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Small Modular Reactors (SMRs) in Latin America: topics, problems, and challenges

Reactores modulares pequeños (SMRs) en América Latina: temas, problemas y desafíos

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Resumen: Los reactores modulares pequeños (SMRs) han ganado creciente atención como una alternativa potencialmente flexible, competitiva en costos y más segura frente a los grandes reactores convencionales, valorada por su compatibilidad con redes descentralizadas, su complementariedad con energías renovables y el menor riesgo financiero para los inversores. En América Latina, sin embargo, su desarrollo sigue en una fase incipiente y enfrenta obstáculos estructurales que la literatura académica ha abordado solo parcialmente. Este artículo revisa 22 publicaciones indexadas en WoS y Scopus centradas en la región, sistematizando las principales líneas de investigación, vacíos temáticos y metodológicos, y desafíos tecnológicos, institucionales, epistémicos y sociopolíticos. Los hallazgos revelan un corpus fragmentado y concentrado en Argentina, con cobertura limitada de otros contextos nacionales y predominio de enfoques técnicos sobre los sociales, regulatorios y territoriales. El artículo sostiene que avanzar hacia una gobernanza legítima y contextualizada de los SMRs en América Latina requiere una agenda de investigación regional más definida, marcos institucionales sólidos, alianzas intersectoriales y atención sostenida a las dimensiones sociales que condicionan la aceptación pública.
Palabras clave: SMRs; América Latina; desafíos tecnológicos; desafíos epistémicos; desafíos regulatorios; desafíos sociopolíticos

Abstract: Small modular reactors (SMRs) have gained growing attention as a potentially flexible, cost-competitive, and safer alternative to large conventional reactors, valued for their compatibility with decentralised networks, their complementarity with renewable energy, and their lower financial risk for investors. In Latin America, however, their development remains at an early stage and faces structural obstacles that the academic literature has only partially addressed. This article reviews 22 publications indexed in WoS and Scopus focused on the region, systematising the main research lines, thematic and methodological gaps, and technological, institutional, epistemic, and sociopolitical challenges. The findings reveal a fragmented corpus concentrated in Argentina, with limited coverage of other national contexts and a predominance of technical approaches over social, regulatory, and territorial ones. The article argues that advancing toward legitimate and contextualised SMR governance in Latin America requires a clearer regional research agenda, solid institutional frameworks, intersectoral alliances, and sustained attention to the social dimensions that condition public acceptance.
Keywords: SMRs; Latin America; technological challenges, epistemic challenges, regulatory challenges; sociopolitical challenges.

1. INTRODUCTION

In the context of the climate crisis and the imperative transition to sustainable energy systems, small modular reactors (SMRs) are emerging as a viable alternative to traditional nuclear energy models. Their smaller-scale design offers the possibility of developing energy sources that could address current decarbonisation challenges and constitute an option for creating low-impact energy systems that support the global energy transition (Raineri et al., 2025; IAEA, 2020). In the current global context, several nations have made significant progress in the design and construction of SMRs. The United States is a notable leader in this domain, with Canada, Russia, China, France and South Korea also being significant players (World Nuclear Association, 2025). In terms of SMR implementation**,** the second decade of the 21st century has witnessed significant milestones. Among these, the achievements of China, which has commercially developed the Linglong One (ACP100) reactor, and Russia, with its Akademik Lomonosov floating reactor, stand out (IAEA, 2020; World Nuclear Association, 2025).

In Latin America, progress has been gradual, but certain countries, including Argentina, a leader in this field with the CAREM-25 model, have made advances in SMR projects. Although these advances are relevant, they have also encountered structural limitations characteristic of a developing region. Such limitations encompass factors such as scarce funding, inadequate regulation, a lack of social legitimacy, safety concerns, and a strong commitment to fossil fuels, which have the potential to hinder their advancement (Ramana, 2024; Ramana and Mian, 2014; Downer and Ramana, 2021; Alfaro et al., 2014). Furthermore, SMRs are not immune to potential tensions surrounding their social acceptance. Although they are presented as safer, concerns and adverse perceptions related to possible accidents and impacts on the environment and society can be generated (Locatelli et al., 2014). Added to this challenge are the problems that may arise in their regulation and management, given the limitations of institutional and organisational capacities in Latin America (Cisternas et al., 2025).

In this regard, various studies have revealed the existence of persistent negative perceptions regarding the cost-benefit ratio of nuclear energy (Wynne, 2006; Jasanoff and Kim, 2009). The social acceptance of SMRs is therefore contingent on institutional and sociocultural factors, with trust in developers, participation, and transparency being of particular relevance. In the extant literature on SMRs, there is a tendency to focus tensions and problems on technical and economic issues in a region with unequal access to technologies, heterogeneous institutional capacities and recurrent socio-environmental conflicts (Raineri et al., 2025). Consequently, academic debate needs to pay closer attention to territorial contexts and institutional frameworks. However, it is imperative to acknowledge the nascent capacity for knowledge generation in this domain, which has been constrained and fragmented, impeding the identification of research strands that integrate social, environmental, and technological dimensions.

In view of the aforementioned problem, the objective of this article is to conduct a critical review of the extant academic literature on SMRs in Latin America and to identify its main themes, gaps, and challenges. The article is organised into five sections that move from the methodological approach to the descriptive and thematic results, the identification of structural and epistemic gaps, the analysis of challenges for a regional research and governance agenda, and a discussion that interprets the findings from a sociotechnical perspective, before presenting the conclusions, which summarise the primary results, acknowledge the limitations of the review and analyse their implications for research and governance of SMRs in the region.

It should be noted that this review does not start from a closed theoretical framework, nor does it deductively apply a specific disciplinary perspective. Its design is inductive, and its primary purpose is cartographic, insofar as it seeks to map an emerging field whose regional academic production remains scarce, fragmented and asymmetrical. The findings, however, allow for an interpretive reading that moves beyond a descriptive diagnosis. The technical predominance that characterises the literature on SMRs in Latin America, the geographical concentration of knowledge and the relative marginalisation of social and institutional dimensions configure a pattern that this review proposes to understand as an early form of knowledge organisation around emerging technologies with low regional maturity. This proposition is developed in the discussion section and makes it possible to situate the article's findings within broader debates on sociotechnical co-production, technological imaginaries, risk and public legitimacy.

2. METHODOLOGY

This review draws on publications indexed in Web of Science (WoS) and Scopus, two databases widely recognised for their international coverage and indexing standards, which makes them appropriate sources for this type of work (Caputo and Kargina, 2022; Zhu and Liu, 2020). The search strategy builds on prior systematic review work developed by the same research team (Vallejos-Romero et al., 2021; Vallejos-Romero et al., 2023) and began with a broad sweep using the generic terms 'nuclear energy', 'atomic energy', and 'nuclear reactor', restricted to title, abstract, and keyword fields across both platforms.

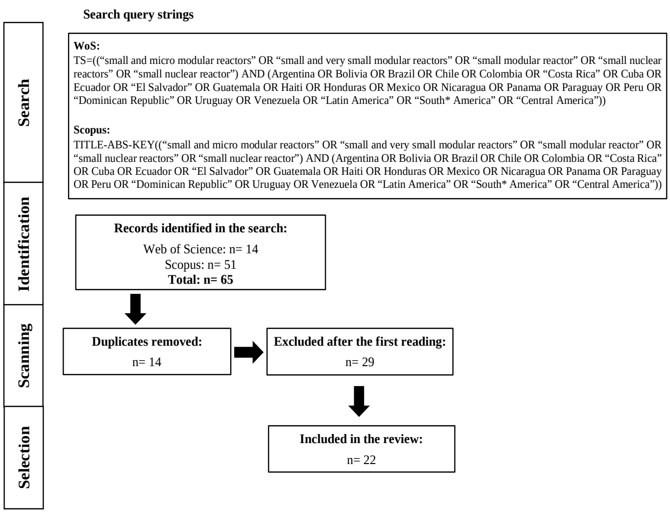
That initial search made it possible to map the diversity of expressions used in the specialised literature to refer to SMRs, which in turn allowed the definitive search strategy to be refined. The most representative variants were incorporated into the final string, among them small and micro modular reactors, small and very small modular reactors, small modular nuclear reactors, and small modular reactors. Given the regional focus of the review, the strategy was further expanded to include the names of all Latin American countries alongside broader geographic terms covering the region and its subregions, Latin America, South

America, and Central America, applied consistently to title, abstract, and keyword fields. The final search string was configured as follows:

> TITLE-ABS-KEY((“small and micro modular reactors” OR “small and very small modular reactors” OR “small modular reactor” OR “small nuclear reactors” OR “small nuclear reactor”) AND (Argentina OR Bolivia OR Brazil OR Chile OR Colombia OR “Costa Rica” OR Cuba OR Ecuador OR “El Salvador” OR Guatemala OR Haití OR Honduras OR Mexico OR Nicaragua OR Panama OR Paraguay OR Peru OR “Dominican Republic” OR Uruguay OR Venezuela OR “Latin America” OR “South* America” OR “Central America”))

The search returned 65 publications in total, 14 indexed in WoS and 51 in Scopus, as shown in Figure 1. These documents went through an initial selection phase to identify possible duplicates, cross-checking key metadata including DOIs, titles, and author names, a procedure that eliminated 14 duplicate records and left 51 unique articles for preliminary analysis. An exploratory reading of abstracts and keywords was then carried out to apply the inclusion criteria established for the review. Articles were excluded when they did not address Latin American countries as an object of analysis or case study, when they corresponded to conference proceedings, when they were written in a language other than Spanish or English, or when the full text was unavailable despite searches in indexed databases and journal websites. After applying these criteria, 29 records were excluded, yielding a final corpus of 22 articles. The search cutoff was May 2025.

Figure 1: Diagram of the search and sampling strategy

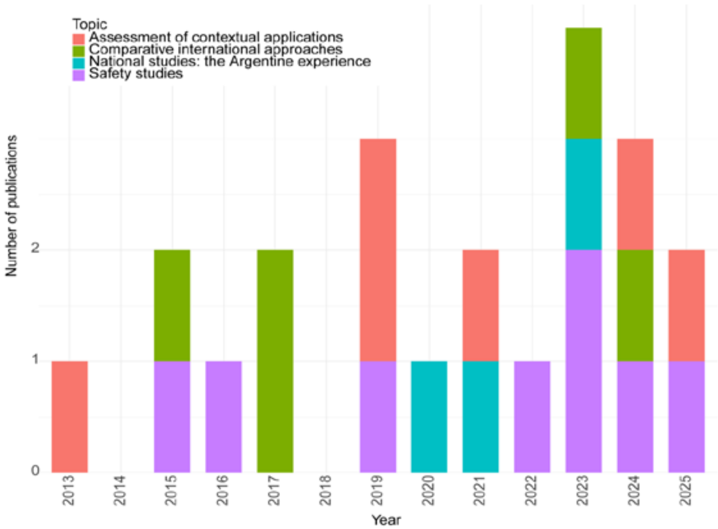


Source: Own elaboration

3. Results
3.1. Descriptive analysis.

The temporal distribution of the corpus is irregular, with no relevant publications identified between 2018 and 2022, and 2023 concentrating the highest number of studies included in the review. The thematic analysis identified four main lines of research, namely international comparative studies, national case studies with particular weight on the Argentine experience, evaluations of contextual applications, and safety and operational analyses. This last category has shown growing recurrence over time, reflecting the increasing prominence of technical and operational concerns in the literature, while studies with a national or regional focus underwent a period of consolidation from 2020 onward, with the Argentine experience standing out as the most developed and widely referenced case in the region (see Figure 2).

Figure 2. Evolution of publications on SMRs



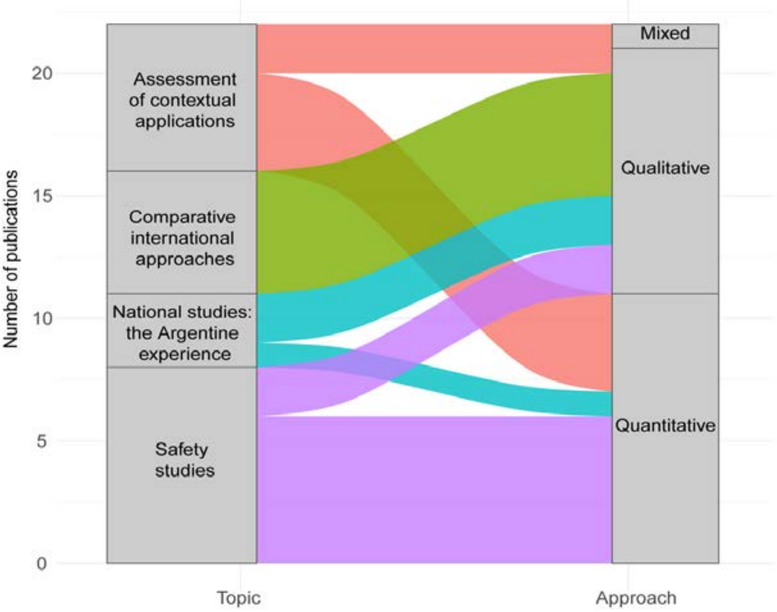
Source: Own elaboration.

With regard to methodological approaches, quantitative studies predominate across the corpus, particularly in research on operational and safety aspects as well as in national case studies, where they have facilitated the analysis of technical and operational variables including reactor performance and reliability (see Figure 3).

Evaluations of contextual applications tend to combine quantitative and mixed methods, reflecting a growing effort to integrate technical variables with territorial, economic, or functional conditions specific to each context.

Qualitative work appears more frequently in international comparative studies and national cases, and is largely absent from safety and operational research, a distribution that reflects, at least in part, the different objects of analysis and disciplinary traditions from which each line of research has developed.

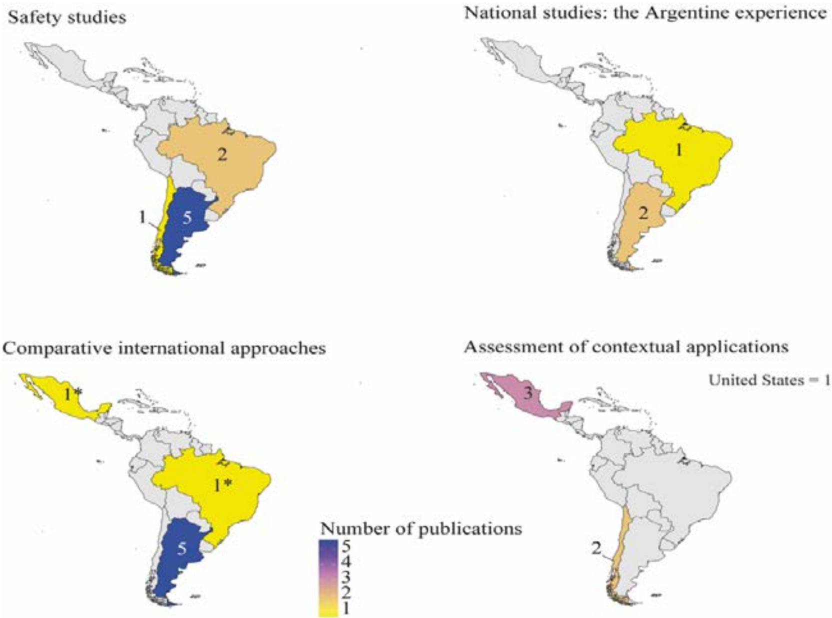
Figure 3. Alluvial diagram of methodological approaches to SMRs



Source: Own elaboration.

Figure 4 maps the geographical distribution of research on SMRs across the region, where the intensity of the fill colour indicates the volume of scientific output per country and the superimposed figures show the total number of publications registered in each territory. Despite the asymmetries that this representation makes visible, the subjects covered in this review have been addressed to some extent across the region, pointing to a gradual territorial expansion of scientific interest in the technology. Argentina, Brazil, Chile, and Mexico account for the highest concentration of studies, consolidating their position as the main reference points in the regional field, while a portion of the corpus draws on international comparative frameworks that extend the analysis to cases in Africa, Europe, Asia, and North America, reflecting the global dimension of debates around SMR implementation, adaptation, and future projection in different geographical and political-institutional contexts.

Figure 4. Geographical distribution of research on SMRs in Latin America.



Source: Own elaboration.

* Indicates a single publication involving multiple countries; these were represented separately for better spatial visualization of the territorial scope of the studies in the region.

3.2 Results of the review

Scientific literature on SMRs has grown steadily in recent years, driven by the broader search for low-carbon energy sources that are safe and adaptable to different contexts. The field remains in an early phase of consolidation, but the corpus reviewed here shows a recognisable thematic organisation that this section analyses across four lines of research, with attention to the contributions, gaps, and challenges each one poses for the development of the field in Latin America.

3.2.1. International comparative approaches.

The first line of research focuses on examining the evolution of SMRs in different national contexts through a comparative approach that seeks to identify the institutional, economic, and technological factors that condition their development (see Table 1 for further details).

Table 1. Summary of review findings in comparative approach in the progress of SMRs

Key findings	Topics	Description	Reference (source)
Factors on SMRs	Institutional and economics factors	Institutional obstacles	Maize (2015), Morales Pedraza (2017)
		Social obstacles	Morales Pedraza (2017)
		Regulatory barriers (countries with stable frameworks)	Guerrero-Lemus & Shephard (2017)
	Technological factors	Implementation phase (difficulties)	Maize (2015), Morales Pedraza (2017)
		Progressive production of SMRs	Guerrero-Lemus & Shephard (2017)
		Common patterns between countries (Latin America)	Popov et al. (2023), Alfaro et al. (2025)

Source. Own elaboration. Note. The main topics detected in the literature on the findings in factors on SMRs are shown.

The picture that emerges from these studies is uneven. Countries like the United States have played a prominent role in nuclear development broadly but have moved slowly on specific SMR projects, facing institutional, social, and regulatory barriers alongside high costs relative to competing energy sources (Maize, 2015; Morales Pedraza, 2017). Argentina, Russia, China, and South Korea, by contrast, have made more concrete advances in construction and commercialisation, supported by stable institutional frameworks, long-term strategic energy policy decisions, and sustained government commitment to nuclear technology (Guerrero-Lemus and Shephard, 2017).

A second strand within this line looks for common patterns among countries that have advanced further, with particular attention to prioritised applications, prevalent designs, and emerging technical challenges. Among those challenges, Popov et al. (2023) identify transport logistics, remote operation, cybersecurity, and radioactive waste management as the most pressing unresolved issues across national contexts, all of which tend to intensify when deployment scenarios involve remote locations, limited infrastructure, or complex geographies. These contributions have helped frame an agenda for the field that moves beyond demonstrating technical feasibility toward addressing the conditions under which SMRs can be implemented in settings with constrained fiscal and institutional capacity, whilst responding to the specific needs of Latin American countries and others in the global south.

Alfaro et al. (2025) bring this comparative perspective closer to the regional reality, offering an overview and historical perspective of the energy landscape in Latin America and the Caribbean, with particular attention to the development of CAREM-25 and SMRs more broadly, and analysing the remaining challenges and future opportunities that this technology offers for the region.

3.2.2. National studies: the Argentine experience.

Among the national cases covered in the corpus, Argentina stands out as the most developed, with the design and construction of the CAREM-25 prototype, promoted by the National Atomic Energy Commission (CNEA), generating the largest body of regional research (see Table 2). This project has been the subject of various analyses addressing both its historical trajectory and its technical and strategic implications for the region. Delmastro (2020) reconstructs the history of the Argentine nuclear programme from its early research reactors through to the formulation and commissioning of CAREM-25, highlighting the technical and economic advantages of the model while acknowledging the challenges posed by its scalability and the transition from an experimental prototype to a commercially competitive design.

Table 2. Summary of review findings in specific national case studies

Key findings	Topics	Description	Reference (source)
Specific national case studies on SMRs	Prototype design and construction	State Promotion and support	Delmastro (2020)
		Strategic regional relevance	Delmastro (2020)
		Scalability challenge	Delmastro (2020)
	Technical analysis	Quality parameters in future scenarios	Marcel (2023), Delmastro (2020)
		Efficiency and operational optimization (argentine case)	Marcel (2023)

Source. Own elaboration. Note. The main topics detected in the literature on the findings in Specific national case studies in SMRs are shown.

Marcel (2023) complements this with a closer technical analysis of the reactor, examining safety parameters, thermohydraulic dynamics, and system performance projections in the context of a possible global revaluation of nuclear fission technologies. Both works converge on the importance of continuing to refine the design and resolve fundamental operational issues. Three research priorities have consolidated within this line: optimising energy performance, improving the efficiency of natural circulation cooling systems, and assessing the viability of multimodular configurations that allow for more efficient use of shared infrastructure. Argentina's experience is not only the most elaborated case in the region but also the closest available reference point for countries in the global south that are exploring SMR options.

3.2.3. Evaluation of contextual applications.

This line of research examines the relevance of SMRs in specific national and territorial contexts and explores their potential for unconventional applications and their contribution to local energy challenges (see Table 3).

Table 3. Summary of review findings in national and territorial relevance of SMRs

Key findings	Topics	Description	Reference (source)
National and territorial relevance of SMRs (Latin American Countries)	Unconventional applications	Seawater desalination	Genco and Genco (2019), Nieto-Pérez (2013), Alonso and Montaño (2025)
		Energy supply in mining and oil production	Novgorodcev and Jarquin-Laguna (2020), Morones-García and François (2024)
	Contribution to local energy challenges	Electrification of isolated areas (decarbonization)	Morones-García and François (2024), El-Genk and Palomino (2019)
		Technical feasibility and economic competitiveness	Alonso and Montaño (2025)
		Decarbonization targets	Novgorodcev and Jarquin-Laguna (2020), Nieto-Pérez (2013), Genco and Genco (2021)

Source. Own elaboration. The main topics detected in the literature on the findings in national and territorial relevance of SMRs are shown.

The applications studied encompass seawater desalination, electrification of remote areas, power supply for mining operations, and integration into offshore oil platforms. In countries such as Chile, Mexico, and Brazil, where energy demands in certain sectors are specific and cannot always be met by conventional infrastructure (Genco and Genco, 2019; Morones-García and François, 2024; Novgorodcev and Jarquin-Laguna, 2020; Nieto-Pérez, 2013), these applications have received particular attention.

Seawater desalination in isolated regions of northern Chile and its viability under conditions of high water stress is examined by Genco and Genco (2019), while Morones-García and François (2024) and El-Genk and Palomino (2019) explore nuclear microreactors for isolated communities and medium-sized industrial facilities in Mexico, emphasising their role in decarbonising sectors still dependent on fossil fuels and suggesting that a microreactor such as the VLSLIM could extend electricity access to remote and rural populations across Latin America. The technical feasibility and economic viability of a hybrid nuclear-renewable system that integrates water desalination, with SMRs as primary infrastructure and photovoltaic and wind energy in a complementary role, is assessed by Alonso and Montaño (2025) for a region facing an obsolete and isolated electricity system alongside high levels of water stress.

Offshore oil platforms in Brazil provide the context for Novgorodcev and Jarquín-Laguna (2020), who examine the use of SMRs to reduce fossil fuel consumption in extraction operations, while Genco and Genco (2021) carry out a comparative assessment of energy sources against the decarbonisation targets set out in Chilean energy policy. An early feasibility study of smaller-scale reactors in Mexico by Nieto-Pérez (2013) rounds out this group, noting technical advantages over conventional designs while acknowledging that public acceptance could face limitations tied to risk perception and the complexity of radioactive waste management.

The literature agrees that SMRs could play a strategic role in diversifying national energy matrices, particularly in sectors where renewable energies face stability or coverage constraints, and that their deployment would contribute not only to local energy goals but also to international commitments on greenhouse gas emissions. The remaining gaps are consistent across studies: limited technological maturity in certain designs, such as submarine SMRs, and a shortage of research that integrates social, economic, and territorial variables when assessing viability (Genco and Genco, 2021).

3.2.4. Safety and performance studies.

This line of research focuses on the operational safety of SMRs, addressing aspects such as remote monitoring, resilience to extreme events, the development of robotic technologies for maintenance, and the overall technical viability of these systems in various environments, all oriented toward ensuring the safe and efficient operation of reactors under both normal and extraordinary conditions (see Table 4).

Table 4. Summary of review findings in operational safety of SMRs

Key findings	Topics	Description	Reference (source)
Operational safety of SMRs (technical focus)	Safe and efficient operation of reactors	SMRs decommissioning strategies (anticipation)	Caldas and Silva (2023)
		Anticipate potential failures	Upadhyaya et al. (2016), Markou and Genco (2019)
		Behavior of fuel rod materials	Afonso et al. (2023)

	Technical aspects (operation)	Robotic technologies for inspection	Pedre et al. (2015)
		Thermal behavior and heat transfer	Ganjaroodi et al. (2024)
		ANNs and GAs – computer codes	Nasiri et al. (2022)

Source. Own elaboration. Note. The main topics detected in the literature on the findings in operational safety of SMRs are shown.

Studies on the CAREM-25 design have evaluated its internal operation using computational models that employ various codes. In relation to the end of the reactor lifecycle, Caldas and Silva (2023) examine decommissioning strategies for SMRs in Brazil, anticipating the problems and institutional responsibilities inherent in such processes.

Upadhyaya et al. (2016) examine remote monitoring systems designed to optimise SMR operation and anticipate possible failures through preventive maintenance strategies, establishing one of the early frameworks for real-time operational control in this type of reactor. From a different but complementary angle, Markou and Genco (2019) model the seismic behaviour of the NuScale design under conditions comparable to large earthquakes, identifying the adjustments required for deployment in high-seismicity regions such as Chile, where natural hazard exposure adds a layer of complexity to any viability assessment. Two further studies extend this operational focus to materials and maintenance infrastructure: Afonso et al. (2023) analyse fuel rod behaviour under conditions specific to the Brazilian electrical system, identifying the need for coating innovations that improve thermal and structural stability, while Pedre et al. (2015) report on robotic technologies for steam generator inspection in fourth-generation reactors, proposing automated solutions for environments that are difficult to access or highly exposed.

Thermal behaviour and heat transfer in the CAREM-25 reactor are examined by Ganjaroodi et al. (2024) through thermohydraulic modelling tools that generate cross-validation data and identify areas for improvement and future research. That same design serves as the basis for a related study by Ganjaroodi et al. (2025), who assess the technical feasibility of replacing uranium fuel with a thorium-based cycle, focusing on core criticality and neutron parameters in response to uranium supply and price concerns, with the dual objective of building a reliable inventory for nuclear safety modelling and developing radiation protection measures for the most harmful radionuclides.

Working from a different computational approach, Nasiri et al. (2022) use artificial neural networks and genetic algorithms to optimise fuel geometry and reactor core operating parameters under dual cooling conditions, with the aim of reducing maximum fuel temperature and improving the operational safety of the modified design relative to the original CAREM-25.

Across this line, the evidence supports the view that passive safety advances in SMRs, while real, leave substantial technical challenges unresolved, among them the optimisation of monitoring systems, the integration of regulatory tools and standards, real-time management, and the development of advanced materials for fuel cladding. In the Latin American context, contextualised assessments of natural hazards such as earthquakes and tsunamis remain an especially pressing requirement, particularly in countries with high seismic exposure such as Chile.

The second type of study focuses on the implementation of computational codes to increase the accuracy, efficiency, and safety of the CAREM-25 design. This approach expands knowledge of the reactor's operational functionality under a range of parameters, conditions, and timeframes, supporting the adaptation and adoption of response measures that enable informed regulation and management of the technology before physical implementation.

4. Gaps and Problems in Research on SMRs in Latin America

Analysis of the specialised literature, within the framework of the lines of research identified above, reveals a set of thematic, structural, and methodological gaps that limit the consolidation of a formalised and contextualised field of knowledge on SMRs in Latin America.

A first gap concerns the absence of research that integrates social and political variables into comparative approaches at the international level, an omission that limits the ability to understand how institutional, cultural, and territorial conditions influence the acceptance or rejection of SMRs. Related to this, public acceptance and risk perception in specific contexts have received limited systematic attention, which may impede progress toward technologically viable and socially legitimate projects in which transparent risk communication plays a central role (Morales Pedraza, 2017; Nieto-Pérez, 2013; Caldas and Silva, 2023). Addressing this dimension requires articulating multilevel governance strategies that involve the state, industry, and citizens in a coordinated manner, alongside instances of cooperation between states and organisations from different countries (Guerrero-Lemus and Shephard, 2017; Alfaro et al., 2025).

A second and closely related limitation is that the majority of the research reviewed adopts a distinctly technical approach, with minimal incorporation of social, regulatory, or institutional perspectives, which reduces the capacity to understand SMRs as complex phenomena that entail not only technological challenges but also economic, political, and cultural ones (Alonso and Montaño, 2025; Guerrero-Lemus and Shepard, 2017; Maize, 2015; Morones-García and François, 2024). The absence of integrative frameworks may in turn limit the formulation of public policies that take into account the heterogeneity of Latin American contexts (Marcel, 2023).

A third gap concerns the geographical concentration of knowledge production, with a pronounced emphasis on Argentina and comparatively limited coverage of other Latin American countries, a pattern that may impede the development of comparative learning and hinder the establishment of shared regional knowledge frameworks. The scarcity of systematic research in countries such as Mexico, Brazil, and Chile limits the formulation of technological guidelines adapted to local challenges, constrains the assessment of public policies, and narrows the possibilities for establishing strategic alliances with countries that have greater experience in SMR development (Morones-García and François, 2024). This is compounded by the widespread mistrust of nuclear energy in significant segments of Latin American society, sustained by a legacy of opposition to energy initiatives regarded as hazardous and lacking social legitimation, opposition that has been reinforced by high-impact accidents such as the 2011 Fukushima disaster (Morales Pedraza, 2017; Nieto-Pérez, 2013; Markou and Genco, 2019).

The review also points to a discernible reliance on external designs from countries with substantial nuclear expertise, including the United States, Russia, and China (Popov et al., 2023), and despite the relevance of Argentina's experience at the regional level, the scientific literature reveals a limited regional capacity to adapt, validate, and certify its own technologies (Marcel, 2023). This reliance can generate technological vulnerability and present challenges with respect to territorial viability, local appropriation of energy solutions, and the prospects for autonomous and sustainable SMR deployment in the region (Morales Pedraza, 2017), a gap that studies on the technical aspects of CAREM-25 have begun to address through computational methods that simulate modifications capable of enhancing reactor performance under specific conditions (Ganjaroodi et al., 2024; Nasiri et al., 2022; Ganjaroodi et al., 2025).

5. Challenges for Development of SMRs in Latin America

The literature reviewed points to several challenges for the implementation of SMRs in the region, challenges that reflect the tensions between the promises of this technology and the structural, institutional, and social conditions of Latin America, and that can manifest both as technical impediments and as dynamics requiring a contextualised and multidimensional perspective.

These challenges can be grouped into four main categories, covering the technological, institutional and regulatory, epistemic, and sociopolitical dimensions. Each is examined below, with attention to the aspects that most urgently require action to facilitate the scientific and technological advancement of SMRs in the regional context (see Table 5).

5.1 Technological challenges

The transition from conceptual designs to the operational and commercial implementation of SMR projects remains a long-term goal for most countries in the region. Despite the progress represented by initiatives such as the CAREM-

25 project in Argentina, efforts remain concentrated in the early stages of experimentation, and the path toward full deployment involves a series of unresolved technical challenges (Delmastro, 2020; Marcel, 2023).

Among those challenges, the need to improve energy efficiency, enhance the reliability of cooling systems, expand installed capacity, and develop multimodular configurations that allow for more flexible use of shared infrastructure stands out as a persistent set of problems. At the same time, the region faces a clear shortage of specialised nuclear infrastructure, as facilities for testing, monitoring, and maintenance have in many cases been dismantled, are obsolete, or simply do not exist, which reduces the possibilities for locally validating the components and systems required to operate SMRs under real conditions (Alfaro et al., 2025; Marcel, 2023). This situation is compounded by the dependence on foreign technological designs that require adaptation to regional geographical, climatic, and seismic characteristics, adaptations that often exceed the technical capabilities available locally (Afonso et al., 2023; Morones-García and François, 2024).

Beyond infrastructure, a further set of operational and safety uncertainties remains unresolved, covering remote unit management, structural resistance to natural disasters, cybersecurity, advanced modelling to predict responses to transient situations and accidents, optimisation of reactor temperature through passive cooling mechanisms, neutron analysis of thorium fuel in response to uranium supply concerns, safe transport of modules, and system reliability in remote or strategically sensitive environments (Popov et al., 2023; Markou and Genco, 2019; Ganjaroodi et al., 2024; Nasiri et al., 2022; Ganjaroodi et al., 2025; Nieto-Pérez, 2013).

Moving beyond these constraints will require sustained investment in infrastructure, rigorous experimental validation processes, and effective mechanisms for technology transfer and appropriation, conditions that have been largely absent across much of the continent and that continue to limit the integration of SMRs into regional energy strategies in ways that are less dependent and more contextualised.

5.2 Institutional and regulatory challenges

Nuclear regulations in Latin America vary considerably in terms of how current, capable, and comprehensive they are, a heterogeneity that creates uncertainty for applied research and for the eventual commercial implementation of SMR technology (Maize, 2015; Markou and Genco, 2019).

Regulatory structures across the region are not yet prepared to address the specificities of SMRs, and several studies emphasise the need to modernise frameworks so that they can effectively evaluate, authorise, and supervise modular reactors whose operating principles, scalability, and flexibility differ substantially from those of conventional nuclear reactors (Alfaro et al., 2025;

Guerrero-Lemus and Shepard, 2017; Nieto-Pérez, 2013). Poor institutional coordination compounds this problem, evident in the fragmentation and sometimes outright absence of relationships between government agencies, research centres, and private sector actors, which hinders the design of coordinated and long-term policies (Caldas and Silva, 2023). Morales Pedraza (2017) and Popov et al. (2023) add to this picture by highlighting the shortage of qualified personnel and training programmes in Latin American countries with interest in SMRs, a human capital gap that reinforces the need for mechanisms that strengthen inter-institutional collaboration, encourage nuclear innovation, and consolidate public-private partnerships capable of supporting context-specific development and implementation.

Access to financing and carbon credits at the global level is also a critical factor (Alfaro et al., 2025; Caldas and Silva, 2023; Guerrero-Lemus and Shepard, 2017), as are government subsidies for initiatives in water-stressed regions that could benefit from SMR desalination capabilities (Alonso and Montaño, 2025). In the context of Argentine development, the literature also explores potential forms of international cooperation as a pathway for facilitating broader SMR implementation across the continent (Alfaro et al., 2025; Morales Pedraza, 2017; Nieto-Pérez, 2013).

Overcoming these challenges requires strengthening the technical competencies of regulatory agencies and adopting a forward-looking perspective that anticipates the complexity and uncertainty inherent in technological development, alongside progress in establishing collaborative governance spaces and designing scientific and technological policies aligned with the goals of energy transition, sustainability, and regional development (Alfaro et al., 2025).

5.3 Epistemic challenges and knowledge gaps

The lack of systematic scientific research is one of the most significant barriers to developing regional knowledge on SMRs in Latin America. Publications remain scarce and heavily concentrated in Argentina, an asymmetry that limits the generation of comparative studies and multidimensional analyses capable of informing viability assessments across different national contexts (Popov et al., 2023; Maize, 2015). In much of the rest of the region, research on the topic is in its infancy, with no consolidated lines of inquiry or long-term agendas focused specifically on SMRs.

This reflects an emerging institutionalisation characterised by a lack of dedicated funding programmes, a scarcity of stable research groups, and a shortage of experts trained in critical areas of SMR technology (Maize, 2015; Alfaro et al., 2025; Caldas and Silva, 2023; Marcel, 2023). As a consequence, prevailing analytical frameworks tend to reproduce technical-regulatory approaches with limited capacity to integrate social, environmental, and territorial factors, even as various studies underscore the importance of generating technical, economic, and social knowledge relevant to the varied applications of SMRs across the region (Morones-García and François, 2024; Guerrero-Lemus and Shepard, 2017; Novgorodcev and Jarquín-Laguna, 2020; Genco and Genco, 2021). That integration requires research adapted to local variables such as specific energy demand, water availability, the functioning of particular configurations in hybrid energy systems under different geographical conditions, exposure to natural hazards, and institutional capacity for waste management and territorial governance (Alonso and Montaño, 2025).

Bridging these gaps calls for a commitment to interdisciplinary approaches capable of articulating knowledge from the natural, social, economic, and environmental sciences, as well as for integrative decision-making methodologies that enable the evaluation of SMRs based not only on their technical performance but also on their compatibility with the region's sustainability, equity, and territorial development aspirations (Caldas and Silva, 2023; Novgorodcev and Jarquín-Laguna, 2020; Genco and Genco, 2021).

5.4 Sociopolitical challenges

Social acceptance of SMRs faces a particularly difficult starting point in Latin America, where a strong historical stigma surrounds nuclear energy, driven by high-impact accidents and a persistent deficit of reliable, accessible, and contextualised information (Alfaro et al., 2025; Markou and Genco, 2019; Morales Pedraza, 2017; Guerrero-Lemus and Shephard, 2017; Nieto-Pérez, 2013).

In countries such as Chile, public debate on nuclear energy has been restricted, preventing an informed social assessment of the risks, benefits, and available technological alternatives. The limited transparency of the debate and its marginal presence in the public sphere and in energy policy have contributed to nuclear energy occupying an ambiguous position in the national conversation (Genco and Genco, 2021; Morales Pedraza, 2017). Addressing this requires effective mechanisms for citizen participation that strengthen deliberative bodies, improve the public communication of science, and establish a clear institutional commitment to transparency, conditions that could generate public confidence, reduce information gaps, and allow the potential of this technology to be seriously evaluated (Morales Pedraza, 2017; Caldas and Silva, 2023; Nieto-Pérez, 2013).

Greater investment in empirical studies that address social perception is also needed, as understanding how citizens' attitudes and expectations toward this technology are formed across different contexts and conditions of inequality remains a significant research gap (Morones-García and François, 2024; Nieto-Pérez, 2013; Maize, 2015).

Taken together, these findings reveal a field of research that is in its infancy, thematically fragmented, weakly institutionalised, and externally dependent in technological terms. At the same time, there are real opportunities to develop a regional agenda for interdisciplinary and applied research oriented toward solving specific energy problems from a territorial perspective. Overcoming the gaps and challenges identified here is a necessary condition for advancing toward legitimate and socially accepted technological governance, and in the Latin American context that means building conditions in which scientific capabilities, coherent public policies, and informed citizen participation can be effectively integrated.

6. Discussion. Knowledge on SMRs in Latin America as an Emerging Sociotechnical Field

The results of this review do not merely describe a scarce field, but a field organised in a particular way. The literature identified is concentrated in a limited corpus, with a strong emphasis on the Argentine experience, a predominance of technical and quantitative studies, and research lines oriented towards the demonstration of feasibility, safety, performance, modelling and regulatory compatibility. This pattern is clearly visible in the descriptive results and in the thematic organisation of the corpus. Studies on CAREM-25, operational safety, thermohydraulic performance, territorial applications, desalination, mining and adaptation to specific energy systems show that SMRs have mainly been treated as objects of design, validation and optimisation. By contrast, questions concerning public trust, territorial justice, participation, controversy, social risk and democratic governance appear in a more limited, dispersed or subordinate way.

This distribution is not accidental, nor can it be attributed only to disciplinary preferences. Büscher (2022) argues that sociotechnical entities cannot be adequately observed when the separation between the technical and the social is maintained without sufficient examination. Applied to the field mapped in this review, this argument supports a more precise formulation. The technical predominance of the literature on SMRs in Latin America cannot be understood only as a disciplinary deficit that will be corrected spontaneously through the future accumulation of social studies. It also expresses a way of organising knowledge in which technology first appears as a problem of control, operation, safety and performance, while its social conditions of legitimacy are displaced to a later stage. The consequence is significant. If social dimensions enter late, they tend to be treated as problems of acceptance, communication or correction of perceptions, rather than as constitutive components of sociotechnical viability.

The perspective of Jasanoff and Kim (2009) makes it possible to extend this reading. On the basis of their comparative analysis of the nuclear field, these authors show that reactors are not purely technical objects that later encounter external conditions of social reception, but co-produced entities in which sociotechnical imaginaries, regulatory arrangements, forms of institutional trust and national trajectories participate in defining what a technology is, what it promises and what it may come to mean in a specific context. This approach is especially relevant for Latin America, where the viability of SMRs cannot be separated from unequal state capacities, social memories associated with nuclear energy, technological dependence, territorial conflicts and distrust towards large infrastructure projects. Along the same lines, Beck et al. (2021) allow SMRs to be situated within a broader debate on sociotechnical transformations towards sustainability, in which visions of the future, public expectations and forms of governance do not simply accompany innovation, but delimit which trajectories become imaginable, fundable and politically defensible.

This point becomes especially important when read alongside Wynne's (2006) critique of the deficit model. Public controversies around risk technologies cannot be reduced to a lack of information or to irrational resistance to expert knowledge. In the case of SMRs, information asymmetries, limited transparency, weak participation and the distance between experts, institutions and territories should be understood as governance problems rather than mere communication failures. Trust is not produced by technical data alone. It depends on institutions capable of responding to public concerns, recognising uncertainties, opening decisions that matter and distributing responsibilities in ways that can be verified.

From this perspective, the contribution of the article does not consist only in showing that social research on SMRs in Latin America is lacking. It consists in showing that this absence reveals how the field is being constituted at an early stage. The reviewed literature constructs SMRs mainly as a technical promise, while the question of their sociopolitical legitimacy remains less developed. This sequence may have lasting effects, since it defines which problems appear as priorities, which actors are recognised as competent and which forms of knowledge acquire authority. Therefore, integrating social, institutional and territorial dimensions is not a task that should wait until SMRs reach technical and commercial maturity. It is a condition for assessing whether such maturity can become socially legitimate in contexts of high inequality, socio-environmental conflict and institutional distrust, as is the case in much of Latin America. The question of what knowledge is produced, from where and for whom is inseparable from the question of what kind of energy transition is possible, desirable and democratically governable in the region.

7. Conclusions

A review of the literature on SMRs in Latin America reveals a strategically important but asymmetrical field. Regional scientific research remains at an early stage, is largely concentrated in Argentina and is oriented towards technical dimensions, with limited attention to governance, social acceptance, territorial justice and participation. This distribution restricts the production of knowledge needed to address the challenges of a region marked by unequal access to technologies, heterogeneous institutional capacities and a history of socio-environmental conflicts that cannot be ignored when assessing the viability of technologies of this scale and complexity.

Insufficient regulatory frameworks and weak coordination between state and non-state actors hinder the development of effective governance models. Progress in this area requires not only updated regulations, but also forms of articulation that include the state, semi-public institutions, companies and citizens. This must be accompanied by the construction of an interdisciplinary and contextualised scientific field capable of grounding research in specific territories, strengthening human capacities and establishing regional collaboration networks that reduce dependence on external analytical frameworks.

This review has emphasised the importance of considering the social and political aspects of this technology. Although nuclear energy is promoted as a clean energy source, it cannot be assumed that it will be readily accepted. The historical trajectory of nuclear energy has been marked by major accidents, public controversies, information asymmetries and limited participation in high-impact decisions. This makes it necessary to strengthen governance mechanisms that involve diverse actors and develop forms of public communication sensitive to the interests of potentially affected parties. Emerging nuclear technologies cannot be conceived through a purely technical-economic rationality, but must be situated within a democratic scenario in which different social actors can participate, deliberate and take responsibility for the conditions under which these technologies could be developed, implemented or discarded (Wynne, 2006; Jasanoff and Kim, 2009).

In interpretive terms, the article shows that SMRs are being constructed in the regional literature mainly as objects of technical promise rather than as fully elaborated sociotechnical problems. This finding brings the discussion back to the centre of the results. The predominance of studies on safety, performance, design, modelling, territorial applications and regulation does not only indicate an incomplete agenda, but a specific way of stabilising the field at an early stage. If social dimensions enter the debate too late, they risk appearing as external obstacles to a technology already defined. If they enter from the outset, however, they may help formulate better questions about legitimacy, justice, trust, institutional responsibility and territorial relevance.

As with any bounded systematic review, this study has limitations. The corpus is restricted to publications indexed in WoS and Scopus up to May 2025, which means that grey literature, reports from international organisations such as the IAEA and NEA, national nuclear policy documents, industry reports and non-indexed academic production were not included. In addition, since the search was conducted through titles, abstracts and keywords, studies addressing SMRs tangentially or under different denominations may not have been captured. These decisions delimit the scope of the article. Its conclusions describe indexed academic production on SMRs in Latin America, not the broader political-industrial ecosystem or public debate surrounding this technology. Future research should therefore complement this review with documentary analyses, comparative studies and empirical work with scientific, regulatory, business and social actors.

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