Addressing context-specific energy modelling risks and dynamics in low- and middle-income countries

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Abstract

Energy modelling tools guide energy transition planning, yet critical questions persist regarding their application in Low and Middle-Income Countries (LMICs). These countries face the complex challenge of meeting growing energy needs in ways that are affordable, sustainable and resilient, while also advancing broader, long-term development goals in uncertain financial, geopolitical, and climatic contexts. Here, we highlight that innovation in modelling practice is required to adequately analyse current planning challenges and avoid the risks of misaligned policy advice. Framed through three features of modelling practice – choice of paradigm, modelling process, and pluralism of expertise - we identify priority areas for methodological advancement. This means innovation across energy planning related to context-specificity, system dynamics and uncertainties, and integration with connected systems. To mainstream innovation, we propose a focus on ensuring data and modelling availability, prioritising support for modelling in low planning capacity contexts, and expanding networks of practice that support LMIC modelling.

To meet the Sustainable Development Goals (SDGs) a clean, reliable and reasonable cost energy system that provides basic services while supporting sustainable economic growth is essential[1]. Many Low and Middle-Income Countries (LMICs) are working to build such systems to meet a broad set of development objectives using energy systems planning processes.

Energy models commonly serve as the underpinning analytical approach for providing decision support to this complex challenge[2,3]. Using scenario modelling approaches, they allow for the exploration of how interrelated factors shape different energy systems pathways. We contend, however, that despite the critical need for energy-enabled development in LMICs, country-scale modelling approaches used in such contexts are often not able to adequately serve their purpose. This is a significant issue for LMICs; in contrast to higher income country (HIC) contexts, there is often limited analytical capacity and lack of diversity of research to inform planning. This means that poorly designed modelling studies are harder to validate or contest based on other evidence and expertise, increasing the risk of poorly informed decision making and system investment in a highly resource-constrained context.

Given this context, we assess the increased risks by identifying limitations of approaches based on three salient and intertwined issues, which we refer to as the 3P framework, namely (1) choice of model paradigm, (2) process of modelling, and (3) pluralism related to disciplinary expertise. This framework comprehensively covers the main features of model-based planning, facilitating structured thinking around the limitations of current approaches and required innovation. Table 1 shows how these three features can help inform modelling approaches, including contextual understanding, demand and supply analysis, uncertainty analysis, and systems integration.

First, the dominant techno-economic modelling paradigm, i.e. the underpinning theory and assumptions that shape how a model represents a given system, underplays many key instabilities particularly salient in LMIC systems. This includes informal, highly dynamic economic sectors, their vulnerability to shocks, less stable governance systems marred by institutional capacity constraints, processual deficiencies and, in some cases, corruption[4], as well as high degrees of financial volatility[5]. By contrast, implicit in the prevalent optimisation approach is a stable market-based energy system guided by normative cost-driven goals. The paradigm risks underestimating systemic instabilities which can be barriers, and in some cases, enablers of system transformation[6], as well as the complexity of necessary policy packages to enable desired change[3].

Second, the modelling process, in which models are used for transitions planning and decision support, often overlooks that pervasive uncertainties are much larger for LMICs, given the system contexts highlighted. Without their consideration, there is a risk that the feasibility and robustness of any emerging planning strategy are overlooked[7], considerations that are even more critical in the absence of a wider evidence base, available data, and diversity of models that can enable systematic review of evidence, as often practised in HIC contexts. This highlights the importance of undertaking analysis that reflects both context-specific capacity for planning, and economic and socio-political realities[5,6].

Third, the pluralism of relevant expertise from other knowledge domains, and integrated approaches to bring these together in informative and actionable ways, is often missing in both designing and interpreting energy models. Particularly, this includes knowledge in political economy[4,8], economics, geopolitics, gender equality and social inclusion (GESI)[9], and environmental science. While these issues are salient in high-income settings as well, the need for pluralism is arguably higher in LMIC contexts which feature unique complex and highly politicised issues such as unequally distributed energy access shortages[10], as well as context-specific energy governance challenges[11]. Furthermore, in countries with smaller analytical communities, it is even more important to draw from the different forms of knowledge that could help inform energy planning and policy formulation[8].

There is a need for modelling practice to improve and respond to the challenges of LMIC planning. If not, there is a risk of limiting the value and influence of energy modelling in guiding transition planning, undermining its credibility among decision makers. Even more problematic, given the central role modelling often plays in planning processes, it can lead to policy advice that is undesirable, infeasible, or unviable, resulting in sub-optimal decisions or recommendations that are ultimately disregarded[6].

As a collective of researchers and modelling practitioners from and working in different LMICs, we draw on the extant literature as well as on our experience in LMIC contexts to assess current modelling practices, identify key gaps and opportunities for innovation. We identify a range of promising practices already emerging across LMICs. These include improved system understanding, a stronger focus on equitable energy access and productive use, better representation of transition dynamics, adoption of systematic approaches to uncertainty, and increased consideration of external drivers and dependencies with environmental systems. These innovations are considered in view of how they support modelling practice, and how they can be mainstreamed.

Divergent energy modelling risk landscape

LMICs differ markedly in terms of the energy modelling-specific conditions they are faced with resulting in different levels of planning risk. Using proxy indicators (Figure 1), this includes macro level instability highlighting limits of current model paradigms, modelling process risk associated with a limited evidence base, and the complexity of energy challenges calling for increased pluralism of expertise and perspectives in energy planning.

Some LMICs like India, Viet Nam and Morocco have proxy indicators that indicate lower risks for the energy planning process. Conversely, other LMICs such as Central African Republic and South Sudan have high paradigm risks, meaning that they face high degrees of macro-level instabilities. Countries such as Vanuatu and Niger, in addition to facing instabilities, face marked process risks as they can't rely existing energy planning studies, implying severe data-specific uncertainties and limited country-level energy system knowledge to build on. Some countries such as Congo and Burkina Faso face both paradigm and process risks, plus low degrees of electrification access, meaning a planning environment that is very challenging.

Paradigm-specific dynamics

There are four core facets of the mismatch between the modelling paradigm informed by stable institutional and market-structures common to developed economy contexts, and considerably more instable realities in many LMICs[12]. These relate to (1) economic, (2) geopolitical, (3) environmental and (4) transition instabilities. While not all of these facets are present in each LMIC, they can combine in ways to exacerbate system-level instabilities.

First, the lack of finance to drive investment reflects less favourable business and regulatory environments in LMICs and higher risk premiums for potential investors, for example well over 10% for much of Sub-Saharan Africa (Figure 1). Combined with other constraints relating to sector governance and institutional capacity, supply chains and skills, this makes implementing system planning particularly challenging. Few modelling studies in African countries represent the on-the-ground realities of high costs of capital[13], risking unrealistic rates of deployment and obscuring the challenge to investment[14].

Second, LMICs often face greater exposure and have low adaptive capacity to respond to geopolitical shocks, as illustrated by the 2022 gas supply crisis in Pakistan perpetuated by LNG suppliers seeking higher profits elsewhere[15]. Oil and gas importing nations are particularly vulnerable to volatility in prices, currency fluctuations and supply disruptions. Exporting LMICs, or those considering investment in export capacity, must navigate how to capitalise on short-term opportunities while avoiding risks of stranded assets resulting from structural decline in global demand for fossil fuels[16]. National models in LMICs rarely build in external risks in their scenarios, and therefore are unable to consider resilience to such global drivers. Furthermore, stable paradigm models are not well suited to consider system resilience to such volatility and risk[17].

Third, LMICs are being disproportionately hit by negative climate impacts, given their higher exposure and sensitivity, and lower adaptive capacity. Such impacts can be large where adaptive capacity is low, suggesting an additional, environmental source of instability in energy systems. This has been sharply felt in Zambia since 2024, as hydro shortages have led to severe load shedding with serious social and economic implications[18]. Energy planning thus needs to prioritise resilience to climate impacts. Consideration of supply side impacts, such as lower hydro output, and demand side impacts, for example increased cooling needs[19], are vital for planning resilient systems. While the energy modelling community is developing approaches to capturing such impacts, this is not being applied systematically and risks underplaying climate impacts[20].

Fourth, while political and financial instabilities pose several risks for energy transitions, the opportunity space of system design options is also broader, due to limited path dependence. For instance, Viet Nam installed 7 GW of solar capacity in December 2020 alone, as developers rushed to benefit from a feed-in tariff set to expire[21]. Notably, rapid shifts can similarly occur in countries with highly unstable macro-environments. In Sierra Leone, a country with a risk premium of 11%, recent import data show that 2024-25 solar PV panels imports could generate electricity equivalent to 61% of total 2023 electricity generation[22]. In Zambia, the last 12 months have seen an 8-fold increase, driven by the energy crisis. These examples suggest that system-level instabilities can impact both the direction and the speed of possible energy system change in LMICs, implying the need for energy planners to consider a range of rapid transition dynamics in their models. Without this, the opportunities for rapid transitions towards clean energy, alongside the recognised challenges, will be missed. Models based on stable markets paradigms are not disposed to simulating such outcomes.

Process-specific risks

While uncertainties are a common challenge for energy planners, they are considerably amplified in LMIC contexts throughout the planning process. These relate to (1) the process of building the energy model per se, as well as (2) translating modelling results into concrete decision making.

First, crucially, LMIC planning contexts often have a very limited evidence base and lack of model diversity[13]. As of August 2025, the median number of energy planning studies in the 76

LMICs assessed was 7. Countries such as Malawi, Gambia and Congo had 3 or less studies, implying that energy planners in these contexts must build the foundational energy analysis with limited context-specific data or opportunities for comparative analysis. The ability to build on a range of model-based evidence that has been assessed and critiqued by stakeholders allows for better understanding of modelling and data uncertainties, to capture a greater amount of nuance and assumptions, and provide the option to conduct country-specific meta-studies. A broader range of studies allows for highly contestable results to be challenged, for example on generation capacity build out in Kenya[23], while more difficult in those countries with fewer studies, such as the role of nuclear in Uganda[24].

Often a lack of energy data inhibits LMIC modelling efforts being grounded in local realities and has hampered the development of transition strategies[12]. What is more, despite the limited evidence base, current modelling approaches in LMICs are often deterministic in nature, without adequate consideration of the robustness of choices given the pervasive uncertainties, or how the range of potential pathways relate to real-world feasibility. A review by Blimpo et al. shows that most Africa-focused modelling studies present three scenarios or less[13]. With fewer studies available, a more systematic assessment of uncertainty is arguably needed.

The degree of uncertainty is arguably exacerbated in LMICs more reliant on international trade and technology diffusion. For instance, changes to fossil fuel import and export markets, to broader global clean technology trends, e.g. technology innovation (for solar PV, batteries)[25], demand for critical minerals, and trade in low GHG commodities such as green hydrogen[26] have significant impacts on energy system solutions in such cases.

Second, in contexts with limited history of research-led decision-making support, translating modelling results into decision-making can be a complex process. For example, recent research regarding the political economy of energy planning in Kenya showed the range of actors, institutions and practices that shape decision making, which strongly determines the role that technical modelling plays[27]. It is key to recognise competing political pressures and divergent goals across energy planning stakeholders so modelling can be positioned productively [6,12].

Improved alignment with and inclusion of political objectives is key to enabling modelling analysis of trade-offs and synergies between feasible policy actions. This includes gender equality and social inclusion (GESI)-related criteria, crucial for ensuring equitable outcomes, which are often not considered in framing, and consequently miss an opportunity to address energy-related needs and vulnerabilities throughout the population[9].

Pluralism-specific needs

An overwhelming majority of energy planning, both in general and in LMICs, only features techno-economic objective functions, often using supply-side optimisation modelling[13]. Techno-economic models focus on the physical energy system, including technologies, commodity flows, and system operation, and their associated costs. Yet on their own, they fail to address a large set of salient issues impacting LMICs including (1) a high variance of energy access rates (Figure 1), (2) complex, polycentric energy governance arrangements, and (3) a general shortage of analytical capacity given the problem at stake.

First, an important and distinctive issue for LMICs is that many households, institutions, and businesses are not yet fully served with sufficient, reliable and modern energy to meet end-use energy services[28]. Energy planning therefore needs to contend with meeting this suppressed demand[29], and plan for future increase in energy demand across groups and sectors in society (both formal and informal). Even with high electricity access rates, for example in Ghana, supressed demand still can be high, at over 15% of total consumption[30]. Crucially, this issue of suppressed demand is not limited to electricity, but includes other energy services such as clean cooking[31] and mobility demand. The associated transition processes go beyond individual knowledge domains, and are rather shaped by complex and context-specific social, economic, institutional, political, and environmental drivers, as illustrated by the adoption of solar technologies in Africa[32].

Planning models therefore need to account for both low access to energy, and heterogeneity of need across different groups. However, this has been limited by poor data availability, and simplified representation of energy users in models. Dioha and Mutiso cite the case of electricity demand in Nigeria being three time higher than what was stated in international datasets[12]. Dioha et al. highlight the failure to account for affordability and the resulting under-utilisation of mini-grid systems, also in Nigeria[33]. Related, broader engagement is needed with the wider research community to fully understand the challenges of different communities. This includes consideration of equity dimensions in energy provisions, related to access, affordability, and reliability, which are often critical objectives for LMIC decision makers[13].

Second, energy planning in LMICs is subject to unique and complex governance systems. Traditional and modern governance structures often coexist, leading to institutional fragmentation and risk of policy incoherence[11]. Specifically in those LMICs with dispersed populations and weak central or strong multi-level governance systems, energy modelling needs to also consider pluralism in terms of geographical distribution of decision-making power. This is key in countries such as Kenya and Zambia that have formal energy governance systems at a subnational level[34]. An interdisciplinary understanding of these governance arrangements is key for energy modelling to provide salient decision support.

Third, existing analytical capacity and research to inform planning is often limited, meaning that insights from any approach used have increased prominence, increasing risks of poor decisions if such approaches are inadequate. This is particularly the case due to the significant diversity in energy planning challenges between LMICs (Figure 1). This diversity strongly highlights the need for context-appropriate planning driven by national experts and stakeholders with expertise on the country's specific challenges and priorities, including those not necessarily embedded with the energy planning community[5,6].

Innovations to address planning needs

Individual LMICs require approaches to energy planning which can address their context-specific paradigm dynamics, process risks and pluralism needs. Recent studies have identified the critical current frontiers in energy planning research, capturing key aspects, which together define an energy planning problem. Specifically, this entails (1) considering context-specificity when defining energy planning models in LMICs, advances in (2) modelling supply, (3) characterising demand, (4) considering system dynamics and uncertainties, and (5) integration with connected systems and policy domains. Energy planners can implement targeted innovations across these five core aspects of energy modelling to address the specific paradigm dynamics, process risks and/or pluralism needs in the individual LMIC context they study (Table 1).

Table 1. Aspects of energy planning innovation to address country-specific paradigm dynamics, process risks and/or pluralism needs in low- and middle-income countries

Aspects of energy planning innovation	Paradigm	Process	Pluralism
Context-specificity	Awareness of how country-level instabilities impact the system, and prioritization of these dynamics for planning	Improved understanding of context-specific decision-making processes, political context and energy governance	Engaging with wider expertise on system mapping including key justice / inclusivity dimensions prior to defining models
Supply-side modelling	Application of technology- and country-specific cost of capital to weigh supply options	Increased variety of energy supply options, including nascent generation options in LMICs	Integration of diverse, local knowledge to assess off-grid and on-grid generation options
Demand-side modelling	Consideration of macro-level system instability in demand estimation	Enhanced representation and triangulation of different types of demand-side data	Explicit consideration of different sub-national domestic, small-scale business and industrial demand
System dynamics and uncertainties	Increased use of socio-technical modelling to improve representation of dynamics	Application of methods that capture uncertainty to identify key risks and ensure robustness of findings	Engagement with social sciences, including complexity economics, political scientists and trade specialists
Systems integration	Explicit integration of national and local development ambitions	Explicit integration of regional energy and environmental systems to plan for system resilience	Explicit integration of sub-national socio-economic and, where appropriate, socio-cultural systems to embed energy planning in local realities

Addressing paradigm-specific dynamics enables improved representation of system instabilities, avoiding modelling overly idealised futures that obfuscate the barriers policies must address to deliver transitions. Systems mapping is an approach that can help identify context-specific dynamics influencing existing systems[25]. It often uses causal loop diagrams to better understand the dynamics of the system, build participation of stakeholders and be a tool for communication with decision makers. Modelling system instability also requires approaches that capture transition dynamics, as revealed in system mapping. Socio-technical approaches, such as system dynamics, is gaining traction in LMIC contexts to better account for system interdependencies, non-linear relationships and transition inertia compared to traditional techno-economic modelling[35,36], as discussed later under pluralism needs.

Key instabilities on the supply side linked to financial and supply chain constraints can be captured through technology deployment rates and differentiated costs of capital. For example, Agutu et al. find that integrating representative costs of capital in supply-side electrification modelling influenced a technology selection shift from mini-grids to off grid for 240 million people in Sub-Saharan Africa, leading to lower costs of electricity[37]. Given the system instability arising from heterogeneity of energy access, use, and supressed demand, modelling that better represents supply-demand imbalance is needed. Dramani et al. focus on understanding the mechanism of supressed demand using a statistical regression model. They estimate the continued growth of already high levels of supressed demand in Ghana, to highlight the need for planning to address supply to informal sectors and address electricity supply infrastructure constraints[30].

Finally, it is important that national and local development ambitions are explicitly integrated to investigate whether modelled pathways support broader planning objectives. Dagnachew et al. focus on the economic benefits of electrification for the sub-Saharan Africa region, demonstrating how building in productive uses to the TIMER model has significant impacts on demand levels, and should be factored in[38]. Such considerations have consequences for technology selection, system size, and electricity sector investment, and therefore require analysis that aligns energy system options and development ambitions explicitly.

Addressing process risks can result in more effective application of energy systems modelling that both recognises the limited evidence base and its use in context-specific political and energy governance systems. Tesfamichael and Fuchs describe how political economy analysis can help modellers increase the relevance and applicability of their insights for decision makers[4]. This is through supporting more relevant framing of modelling studies by reflecting real-world political trade-offs and implementation capacity limitations, and the feasibility of available policy options. Issues such as historical context, political saliency, and institutional processes are also critical to help navigate the process and determine where modelling can support.

Increasing the variety of supply-side technologies, and uncertainties associated with their integration, supports more rigorous consideration of implementation feasibility. Blimpo et al. argue that supply technology options and associated infrastructure is often not considered comprehensively, adding to uncertainty regarding infrastructure planning and investment costs[13]. Trotter et al. find that integrating key political factors into supply-side planning can reduce implementation uncertainty associated with politically contentious generation and transmission options[39].

Key to navigating uncertainty of energy demand is addressing deficits in data availability with innovative methods that enhance and triangulate representation. Recent innovations led by the International Energy Agency (IEA) have focused on producing spatial datasets derived from satellite imagery and other sources, combined with machine learning, to understand energy use in households and industry, supplementing conventional energy statistics[40]. Gonzalez-Garcia et al. show how representing detailed customer classes and integrating higher spatio-temporal resolution can identify cost-effective mini-grid solution to support electrification in Uganda[41]. Improving data availability in LMICs can also help support inclusion of finance constraints in modelling[42], which helps navigate investment uncertainty.

Methods that systematically capture uncertainty are also needed to identify robust planning strategies more broadly, notably where few studies exist on which to base decisions. For example, a recent report for the Inter American Development Bank (IDB) used robust decision making (RDM) to identify key actions towards net-zero pathways ensuring regional development in Latin America and the Caribbean, finding median net benefits of USD 1 trillion across all futures explored and key action on electrification and afforestation[43]. This included countries with limited studies, such as Bolivia and Haiti (Figure 1).

Explicit integration of regional energy and environmental systems is particularly important given the dependency of many energy systems on land for bioenergy and infrastructure, and water for hydro generation highlight the increasing importance of this type of analysis. Detailed hydrological models are increasingly linked with energy models to assess climate impacts on hydro power generation, for example in Nepal[44]. A range of LMICs are using the Climate Land Energy Water Systems (CLEWS) framework to consider system dependencies and linkages[45].

Pluralism needs can be addressed by engaging with diverse expertise via participatory measures to develop pathways toward energy access improvement and help navigate complex energy governance arrangements in the absence of pre-existing analytical processes. Smit et al. demonstrate this, using a participatory systems mapping to explore the opportunity for renewable energy in an informal settlement in South Africa, highlighting issues of energy access and factors impacting fuels choice[35]. Mirindi et al. used a similar approach to assess how to plan for sustainable resource use in the complex urban setting of Goma, in DRC[36]. Dioha and Mutiso argue for integration of diverse expertise, including historians, lawyers, artists, and scientists to enhance representation of Africa-specific features in modelling studies[12].

Explicit integration of socio-economic and socio-cultural systems, particularly with respect to key equity and justice considerations is necessary to improve access and support more comprehensive energy governance. Some LMICs with high degrees of sub-national electrification inequality have recognised the need for more plurality. Through its 2023 National Energy Policy, Uganda has created a close link between central government and sub-national districts to tailor its rural electrification masterplan to different sub-national realities. Research has shown that markedly reducing the difference sub-national electrification rates in Uganda can be done at little extra investment, but requires such types of collaborations in energy planning[24].

Bergman et al. propose a GESI framework for energy and transport modelling that can guide modellers to produce results that recognize context and foster more equitable outcomes[9]. This involves integrating GESI considerations at each stage of the modelling process – study design, model implementation, results analysis, and communication, showing how energy planning can be better embedded in local realities.

Participatory systems are also useful to facilitate interdisciplinary analysis and dialogues across these nexus issues, for example through implementation of the CLEWS framework[45]. Developing understanding of system resilience to climate impacts has implications for supply-side resilience and demand-side implication. Sridharan et al. assessed the impacts on hydro in the East African Power Pool area and identified resulting electricity price volatility where resilience measures were not considered, notably in Uganda and Tanzania[46].

Engagement with social scientists is crucial to understand broader system dependencies and uncertainties related to external global drivers related to fossil fuel markets, technology innovation and trade in critical minerals and low GHG energy commodities. The Natural Resource Governance Institute (NRGI) highlight the risks for resource-constrained national oil companies in LMICs, estimating many countries not achieving returns on investment at lower market demand e.g. 80% of Uganda and Cameroon’s investment pipeline is at risk if oil prices fall below $45 per barrel[47]. Egli et al., found that cost of capital of hydrogen supply from African countries to Europe was not cost competitive without targeted and strategic de-risking policies[26].

Conclusions

Innovative practice needs to be mainstreamed with improved representation of country context and planning capacity. We present an expanded set of energy planning considerations and related modelling methodologies that can better capture the diverse risks LMICs often contend with when building energy systems in contemporary conditions. We propose three ways of taking this forward – i) focusing on making data and modelling available, based on open science principles; ii) prioritising context-specific support for modelling in countries with lower planning capacity; and iii) developing and expanding networks of practice that support LMIC modelling practitioners.

First, interdisciplinary research networks have a key role in sharing effective modelling practice and innovation, notably between LMICs, and in helping inform development partners of priority topics and new approaches. Networks include the African Institute of Sustainable Energy and Systems Analysis (AISESA), the DDP Initiative and Climate Compatible Growth (CCG) Programme. While these are focused at the country level, further efforts to bring in regional and global modelling efforts are needed. Second, support from research networks and funders should be focused on building capacity in countries where it is limited, bringing innovative model practice into planning. This needs to extend to ensuring buy-in from decision makers, with the capacity built able to respond to their questions, policy priorities and support the challenging aspects of their decision making process. Third, there needs to be a continued focus on developing open models and data, to provide a sustainable basis for innovating and building capacity.

Without further innovation in modelling practice that can be mainstreamed, there is a risk that modelling fails to reflect country context, is overly reductionist and idealised in respect of system dynamics, lacks consideration of domestic capacity constraints, and therefore struggles to produce meaningful insights for policy makers. This matters even more given the centrality of modelling in supporting energy system, investment and operations planning.

Competing Interest

The authors declare no competing interests.

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Contributions

S.P., M.D., P.T. and C.B. contributed to the conceptualization of the manuscript, and co-led the writing of the manuscript; P.T. and L.H. led the development of Figure 1; M.A., M.B., H.B., G.B., D.B., J.B., J.C., L.H., A.H., L.H., A.H., K.L., F.L., E.R., B.L., A.L., P.L., D.M., B.M., Y.M., D.Q., J.Q., L.S., B.T., J.T., B.V., S.V., and H.W. contributed to writing and reviewing the manuscript.

Captions

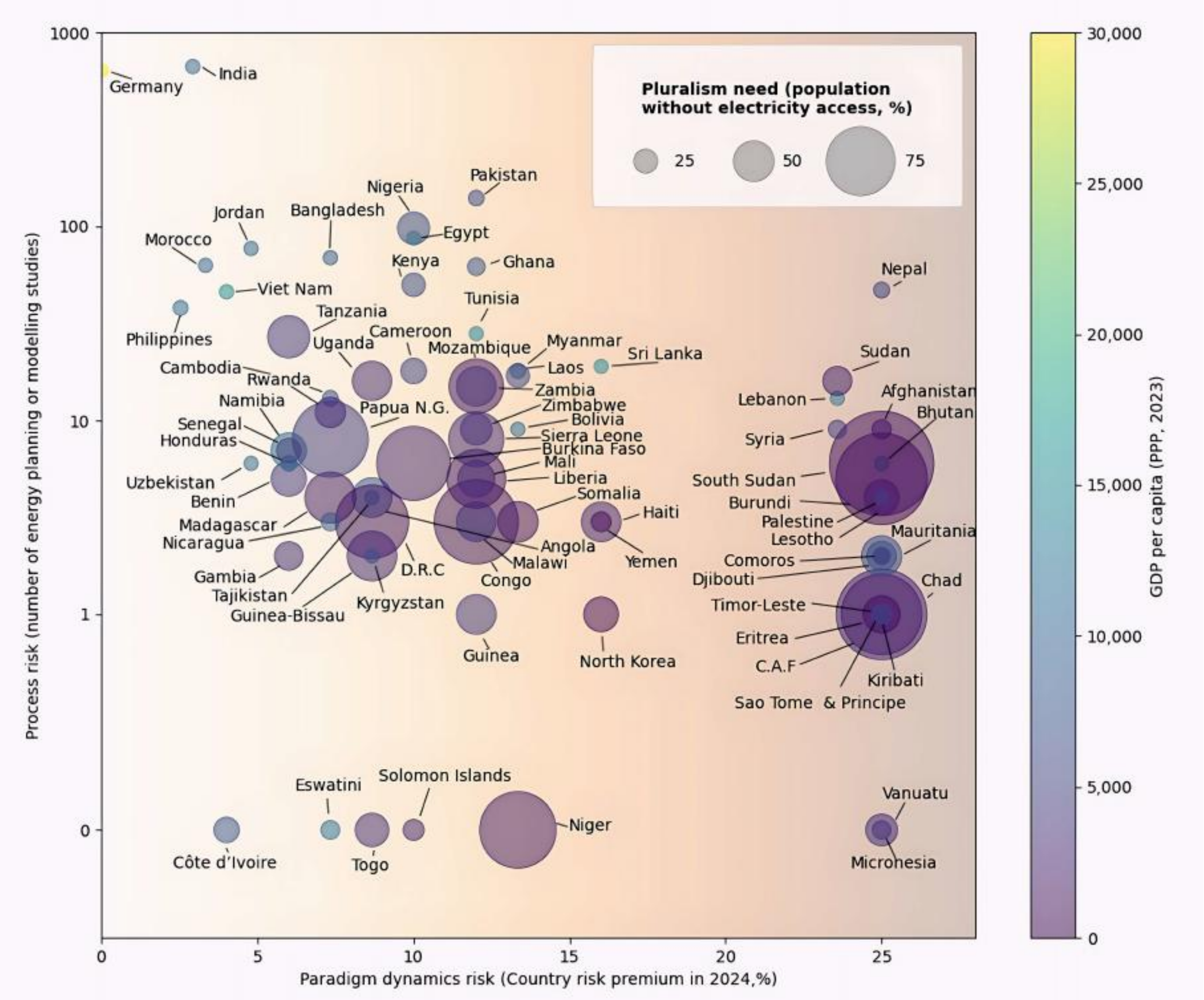

Figure 1. Country-level energy modelling risks in low- and middle-income countries (LMICs). Indicators are selected for the risks associated with the modelling paradigm, process of modelling and need for pluralism in 74 LMICs. Country risk premiums (x axis) reflect company and investor risks associated with conflict, corruption, political structure and the strength of legal systems[48]. This is a proxy for modelling paradigms that are often unable to capture emergent system instabilities due to lack of representative dynamics and a focus on equilibria. Countries with weaker institutions and more fragmented markets receive higher values while those without a quantified country risk premium are rated at 25% given that they represent countries with severe limited political and governance structures. On the Y-axis, a proxy for modelling process-specific risks is the number of energy planning or modelling studies for each country. These were identified using a structured search in SCOPUS to identify peer-reviewed studies on energy modelling or energy planning for each country. The search strategy checked if the title, abstract or keywords contained the terms "energy model*" or "energy plan*" combined with national keywords that accounted for both current and historic country names. Results were limited to articles and reviews to ensure the inclusion of substantive, peer-reviewed research. Any results that matched the search parameters but were clearly not related to energy system planning or modelling were excluded. The third dimension, captured by the size of the country bubble, reflect energy access rates using data taken from the World Bank's SDG 7 2025 report[49]. This indicator is a partial proxy for the need for pluralism, reflecting the importance of expanding the expert community involved in planning given the interdisciplinary nature of the challenge. As set out in the section 'Pluralism-specific needs', the need for pluralism extends beyond the issue of addressing the energy access challenge, to other key factors related to governance, institutional capacity, and expert networks.

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