Climate urgency enables political alignment for Latin American power integration

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Article

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Posted Date: October 7th, 2025

DOI: https://doi.org/10.21203/rs.3.rs-7547364/v1

Additional Declarations: There is **NO** Competing Interest.

Climate urgency enables political alignment for Latin American power integration

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Abstract

Political fragmentation continues to block urgently needed power integration in Latin America, despite the region's vast renewable energy potential. Using the Multiple Streams Approach (MSA), we argue that the escalating climate crisis now acts as a focusing event, aligning a pressing energy problem, viable integration solutions, and growing political will. This alignment signals that a policy window is currently open. We combine MSA with system modeling to quantify overlooked political costs of inaction—specifically, geopolitical tensions and erosion of trust—offering new leverage for policy entrepreneurs. Simulations for 2025–2050 show that continued fragmentation increases system costs by up to 7%, reduces resilience to hydroclimatic shocks, and concentrates benefits within narrow cooperating blocs under low-trust conditions. These measurable and rising costs underscore that regional energy integration is no longer just a technical or economic issue—it is a political imperative. Bold leadership must act now to seize this fleeting window of opportunity.

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1 Main

Decarbonization urgency has reached historic levels. In 2024, global temperatures exceeded the 1.5 °C threshold for the first time in history above preindustrial levels, intensifying climate risks to ecosystems, economies, and communities[1]. As one of the leading sources of greenhouse gas emissions, the energy sector must accelerate the replacement of fossil fuels with clean alternatives to reduce emissions and enhance system resilience[2–8]. Latin America (LA) is well-positioned to lead this transition. In 2023, 62% of its electricity came from renewable sources—well above the global average[9;10]—yet heavy reliance on hydropower ($\sim 45\%$) exposes the region to hydrological variability and capacity losses projected at up to 17.4% by the century's end[11;12], a vulnerability widely recognized in global assessments of climate impacts on energy systems[2]. Indeed, extreme droughts between 2021 and 2025 in Colombia's Guavio reservoir and across the Rio de la Plata Basin triggered blackouts and rationing[13–17]. Under this context, regional integration—complementing solar in northern Chile, wind in Patagonia, and flexible hydro in the Amazon—offers a technical solution to buffer variability and bolster cross-borders resilience[9;18;19].

Regional power integration, complementing northern solar, Patagonian wind, and flexible hydro, can enhance resilience and reduce costs[9;18;20–23]. Yet, despite decades of recognizing these benefits[24;25] and numerous initiatives[26–29], multilateral integration remains stalled[29–31]. While subregional projects like Central America's SIEPAC show cooperation's value[32–35], broader progress is hindered by political and institutional factors[29;36;37]. Governance asymmetries, mistrust, sovereignty concerns, and fragmented regulations —challenges seen elsewhere[33;38–43]— hinder feasible integration. Indeed, global interconnection reviews consistently conclude that strong multilateral governance and precise dispute-resolution mechanisms are indispensable for deploying cross-border transmission[41;44–48]. Hence, understanding how to overcome and prevent political inertia and dynamics is still a critical literature gap[36;44;49–52] in cross-border power integration that shapes energy transitions in Latin America and emerging regions[53–59].

To navigate these complexities, the Multiple Streams Approach (MSA) offers a comprehensive framework that elucidates the intricate interplay between problems, policies, and political dynamics during the pivotal policymaking process[60]. This approach emphasizes the significance of three distinct streams—problems, policies, and politics—converging at critical junctures, often called "windows of opportunity."

This paper examines Latin American energy integration in the context of the escalating climate crisis and the urgent need for decarbonization, employing the Multiple Streams Approach (MSA) as its analytical framework[60;61]. According to the MSA, policy windows emerge when the problem, policy, and politics streams converge, often triggered by focusing events that heighten political attention[62–65].

This policy window is open in Latin America. The intensifying impacts of climate change—including hydropower variability, droughts, and regional energy insecurity—act as powerful focusing events, elevating the political salience of energy system resilience and integration[53;66;67]. These events trigger an emerging political will (politics stream), signaled by declarations like the 2023 Brasília Consensus and increased multilateral financing[55;68–70].

Our integrated modeling shows the political costs of inaction, such as geopolitical and mistrust costs, revealing that fragmentation increases costs by up to 7% and erodes resilience during hydro-shocks, highlighting the tangible stakes. These results offer new, evidence-based leverage for policy entrepreneurs[38;50;71;72] aiming to consolidate political alignment. Thus, these results finally explain why this is a crucial time for advocating for decisive political leadership in Latin America to speed up the energy transition and decarbonization leveraging the ongoing climate crisis.

1.1 MSA patterns in the history of Latin American integration

Following independence, Latin American nations largely prioritized national sovereignty, fostering fragmentation even amidst diverse twentieth-century integration efforts[73–75]. In contrast, the energy sector was recognized at an early stage for its critical importance and potential for synergy, emphasizing the ongoing incoherence between national priorities and regional cohesion.[71;76].

Therefore, early country system development was primarily focused on national economies of scale, but in the middle of the century, interest in interconnection grew. CIER's creation in 1964, driven by specific national energy challenges, marked a step, though its foundational congress acknowledged inherent integration difficulties[75;77]. The 1970s oil crises and Cold War dynamics significantly pressured regional economies. In 1973, OLADE was established to promote cooperation[74;78]; however, action remained primarily bilateral, with large-scale hydropower serving as the practical technical solution at the time (policy stream)[79].

This period exemplifies a classic MSA configuration[60], where convergence of streams was largely driven by exogenous forces. The problem stream (oil crisis) and the politics stream (Cold War geopolitics) were shaped by global dynamics. Coupled with binational hydroelectric policies and enabled by policy entrepreneurs, this opened a policy window that led to landmark bilateral projects such as Itaipú, Salto Grande, and Yacyretá[79–81]. Similar cyclical patterns of cooperation and subsequent stagnation, driven by resource availability and national policy shifts, have characterized other energy integration efforts in the region, such as the Argentina-Chile gas interconnections[82] However, while the window opened, the policy stream was inherently bilateral—constrained by national interests and focused on managing transboundary resources between specific state pairs[83;84]. This configuration ultimately hindered broader multilateral coordination and reinforced institutional fragmentation.[73;75;85] In contrast, the SIEPAC case in Central America represents a different MSA pattern—one driven more by endogenous forces. Here, the problem stream was rooted in shared regional vulnerabilities: small, isolated electricity systems lacking scale, resilience, and affordability. The policy stream—SIEPAC itself—was designed explicitly for multilateral implementation, incorporating gradual integration to mitigate sovereignty sensitivities. The politics stream also emerged internally, aligned with regional frameworks like SICA, and reinforced by a shared urgency around supply risks and cost inefficiencies. This convergence allowed for effective multilateral coupling and progress.[32]

A third case, IIRSA, offers a hybrid perspective. Created to promote infrastructure integration across South America—including energy, communications, and transport—IIRSA saw mixed results. Road transport advanced significantly as the streams aligned: a common logistical problem, ready-made technical solutions, and a political consensus around export-led growth, partly driven by exogenous demand from China. Crucially, private-sector actors acted as policy entrepreneurs, steering integration efforts toward global market access rather than intra-regional exchange.[86] Energy integration, however, lacked this alignment. While the problem was acknowledged, the policy stream remained nationally framed, and the politics stream fragmented by sovereignty concerns—stalling progress.[74;86]

Understanding these three patterns through the lens of MSA is critical. The first case shows that exogenous drivers can open policy windows but often lead to bilateral outcomes. The second reveals that shared endogenous vulnerabilities can produce deeper multilateral alignment. And the third illustrates how private entrepreneurial action and external economic drivers can selectively align streams. This comparison is particularly relevant today: although the climate crisis is exogenous in origin, it generates deeply shared, endogenous vulnerabilities across Latin America—such as water stress, energy insecurity, and economic disruption. These conditions more closely resemble the SIEPAC context than the fragmented geopolitics of the 1970s, suggesting that the current policy window may favor multilateral convergence—if political will aligns accordingly.[20;61;62]

1.2 The problem stream: Climate vulnerability and energy insecurity

Despite Latin America's high renewable electricity share (62% in 2023), its profound reliance on hydropower ($\tilde{4}5\%$) creates a critical vulnerability[87]. Climate-driven hydrological variability increasingly compromises energy security across numerous nations, transforming a regional asset into a growing liability[2;87;88].

Recent climatic events starkly illustrate this escalating risk. Indeed, a prominent paper has found that the current drought in Central Brazil is unprecedented in the last 700 years[88]. In 2023, Colombia's Guavio reservoir dropped to critical levels, jeopardizing national grid stability, while the 2021–2022 drought saw the Paraná River basin in the Southern Cone reach historic lows, severely impacting hydroelectric output and vital navigation routes[13;14;81]. Such anomalies show increasing links to intensified

El Niño–Southern Oscillation (ENSO) patterns, which are projected to become more frequent and severe under continued global warming[89;90].

Modeling studies project that Latin America's hydroelectric potential could diminish by 7.5% to 17.4% by the end of the century, contingent on global emissions pathways[2;11;91;92]. These impacts are regionally heterogeneous: consistent declines are anticipated in Central America, Mexico, and Southern Cone nations (e.g., Argentina, Chile), whereas the Andean region (e.g., Colombia, Peru) might experience stabilization or marginal gains due to altered precipitation[93–95]. This differential exposure significantly exacerbates risks for highly hydro-dependent countries like Paraguay and Ecuador and starkly underscores how escalating global emissions intensify regional energy vulnerability[12;15;96].

Within the Multiple Streams Approach (MSA), the intensifying effects of climate change activate the problem stream. No longer abstract forecasts, energy disruptions now take the form of blackouts, forced rationing, and soaring electricity tariffs across Latin America. As nations scramble for costly alternatives, these obvious impacts elevate public anxiety and political attention, transforming energy resilience from a technical issue into a politically salient priority[12;97]. This shift aligns with Kingdon's logic that issue salience surges when physical conditions (like climate-induced disruptions) are framed as urgent public problems. Indeed, recent research on drought policy in Brazil[61] demonstrates how such "creeping crises," initially perceived as regional or cyclical, can escalate to become powerful focusing events that prime national policy agendas when their impacts accumulate and expand. Likewise, as shown in Paraguay's stagnant energy reforms, climate-induced shocks can prime the policy agenda even in the absence of institutional overhaul—though lasting change depends on political coupling and policy entrepreneurship[83].

In sum, climate-induced vulnerability and entrenched hydropower dependence have converged to frame a systemic regional risk. This convergence has sharply focused public and institutional attention on Latin America's energy fragility—solidly activating the problem stream within the Multiple Streams Approach (MSA). The urgency and visibility of these risks heighten the demand for credible, practical solutions. In this context, a range of technically viable and economically sound integration proposals have emerged, suggesting that the policy stream—comprised of feasible, acceptable, and implementable alternatives—is also taking form. The following section examines how regional integration, supported by model-based evidence, offers a compelling response to the systemic energy vulnerabilities now facing the region[84].

1.3 The Policy Stream: The Quantified Value of Regional Integration Amidst Climate Change

Solutions to societal problems often germinate within specialist communities—Kingdon's[60] "policy primeval soup"—long before capturing widespread political attention. Regional electricity integration in Latin America exemplifies this: despite numerous studies highlighting its potential benefits for sustainability, security, and efficiency[19;55;98–100], its implementation remains uneven, particularly in South America compared to Central America's SIEPAC experience[32;37;55;101]. While various factors explain this gap, the shared vulnerability to climate change is emerging as a potentially unifying driver demanding regional cooperation[21;67;102].

This study contributes directly to this policy stream by rigorously quantifying the benefits of integration using an optimal power system planning model tailored for Latin America's context (see Methods for model details). The model co-optimizes investments in generation, storage, and cross-border transmission infrastructure (2025-2045) to minimize total system costs (OPEX, CAPEX, carbon costs) while meeting national demands and decarbonization goals, explicitly leveraging the complementarity of the region's diverse renewable resources under various hydrological scenarios.

1.3.1 Quantitative Benefits of Regional Integration:

Our simulations starkly contrast integrated versus isolated national systems, revealing substantial benefits achievable through coordinated regional action:

Reduced Emissions: Optimized regional interconnection significantly curtails power sector CO2 emissions. By 2045, integrated scenarios achieve emissions levels between 42–99 MtCO2 annually, drastically lower than the 174–324 MtCO2 projected without new interconnections, especially under challenging low-hydropower conditions (Table 1). These results demonstrate a deeper decarbonization potential compared to scenarios like the Sustainable Growth Scenario (SGS) from De Oliveira-De Jesus et al.[67] and align with reduction potentials identified by Kober et al.[23]. The avoided emissions, visualized in Fig. 1, underscore integration's role as a key climate mitigation tool.

Lower System Costs: Integration yields compelling economic advantages by enabling efficient resource allocation. By 2045, total system costs in integrated scenarios range from $106–130 billion USD annually, compared to $126–162 billion USD for isolated systems (Table 2). This translates into potential net economic savings (avoided losses) reaching up to $32 billion USD annually by that year, particularly significant during periods of water scarcity (Fig 2). These findings are notably consistent with savings projected by Barbosa et al.[103], reinforcing the economic rationale for interconnection.

Optimized Investment: While decarbonization requires substantial capital investment (reaching $96–111 billion USD by 2045 in our integrated scenarios, Fig 3), integration ensures this capital is deployed more efficiently across the region. These investment levels are consistent with projections from ambitious climate scenarios in studies like Kober et al.[23] and recent IEA[104] estimates for renewable energy needs, suggesting our model captures realistic investment scales. Integration facilitates optimal use of VREs, channeling investments effectively.

Enhanced Resilience and Complementarity: Given the diverse and significant climate change impacts on energy systems projected globally and regionally, enhancing system resilience is paramount[2]. Regional interconnection is widely recognized as a powerful instrument for managing climate-induced hydrological risk, leveraging the strategic complementarity of diverse energy resources[12;18;87]. Our model explicitly quantifies how interconnected Latin American systems can harness these geographic and technological synergies—balancing variable solar and wind generation across regions while compensating for hydropower deficits during droughts (as modeled

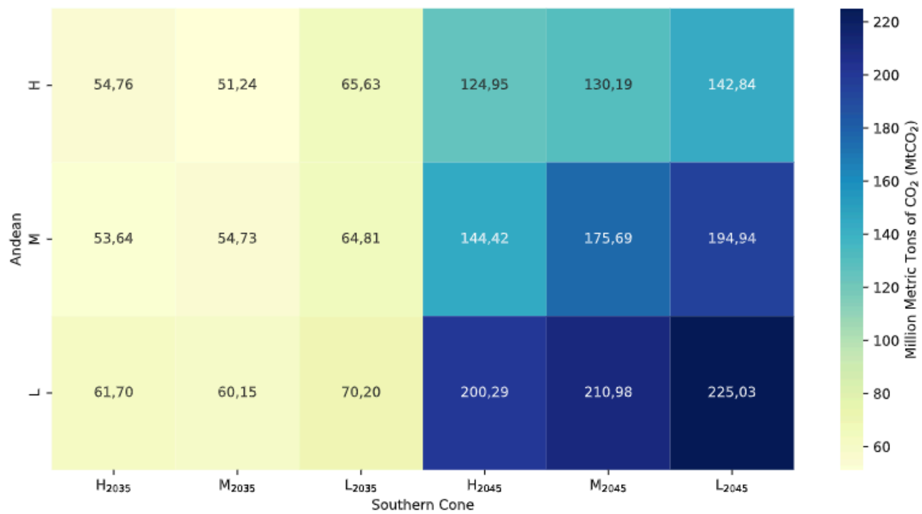

Fig. 1 Regional power integration significantly curtails CO_2 emissions from Latin America's power sector, enhancing decarbonization efforts by 2045. This figure quantifies the annual reduction in CO_2 emissions ($MtCO_2yr^{-1}$) achieved through optimized regional electricity interconnection relative to a counterfactual scenario where national power systems operate in isolation. Emissions data, presented for the year 2045, are disaggregated across nine distinct hydrological scenarios, reflecting a 3x3 matrix of High (H), Medium (M), and Low (L) hydropower availability in the Andean (rows) and Southern Cone (columns) regions (see Methods and Supplementary Materials for detailed scenario definitions and absolute emission figures). The substantially greater avoided emissions under low-hydropower conditions particularly underscore the critical role of integration in building resilient, low-carbon energy systems capable of meeting climate targets even under hydrological stress.

for the Andean and Southern Cone regions) through imports from neighbours. This approach provides crucial levels of resilience and flexibility often unattainable within isolated national systems that are heavily dependent on variable hydro resources

The quantitative results from this analysis provide robust, multi-faceted evidence for the technical viability and socio-economic desirability of enhanced regional electricity integration as a core strategy for Latin America's energy transition. Visualizations derived from the model (Figs. 1-3) offer concrete tools to aid policymakers in understanding trade-offs and benefits. A strong "policy stream"—rich in data, supported by consistent findings across multiple studies (including this one), and featuring well-defined, technically sound solutions—clearly exists. The critical bottleneck, therefore, lies not in the absence or weakness of viable policy options, but in achieving the political consensus and institutional coordination necessary for their implementation, a challenge explored next. Indeed, similar compelling economic and security benefits are increasingly recognized for other forms of energy integration within Latin America, such as natural gas interconnections, highlighting a broader regional potential for cooperative energy strategies[82].

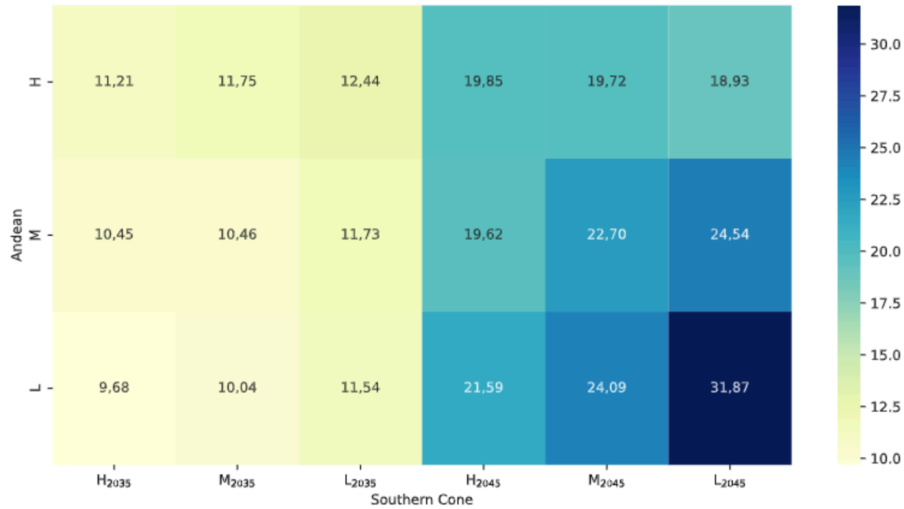

Fig. 2 Substantial economic savings are unlocked through regional power integration in Latin America by 2045. The figure illustrates the net annual economic benefits (billion USD.yr^{-1}) derived from optimized regional power system interconnection compared to the higher costs associated with isolated national systems. These savings are projected for the year 2045 across a 3x3 matrix of nine hydrological scenarios, encompassing High (H), Medium (M), and Low (L) hydropower availability in both the Andean (rows) and Southern Cone (columns) regions (refer to Methods and Supplementary Table 2 for detailed scenario parameters and absolute system cost data). The results highlight the compelling economic advantages of a coordinated regional approach, with particularly pronounced savings achieved during periods of significant water scarcity, thereby enhancing economic resilience against climate-induced shocks.

1.4 The Politics Stream: Overcoming Fragmentation by Quantifying its Costs

Public policies emerge from complex political negotiations, not solely rational planning[60]. In Latin America, this 'politics stream' is particularly challenging for energy integration, often stalled by dynamics like strong interest groups, sovereignty concerns, and historical distrust that favor national interests over collective action[75;83;84]. While previous studies have quantified the economic benefits of regional power integration[23;55;103], our study advances this literature by explicitly nuancing the geopolitical dimension of trust and mistrust into the analysis. Using our detailed energy system model, we quantify the economic costs not only of non-cooperation in general but also of political fragmentation driven by historical distrust and sovereignty concerns, barriers also consistently identified by regional institutions analyzing the slow pace of energy cooperation[105]. This novel framing translates abstract political dynamics into concrete, comparable trade-offs—offering policymakers a clearer understanding of how trust (or the lack thereof) materially shapes the regional energy landscape and the potential returns of overcoming these barriers.

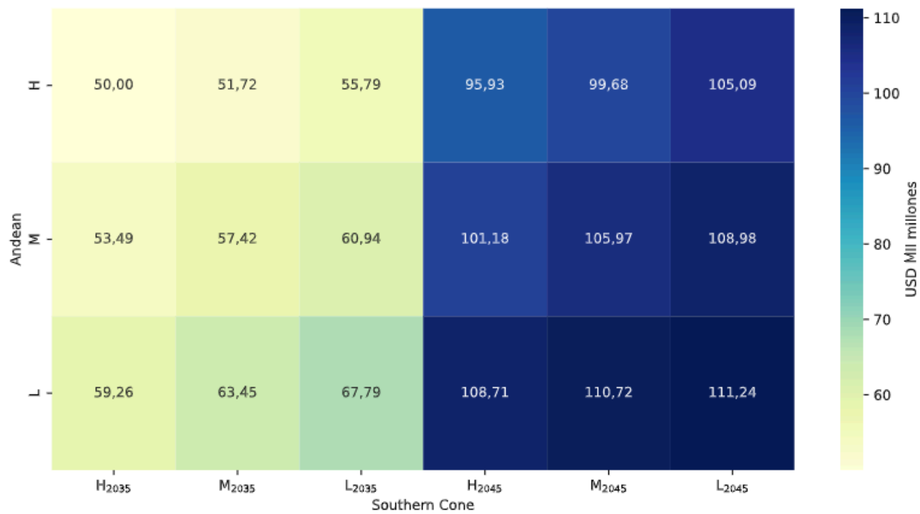

Fig. 3 Regional integration facilitates optimized and efficient capital investment for Latin America's power sector decarbonization by 2045. This figure presents the projected annual capital expenditure (billion USD.yr^{-1}) required for generation, storage, and cross-border transmission infrastructure under the optimized regional integration scenarios for the year 2045. Investment levels are detailed across nine distinct hydrological scenarios (a 3x3 matrix of High (H), Medium (M), and Low (L) hydropower availability in the Andean and Southern Cone regions; see Methods for comprehensive modeling assumptions). While substantial, these investments represent an efficient allocation of capital across the region, made possible by integration, which is crucial for achieving ambitious decarbonization goals through the optimal deployment of variable renewable energy (VRE) sources and the strategic sharing of power resources.

1.4.1 Quantified Costs of Political Factors

Our analysis operationalizes and quantifies key political costs:

The 'Geopolitical Cost' of Sovereignty Preference: We estimate the economic penalty incurred when national sovereignty constraints hinder optimal regional cooperation (see Methods; Fig. 4). This cost reveals a significant inefficiency, amounting to several billion USD annually ($4.6–7.9 billion by 2045 with integration), driven by suboptimal system deployment when national priorities are prioritized over regional synergy. Detailed dynamics are presented in Fig. 4.

The 'Economic Loss from Trusting' (Risk Exposure): This metric captures the economic risk perceived by countries relying on an integrated system that might underperform (Methods; Fig. 5). This quantifies risk aversion, identifying nations like Bolivia and Uruguay as particularly exposed (See Fig. 5 caption), thus highlighting the need for robust regional guarantees to foster trust.

The 'Economic Loss from Not Trusting' (Opportunity Cost of Fragmentation): This quantifies the substantial opportunity cost of continued fragmentation (Methods; Fig. 6). This reveals the direct economic penalty of the status quo, showing that Brazil—along with Paraguay, Colombia, and Peru—faces multi-billion dollar

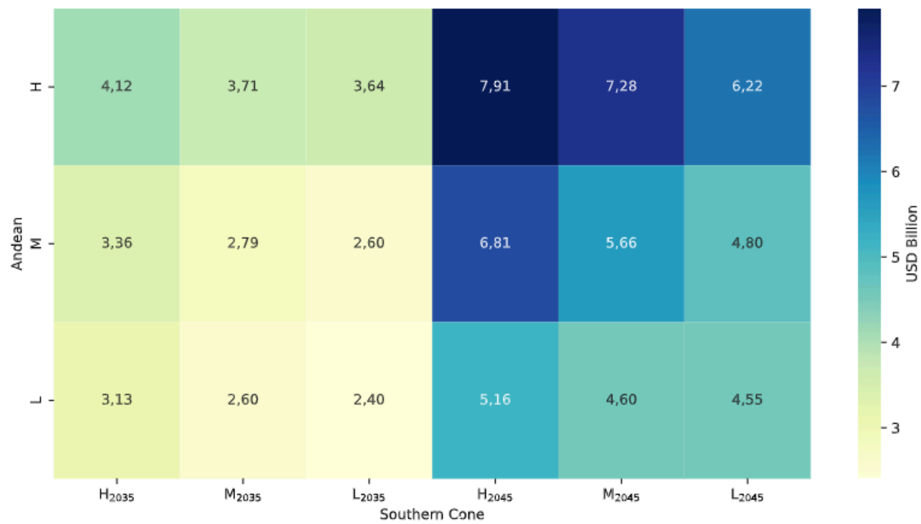

Fig. 4 The Geopolitical Cost of Prioritizing Energy Sovereignty over regional cooperation. Heat maps illustrate the estimated annual 'Geopolitical Cost' across Latin America for 2035 and 2045, under scenarios with optimized transmission investments. This cost, calculated as the difference in total system cost between scenarios with and without national energy sovereignty constraints (see Methods), represents the economic inefficiency (in billions USD) imposed by prioritizing national self-sufficiency over fully optimized regional synergy. Results are shown across a 3x3 matrix combining High (H), Medium (M), and Low (L) hydropower availability scenarios for the Andean (rows) and Southern Cone (columns) regions. Notably, costs increase significantly by 2045 due to higher demand and can be counter-intuitively higher under abundant hydropower, as this reduces the immediate economic pressure for optimal cross-border exchange, thus magnifying the inefficiency cost of the sovereignty constraint. Costs range from $2.40–4.13 billion (2035) to $4.55–7.91 billion (2045).

annual losses by failing to integrate deeply, especially under climate stress (See Fig. 6 caption).

1.4.2 Leveraging Quantified Costs for Political Strategy

These quantified metrics serve as strategic political tools. The significant 'Loss from Not Trusting' pinpoints nations with the strongest economic incentive for integration, positioning Brazil as a potential policy entrepreneur and Paraguay, Colombia, and Perú as key allies[60]. Concurrently, 'Loss from Trusting' highlights where institutional design must actively mitigate perceived risks (e.g., for Bolivia and Uruguay) to enable broader participation. Our analysis provides actionable intelligence for coalition building and targeted negotiation strategies based on quantified national interests and vulnerabilities.

While the politics stream remains the integration bottleneck, the climate crisis (problem stream) and viable solutions (policy stream) offer a window of opportunity. This study provides crucial leverage by demonstrating the quantifiable, multi-billion-dollar annual costs associated with political fragmentation, sovereignty constraints,

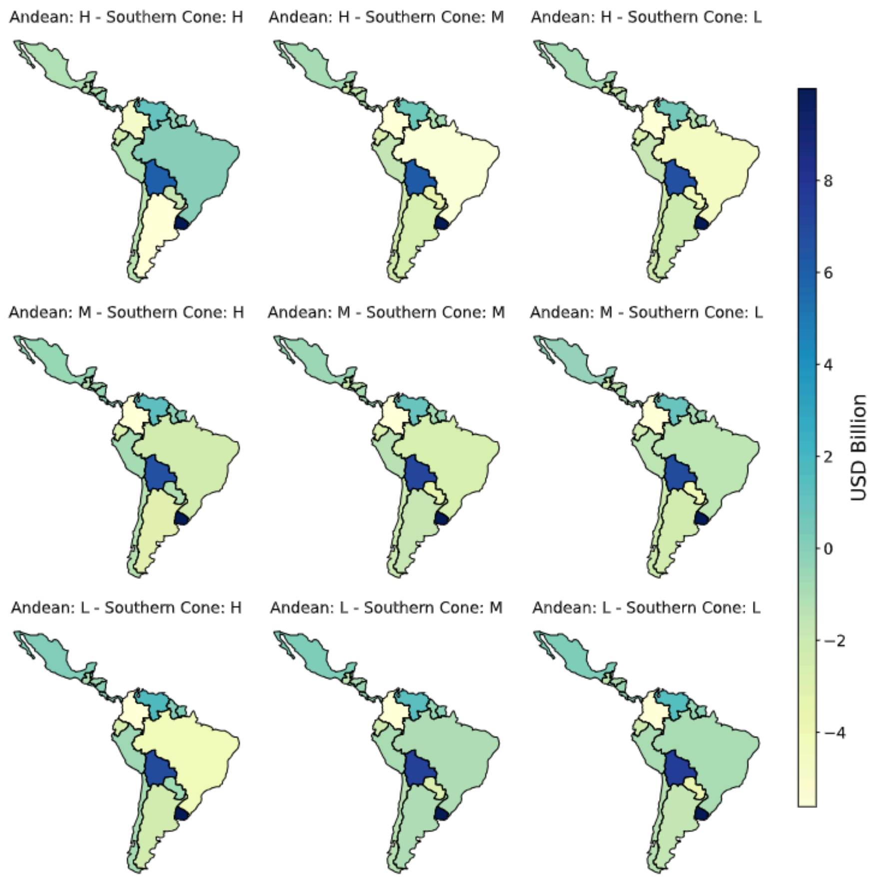

Fig. 5 Economic Loss from Trusting. Quantifying risk aversion to regional integration. Heat maps show the potential 'Economic Loss from Trusting' for individual Latin American countries in 2045 (in billions USD). This metric quantifies the economic risk exposure if a country relies heavily on an integrated regional system (forgoing national investments) that subsequently underperforms or fails to deliver expected benefits (scenario assumes no national sovereignty constraints; see Methods). Results are shown across a 3x3 matrix combining High (H), Medium (M), and Low (L) hydropower availability scenarios for the Andean (rows) and Southern Cone (columns) regions. Color scale indicates loss magnitude (yellow=low/negative, blue=high). Bolivia and Uruguay consistently show the highest potential losses, reflecting greater perceived risk and potential aversion to deep integration, highlighting the need for trust-building and risk mitigation mechanisms.

and mistrust. This evidence, which quantifies the multi-billion-dollar costs of inaction and identifies specific national vulnerabilities, provides crucial leverage. Equipping negotiators and policy entrepreneurs with these concrete metrics—highlighting who bears the greatest losses from fragmentation and whose risks require mitigation—can help overcome historical inertia, foster necessary coalitions, and ultimately align the politics stream towards a secure, decarbonized regional energy future[61].

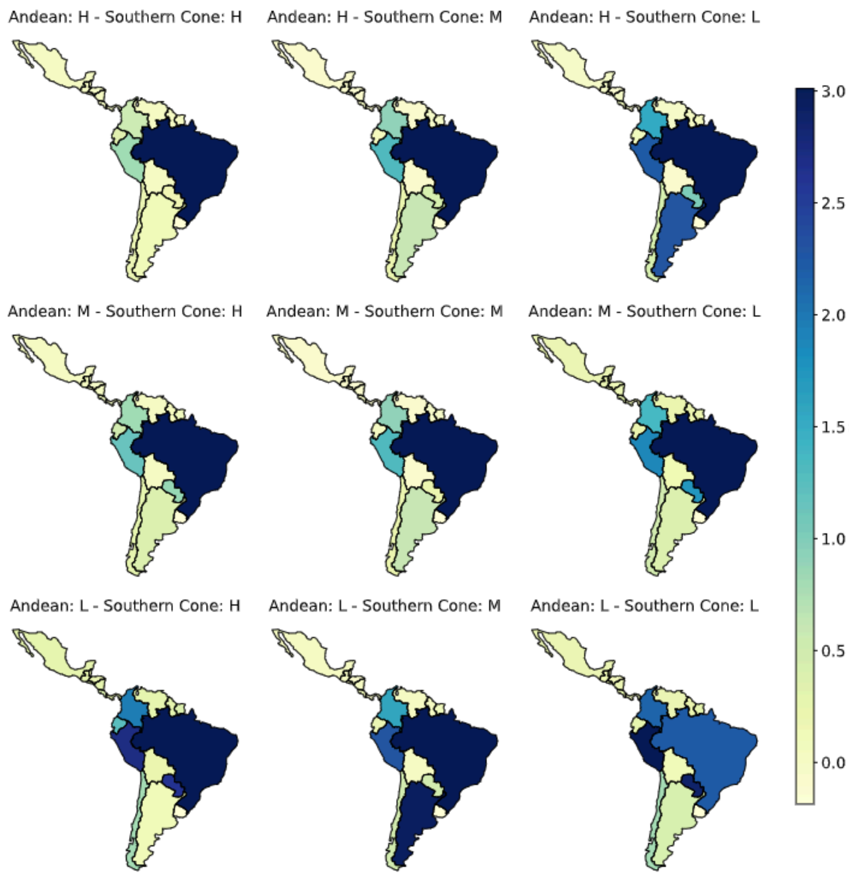

Fig. 6 Economic Loss from Not Trusting. The opportunity cost of fragmentation. Heat maps show the 'Economic Loss from Not Trusting' for individual Latin American countries in 2045 (in billions USD). This metric quantifies the opportunity cost or economic damage incurred by not participating fully in an optimized regional integration (i.e., maintaining fragmentation, modeled here with sovereignty constraints active and potentially limited transmission compared to optimum). Results are shown across a 3x3 matrix combining High (H), Medium (M), and Low (L) hydropower availability scenarios for the Andean (rows) and Southern Cone (columns) regions. Color scale indicates loss magnitude (yellow=low, blue=high). Losses are most severe under low hydro conditions. Brazil consistently incurs the largest absolute losses, followed significantly by Paraguay, Colombia, and Peru, indicating their strong economic incentive to pursue deeper regional cooperation.

2 Discussion

This study offers a critical and timely contribution not only to the academic literature on energy policy and regional integration but, more pressingly, to the current geopolitical energy praxis in Latin America. We move beyond describing persistent political barriers by providing a novel, actionable framework: combining the Multiple Streams Approach (MSA) with quantitative optimal energy expansion modeling to translate abstract political dynamics—such as historical distrust and sovereignty concerns—into concrete, billion-dollar economic trade-offs. This assessment of the political costs of inaction (Section 1.4) provides policymakers and policy entrepreneurs with unprecedented, evidence-based leverage. Our analysis indicates that the escalating climate crisis, with its severe impacts on regional energy security, is not merely a "focusing event" triggering conditions to overcome decades of integration policies stagnation[2;12;61].

The convergence of streams is palpable: a highly salient Problem Stream (Section 1.2), where climate-induced energy disruptions are no longer abstract forecasts but immediate crises; a well-evidenced Policy Stream (Section 1.3), where regional integration is demonstrably a technically viable and economically superior solution; and an evolving Politics Stream (Section 1.4), evidenced by emerging high-level commitments like the 2023 Brasilia Consensus and invigorated multilateral funding[68;69]. Further evidenced by recent calls to action and strategic analyses from key regional institutions like OLADE, which highlight both the urgency and the renewed potential for advancing electrical integration[105]. This stream convergence indicates that Latin America may now be transiting more than just an agenda-setting window; the region appears to have entered a decision window, where long-standing proposals for regional electricity integration can be translated into concrete policy action[106]. Hence, the core contribution of this paper is to alert the openness of this crucial but fading decision window, as well as support those strategic actors by providing an evidence-based foundation—through quantified geopolitical and economic costs of non-cooperation—for seizing it and moving integration from political discourse into institutionalized policy.

To seize this critical juncture, we propose a new generation of regional energy policy, headlined by a foundational "Latin American Energy Pact". This high-level political agreement should aim for the phased establishment of a LA Electricity Integration System (SIEAL). A critical deliverable of this Pact should be the development of a coordinated legal corpus, akin to a new LA Energy Treaty. The notion of a regional energy treaty aimed at promoting collaboration and a stable investment environment, especially in South America, has been previously examined[74], highlighting its capacity to alleviate risks such as resource nationalism and draw essential infrastructure investment. We propose to extend this view to the LA region by a macro-treaty that would aim not to reinvent existing frameworks but to harmonize and ensure compatibility among current bilateral and sub-regional agreements (such as SIEPAC, Itaipú, Yacyretá, and Salto Grande) and broader initiatives (e.g., past UNASUR energy efforts and MERCOSUR energy forums). In this sense, key actions must include: (a) standardizing core technical and commercial rules for cross-border electricity trade to reduce regulatory costs and administrative barriers; (b) prioritizing strategic interconnection corridors with high energy complementarity and mobilizing joint public-private resources for transmission and storage; (c) creating a Regional Energy Integration Fund (e.g., via CAF/IDB) to de-risk investments and ensure equitable benefit distribution; (d) implementing a phased regional rollout with clear milestones to build mutual trust and demonstrate tangible benefits; and (e) establishing simple monitoring indicators (e.g., trade volumes, emission reductions, cost savings) for accountability and adaptive management. Existing institutions like OLADE/CIER should be empowered to support SIEAL's implementation and ongoing coordination.

Further crucial steps include directly addressing the "cost of trust" through regional risk-sharing mechanisms and harmonized contracts to reduce investment uncertainty, particularly for risk-averse nations (Section 1.4.1). Enhanced planning and coordination via a Regional Master Plan for Interconnections, supported by multilateral platforms involving all key stakeholders, is also essential. Finally, activating and empowering diverse policy entrepreneurs across governments, MDBs, academia, and civil society is vital to champion integration and build the broad coalitions needed to overcome institutional inertia.

Finally, the cost of inaction is no longer speculative but a quantifiable and rising burden, as our findings demonstrate. While this study's MSA framework illuminates the current opportunity and our modeling quantifies key trade-offs, we acknowledge limitations: MSA does not fully model implementation intricacies or power asymmetries, and our energy simulations assume idealized cooperation[84]. Future research could incorporate complementary theories (e.g., Punctuated Equilibrium[107], Advocacy Coalition Framework[108]) and simulate asymmetric cooperation[109] to deepen understanding of energy policy change in Latin America and other fragmented regions.

In conclusion, Latin America confronts a pivotal, time-sensitive opportunity to transform its fragmented power systems into a resilient, integrated regional network. The convergence of recent crises has aligned the necessary conditions for bold action. Regional integration offers a viable, evidence-based path forward, but seizing this window requires decisive political leadership, a shared strategic vision, and the collective will to overcome historical barriers, leveraging the now-quantifiable costs of non-cooperation. The time to act is now, before this critical opportunity closes.

Methods

This study employs a mixed-methods research design, combining qualitative political analysis grounded in the Multiple Streams Approach (MSA) with quantitative, long-term energy system expansion modeling. This integrated framework allows for a comprehensive assessment of the political-economic challenges and techno-economic opportunities for enhanced regional electricity integration in Latin America, examining both the structural drivers of historical policy inertia and the concrete benefits of increased cooperation.

Qualitative Analysis: Multiple Streams Approach (MSA) Application

The MSA, as conceptualized by Kingdon[60], provides the theoretical lens to understand how major policy change becomes possible when its three constituent streams—problem, policy, and politics—converge, often facilitated by 'focusing events' and 'policy entrepreneurs'. The conceptualization is made in three stages. In the first stage, **(a)** we conducted a comprehensive review of existing academic literature on LA integration, the impact of climate change on energy resources and policy analisis[9;10;13–18;20–25;29;30;32–38;50;51;53–56;61;71;72;74–77;79–81;83–88;90–100;102;103], energy policy reports from key regional and international organizations[1;11;12;26–28;69;70;82;104;110], and an examination of recent, pivotal policy documents and political declarations[68] (comprising in total more than 100 papers along 70 years of history) to understand the historical context and identify long-term patterns (informing Section 1.1). In the second stage, to assess the current policy window (informing the Discussion section), we conducted a coding process[111] for interpreting these secondary data (reports, declarations, academic literature) involved identifying text excerpts and documented events aligning with predefined codes based on MSA theory: 'problem stream indicators', 'policy stream elements' (including proposed solutions and their perceived viability), 'politics stream signals' (national mood, political forces, government changes), 'political entrepreneurs,' 'policy entrepreneurs,' 'focusing events,' 'policy windows,' 'agenda window,' and 'decision window'. The analytical period for the contemporary analysis was primarily chosen to correspond with the availability of detailed data and recent policy shifts (2020-2025). The final step involved interpreting these coded elements and documented events, using deductive inference to reconstruct the interplay of the streams and assess the nature and openness of the historical patterns of MSA in LA energy integration and current policy window. A timeline approach was used internally to organize facts and events within the problem, policy, and political streams to identify their convergence. Following these facts are framed by a quantitative analysis of the impacts of LA integration on regional power system evolution.

Quantitative Analysis: Regional Power System Expansion Model

To quantify the technical, economic, and CO_2 emission implications of different regional integration pathways and specific political-institutional constraints, we developed and utilized a detailed multi-country power system expansion model for Latin America.

To enhance transparency and facilitate reproducibility, the complete set of simulation outputs (generation mixes, transmission flows, investments, and costs) is accessible through an interactive visualization platform: https://explorer.energia.la/.

Model Formulation and Objectives.

The model is a multi-period linear optimization tool, formulated to co-optimize investment in and dispatch of generation, storage, and cross-border transmission infrastructure across 21 Latin American nations. The optimization horizon spans from 2025 to 2050, with results typically analyzed in five-year increments. The objective function is to minimize the total discounted system costs, which include annualized capital expenditures (CAPEX) for new generation, storage, and transmission assets, as well as fixed and variable operational cost (OPEX) where relevant. The CAPEX and OPEX for each technology are portrayed in Table 1 and Table 2 in the Supplementary Information. The model was implemented in Python, leveraging the Pyomo optimization modeling language and solved using (Gurobi). The model operates on a multi-decadal time horizon, covering the period 2025 to 2050 in five-year increments.

To capture daily variability in renewable generation and demand, it uses representative days with hourly resolution, allowing the simulation of intraday dynamics and the evaluation of flexibility needs. Key decision variables include (a) generation capacity additions, by technology and country; (b) energy dispatch across hours and seasons; (c) storage deployment and operation, particularly (d) batteries and hydro reservoirs; and (e) expansion of cross-border transmission capacity, including both existing and planned interconnections (See Supplementary Information - Section 1). The model includes several critical technical and policy constraints, ensuring realistic operation: Reliability requirements, including minimum reserve margins at national and regional levels; emissions limits, allowing comparison of high- and low-carbon scenarios; minimum renewable penetration targets, consistent with national energy plans and climate commitments; and transmission modeling, incorporating power losses, capacity limits, and inter-country flow constraints based on existing and planned infrastructure. Further details can be seen in Supplementary Information (Table 4). Spatially, the model represents each country as a node in a regional network, with transmission links reflecting physical interconnections. It captures both domestic generation mix and import/export dynamics, enabling the evaluation of regional synergies and the role of integration in enhancing resilience.

Geographical Scope, Input Data, and Key Variables

The geographical scope encompasses all the countries in South America, Central America, and Mexico. This selection covers the vast majority of the region's electricity demand and renewable resource potential.

Key input data and variables, derived from official national energy plans, IDB, OLADE and IEA databases[19;104;105;112], recent technical reports, and relevant literature , include:

- **Electricity Demand Projections:** National-level hourly demand profiles (MW) projected to 2050, accounting for baseline GDP growth, population trends, and varying electrification pathways (e.g., for transport and industry).
- **Technology Cost and Performance Parameters:** Investment costs (USD/kW), fixed O&M costs (USD/kW-year), variable O&M costs (USD/MWh), economic lifetimes, efficiencies, and key operational parameters (e.g., ramp rates, availability factors) for a portfolio of generation technologies (solar PV, onshore/offshore wind, hydropower with reservoir and run-of-river configurations, natural gas (CCGT, OCGT), geothermal, biomass), battery energy storage systems (BESS), and HVDC/HVAC transmission lines.
- **Renewable Energy Potentials:** Spatially explicit hourly generation profiles (per unit of capacity) for solar irradiance and wind speeds across different resource zones within countries. Country-specific developable potentials (GW or TWh/year) for hydro, solar, and wind, adjusted for geographical, technical, and broad socio-environmental considerations.
- **Emission Factors and Fuel Costs:** Technology-specific CO_2 emission factors (tCO_2/MWh) and projected international/regional costs for fossil fuels (e.g., natural gas).

- **Existing and Committed Infrastructure:**The model is initialized with the existing generation fleet (capacity, technology, age), storage capacities, and current cross-border interconnection infrastructure (voltage levels, thermal capacity limits). Firmly committed expansion projects reported in national plans are also incorporated.

National electricity systems are represented as single nodes, and transmission constraints between countries are explicitly modeled as capacitated links, respecting regulatory and geopolitical boundaries for energy exchange.

These assumptions allow for a clear estimation of the structural economic and environmental costs associated with different degrees of political fragmentation and the corresponding benefits of enhanced cooperation under specified, idealized conditions.

Key Model Constraints

The optimization is subject to several critical technical and policy constraints to ensure realistic system operation:

- **Energy Balance:** Hourly electricity generation (including net imports) must meet demand at each national node for all representative periods.
- **Reliability Requirements:** Minimum planning reserve margins (or other reliability metrics like LOLP, if used) are enforced at national or regional levels, depending on the scenario, to ensure security of supply.
- **Renewable Energy Targets and Emission Limits:** Scenarios incorporate national or regional renewable energy penetration goals and CO_2 emission reduction targets (or carbon prices) consistent with stated climate commitments or policy ambitions.
- **Generation and Storage Operational Limits:** Constraints on ramping capabilities, minimum stable generation levels, energy storage operational characteristics (efficiency, charge/discharge rates, storage capacity), and hydro reservoir energy limits and flow constraints are included.
- **Transmission Constraints:** Power flow on existing and candidate interconnection lines is limited by their thermal capacities, and electrical losses are accounted for.

Scenario Design for Policy Analysis

To evaluate the impact of regional integration under varying political, institutional, and physical conditions, we developed a comprehensive set of policy-relevant scenarios. This design enables sensitivity analysis of key system outcomes (e.g., total costs, CO_2 emissions, energy security metrics) under different degrees of inter-country cooperation and specific exogenous stressors. The scenario architecture is structured around the following key dimensions:

- **Level of Regional Integration:** This primary dimension explores pathways ranging from: (a) Full Integration, assuming complete coordination in planning, investment, and dispatch across all 21 modeled countries, with minimal institutional barriers to electricity trade; (2) Partial Integration, simulating cooperation among specific sub-regional blocs (e.g., Andean Community, Southern Cone, SIEPAC), reflecting existing political alliances, historical precedents, or plausible intermediate steps towards wider integration; and (3) Fragmented Systems (or Status Quo), where each country optimizes its system primarily on a national basis, with limited or no new cross-border coordination beyond currently existing interconnections and bilateral agreements.

- **Institutional Assumptions (Operationalizing Political Factors):** To explore the impact of political realities, specific parameters are varied:
  - *Sovereignty Preference (Geopolitical Cost):* This is modeled by comparing the fully integrated regional optimum with scenarios where national systems are constrained to prioritize a certain degree of energy self-sufficiency or limit reliance on specific neighbors, even if this results in higher regional costs. The economic penalty incurred represents the 'Geopolitical Cost'. The formulation and further explanation of the Geopolitical cost can be found in Section 2.1 of the Supplementary Information.
  - *Trust Level Costs (Cost of Trusting/Not Trusting):* These are reflected through adjustments to inter-country electricity exchange limits, differentiated risk premiums applied to investments in cross-border infrastructure, or varying transaction costs on traded electricity, particularly in partial integration or fragmented scenarios. Lower perceived trust translates into stricter operational constraints or higher financial hurdles for cooperative projects. The formulation and further explanation of the Trust Level Costs can be found in Section 2.2 of the Supplementary Information.
- **Climate and Demand Stressors:** All integration levels and institutional settings are analyzed under a range of exogenous conditions, including: (1) varying hydrological conditions for hydropower (e.g., average inflow years, multi-year dry periods based on historical El Niño cycles); and (2) different demand growth trajectories (e.g., baseline projections vs. high electrification scenarios driven by accelerated uptake of electric vehicles and industrial decarbonization). The geographic illustration of the achieved optimal interconnections can be found in Supplementary Information (Section 5).

This multi-dimensional scenario matrix allows for the robust quantification of metrics such as the "Geopolitical Cost," the "Economic Loss from Trusting," and the "Economic Loss from Not Trusting," as presented and discussed in Section 1.4. It is important to note that these scenarios are designed as analytical tools to illuminate strategic trade-offs and guide policy design, rather than to provide precise predictions of future outcomes.

Model Validation

To ensure the credibility of the model outputs, the base-year (2025) configuration and generation mix were calibrated against recent historical data (e.g., 2022-2023) from national energy balances and OLADE statistics. Likewise, the results are compared with relevant papers in the literature in order to ensure that the magnitude order is coherent[21;23;67;103]. Key model parameters, such as technology costs and renewable potentials, were benchmarked against IEA reports, IRENA data, and recent regional studies[12;104;105;112]. While perfect replication of complex national systems is challenging, these steps ensured that the model provides a plausible representation of regional energy dynamics and a robust basis for comparative scenario analysis.

Data availability. The datasets used to construct the energy system model are derived from publicly available sources, including IDB, OLADE, and IEA reports[12;19;104]. Additional regional data on transmission infrastructure, renewable potential, and technology costs were obtained from official reports and academic literature[21;23;87;103]. All relevant data supporting the findings of this study are available from the corresponding author upon reasonable request. In addition, the complete set of simulation outputs (generation mixes, transmission flows, investments, and costs) is publicly accessible through an interactive visualization platform at https://explorer.energia.la/, whose source code is openly available at https://github.com/gerardoblancopy/LatamEnergyIntregrationExplorer.

Code availability. The energy system optimization model was implemented in Python using open-source libraries. Custom scripts used for scenario generation, simulation, and visualization are available from the corresponding author upon reasonable request. A repository with anonymized, reproducible versions of the model and key inputs will be made available upon publication.

Declarations

Acknowledgements

We thank A. Livino, F. Garcés and A. Rebolledo for their valuable discussions as part of the expert panel. This research was supported by a grant through a collaboration agreement between the Faculty of Physical and Mathematical Sciences at the University of Chile and the Asociación de Transmisoras de Chile, under Resolution No. E2083. We also acknowledge support from the Agencia Nacional de Investigación y Desarrollo (ANID) [grants PIA/PUENTE AFB230002, FONDECYT 1231924]. This work was performed in part at the Instituto Sistemas Complejos de Ingeniería (ISCI) and the Pontificia Universidad Católica de Valparaíso.

Conflict of interest/Competing interests

The authors declare no competing interests.

Ethics approval and consent to participate

Not applicable. This study does not involve human participants or animal subjects.

Consent for publication

Not applicable. No individual person's data is included in this manuscript.

Additional information

Supplementary information The online version contains supplementary material available at https://XXXXXXXXX.

Correspondence and requests

Should be requested from the corresponding author(s).

Author contribution

R.M., G.B., and L.R. conceived the idea and designed the experimental framework. L.R. constructed the model, collected the data, and conducted the simulations. L.R. and F.S. performed the experiments and analyzed the results. G.B. and R.M. contributed to the data verification and interpretation. L.R. and G.B. wrote the manuscript. R.M. supervised the project. G.B. contributed conceptual guidance throughout. L.B. and W.F. participated in the discussion and contributed to the interpretation of regional implications. All authors contributed to the revision of the manuscript.

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