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Critical Assessment of Energy Modelling Approaches for African Contexts

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Abstract

Most energy models applied in Africa were built for industrialised economies. To ensure that these tools produce policy-relevant strategies, we need to understand to what extent they actually capture the specific conditions of African energy systems.

We assembled a structured inventory of 66 modelling applications across 54 African countries, developed during the period 2010-2025. The dominant tools, including OSeMOSYS, LEAP, TIMES, and MESSAGE, were all developed in Europe or North America, and over half the studies in our sample are led by non-African institutions. We assessed how well these studies capture the features that are relevant for African energy planning, and the mismatches are striking. The informal economy, which provides livelihoods for over 80% of workers in Sub-Saharan Africa, appears in just 9% of studies. Biomass and charcoal, the principal cooking fuels for hundreds of millions of people, are addressed in only 21%. Power supply reliability features in just 30%. Meanwhile, 85% of modelling exercises remain disconnected from policy processes, and few are part of a sustained effort owned by local institutions.

These gaps reflect structural forces, among them funding dependencies, data scarcity, limited local capacity, and a disconnect between modelling and decision-making, that reinforce one another. Closing them requires a shift from tool-driven to problem-driven modelling, led from within Africa. This paper maps the gaps, examines their causes, and lays out the analytical agenda for AISESA's Cluster 1 programme on Energy Transition Pathways and Sustainable Development.

Keywords: energy modelling, Africa, energy transition, energy access, informal economy, development, modelling tools

1. Introduction

More than 600 million Africans do not have access to electricity (IEA, 2022). In Sub-Saharan Africa, the informal economy absorbs over 80% of employment, traditional biomass remains the dominant cooking fuel for hundreds of millions of households, and chronic power outages cost affected countries between 2 and 4% of GDP (IEA, 2022; Blimpo and Cosgrove-Davies, 2019). What has received far less attention is whether the analytical tools used to plan Africa's energy future are actually equipped to deal with them.

Energy system models now occupy a central place in policymaking. They feed into national strategies, guide investment decisions, and underpin the climate pledges that

African countries have made under the Paris Agreement. But no model is neutral. Each one reflects choices about what counts, what gets measured, and what futures are considered worth exploring. Get those choices wrong, and the policies that follow will be off target. Mulugetta et al. (2022) have made the point clearly: Africa needs context-relevant evidence, and the tools producing that evidence need to match the context.

The trouble is that they mostly do not capture these conditions. OSeMOSYS, LEAP, TIMES, MESSAGE, and the other platforms that dominate African energy modelling were all built in Europe or North America, for systems where formal markets, stable grids, extended power infrastructure and rich datasets are the norm (Bhattacharyya and Timilsina, 2010; Pandey, 2002). These tools have been applied across the continent with varying degrees of adaptation. Whether those adaptations go far enough has been questioned (Debnath and Mourshed, 2018; Dioha and Mutiso, 2023) but never tested against a broad empirical picture.

That is what this paper aims to do. We start not from the models but from the problems, asking what African energy systems actually need from their analytical tools. We then assess current practice against those needs, drawing on a survey of 66 modelling applications covering 54 countries. The goal is diagnostic rather than exhaustive. We want to establish where the most consequential mismatches lie, and to lay the ground for the work that AISESA's Cluster 1 is being set up to do.

2. What African energy systems need from models

To judge whether a model is fit for purpose, it is essential to know what a fit model looks like. Before turning our attention to the tools, we therefore identified the features they would need to master in order to be genuinely useful in the African context.

We start with the informal economy. Over 80% of workers in Sub-Saharan Africa operate outside formal structures (International Labour Office, 2018). They run market stalls, small workshops, food-processing operations, and transport services. Even a basic service like phone charging underpins entire economic chains, from mobile payments to commodity trading, that formal demand categories simply do not capture. Their energy use looks nothing like the neat industrial and residential categories that models typically work with. If a model cannot represent these demand patterns, it is blind to the energy reality of most Africans. That is a major gap. It means that any projection of demand, any assessment of energy access, any scenario of how electrification might unfold overlooks the productive uses of energy that sustain most African livelihoods.

Then there is biomass. Unlike other regions, where household energy represents a small fraction of total consumption, in Sub-Saharan Africa it accounts for a dominant share. In many countries, biomass is the single largest source of primary energy. Charcoal alone sustains cooking in cities across the continent (Kemausuor et al., 2011). Behind that simple fact lies a complex chain of production, trade, health damage through indoor air pollution, and pressure on forests. Dagnachew (2021) showed both what it takes to model clean cooking transitions in Sub-Saharan Africa and how far current frameworks still fall short. A model that treats biomass as a footnote, or skips cooking energy entirely, misses the point. Biomass cannot be modelled like other energy sources. Fuel-switching away from charcoal does not follow the same logic as switching from coal to gas in a power plant. It depends on household income, on the availability and affordability of LPG or electricity, on cultural practices, and on the local charcoal supply chain. Standard energy transition pathways built around technology cost curves and carbon prices do not capture these dynamics.

Power system infrastructure is a third dimension that cannot be left out. In most of Africa, power outages are not exceptional events but a permanent feature. They push households toward expensive generators, reshape how firms invest, and change the whole calculus of grid extension versus off-grid alternatives (Blimpo and Cosgrove-Davies, 2019). Optimisation models that assume supply simply meets demand have no mechanism to capture any of this. Most of these models also take centralised grid infrastructure as a given, when in practice decentralised and off-grid systems serve a growing share of African consumers and may well be the more relevant delivery mode in many settings. The absence of extended grid infrastructure could in principle be an opportunity for renewable-based decentralised systems, but current models are no better equipped to assess that path.

There is also the question of heterogeneity. All world regions contain diverse energy systems, and Africa is no exception. But the difference is in how this diversity is handled analytically. Most European countries have dedicated national models, maintained by local teams with access to detailed data. In Africa, most countries appear only through continental or regional models where national circumstances are averaged away. A Sahelian country with minimal grid coverage has little in common with Ghana's emerging power market or Kenya's geothermal ambitions, yet they are routinely represented by the same set of regional parameters.

And finally, energy planning in Africa is inseparable from the broader development agenda. All countries face the challenge of integrating energy with socio-economic objectives, but in Africa the nature of this integration is structurally more complex, spanning basic access, poverty, industrialization, food security, health, and rapid urbanization simultaneously. Current models are poorly equipped for this because they treat development outcomes as exogenous assumptions rather than endogenous results, leaving the trade-offs and synergies invisible. Dagnachew (2021) demonstrated this clearly for Sub-Saharan Africa using the IMAGE model, showing how deeply connected energy access, clean cooking, and climate goals are, with dynamics that only surface when modelled together.

To this must be added the reality that a significant number of African countries face political instability or armed conflict, conditions under which long-term planning assumptions break down, and data collection becomes nearly impossible.

With these requirements in mind, we now turn to the survey we assembled to test how far current modelling practice meets them.

3. Approach

The survey draws on keyword searches in Google Scholar, ScienceDirect, IEEE, and MDPI, combined with existing reviews by (Akpahou et al., 2024), (Musonye et al., 2020), and (Dioha, 2017). We traced references iteratively and brought in reports from the IRENA, the IEA, and the African Development Bank. Each study was recorded in a structured database covering model type, approach, sector and technology scope, time horizon, geography, institutional affiliation, and the treatment of features specific to African settings, in particular informal demand, biomass, and supply reliability.

The result is an inventory of 66 distinct modelling applications spanning 28 different tools and 54 African countries, drawn from over 50 publications released between 2010 and 2025. This is not a PRISMA-style systematic review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol, and may underrepresent grey literature and work published in languages other than English and French. It is, however, broad enough to expose dominant patterns and consequential blind spots. Full inventory is available through an interactive platform[1], developed as part of this work to support AISESA's ongoing research.

1. Source code of the platform is available at https://github.com/aymardino/Africa_modeling_landscape. The platform and its underlying database are under active development and will be expanded as part of ongoing AISESA research

4. What current practice looks like

Held up against those requirements, the picture is sobering.

A few tools dominate. OSeMOSYS leads the way with 17 occurrences in our inventory, followed by LEAP with 13, TIMES/MARKAL with 7, Flextool with 6, ONSSET with 6, and MESSAGE with 5. These counts include hybrid studies which combine two or more tools, therefore a single study may appear under several platforms. Taken together, these six tools account for most of the field. The rest is scattered across HOMER Pro, PyPSA, Plexos, SPLAT, IMAGE and various custom-built models.

About 80% of the work in our inventory deals with the electricity sector alone. Only 15% look at the energy system more broadly, including households, cooking, or transport. The field operates, in effect, inside an electricity supply silo. Most of these are bottom-up optimisation models built to find least-cost supply pathways, which partly explains the electricity focus. LEAP, the main simulation platform, can in principle represent the full energy system, yet even LEAP-based studies in our inventory tend to focus on power supply, suggesting that the narrowness of the field reflects how tools are used, not just what they can do.

The geography is similarly uneven. By power pool, WAPP (West Africa) attracts the most studies, followed by EAPP (East Africa) and SAPP (Southern Africa). The Central Africa Power Pool (CAPP) trails far behind. Among individual countries, Nigeria leads with 19 studies, Kenya follows with 17, then Ghana with 15, and South Africa and Egypt each with 14. Countries like the Democratic Republic of Congo, Chad, or the Central African Republic only show up in the inventory through continental or regional models, but never at a resolution which could be useful for national planning. The result is that much of the continent, particularly in its Francophone and Central regions, lacks the country-specific analytical basis that informed energy policy requires (Figure 1).

Who does the modelling is also revealing. According to our inventory, 51.5% of studies are led by teams based entirely outside Africa, mainly in Europe and the United States. Local African-led work accounts for 31.8%, and collaborations between African and non-African institutions make up the remaining 16.7%. Dioha and Mutiso (2023) and Musonye et al. (2020) have both documented how this external dominance tends to embed assumptions that reflect distance from local conditions rather than familiarity with them. For example, externally led studies routinely assume grid connection costs based on European benchmarks, ignoring the higher per-kilometre costs of extending networks in sparsely populated rural areas.

Perhaps the most telling statistic concerns the models' use. Two distinct problems emerge. The first is policy integration: only about 15% of the studies in our inventory feed into concrete policy processes such as national energy plans or NDC preparation. The rest remain within academic or consultancy circles. The second is continuity: 85% of applications are one-off exercises that are never updated or maintained, meaning that even when a country has been modelled, the analytical capacity does not persist. South Africa's SATIM model, maintained over years by the Energy Research Centre alongside national planners, remains one of the rare exceptions.

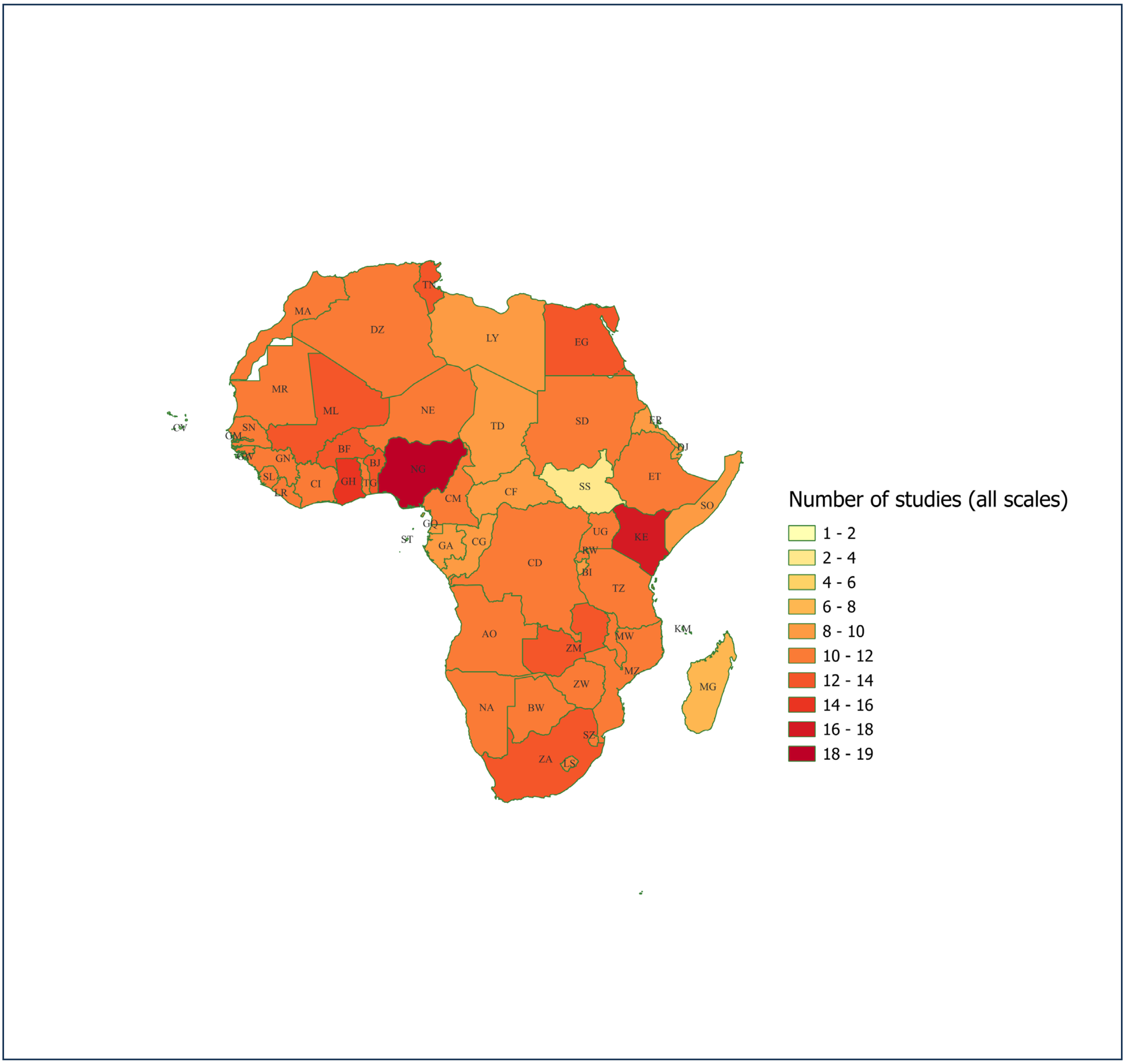

Figure 1. Geographic distribution of energy modelling studies across Africa (2010-2025). Colour intensity indicates the total number of modelling applications per country, combining national, regional, and continental-scale studies (N=66 studies across 54 countries). Source: Author inventory.

Against the specific benchmarks set out in the previous section, the shortfall is clear. Only 9% of studies engage with informal economic activity. Biomass and charcoal appear in 21% of applications. Power reliability is addressed in 30% of studies. About 82% of studies align with SDG 7, but engagement with poverty, health, food security, or industrialization goals barely registers. Methodologically, over 90% of studies use bottom-up approaches, which means that macroeconomic feedbacks such as employment effects or GDP impacts, dimensions that matter most to African policymakers, are largely absent from the analysis. Stochastic methods, suited to African conditions of deep uncertainty, appear in only two studies out of 66.

5. Why these gaps persist

These patterns did not emerge at random. They are held in place by structural forces that feed into one another.

Funding comes first, and it shapes more than the choice of tools. Most energy modelling for Africa is paid for by international donors and multilateral agencies. These organisations work within established analytical traditions and tend to commission both the tools and questions they already know. The result is that donor priorities determine the scope of analysis. Climate mitigation and grid-scale power planning attract funding, while cooking energy, productive uses in the informal sector, or demand-side questions receive far less attention, not because they matter less but because they sit outside the frameworks that donors operate with. This produces path dependency at two levels: the same platforms get reused, and the same types of questions keep getting asked. African research institutions, working with smaller budgets, have limited scope to set a different agenda (Ouedraogo, 2017).

Data availability makes things worse. The features flagged above (informal demand, charcoal economics, sub-national consumption) are hard to model partly because the tools are not designed for them but also because the data is limited. Our readiness assessment (available on the platform) found that only 6 out of 54 countries have good data availability which based on the existence of recent national energy balances, household survey data, and publicly accessible sub-national statistics. National statistical systems in many countries could in principle produce granular energy data, but the surveys required, particularly for informal economy activity and household fuel use, are resource-intensive, and the funding to conduct them is rarely available. In the absence of adequate data, the standard response is to run data-hungry models on rough proxies, producing outputs that look precise but tell you surprisingly little about what is actually happening , let alone what might unfold over the next thirty or fifty years (Currie and Musango, 2016).

Capacity constraints complete the picture. International programmes train African researchers to use existing tools, not to redesign them. The result is a growing number of skilled operators working within frameworks they did not build and cannot easily modify. Our readiness assessment scored institutional capacity based on the presence of a dedicated energy modelling unit, a track record of published modelling work, and ongoing relationships with policy institutions. Only 2 out of 54 countries meet all three criteria. This consolidates the position of externally developed platforms and shrinks the space for innovation grounded in local conditions (Debnath and Mourshed, 2018).

On the other side of the equation, many energy ministries and regulators lack the resources or the structures to request modelling work, make sense of its outputs, or integrate them into decisions. Beyond the communication gap between modellers and policymakers, the deeper issue is continuity. One-off studies, however well communicated, do not build lasting relationships between modelers and policy institutions. Where such relationships exist over time, they create a virtuous cycle: policymakers progressively take ownership of the analytical process, and their participation in turn ensures that modelling work addresses the questions that actually matter for policy. Without this sustained engagement, even good analytical work ends up stranded in journals (Fuchs et al., 2024).

6. What needs to change

Tweaking existing tools will not close these gaps. The evidence assembled here points towards something more fundamental.

The first shift is from tools to problems. The issue is not that models need to integrate every dimension that matters for African energy planning. No single tool can do that. The issue is that modelling exercises are too often structured around what a given platform can do, rather than around the question that needs answering. A more relevant approach starts by recognizing the key aspects of the story to be investigated, and then uses the model as one instrument among others to inform parts of that story, not to tell it entirely. Waisman et al. (2019) have argued this point in the context of national low-emission development strategies, through what they call a Deep Decarbonisation Pathways (DDP) framework: the critical step is designing a broader pathway framework first, within which models play a defined and bounded role. Applied to Africa, this means that a study on energy access in informal areas does not need a tool that fully represents the informal economy. It needs an analytical framework that places informal demand at the centre, and then draws on modelling, fieldwork, and stakeholder knowledge as complementary inputs.

Open-source platforms like OSeMOSYS, PyPSA, and Calliope offer a practical way forward because they are modular and extensible. Standardised modules for informal demand, biomass dynamics, and reliability-constrained dispatch could make them substantially more useful in African settings. But designing those modules requires people who understand the settings, which means the work has to be led from within Africa.

Investing in institutions matters as much as investing in individuals, but the question is broader than building modelling teams. What is needed are institutional arrangements that enable country-driven scenario processes, in which modelling is one input alongside stakeholder consultation, policy dialogue, and iterative co-construction. The recent DDP project conducted by ENDA in Senegal illustrates what this can look like in practice: a nationally owned process where models informed a broader pathway design rather than defining it (Waisman et al., 2019). South Africa's Energy Research Centre offers another example with the SATIM model, though its success reflects research and institutional conditions that are not easily replicable across the continent.

This perspective is designed as a foundation for AISESA's Cluster 1 programme on Energy Transition Pathways and Sustainable Development. The gaps it maps point directly to what that programme should prioritise: not only strengthening African modelling capacity, but building the broader analytical frameworks within which models serve as one instrument among others. This means supporting country-driven scenario processes, fostering institutions that can organise iterative dialogue between modellers and policymakers, and extending meaningful coverage to the countries, particularly in Central and Francophone Africa, that current practice has overlooked.

Conclusion

The gaps documented here are not technical oversights to be fixed one tool at a time. They reflect how energy modelling for Africa is funded, led, and used. Addressing them requires placing African policy questions, not externally developed tools, at the center of the analytical process. That is the shift this paper calls for, and the agenda that AISESA's Cluster 1 is built to pursue.

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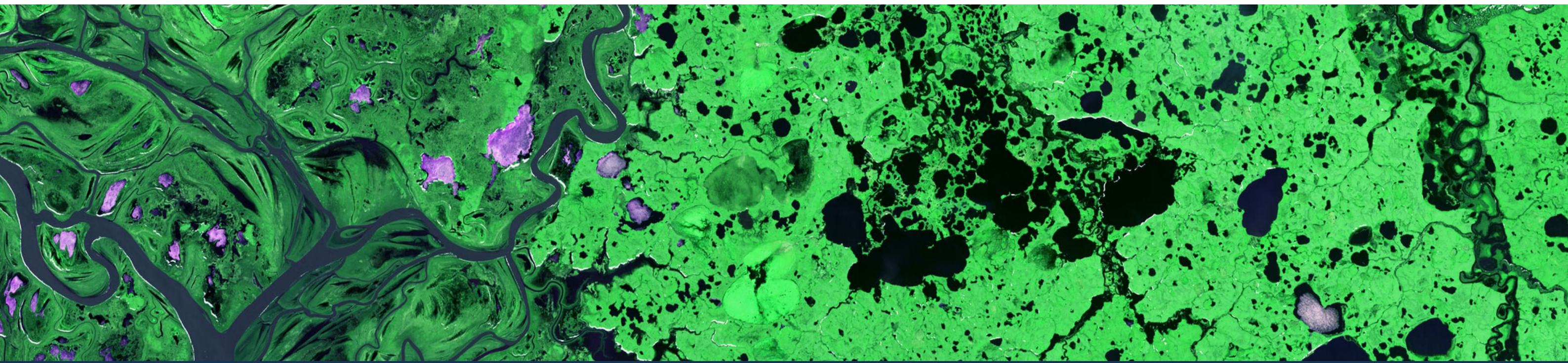

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