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Co-Creating Energy Models in Africa: Stakeholder Perspectives from Morocco, Mozambique, and Mali

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ABSTRACT

Stakeholder engagement, data collection, and more importantly, the analysis of the collected data and their implementation are critical components for an effective energy system modelling. The energy modelling needs to also address local specificizes as in this case focused on African continent these needs to include specific energy challenges, such as inadequate access to electricity, unreliable energy supply coupled with a heavy reliance on traditional biomass. Stakeholder views on the energy modelling process within the three African regions with specific case studies in Morocco, Mozambique and the Niger river basin in Mali are investigated. To effectively capture the diverse and multifaceted viewpoints of stakeholders, a mixed-methods approach was employed, combining surveys with interviews and focus group discussions. The stakeholders included through Quadruple helix approach are representing academia & research institutions, civil society, policy makers and investors in the mentioned countries. The objectives of the research were to understand energy needs and priorities in different countries, assess current practices when it comes to energy modelling, facilitate collaboration between different stakeholders, and gather insights for development of energy models.

Keywords

Stakeholder engagement;
Data collection;
Energy modelling;
Sustainable energy

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1. Introduction

The African continent stands at a critical juncture in its pursuit of sustainable development and economic growth. Energy access and reliability are fundamental components of this journey, yet many African countries continue to grapple with significant energy challenges [1]. These include inadequate access to electricity, frequent power outages and a heavy reliance on traditional biomass [2]. According to the International Energy Agency (IEA), nearly 600 million people in sub-Saharan Africa live without access to electricity, highlighting a stark energy divide that impedes socio-economic development and exacerbates poverty levels [1]. Addressing these issues requires a transformative approach that leverages comprehensive and context-specific energy models capable of incorporating diverse stakeholder perspectives and reliable data [3].

Unlocking Africa's economic potential hinges significantly on scaling up the share of renewable electricity in the energy mix [4]. The energy landscape in Africa is characterized by a complex interplay of factors. The potential for renewable energy in Africa is immense [5].

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The continent is endowed with vast renewable energy resources, including solar, wind, hydro, and geothermal energy, which, if harnessed effectively, could significantly enhance energy security, promote economic development, and contribute to global efforts to combat climate change [6].

However, realizing this potential is impeded by substantial barriers, including financial constraints, technological limitations, and insufficient infrastructure[7]. Moreover, the heavy reliance on traditional biomass for cooking and heating contributes to deforestation and adverse health impacts due to indoor air pollution [3,8]. These challenges necessitate a paradigm shift towards sustainable and inclusive energy solutions that can meet the diverse needs of African populations while mitigating environmental impacts [9].

One of the first steps in addressing these challenges is the development of robust energy models that are tailored to the specific contexts of different African regions [10]. Such models can provide valuable insights into optimal energy mix strategies, infrastructure development needs, and policy interventions required to achieve sustainable energy goals [11]. These models must be informed by reliable data and must incorporate the diverse perspectives of stakeholders across different sectors [2].

The concept of the Quadruple Helix model offers a comprehensive framework for stakeholder engagement in energy modelling [12]. This model emphasizes the collaboration among four key stakeholder groups: academia and research institutions, civil society, policymakers, and investors [13]. Each group brings unique expertise, insights, and resources to the table, contributing to a holistic understanding of the energy landscape and facilitating the development of more effective and inclusive energy solutions [14,15].

In the context of African energy transitions, stakeholder engagement is particularly important because of the diverse and often conflicting interests involved [16]. For example, while governments may prioritize energy security and economic growth [17], civil society organizations often emphasize the need for environmental protection and social equity [18,19]. Similarly, while investors may be primarily concerned with financial returns, academic institutions may focus on the development of innovative and sustainable energy technologies [5]. Effective energy models must therefore balance these competing interests and ensure that the voices of all stakeholders are heard and considered [20].

The engagement a wider network of stakeholders in the planning and implementation of future community renewable projects is considered significant to increase the chances of successful project implementation [21]. Furthermore, this supports a better understanding as well as inclusion of local conditions and specific assumption for African countries to secure accurate as possible energy system modelling and development of future scenarios [22].

Recent literature underscores the power of participatory and local context energy planning. In [23] it presents multi-criteria evaluation methods for sustainable energy pathways in developing regions while [24] examines configurations of renewable microgrids for urban-rural energy integration. Furthermore [25] addresses dynamic system optimization for energy-scarce regions and supports energy modelling for development of energy systems in Africa's remote communities as well as [26] which focuses on resilient grid structures.

This paper builds on these insights. Its primary aim is to explore the critical components of stakeholder engagement and data collection in the context of energy modelling for African countries, with case studies in Morocco, Mozambique, and the Niger River Basin in Mali. These cases illustrate the importance of context-specific approaches to energy modelling and the need for inclusive policies that account for socio-economic and environmental impacts on local communities [13,27,28].

Recent advances emphasize the need to combine robust technical energy-system modelling with participatory, context-sensitive stakeholder processes to ensure models are actionable and socially acceptable across diverse African settings. Work on hybrid and microgrid solutions, multi-criteria and dynamic optimization methods, and water-energy-food nexus approaches demonstrates practical pathways for resilient, locally-appropriate electrification that integrate socio-economic and environmental constraints [29–33]. Several studies highlight the importance of explicitly incorporating community preferences, behavioural responses and governance constraints into modelling workflows to improve uptake and implementation outcomes in rural and peri-urban contexts [34–36]. Moreover, recent reviews call for improved data governance, open datasets and the coupling of system models with GIS, remote sensing and machine-learning tools to reduce uncertainty and better reflect local conditions in scenario analysis [23,24].

The paper aims to explore the critical components of stakeholder engagement and data collection in the context of energy system modelling for African energy transitions, with a specific focus on Morocco, Mozambique, and the Niger River Basin in Mali. The primary objective is to demonstrate the application of the Quadruple Helix stakeholder model in developing comprehensive energy models that address the diverse and often conflicting interests of different stakeholder groups. Through a mixed-methods approach combining surveys, interviews, and focus group discussions, the study seeks to identify both commonalities and region-specific priorities in energy modelling approaches, while uncovering shared challenges such as data access, regulatory barriers, and infrastructure limitations.

Ultimately, the research aims to provide vital guidance for improving energy system modelling across Africa by emphasizing the necessity of collaboration, innovation, and stakeholder-driven approaches that ensure energy solutions are technically sound, socially equitable, economically viable, and environmentally sustainable.

The paper is structured in four main sections. The first section establishes the geographical context and outlines the aims and significance of stakeholder engagement in energy modelling in Africa. Section 2 presents the methodology employed, explaining the mixed-methods approach combining surveys, interviews, and focus group discussions across the four stakeholder groups (academia, civil society, policymakers, and investors) in Morocco, Mozambique, and in Mali. Section 3 presents and analyses the research findings across six key dimensions: data collection practices, energy markets, regulatory frameworks, infrastructure aspects, technical and financial tools, and social value considerations, concluding with actionable recommendations for improving energy system modelling practices across African contexts. Section 4 provides conclusions of the findings and presents potential for future research.

2. Methods

Effective stakeholder engagement is pivotal for the success of energy modelling initiatives. It ensures that the models are grounded, addressing the actual needs and constraints of different communities and regions [13]. This study employed a mixed-methods approach to capture the diverse and multifaceted viewpoints of stakeholders. This approach combined surveys with interviews and focus group discussions, providing a comprehensive understanding of the energy landscape [15]. Each stakeholder group plays a crucial role in the data collection and analysis process. Academia and research institutions provide the technical expertise and analytical skills necessary for developing and validating energy models [13]. Civil society represents community interests, ensuring that the models address social and environmental concerns [27]. Policymakers are instrumental in integrating the models into national energy strategies and policies, while investors provide the financial resources needed for implementing and scaling energy solutions [20].

The mixed-methods approach to stakeholder engagement allows for the collection of both quantitative and qualitative data, providing a rich and nuanced understanding of the energy landscape. Quantitative surveys helped identify common trends and issues, while qualitative interviews and focus group discussions offered deeper insights into specific challenges and opportunities [14]. This comprehensive approach ensures that the energy models are going to be robust, context-specific, and capable of addressing the diverse needs of different regions and communities.

Stakeholder engagement also facilitates collaboration and knowledge sharing among different groups. By bringing together academia, civil society, policymakers, and investors, the Quadruple Helix model promotes a holistic approach to energy modelling enabling the stakeholders to leverage their collective expertise and resources [13]. This collaborative framework enables stakeholders to leverage their collective expertise and resources, leading to more effective and inclusive energy solutions. The engagement process also builds trust and fosters a sense of ownership among stakeholders, enhancing the likelihood of successful implementation and sustainability of the energy projects [15].

Overall, stakeholder engagement is a dynamic and iterative process that requires continuous communication, feedback, and adaptation. The diverse perspectives and insights gathered from stakeholders will enrich the energy models and ensure that they are well-suited to the specific contexts of the African regions studied. This inclusive approach is crucial for developing energy solutions that are not only technically sound but also socially equitable, economically viable, and environmentally sustainable [13]. The overall process with the steps of collecting the answers from the stakeholders is presented in the next figure.

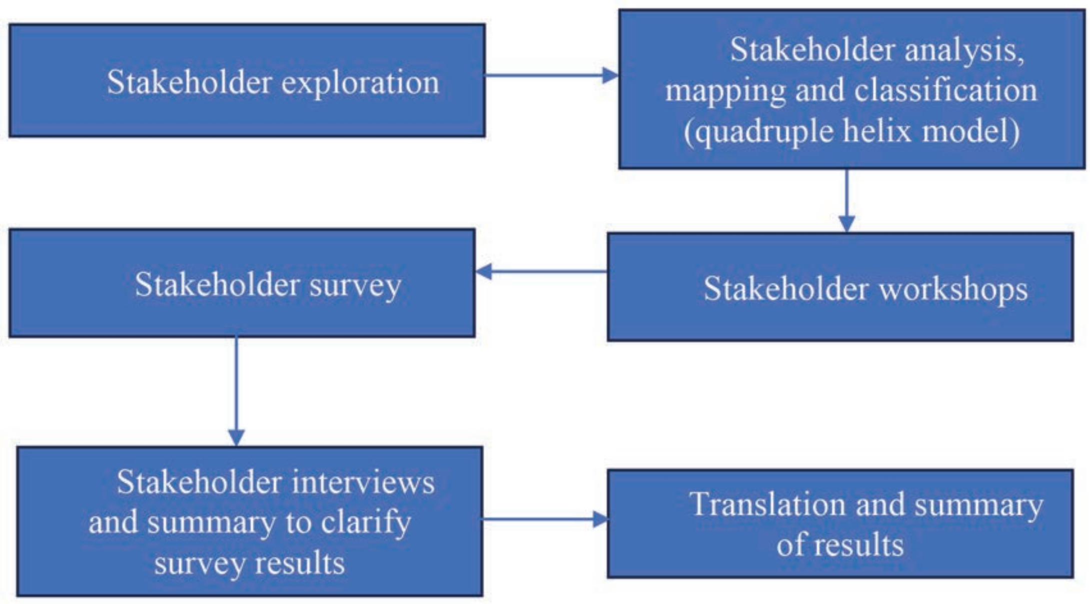

Figure 1: Steps in gathering stakeholder results.

The number of stakeholders participated in each of the countries in the workshops and provided answers to the survey are listed in table 1. The workshops were meant to introduce energy modelling to the participants and to provide them with introduction of the energy modelling tools that are developed during the EMERGE project. The surveys were distributed after the workshop and responses were collected in the stakeholder's native languages which was then summarised and refined by local project partners which conducted final interviews with one stakeholder from each group to further refine results. The results were translated to English presented here.

The survey consists of 6 categories: Data collection; Energy markets; Regulatory, administrative and legal support; Infrastructure aspects; Methods and technical and financial tools; Value and needs of citizens and communities on a social level. Below are presented the results of the survey for each of the categories and for all case studies.

3. Results and discussion

The results presented in this section provide a comprehensive analysis of the current landscape, challenges, and opportunities in energy system modelling across Morocco, Mozambique, and the Niger River Basin in Mali. Drawing on diverse stakeholder perspectives, the analysis covers a range of dimensions that collectively shape the views of the stakeholders on the energy modelling in the mentioned countries. By examining factors such as data collection practices, market dynamics, regulatory frameworks, infrastructure requirements, technical and financial tools, and the social value of energy systems, results aim to uncover both commonalities and

Table 1: Number of stakeholders per country involved in activities.

	Mali	**Mozambique**	**Morocco**
Number of stakeholders	20 overall (Academia: 2, Civil society: 4, policymakers: 12, Investors: 2)	12 overall (Academia: 2, Civil society: 6, policymakers: 2, Investors: 2)	79 overall (Academia: 59, Civil society: 7, policymakers: 7, Investors: 6)
Number of surveys collected	20 overall (Academia: 2, Civil society: 4, policymakers: 12, Investors: 2)	12 overall (Academia: 2, Civil society: 6, policymakers: 2, Investors: 2)	31 overall (Academia: 26, Civil society: 1, policymakers: 2, Investors: 2)
Number of interviews	4, one per group	4, one per group	4, one per group

unique regional priorities that are needed for the development of robust energy models.

The results provide vital guidance for future improvements in energy system modelling in Africa, emphasizing the necessity of collaboration, innovation, and a stakeholder-driven approach. The data collected revealed several key insights, including the critical need to upgrade and expand energy infrastructure, the importance of increased investment in renewable energy sources, and the necessity of stakeholder involvement and capacity-building initiatives.

The results are organised in subsections which present detailed findings in a structured manner, beginning with methodologies and approaches to data collection and management, followed by an exploration of energy market integration, regulatory and legal support structures, and infrastructure capacities. Further, the analysis focused into the application and anticipated evolution of modelling tools, as well as the inclusion of social and environmental benefits into the model results. By synthesizing insights from multiple regions and stakeholder groups, this section highlights not only shared challenges such as data access and governance, but also region-specific responses that reflect local contexts and needs.

3.1 Data Collection

This analysis focuses on several key aspects, including involvement in energy system modelling, data collection and management methods, crucial data types for modelling, challenges in acquiring reliable data, needs for model creation or expansion, and reliance on specific data sources or databases (Figure 2). Stakeholders across Morocco, Mozambique, and the Niger River Basin in Mali are similarly involved in energy system modelling. They engage in activities like research, consulting, and

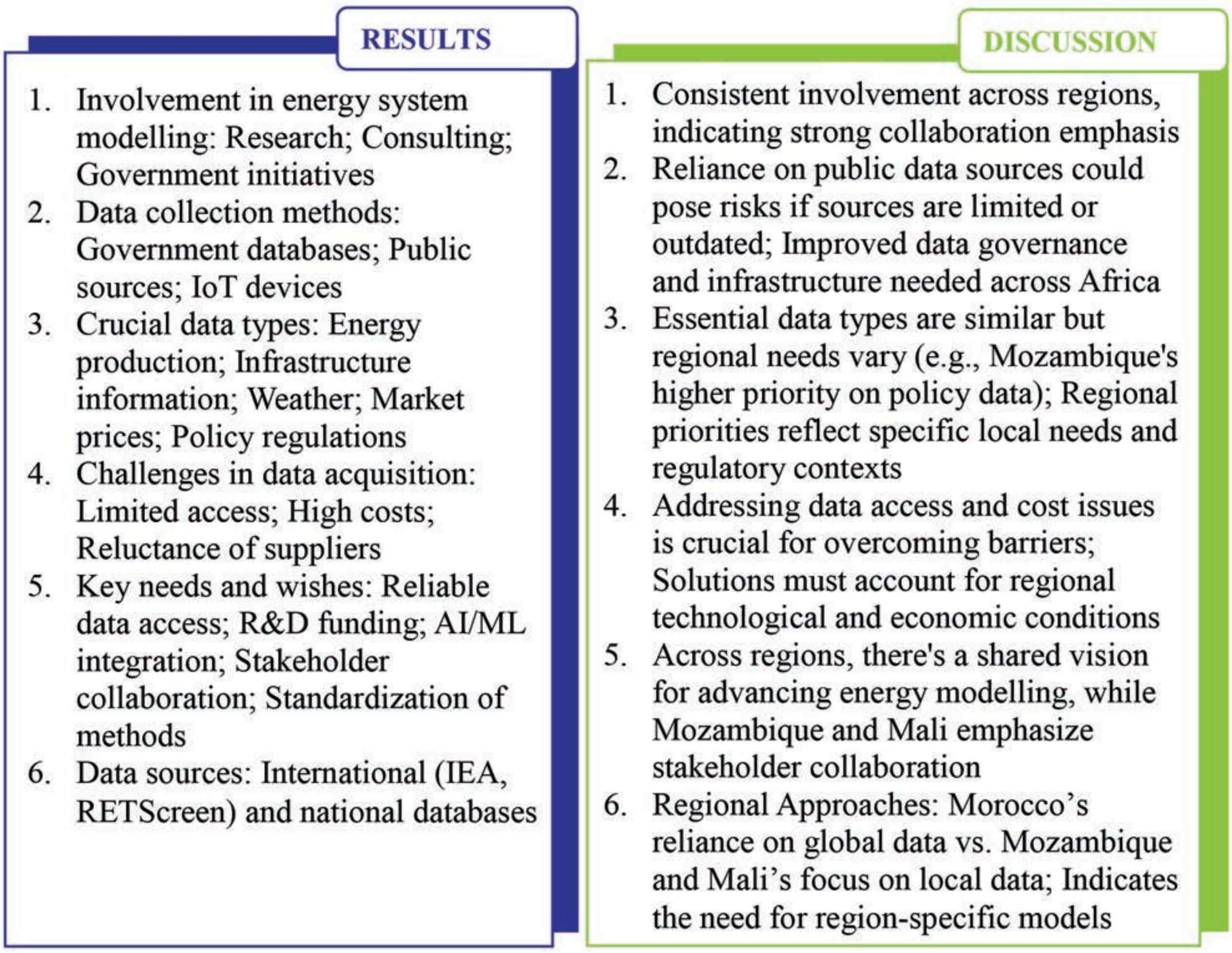

Figure 2: Data collection analysis from stakeholders in Africa.

participating in government initiatives. Despite regional differences, this consistent involvement shows a widespread recognition of the importance of collaboration in developing comprehensive energy models.

In all regions, stakeholders use a mix of government databases, public data sources, and modern technologies like IoT devices for data collection. This approach underscores the importance of both traditional and advanced methods. However, the reliance on publicly accessible data highlights potential vulnerabilities, particularly if these sources are limited or outdated. The types of data considered essential are consistent across regions, with a focus on energy production, infrastructure, weather, market prices, and policy information. However, slight differences in prioritization reflect local needs; for instance, Mozambique places higher importance on policy data, indicating a need for regulatory clarity.

All regions face similar challenges, including limited data access, high costs, and reluctance from data suppliers. These common barriers highlight the need for improved data governance and infrastructure across Africa. The impact of these challenges may vary depending on local technological and economic conditions.

Stakeholders share common needs: access to reliable data, financial support, collaboration opportunities, and the use of advanced technologies like AI. These needs reflect a shared vision for advancing energy modelling across Africa, though the emphasis on collaboration in Mozambique and the Niger River Basin in Mali suggests a greater need for partnerships.

There are regional differences in data sources. Morocco relies on international databases like RETScreen, while Mozambique and the Niger River Basin in Mali use more localized data. This is in line with case studies in West Africa that show that local datasets, remote sensing and nexus modelling can produce locally relevant scenarios [37]. Quadruple helix method and survey studies further demonstrate that stakeholder priorities differ by role and geography which is consistent with our observation that Mozambique and the Niger Basin emphasize policy and collaboration while Morocco relies more on international databases [38,39]. These differences reflect the varying levels of data infrastructure and the specific needs of each region, with Morocco possibly having more access to global resources due to its more developed energy sector.

Finally, methodological reviews and recent advances stress that data quality, governance and stakeholder-oriented tools are critical enablers for trustworthy, actionable models validating our recommendations for improved data governance, capacity building, and open tools [37–40].

3.2 Energy Markets

Stakeholders in all three regions agree on the importance of incorporating several market trends into energy system models. These include technological advancements in energy production and distribution, fluctuations in energy prices driven by supply and demand, and shifts in consumer preferences towards renewable energy. Without including those we risk underestimating renewable uptake potential in fast-changing markets [24–26]. The uniformity in these concerns across the regions highlights a shared recognition of the need for models that can adapt to evolving market conditions and technological innovations (Figure 3) which is in line with results of [41].

To adapt to changes in market dynamics, stakeholders in Morocco, Mozambique, and the Niger River Basin in Mali suggest the integration of machine learning algorithms for dynamic model calibration and the inclusion of real-time data to better reflect current market conditions, an approach supported by recent work showing that deep learning and hybrid ML methods substantially improve short-term forecasting and operational responsiveness in energy systems [42]. Additionally, implementing scenario analysis is seen as essential for anticipating and responding to market fluctuations. This approach emphasizes the need for energy models to be not only reactive but also predictive, enabling them to better manage uncertainty in energy markets as shown in West African contexts [37].

Energy system models play a critical role in optimizing market operations and efficiency in these regions. By forecasting energy demand and supply, they facilitate more efficient resource allocation. Additionally, these models can identify opportunities for cost reduction and revenue generation through market optimization. Improving network stability and reliability by simulating various operating scenarios is another significant contribution, ensuring that energy systems remain robust under different conditions which is like findings for sub-Saharan Africa [43].

The analysis reveals a consistent understanding across Morocco, Mozambique, and the Niger River Basin in Mali of how energy system models and markets interact.

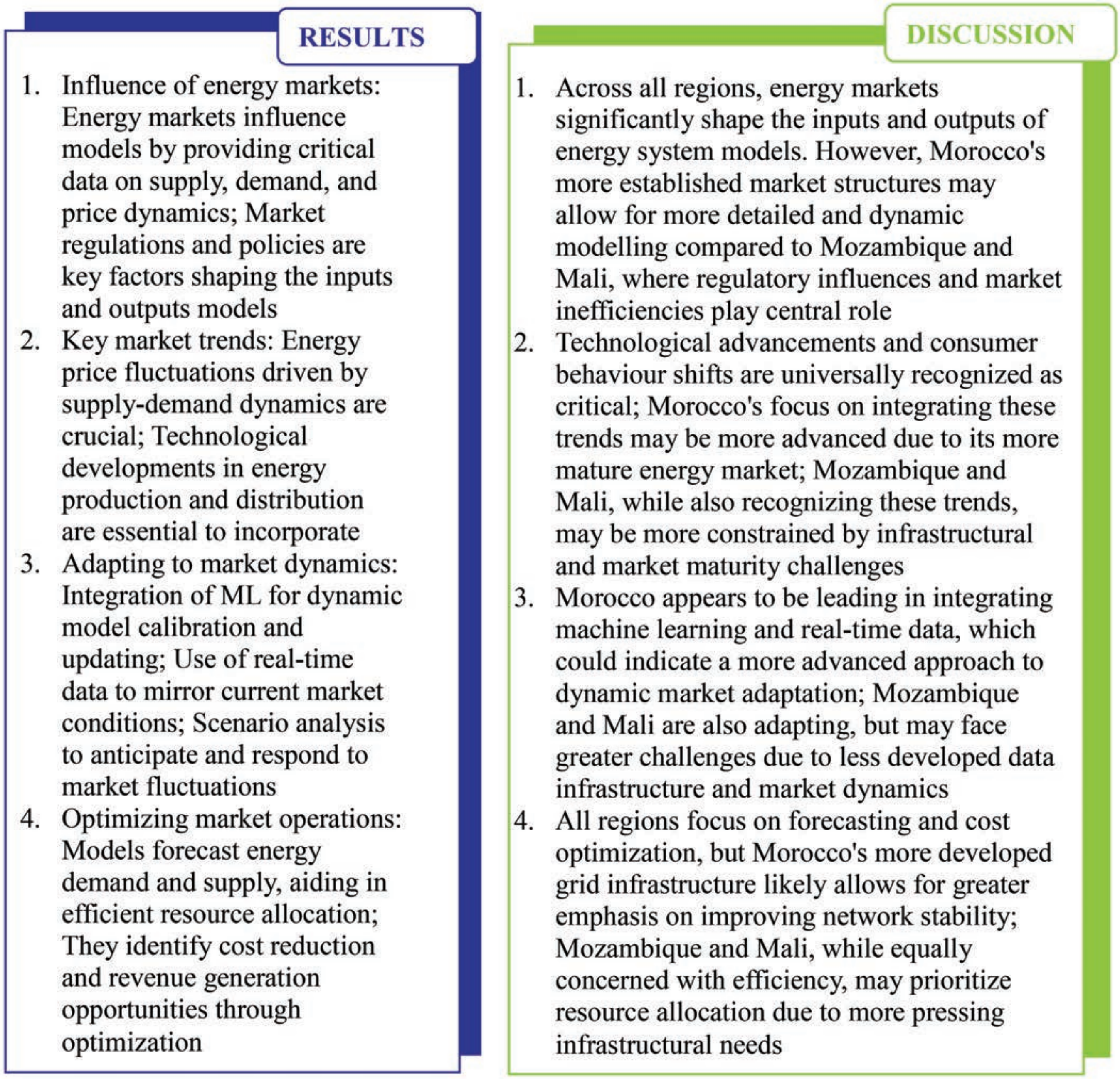

Figure 3: Energy markets analysis from stakeholders in Africa.

Despite regional differences, there is a shared emphasis on the need for energy models to be closely integrated with real market data, adapt to dynamic conditions, and contribute to market efficiency. This commonality reflects the broader challenges and opportunities faced by African countries as they work to develop sustainable and efficient energy systems [42].

3.3 Regulatory, Administrative and Legal Support

Stakeholders across Morocco, Mozambique, and the Niger River Basin in Mali identified several key areas of regulatory, administrative, and legal support necessary for the success of energy system modelling projects (Figure 4). Clear and streamlined regulatory processes for data acquisition and sharing were universally seen as essential, ensuring that models have access to the necessary data without unnecessary bureaucratic delays. Adequate funding mechanisms were also highlighted as crucial across all regions, reflecting the need for financial support to drive modelling initiatives.

Furthermore, collaboration between regulators and industry stakeholders is necessary to address regulatory gaps, with legal frameworks ensuring the protection of intellectual property and data privacy. Standardized administrative procedures for project approval and implementation were also emphasized as important for reducing the time and complexity involved in launching modelling projects. The regulatory hurdles encountered by stakeholders are consistent across the regions, with limited access to essential data due to regulatory constraints being a common issue. Complex licensing requirements for proprietary software tools also pose significant barriers, potentially limiting the capabilities of the models.

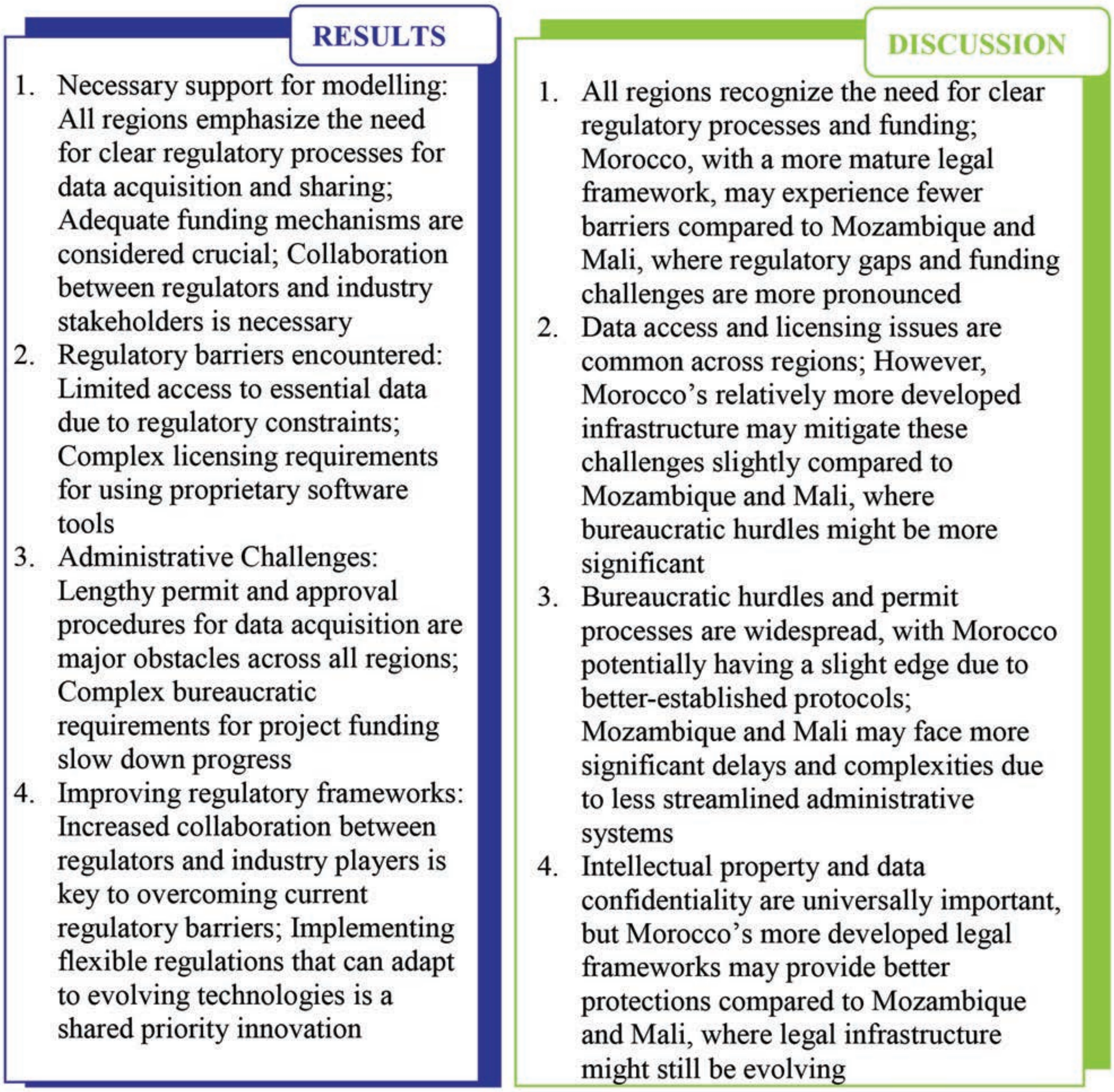

Figure 4: Regulatory, Administrative and Legal Support analysis from stakeholders in Africa.

Additionally, unclear regulatory guidelines for integrating renewable energy sources into energy systems is identified as a challenge, since it increases uncertainty of the energy modelling. Therefore, the need for more precise and supportive regulations for renewables integration would be beneficial which is in line with the finding in [44] where national and institutional barriers/lack of regulation is considered crucial barrier in energy transition.

Legal considerations that need more attention or clarification include intellectual property protection, data privacy, and transparency in regulatory processes. In Morocco, stakeholders also pointed out the importance of collaboration with legal experts to navigate these challenges effectively. Mozambique highlighted the need for more attention to privacy and data protection issues, reflecting a broader concern about safeguarding sensitive information. To better support the development and deployment of energy system models, stakeholders across the regions suggested increased collaboration between regulators and industry players as it was pointed in the previous work for sub-Saharan Africa [45]. This collaboration would help bridge the gap between regulatory needs and industry capabilities.

Providing incentives for research and development in energy modelling was another common recommendation, indicating a need for policies that actively promote the advancement of energy system models.

3.4 Infrastructure Aspects

In the realm of energy system modelling, Morocco, Mozambique, and the Niger River Basin in Mali all identify critical infrastructure needs, though their priorities differ somewhat (Figure 5). Morocco prioritizes high-performance computing and integration with existing energy systems, followed by data management and collaborative platforms. Cybersecurity is also a key focus across all regions. Mozambique places a strong emphasis on collaborative platforms, highlighting the need for shared resources and tools. High-performance computing and data management are also crucial, with integration and cybersecurity following closely. Stakeholders in Mali prioritize data storage and management, reflecting its need to handle extensive datasets. High-performance computing and collaborative platforms are similarly important, with integration and cybersecurity remaining essential.

All regions face challenges with diverse data formats and standards, which hinder interoperability. Coordinating stakeholders and managing resources for integration is complex and scalability issues related to processing large-scale data are common concerns. Advancements such as IoT devices for real-time data collection, cloud computing for scalable solutions, and smart grid technologies are pivotal. These technologies help improve the accuracy and scalability of energy system models, addressing many of the challenges identified. This analysis highlights the shared priorities and unique focuses of each region, alongside the common challenges and technological solutions relevant to energy system modelling infrastructure.

These findings are consistent with the broader literature. A comprehensive review of IoT-based smart grid infrastructure documents the vital role of real-time data handling, edge/cloud platforms, and cybersecurity in optimizing energy systems for developing contexts [46]. Similarly, the concept of edge intelligence in smart grids has been shown to enhance data processing efficiency, improve security measures, and reduce latency, specifically for resilient African energy models [47].

3.5 Methods and Technical and Financial Tools

In energy system modelling, technical and financial tools are critical for developing effective and cost-efficient solutions. Morocco, Mozambique, and the Niger River Basin in Mali each identify key tools and approaches that are crucial for their modelling tasks, though their preferences and focuses exhibit some variations (Figure 6). All three regions emphasize the importance of optimization algorithms for identifying cost-effective solutions, financial modelling software for assessing project viability, and simulation software for modelling complex system dynamics. Geographic Information Systems (GIS) for spatial analysis and visualization are also highlighted as essential tools, particularly in Mozambique and the Niger River Basin in Mali, reflecting a common need for advanced spatial analysis capabilities. This can also be observed in previous work where is pointed that integrating detailed infrastructure data, HPC, and collaborative code environments can significantly advance modelling capability and transparency on the continent [48]. This uniformity in the choice of tools indicates a shared understanding of the core technical requirements for effective energy system modelling.

When it comes to specific software tools, Morocco prefers Plexos, HOMER Pro, EnergyPlus, MATLAB/Simulink, and OpenDSS, indicating a diverse toolkit for

Figure 5: Infrastructure aspects analysis from stakeholders in Africa.

various aspects of modelling and simulation. Mozambique leans towards MAED, LEAP, FINPLAN, WASP, and SIMPACTS, which reflects its focus on models suited for demand analysis, supply strategy, and financial planning. Stakeholders from Mali use models like MAED and MESSAGE, and tools such as HOMER Pro and ESST, aligning with its needs for energy demand analysis and environmental impact assessments.

These preferences highlight regional variations in software use, tailored to specific modelling requirements and project contexts. These practices reflect broader methodologies where [49] compared optimization (MARKAL/TIMES) and agent-based approaches to system planning, showing that hybrid modelling can better account for investment behaviours and policy dynamics, leading to more realistic, stakeholder-reflective outcomes. In assessing financial feasibility, all regions conduct comprehensive cost-benefit analyses to evaluate project returns. They also estimate initial investment costs and ongoing operational expenses and analyse potential revenue streams and cost savings derived from modelling insights. Comparing net present value (NPV) and internal rate of return (IRR) of alternative approaches is emphasized, reflecting a focus on evaluating different modelling strategies' financial impacts. Additionally, assessing uncertainties and risks is a common practice, underscoring the importance of understanding potential financial variability in project performance.

Looking ahead, all regions anticipate significant impacts from several technological advancements. Artificial intelligence (AI) and machine learning are

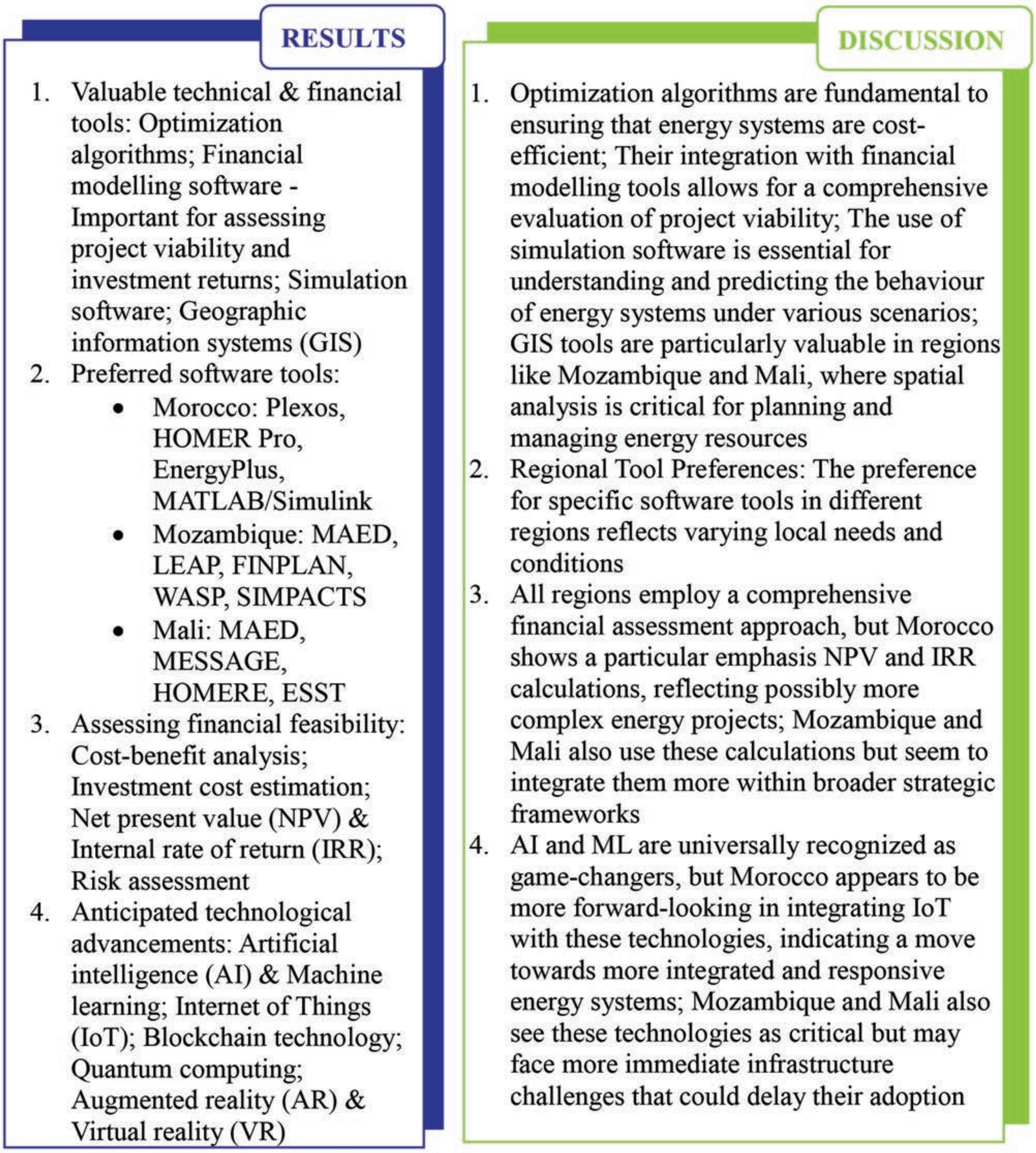

Figure 6: Methods and Technical and Financial Tools.

expected to enhance predictive modelling capabilities. The Internet of Things (IoT) will improve real-time data collection and integration, while blockchain technology is anticipated to ensure secure and transparent data management. Quantum computing is seen as a potential solution for complex optimization problems, and augmented reality (AR) and virtual reality (VR) may offer immersive visualization and analysis tools. These anticipated advancements reflect a forward-looking approach to enhancing the accuracy and efficiency of energy system modelling.

3.6 Value and Needs of Citizens and Communities on a Social Level

The analysis of social-level values and needs in energy system modelling across Morocco, Mozambique, and the Niger River Basin in Mali highlights both commonalities and region-specific priorities. All three regions emphasize environmental sustainability, community engagement, and equity in access to energy as crucial components of energy system models (Figure 7) which is also emphasised in previous works [50]. However, the nuances in their responses reflect unique regional contexts and challenges. Across the board, environmental sustainability and reducing carbon emissions are universally prioritized. This reflects a broad recognition of the need for energy systems that not only meet current demands but also mitigate environmental impacts, contributing to global climate goals.

In Morocco and the Niger River Basin in Mali, there is an additional focus on ensuring energy resilience and reliability, which is critical for withstanding disruptions, particularly in regions prone to instability or natural disasters. Mozambique and the Niger River Basin in Mali place a strong emphasis on community engagement and empowerment in the decision-making process, signalizing a shift towards more participatory approaches in energy planning. This approach is seen as essential for fostering local ownership and ensuring that the benefits of energy systems are equitably distributed[51]. Mozambique also highlights the importance of gender equity in energy strategies, reflecting broader social justice considerations in its energy planning.

When it comes to integrating environmental and social justice considerations into energy system models, all regions acknowledge the need to address greenhouse gas emissions, water consumption, and the impact on ecosystems. Mozambique additionally points to the need for community awareness in the energy transition process, particularly regarding environmental protection and the benefits of renewable energy. This indicates a need for robust public education and engagement efforts to support the adoption of sustainable energy practices.

In envisioning a value-based proposition for energy system models, the regions uniformly prioritize environmental sustainability, equitable access to energy resources, and economic development through clean energy initiatives. This alignment suggests a shared understanding that energy systems must be both environmentally and socially sustainable to achieve long-term success which is in line with the previous findings in the Nigerian electricity sector [17].

Looking ahead, the regions anticipate significant growth in energy systems, which will necessitate capacity-building measures. For instance, Mozambique underscores the importance of strengthening institutional capacity in energy modelling, while Morocco emphasizes collaboration, knowledge sharing, and access to data. These insights point to a need for targeted training and education programs to build the technical expertise required for effective energy system modelling.

In terms of addressing the needs of local communities, all regions agree on the importance of engaging communities in the modelling process, conducting awareness programs, and collaborating with local organizations to develop solutions tailored to local needs. Effective community engagement is seen as a critical factor in ensuring that energy systems are aligned with the values and priorities of the people they serve. To promote equity and inclusivity, the regions advocate for conducting community needs assessments, partnering with community-based organizations, and providing training to empower marginalized groups which is in line with finding for sub-Saharan Africa [52].

Health-related concerns are also prominent across the regions, with a shared focus on the impacts of energy production on air quality, public health, and social determinants of health. These concerns underline the importance of integrating health considerations into energy system models to safeguard community well-being.

Lastly, effective communication channels such as social media, radio, television, and public forums are seen as essential tools for reaching different demographic groups and involving citizens in decision-making processes. The regions agree that long-term societal benefits of successful energy system modelling include reducing greenhouse gas emissions, increasing energy

Figure 7: Value and Needs of Citizens and Communities on a Social Level.

access, creating green jobs, and improving public health outcomes.

In conclusion, while the core values and needs are consistent across the regions, the specific approaches and priorities reflect the unique social, environmental, and economic contexts of Morocco, Mozambique, and Mali. These insights provide a comprehensive framework for developing energy system models that are not only technically sound but also socially responsive, ensuring that they meet the diverse needs of communities and contribute to broader societal goals.

4. Conclusion and recommendations

This study offers valuable insights into how energy system models can be shaped to meet the needs and values of diverse stakeholders across Morocco, Mozambique, and Mali. The analysis highlights key differences and similarities in stakeholder perspectives across these regions, reflecting the diverse social, environmental, and economic contexts within the African Union.

Across all three regions, the integration of social values into energy system models is paramount, but the emphasis differs based on local conditions. Environmental sustainability is a shared priority, aligning with global efforts to mitigate climate change. However, the focus on energy resilience in Morocco, contrasted with the emphasis on community engagement and empowerment in Mozambique and the Niger River Basin in Mali, suggests that energy system models must be adaptable to regional needs. Morocco's focus on resilience likely stems from its more advanced energy infrastructure and the need to ensure stability, while the emphasis on empowerment in Mozambique and the Niger River Basin in Mali indicates a pressing need to involve communities in the decision-making process, addressing issues of equity and social justice.

The study also reveals varying degrees of attention to environmental and social justice considerations across the regions. Morocco's holistic approach, which includes considerations of greenhouse gas emissions, water consumption, and ecosystem impacts, contrasts with Mozambique's focus on gender equity and the Mali's emphasis on local economic development. These differences highlight the necessity of customizing energy system models to address the specific environmental and social challenges faced by each region. This regional customization is essential for ensuring that energy transitions are not only technically sound but also socially inclusive and environmentally sustainable as it was previously discussed in [22] for the case of Nigeria. This also leads to future research avenue which could test the research approach and results in diverse African regions, such as East and Southern Africa, and in contrasting settings like grid and of grid or urban vs. rural.

In terms of capacity building, the study identifies significant regional disparities in anticipated growth and the associated needs for capacity development. Morocco's focus on collaboration, knowledge sharing, and access to data reflects a more advanced stage in its energy transition, where the enhancement of existing systems is critical. Conversely, Mozambique and the Niger River Basin in Mali demonstrate a need for more fundamental capacity-building initiatives, particularly in strengthening institutional frameworks and engaging local communities. This disparity underscores the importance of a tailored approach to capacity building that addresses the specific needs of each region, ensuring that all stakeholders can effectively contribute to and benefit from the energy transition.

Engagement with local communities emerges as a critical factor across all regions, with varying approaches suggested for ensuring active participation in the energy system modelling process. While Morocco emphasizes the use of digital tools and communication strategies to mobilize communities, Mozambique and the Niger River Basin highlight the importance of public consultations, hearings, and the involvement of local leaders. These findings suggest that successful energy transition efforts in the African Union will require flexible engagement strategies that consider local communication preferences and cultural contexts. The findings of this study underscore the importance of a nuanced, region-specific approach to energy system modelling within the African Union, guided by the Quadruple Helix framework. By integrating the perspectives of government, industry, academia, and civil society, energy models can better reflect the diverse needs and values of stakeholders across different regions.

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