Agricultural Productivity in Rural Communities in Guatemala

INTRODUCTION

Subsistence agriculture in Guatemala is highly dependent on seasonal rainfall. This condition interrupts agricultural production during dry periods and increases small-scale farmers' exposure to crop losses (Allen et al., 2006). In La Candelaria village, Taxisco, Santa Rosa, water availability is essential to maintaining agricultural production and reducing the vulnerability of families that depend on it. Irrigation provides an alternative for reducing this dependence and sustaining food security among people without regular access to vegetables. The National Irrigation Policy 2024–2033 proposes capturing and storing water during the rainy season for use in the dry season, with the aim of increasing production and the number of production cycles (MAGA, 2024), while expanding access to irrigation technologies, particularly for small-scale and subsistence producers.

Access to energy is another condition that must be considered in rural areas far from urban centers. The Ministry of Energy and Mines estimated that 91.74% of the population had access to electricity in 2025, while some communities still required electrification projects (MEM, 2025). In such locations, conventional pumps may constrain implementation of irrigation systems. This is especially relevant during the dry season, from November to April, which represents half of the year in Guatemala and interrupts production cycles for some crops, particularly subsistence crops.

Photovoltaic-powered pumping offers an alterna-

tive for decentralized irrigation systems. IRENA indicates that solar pumping can provide power for irrigation services, help reduce vulnerability to changes in rainfall patterns, and, under certain conditions, lower fuel-related expenses (IRENA, 2016). The proposed pilot project in La Candelaria village directly supports Sustainable Development Goal 2, particularly targets aimed at increasing the productivity of small-scale producers and promoting sustainable, drought-resilient agricultural practices (United Nations, 2026), as well as the “Zero Hunger” goal by reducing vulnerability associated with the country’s prevailing malnutrition rates.

OBJECTIVE

To propose a basic solar-powered system to improve subsistence agricultural productivity in a Guatemalan community.

METHODOLOGY AND SYSTEM DESIGN

Area of Application

The proposed pilot project for La Candelaria village, Taxisco, Santa Rosa, Guatemala, examines agricultural-production conditions, water availability, access to electricity, and the financial capacity of small-scale producers. The projected irrigation area covers four manzanas of rural land for growing maize, watermelon, sesame, and cattle pasture (one manzana is approximately 7,000 m²).

For the economic assessment, a pump of approxi-



mately 2 HP is considered. Its estimated consumption is 1.5 kW; operating six hours per day, this represents approximately 9 kWh daily and 270 kWh monthly. Using the tariff values in the original proposal, this is equivalent to approximately Q405 per month at Q1.50/kWh and Q594 at Q2.20/kWh. These values should be validated against current tariffs and the service arrangement applicable at the pilot site.

System Components

The system will consist of a photovoltaic-panel array, a controller or regulation unit, a submersible pump, an optional storage tank, and a drip-irrigation system, depending on the crop type and its water requirements.

The photovoltaic array's capacity and the pump rating will not be set at fixed values; they must be determined from crop water demand, required flow rate, total dynamic head, system efficiency, and solar-radiation conditions at each study site.

A storage tank may serve as a complementary component that facilitates water availability and distribution to crops. Drip irrigation applies water in a controlled manner to the crop's root zone and reduces losses associated with inefficient distribution. The irrigation method is selected according to crop type and water requirements.

Sizing

Sizing begins with determining the crop's water demand. Crop evapotranspiration is estimated as follows:

$$ET_c = ET_o \times K_c$$

where ET_c is crop evapotranspiration, ET_o is reference evapotranspiration, and K_c is the crop coefficient. This relationship is used in the FAO methodology to estimate crop water requirements (Allen et al., 2006).

The required flow rate and operating hours are determined from the water demand. The required hydraulic power is then calculated:

$$Ph = \rho \times g \times Q \times H$$

where ρ is water density, g is gravitational acceleration, Q is flow rate, and H is total dynamic head. Electrical power depends on pump-motor efficiency. These results are used to determine installed capacity, the number and rating of panels, pump specifications, piping, and, where applicable, tank volume. For La Candelaria village, four panels were installed on a simple galvanized-metal structure coated with zinc to prevent corrosion and extend service life, as the project is located 200 meters from Guatemala's Pacific coastline.

Total dynamic head must account for the static water level, drawdown, elevation to the irrigation point, friction losses, and losses associated with filters and sprinklers.

Economic Assessment

The economic assessment examines initial investment and operation and maintenance costs. Direct costs include photovoltaic panels, the

pump, inverter or control equipment, piping, a tank (not included in the pilot), a drip-irrigation system (not included in the pilot), and labor. Indirect costs include design, transport, supervision, and contingencies. The energy cost of the photovoltaic array is also compared with the estimated cost of operating a pump using grid electricity or fuel. This comparison makes it possible to estimate the payback period and identify the economic conditions under which the photovoltaic alternative is favorable.

EXPECTED RESULTS

Implementing the system provides water for irrigation during drought periods and reduces direct dependence on rainfall. The optimal technical outcome is a pumping system sized according to crop water demand and site hydraulic conditions, significantly contributing to rural communities' adaptation and resilience to climate change and historically rising temperatures. The pilot system was installed in three hours over a previously constructed artisanal well nine meters deep, with the water table at six meters and an available water column of approximately three meters.

This infrastructure mitigates drought-related losses and supports stable agricultural cycles, since a controlled water supply preserves the cultivated area during periods that traditionally depend on rainfall. As shown in the photographic annex, the pilot unit supplies water continuously and immediately through a two-inch pipe.

From an economic perspective, the system reduces operating costs associated with water pumping, particularly where alternatives involve high public-utility tariffs or fossil-fuel use. The financial assessment considers initial capital cost, maintenance expenses, energy savings, and investment payback.

The pilot project makes it possible to assess the feasibility of small-scale photovoltaic systems as a highly promising irrigation alternative for rural communities with severe energy-infrastructure constraints. Its results can serve as a reference for adapting the solution to other communities with similar conditions.

FINAL REMARKS

Reliance on seasonal rainfall represents a constraint on the stability of subsistence agriculture. The incorporation of irrigation can reduce this dependence and help maintain production during the dry season, aligning with the objectives of the 2024–2033 National Irrigation Policy.

Photovoltaic pumping offers an accessible alternative that can be technically suitable for rural communities with limited power grid access or where pumping costs exceed the population's economic means. The viability of a project depends on sizing the water demand, the capacity of the water source, flow rate, total dynamic head, system efficiency, and solar radiation conditions in the study area.

The proposal for the village of La Candelaria,

Taxisco, Santa Rosa, provides clear and straightforward evidence for replicating these systems, allowing for the evaluation of the technical, economic, and productive aspects of photovoltaic

irrigation. In a subsequent phase, field measurements must be incorporated to revalidate and assess productivity and determine the full benefits of the system.

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Annex

Annex 1. Photographs of the pilot project developed in the village of La Candelaria, Taxisco, Santa Rosa, Guatemala.



"The growing presence of women in energy strengthens the entire value chain, **bringing the knowledge, leadership, and innovation** needed to propel the sector's transformation."

Beyond *Diversification:* Jamaica's Road to a Resilient Energy Future

Jamaica has made meaningful progress toward energy diversification through LNG, renewable energy, storage, and regulatory reforms. However, achieving a resilient, affordable, and secure energy future will require faster renewable deployment, loss reduction, strategic electrification, grid resilience investments, and balanced system planning.

A Vision That Remains Relevant

Jamaica's National Energy Policy 2009-2030 established one of the most ambitious energy-sector transformation agendas in the Caribbean. The policy sought to reduce the country's longstanding dependence on imported petroleum through fuel diversification, renewable-energy development, energy efficiency, and infrastructure modernization.

The vision was clear: a modern, diversified, efficient, and environmentally sustainable energy sector capable of providing affordable, accessible, and secure energy. Initially, the policy targeted renewable energy to contribute 20 per cent of the national energy mix by 2030 while emphasizing security of supply, governance reform, conservation, and industrial competitiveness.

Jamaica's heavy reliance on imported petroleum exposed the country to fuel-price volatility, foreign-exchange pressures, supply-chain disruptions, and geopolitical uncertainty. Energy diversification therefore became a critical component of national resilience and economic competitiveness rather than solely a climate objective.

Over time, natural gas emerged as the principal transition fuel for electricity generation, while the Government increased its ambition by establishing a target for renewable sources to provide 50 per cent of electricity generation by 2030.

Nearly two decades after the policy's introduction, Jamaica has achieved meaningful progress. Yet improvements in renewable-energy penetration, affordability, operational efficiency, and system resilience have not advanced at the pace required to achieve national targets. At the same time, recent global disruptions and increasingly severe climate events have reinforced a critical lesson: energy transitions cannot be measured solely by diversification of generation fuels. They must create energy systems that are affordable, reliable, resilient, and capable of supporting long-term economic development.

Progress Since 2009

Jamaica's electricity sector operates under a single-buyer market structure. Jamaica Public Service Company Limited (JPS) serves as the licensed transmitter, distributor, system operator, and retailer, while electricity generation is supplied by both JPS and independent power producers under long-term power-purchase agreements.

This framework has supported significant private-sector investment and facilitated a reduction in the country's near-total historical dependence on liquid petroleum fuels. The introduction of liquefied natural gas (LNG) represented a major milestone in the



diversification process by lowering emissions and heat rates relative to oil-fired generation.

LNG has also enabled self-generation opportunities within energy-intensive sectors, particularly tourism and manufacturing. While these developments have enhanced energy options for large consumers, growing self-supply arrangements highlight the need to carefully balance customer choice with the long-term financial sustainability of the national grid.

Renewable-energy deployment has also expanded. Approximately 155 MW of utility-scale wind and solar capacity has been developed, while renewable energy currently contributes approximately 12 per cent of electricity generation on an energy basis. Although this represents significant progress compared with 2009, the country remains well below its 2030 objective.

Advances have not been limited to generation. In 2019, JPS commissioned a 24.5 MW hybrid energy-storage facility combining flywheel and lithium-ion battery technologies. The facility has demonstrated the importance of storage in supporting frequency regulation, responding rapidly to fluctuations in renewable output, and improving overall grid stability.

Customer participation in the energy transition has also increased through distributed renewable generation. Under the Net Billing Programme, households and businesses may generate electricity for self-consumption and export surplus production to the grid. As of July 2026,

more than 1,300 licences had been issued under the programme, representing approximately 28 MW of installed capacity.

Electrification initiatives have similarly gained momentum. Electric-vehicle adoption continues to grow, supported by expanding charging infrastructure and public-policy incentives. The emergence of electric mobility represents an important opportunity to reduce petroleum consumption while increasing productive electricity demand across the national grid.

Institutionally, the sector has benefited from important regulatory reforms, including the implementation of the Electricity Act 2015 and the development of Integrated Resource Planning. Jamaica's Integrated Resource Plan (IRP) provides a long-term framework for generation expansion and establishes a structured approach to balancing reliability, affordability, and sustainability objectives.

Collectively, these developments have created an important foundation for Jamaica's next phase of energy-sector transformation.

The Remaining Performance Gap

Despite substantial progress, the gap between current performance and stated policy objectives remains significant.

The Integrated Resource Plan identifies the need for approximately 750 MW of additional

renewable generation and 264 MW of energy-storage capacity to achieve the national target of 50 per cent renewable energy by 2030. However, project development and procurement have progressed more slowly than anticipated.

Although the Government awarded licences for 100 MW of renewable generation following a competitive process in 2025, this represents only a small portion of the capacity required. Additional procurement rounds for renewable generation and storage, together with replacement generation projects identified within the IRP, remain subject to timing and implementation uncertainty.

These delays have generated concern among investors and developers seeking greater clarity regarding future procurement opportunities and project timelines. Accelerating deployment will require coordinated action across multiple areas, including procurement, financing, environmental approvals, transmission planning, interconnection processes, and construction delivery.

The challenge extends beyond renewable deployment. Affordability remains one of the most significant barriers to achieving the broader objectives of the energy transition.

System losses of approximately 27 per cent, with an estimated 80 per cent attributable to electricity theft and unauthorized connections, continue to impose substantial costs on customers and the wider economy. High losses increase the amount of electricity that must be generated, purchased,

and financed, thereby undermining affordability and reducing overall system efficiency.

The impact extends well beyond the electricity sector itself. High energy costs discourage investment in emerging industries that depend upon reliable, competitively priced electricity, including digital services, advanced manufacturing, logistics, and data-centre operations.

Reducing losses must therefore be viewed not only as a utility objective but as a national economic priority. Achieving the Government's target of reducing losses to 12.3 per cent by 2035 will require sustained collaboration among government, regulators, utilities, law-enforcement agencies, communities, and consumers.

Ultimately, the success of Jamaica's energy transition should not be measured simply by megawatts installed. The more relevant indicators are affordability, reliability, efficiency, security of supply, and economic competitiveness.

Making Resilience a Core Design Principle

For small island developing states, resilience must become a central criterion for energy-transition planning.

An effective transition creates a system capable not only of reducing emissions but also of absorbing shocks, restoring service rapidly, and adapting to changing conditions. Resilience cannot be treated as an outcome that

follows renewable deployment; it must be integrated into planning, engineering standards, investment decisions, and operational practices from the outset.

Recent hurricane impacts have underscored the vulnerability of energy infrastructure throughout the Caribbean. Generation assets, renewable-energy facilities, transmission networks, substations, telecommunications systems, and digital-control platforms are all exposed to increasingly severe climate-related threats.

Strengthening resilience, however, presents a difficult policy challenge. Grid hardening, infrastructure reinforcement, and disaster-recovery investments can improve reliability but often increase customer costs. For a country already facing relatively high electricity prices, achieving the appropriate balance between resilience and affordability is essential.

A risk-based planning framework can help address this challenge. Investments should be prioritized based on the probability and consequences of infrastructure failure, ensuring that available resources are directed toward assets and communities facing the greatest exposure to risk.

A Dual Strategy for Energy Sector Transformation

Jamaica's next phase of energy sector development will require coordinated action on both the supply and demand sides of the elec-

tricity system.

On the supply side, achieving national energy transition objectives will require a significant acceleration in the procurement and deployment of renewable energy and energy storage resources. At the same time, future system planning should include investments in gas-based thermal generation to provide operational flexibility, maintain adequate reserve capacity, support higher levels of renewable energy integration, and ensure the continued reliability and security of the island's electricity grid.

Equally important is the work of a National Task Force in advancing initiatives aimed at substantially reducing system losses. Non-technical losses should be viewed as one of Jamaica's most cost-effective energy resources. Every kilowatt-hour recovered through improved metering, enhanced enforcement, greater operational efficiency, and the reduction of unauthorized consumption reduces the need for additional generation investment and fuel imports while improving the overall performance of the electricity sector.

Demand-side transformation is also critical to achieving a sustainable and resilient energy future. Increased electrification presents an opportunity to reduce direct fossil fuel consumption, stimulate productive electricity demand, and improve the overall economics of the power system.

The transportation sector should remain a

priority, particularly high-utilization segments such as public transport fleets, government vehicles, and commercial operators. Electrification in these areas offers the greatest potential for fuel displacement while creating stable and predictable growth in electricity demand. Additional opportunities exist within the building and industrial sectors through the adoption of more efficient cooling technologies, industrial processes, and commercial equipment.

However, policymakers must also carefully manage the risk of increasing grid defection. A large-scale migration of customers away from the electricity network could transfer costs to remaining consumers and undermine the financial sustainability needed to support future grid investments. Establishing a balanced policy framework that encourages distributed energy resources while preserving the economic viability of the national grid will therefore be essential to ensuring a successful and equitable energy transition.

Conclusion

Jamaica's energy transition has delivered meaningful gains in diversification, governance reform, renewable-energy development, and private-sector participation. Yet diversification alone is not the final objective.

The country's next challenge is to transform these achievements into a resilient, affordable, and modern energy system capable of supporting future economic growth. Ultimately, progress should be judged by measurable outcomes: imported fuel displaced, electricity losses reduced, customer costs lowered, outage impacts minimized, essential services maintained, and communities made more resilient.

That is the true measure of a successful energy transition and the standard by which Jamaica's energy future should be evaluated.

"Electrifying Latin America and the Caribbean is about **connecting communities, unlocking potential**, and bringing new voices together to shape our energy future."

Energy for all, *decided by all:* inclusion, equity, and participation in energy access

Beyond the Kilowatt

For decades, talking about "energy access" meant talking about infrastructure: transmission lines, utility poles, electricity meters. That view, while necessary, is insufficient today. A connected household does not guarantee that energy is affordable, reliable, and sufficient for productive uses, nor that the family or end user had a voice in how the system supplying them was planned. Full access is a condition for exercising other rights—such as health, education, decent work, and safety—not an end in itself.

This is why it is useful to distinguish among three concepts that are often mentioned together: inclusion, equity, and participation. Inclusion asks who is kept in and who is left out of the system; equity asks how costs and benefits are distributed among those already inside; participation asks who decides. A system can expand coverage while simultaneously reproducing tariff injustices or leaving entire communities out of decision-making. These three pillars must advance together.

These three pillars are often grouped under a just energy transition: ECLAC, for example, calls for the transition to incorporate citizen participation, respect the rights of local and indigenous communities, and integrate a gender perspective across all its stages (Economic Commission for Latin America and the Caribbean, 2025). Here, I prefer to address them separately, because only then do the tensions that arise among them become visible.

Inclusion: Closing the Gap for Those Still Left Out

Energy inclusion begins by acknowledging energy poverty, a multidimensional phenomenon that goes far beyond having or not having a connection. It occurs when accessing the energy required for a dignified life forces a tradeoff, or is simply impossible. This silent deprivation almost never appears in coverage statistics, hiding a large part of real exclusion.

In our context, the gap has concrete faces: scattered rural communities with difficult topography, suburban neighborhoods with high levels of informal connections, female-headed single-parent households, and users whose ability to pay is so low that no conventional commercial scheme reaches them.

The Dominican Republic clearly illustrates this distance between connection and full access. Electricity coverage currently exceeds 98%: barely 64,144 households—1.72% of the population, concentrated in rural areas—remain without a grid connection, and the State aims to reach 99.5% by 2030 (Araujo, 2025). Yet this near-universal coverage coexists with two signs that access is far from equitable. The first is losses, and the second is affordability: over 543,000 families rely on the targeted Bonoluz subsidy to afford consumption of up to 100 kWh per month (MEM, 2024). Connection is nearly resolved; equity and the sustainability of distribution are not: having a meter is not equivalent to having access.



Gender deserves specific attention. The lack of modern energy hits women hardest, as they bear time- and energy-intensive caregiving and domestic tasks; furthermore, inequalities persist in their economic and political participation within the sector (Dialogue Earth, 2025). Hence, a shift in perspective is gaining ground: moving away from viewing women as a group to be included, and recognizing them as key actors in the transition.

Closing this gap requires combining tools. Grid expansion will remain key where viable, but distributed generation, off-grid systems, and microgrids arrive faster and cheaper where the conventional grid would take years. Even so, technology is only half the answer; the other half is the institutional design that supports it.

Equity: Fairly Distributing Costs and Benefits

Expanding access is not enough if the system unfairly distributes what it costs and what it produces. Equity has two sides: distributive equity—how burdens and benefits are allocated—and procedural equity—whether the rules of the game were fairly constructed.

Subsidies illustrate this tension well. Nearly 74% of countries in the region have some mechanism to subsidize consumption, but many are poorly targeted toward vulnerable populations, providing temporary relief without addressing the root problem (Redalyc, 2023). Equity requires the opposite: smart targeting and well-designed social tariffs, a tool with a long regional track re-

cord (OLADE / Canese, 2013).

The energy transition adds a less obvious layer. Rooftop solar generation with net metering primarily benefits those with capital to invest: higher-income households and businesses. If those users reduce their contribution to the fixed costs of the grid while continuing to rely on it as a backup, those costs are shifted onto those unable to invest—low-income consumers. This is the cost-shifting problem: not an argument against distributed energy, which is necessary, but a warning that, without good regulatory design, the transition can widen the very inequalities it claims to combat.

Hence the concept of a just transition. Decarbonization is not merely changing the generation matrix: it is ensuring that benefits—jobs, cleaner air, stable prices—reach lagging communities as well, and that burdens do not fall on those least able to absorb them (Oxfam, 2025). It is also a politically fragile process: in Argentina, a framework that defined inclusion in 2021 as universal and equitable access was reduced a few years later to a simple emissions target (Oxfam, 2025). Equity, if not institutionalized, can be reversed.

Participation: From Passive Consumers to Active Agents

The third pillar transforms the role of the citizen. For a long time, the user was a passive receiver: paying for and consuming whatever arrived. The new paradigm transforms the user into an active agent, operating on two levels.

The first level is participation in the system: the prosumer generating their own energy, energy communities producing and sharing electricity, cooperatives, and collective self-consumption. These models democratize generation, retain economic value within territories, and foster local ownership of infrastructure. The Dominican Republic already has living examples: community micro-hydroelectric plants operate under a model where neighbors participate at every stage, contributing labor and resources while managing the system technically and administratively (Global Voices, 2026); in Elías Piña, solar projects sustained by local committees have opened up economic opportunities, particularly for women (Diario Digital RD, 2026).

The second level is participation in decision-making: who defines expansion plans, how tariffs are set, and what priorities guide public investment. Many decisions affecting daily life are made not in capital cities, but at the municipal level (Climate Reality, 2026), and social dialogue—including the voice of sector workers—is an essential link (ISTAS). Deliberative mechanisms such as mini-publics—randomly selected citizen bodies assembled to deliberate on energy matters—are even being tested (Oxfam, 2025).

Real participation, however, cannot be a symbolic formality. It requires accessible information, adequate timeframes, and mechanisms where citizen input meaningfully influences outcomes. Convening a community after decisions have already been made is not participation: it is tokenism.

Persistent Barriers

Recognizing the goal does not remove the obstacles. Low-income households face upfront capital barriers even when investments are profitable in the long run; regulatory frameworks designed for a centralized model are slow to accommodate energy communities, net metering, or collective self-consumption; information asymmetry leaves vulnerable users without tools to claim their rights; and a lack of coordination among regulators, planners, distributors, and system entities fragments programs. None of these barriers are technical: all are matters of institutional design.

A Possible Path Forward

No single pillar can be resolved in isolation. Planning with disaggregated data is the starting point—one cannot include what is not measured (ECLAC, 2021); on that foundation, every tariff, incentive, or subsidy should be evaluated for its distributive impact before approval, and participation must be a structural component of planning rather than an occasional gesture. Only then can citizens view themselves as co-authors of the transition rather than merely its recipients.

Conclusion

Energy is infrastructure, yes, but it is also a social contract. How a country chooses to include the excluded, distribute the costs of its transformation, and open decision-making speaks volumes about the society it aspires to be. A transition that

only changes the generation source while leaving inequalities in access, distribution, and participation intact will have changed nothing more than the technology. The challenge is ensuring that the energy of the future is both cleaner and fairer.

Near-universal coverage was the achievement of one generation. The question facing ours is different: Access just to turn on a light, or access to live better? How we answer will determine just how fair our transition really is.

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Beyond *Generation:* Sustainability in the Energy Sector

Latin America discarded 53,000 GWh of renewable energy in 2024 due to an inability to make use of it. The challenge is no longer merely generating clean energy, but bridging the mismatch between generation and consumption.

The Blind Spot of the Metric

When discussing sustainability and emissions in the power sector, attention is generally focused on the percentage of renewables in the energy matrix, rather than how much of that energy actually gets used. This is a supply-side metric applied to a system-wide problem.

This is why it is essential to link the sector's sustainability by considering the entire value chain: generation, transmission, distribution, and commercialization. This distinction is not merely conceptual. The goal of achieving net-zero emissions by 2050 puts the full value chain to the test, as electricity and heat generation represent the single largest source of global emissions—accounting for 33.6% of total global greenhouse gas emissions according to 2023 data (World Resources Institute, 2026). This makes it a central pillar of any roadmap designed to remain within the global warming limits defined by the IPCC.

It is worth highlighting that the energy transition is characterized by the "3Ds": "Decarbonization," addressing the challenge of integrating renewable energy; "Digitalization," applying digital asset and information management to the grid; and "Decentralization," shifting from centralized to distributed generation.

Public debate usually focuses on the first. This article addresses the other two, as they operate directly on the problem that follows.

The Mismatch and Its Cost

Decarbonizing generation is necessary, but insufficient. The variability of renewable energy sources creates a mismatch between generated power and demand.

In Latin America and the Caribbean, this tension between generation and utilization represents a measurable loss. The region loses approximately USD 7 billion annually (OLADE, 2025) due to renewable energy curtailment: hydroelectric, wind, and solar electricity generated by power plants that is discarded due to a lack of reservoir storage capacity, grid constraints, or insufficient demand. According to the technical document by the Latin American Energy Organization, renewable energy waste in the region reached nearly 53,000 GWh in 2024, equivalent to 3.2% of total annual generation.

Why does this happen? Renewable energy fluctuates in availability, creating a temporal mismatch. Additionally, centralized generation requires coordination of the transmission system to prioritize renewable sources when available.

- Temporal mismatch: Peak generation does not coincide with peak consumption.
- Spatial mismatch: Power is generated far from where it is consumed. Spatial mismatch



Table 1

The Mismatch: Generation and Consumption Do Not Fit

Temporal	Spacial
Generated when it is not consumed	Generated far from where it is consumed

Summary of temporal and spatial mismatch. Source: Authors' own elaboration.

did not originate with renewables, but it becomes a decisive factor with them.

It should be noted that this observation is not an argument against renewable technologies. No energy source is perfect; in fact, the goal of any energy policy is to find the ideal balance to provide reliable, clean, and affordable energy.

The following alternatives are proposed to overcome these mismatch barriers, reduce renewable energy curtailment, and improve overall system sustainability.

Alternatives to Reduce the Mismatch

Solutions Addressing the Temporal Mismatch

Energy storage provides a way to store surplus renewable energy and avoid waste: it moves energy across time. Battery Energy Storage Systems (BESS) have become one of the most versatile tools for providing short-term flexibility to the power system, typically shifting energy consumption by 2 to 4 hours. Hydrogen is another alternative that allows

energy to be stored over longer periods, serving as a complement to batteries.

On the demand side, dynamic tariffs are a known practice, but so far they have demonstrated limited impact, as user habits are not easily adaptable. A tariff pilot conducted by the Brazilian distributor Energisa showed that even with tariffs up to ten times higher during peak hours, residential consumers barely altered their consumption habits, demonstrating that price signals alone are insufficient without automation (Eixos, 2026).

To address this limitation, home automation can be deployed to reduce or eliminate the human factor. Germany is already applying this: since 2024, its Energy Industry Act (Section 14a of the EnWG) mandates the connection of residential appliances such as electric vehicle chargers or heat pumps, enabling grid operators to automatically throttle their consumption during overload risks without relying on voluntary user action.

In industry, automation is a solution adopted for over 40 years, yet it faces operational challenges that limit its flexibility regarding dynamic tariffs or peaks in energy supply. Against this backdrop, an emerging alternative has appeared:



humanoid robots. An example can be seen in companies operating on one or two shifts, concentrating their most energy-intensive processes without considering periods of higher resource availability or lower cost. Shifting these activities to other times would require enabling an additional shift or dynamically reorganizing the workforce—options that are rarely viable due to associated costs and existing labor regulations. In this scenario, automation via humanoid robots provides the required flexibility: they complement standard working hours and allow energy-intensive operations to be shifted to hours with higher renewable supply or more competitive tariffs.

This establishes a new paradigm: energy availability, rather than just workforce availability, begins to dictate when production occurs, helping narrow the temporal mismatch.

While this technology is still emerging and

lacks widespread adoption, successful use cases exist—such as BMW, which has completed a year of real-world operation using humanoid robots in the production of over 30,000 vehicles. This demonstrates that the leap from proof-of-concept to the production line has already been achieved. Although technical and cost constraints still limit widespread adoption, capital invested in the industry tripled between 2023 and 2025, reaching US\$ 40.7 billion annually.

Solutions Addressing the Spatial Mismatch

The solution is not aimed at transporting energy better, but at bringing supply and demand closer together. Distributed Generation (DG) refers to electric power generated from renewable sources directly at the point of consumption by users connected to the distribution network.

One of its main benefits is avoiding transmission losses. Over the last three decades, approximately 17% of the energy generated in Latin America and the Caribbean was lost in transmission (IDB, 2024). Every kWh generated at the point of consumption is a kWh that does not pass through that transmission chain.

Additionally, it reduces the need for investment in power grids and storage. Distributed generation does not require that infrastructure because it does not use it.

Finally, distributed generation decentralizes the system and improves security of supply: a network

with distributed generation is less vulnerable to the failure of a single asset or transmission line. Nonetheless, while distributed generation resolves spatial mismatch, it leaves temporal mismatch untouched and, if expanded without coordination, can even aggravate it. It is therefore relevant to combine it with storage at the same point of consumption. The Brazilian experience, analyzed below, follows precisely this trajectory.

Accelerating Sustainability in the Energy Sector

It is possible to combine several of the proposed alternatives to address both the temporal and spatial mismatches of renewable energy. For instance, a distributed generation system with storage at the point of consumption can be deployed. Adding automation to shift consumption toward hours of peak generation improves the equation even further.

However, it is worth clearly stating what these combinations accomplish beyond efficiency: every MWh of avoided curtailment is a MWh of clean energy that was already generated and would otherwise be replaced by firing up a thermal power plant to support the grid. Closing the mismatch is not merely a system issue; it is directly the difference between meeting or failing the emissions targets outlined at the beginning of this article.

The region itself demonstrates that this outcome does not depend solely on technology. Under Law 27.424, Argentina barely exceeded 59 MW

of installed distributed generation by December 2024. Brazil, during the same period, had accumulated 43.5 GW across 3.87 million connected systems in 5,565 municipalities—a three-order-of-magnitude difference explained neither by solar resource availability nor battery costs, but by Law 14,300, the regulatory framework that enabled that scale.

However, Brazil's rapid growth shows that regulation is not a single event, but a process that must mature alongside the system, and that the sustainability of a solution is measured not at the time of installation, but in how it is integrated afterward.

Law 14,300 fostered the massive connection of distributed generation in Brazil, but because it was not coordinated with grid capacity, curtailment of solar and wind farms grew significantly (Além da Energia, 2026). To correct this mismatch, Brazil advanced its storage regulatory framework: Law 15,269/2025 incorporated batteries as a regulated activity with tax incentives (Tractebel, 2026), seeking to prevent clean energy waste. That curtailed energy represents a lost opportunity in terms of emissions—renewable energy that failed to replace a single thermal MWh.

Germany presents another case displaying the same pattern on the other side of the meter: the aforementioned Section 14a of the EnWG did not leave demand automation to voluntary adoption, but mandated it for residential appliances exceeding 4.2 kW.

Only when both dimensions are addressed toge-

ther does installed capacity translate into avoided emissions.

Now, none of these solutions are climate-neutral on their own. As noted initially, no solution is perfect: manufacturing batteries carry its own footprint and impacts other indicators, such as water usage. While storage and distributed generation mature, the grid continues to require thermal backup to maintain stability. Reducing the mismatch does not eliminate that footprint; it makes it smaller and more manageable. That is the realistic standard of sustainability for the sector: minimizing impact as much as possible. Across the three fronts of distributed generation, storage, and demand shifting, the ceiling is not technological. Costs are falling and technologies work; the ceiling is a lack of regulation that not only guarantees grid stability but is explicitly aligned with emissions targets rather than capacity targets alone.

Once that initial problem is resolved, a second arises—which is also a matter of sustainability: who finances the first wave of adoption. Today, distributed generation and technology deployment require investments that need measurable returns to be justified. If the numbers add up, the transition will proceed faster.

That barrier is also resolved through clear regulations: for years, the Argentine state, for example, subsidized energy costs—a policy that incentivized consumption habits opposing the path to sustainability. The fundamental question that every state in the region must ask itself lies in

the allocation of its budget resources: whether to maintain subsidies for an obsolete and unsustainable generation model, or to finance the transition toward a sustainable energy matrix.

ble energy that, despite being capable of being generated, is not utilized due to transmission of grid constraints or insufficient demand.

Glossary

Curtailment (Vertimiento): Renewa-

GHG (GEI): Greenhouse gases.

BESS: Battery Energy Storage System.

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Until the Mind Can Take No More: Resilience, Emotions, and the Right to Energy

Energy deprivation not only causes material impoverishment; it also harms the mental health of those who experience it. The law already recognizes both rights separately. What remains is to link them as a single enforceable legal obligation.

The Importance of the Emotional and Sensory Turn in Energy.

Access to energy shapes everyday life to such an extent that it cannot be measured in kilowatt-hours alone. For this reason, academic interest in the emotional dimensions of energy is growing rapidly (Martiskainen and Sovacool, 2021). This interest has generated a substantial body of scholarship. A recent review of 47 studies found that fuel poverty—understood as a household’s inability to meet its basic energy needs—was associated with mental health harms in 46 of them (Khavandi et al., 2024), through symptoms manifested as thermal discomfort, social isolation, and/or financial insecurity. The relationship between emotional states and energy has already been identified and documented by researchers in countries as distant and diverse as the United Kingdom, Spain, and China, who have focused on women engaged in household work, older adults, and children. The law, however, continues to treat access to energy almost exclusively as an infrastructure and public-service issue, disconnected from the mental health that this very lack of access erodes. Legal professionals persist in relying on what engineering can measure, leaving aside what, according to the available evidence, most determines the

well-being of those living without sufficient, reliable, clean, and continuous electricity.

Who Has Already Studied It, and from Which Scientific Perspective

Several disciplines have already entered this field, each from a different angle. From a public health perspective, Khavandi et al. (2024) systematized the epidemiological evidence linking fuel poverty to anxiety, depression, and other mental health harms. In energy transition studies, Martiskainen and Sovacool (2021) documented the growing interest in emotions as a legitimate subject of research in the sociology and political science of energy. From the perspective of feminist epistemology, Rincón Rubio and Cedano-Villavicencio (2023) showed how women in southern Mexico experience the energy transition as an affective experience that extends beyond rational calculation, while Rincón Rubio and Alcázar Ballinas (2024) propose body- and sensory-centered methodological approaches for studying it. Each discipline documents one piece of the same phenomenon, using its own methods and vocabulary, without necessarily engaging in dialogue with the others. None offers—because that is not its function—a path for turning these findings into an enforceable legal obligation vis-à-vis the State or a private party. Psychology, sociology, anthropology, and public health are documenting emotional harm with growing rigor. The law, thus far, has barely listened, beyond recognizing with increasing clarity that access to energy and health are human rights in themselves.



Two Rights Still Viewed on “Separate Tracks”

The right to energy is beginning to take shape as an autonomous human right and as an instrumental right for safeguarding life and adequate housing, with the Inter-American Human Rights System at the forefront of this doctrine (Hessling-Herrera et al., 2023; Hessling-Herrera, 2024). In Mexico, legal scholarship regards access to electricity as a derivative right, indispensable to the use and enjoyment of housing, education, health, and work. The State, through the Federal Electricity Commission, acts as the ultimate guarantor, even when the relationship with the user is structured through a contract presumed to be commercial in nature (Carmona Díaz de León, 2023). In turn, the UN Committee on Economic, Social and Cultural Rights has recognized mental health as an inseparable component of the right to health for more than two decades (2000), and the 2022 reform expressly incorporated it into Mexico’s General Health Law (Official Gazette of the Federation, 2022). Although both rights are recognized, they are regulated and enforced separately: one before the energy authorities and the other before health authorities. Yet if lack of energy causes measurable and documented harm to mental health, the deprivation ceases to be exclusively material and also affects the essential core of the right to health, making it difficult to identify the responsible party. Recognizing this link would open two avenues. The first would be litigation: alleging mental health harm as part of the violation of the right to energy, following the same instrumental

logic that already connects it to life and housing. The second would be regulatory: incorporating mental health impact criteria into fuel-poverty programs and social impact assessments, in a manner analogous to environmental assessments. Neither avenue is simple. Proving that a specific deprivation caused measurable harm requires an evidentiary standard that climate litigation took years to develop and that energy litigation is only beginning to explore. Moreover, a population-level statistical association is not enough to establish causation in an individual case or attribute it to a specific state omission. This difficulty, however, should not prevent the law from developing the standards needed to make such protection viable.

The Risks This Proposal Poses to Energy Development

Linking these two rights is not without risks. There are three main ones.

The first is regulatory uncertainty. Expanding the grounds on which a project may be challenged increases both the cost and duration of its financing and permitting procedures. Litigation concerning prior consultation and cultural rights in relation to solar and wind farms in the Yucatán Peninsula illustrates this risk. That litigation generated important case law, but also weak implementation and prolonged conflicts (Herrera, 2025). The same pattern could recur if this new basis for litigation lacks clear rules governing its scope and evidentiary requirements.

The second risk is perhaps the most delicate because it is paradoxical. A tool designed to protect those who lack energy could instead be used to block or delay the very projects meant to provide it. It is therefore important to distinguish between two possible uses. Invoking it as a shield against an existing deprivation is very different from invoking it as a weapon against the expansion that would reduce that deprivation.

The third risk concerns equity. A mental health impact criterion adds research costs and delays. Large developers are better able to absorb those costs than public rural electrification programs. Yet those programs serve precisely the populations experiencing the greatest fuel poverty—the very people the proposal is intended to protect. The result would be the opposite of its purpose.

None of these risks justifies abandoning the proposal. They do, however, require conditioning it on demanding causation standards, filters that discourage speculative litigation, and an explicit legal distinction between protecting those who lack energy and obstructing those who seek to provide it.

Conclusions

The emotional and sensory turn now being explored by public health, sociology, and feminist epistemology has given energy a dimension that

engineering could never measure. Linking the right to energy with the right to mental health gives that dimension a place to land: a concrete, justiciable, and regulable state obligation that does not yet exist. If poorly calibrated, however, that same obligation could become one more obstacle to the infrastructure the region needs to build. The challenge is not to choose between protecting rights and developing energy, but to design the former so that it advances the latter.

This task falls to several actors at once. Courts that already recognize the right to energy as instrumental to life and housing can extend the same logic to mental health. Regulators that currently require environmental impact assessments before authorizing a project can, over time, incorporate an equivalent psychosocial impact criterion. And lawmakers designing the next generation of rural electrification programs in Latin America and the Caribbean can do so knowing that the deprivation they seek to address is measured not only in kilowatts, but also in the mental health of millions of people who endure it in silence today.

None of this requires inventing a new right. It requires, rather, that we stop treating as separate two rights that, according to the scientific evidence itself, are harmed together when energy is lacking. This is a perspective that the region's energy law has yet to examine with the same rigor with which it recognizes its benefits and risks.

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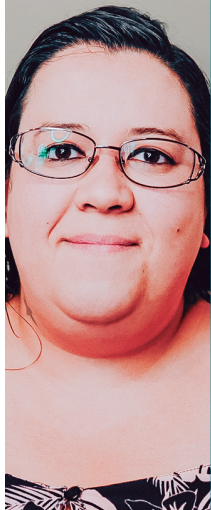
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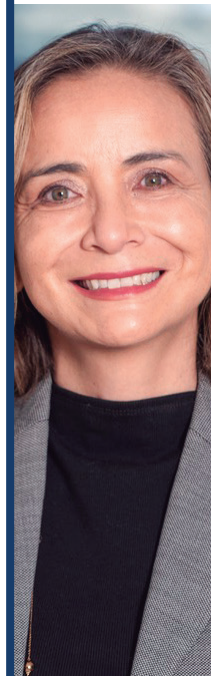


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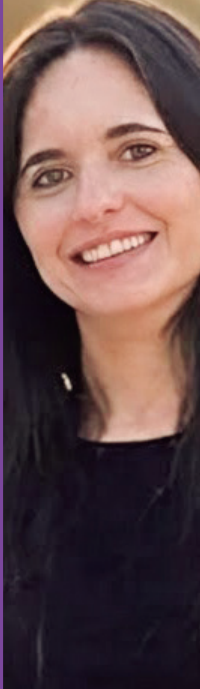
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