Energy System Modelling for Green Development of Africa

Grant Agreement N° 101118278

EMERGE – Stakeholder data collection summary

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1 Initial survey for identification of stakeholder needs

Effective stakeholder engagement is pivotal for the success of energy modelling initiatives. It ensures that the models are grounded in reality, addressing the actual needs and constraints of different communities and regions. In the project, a mixed-methods approach for stakeholder engagement was employed to capture the diverse and multifaceted viewpoints of stakeholders. This approach combined an initial survey, complemented by qualitative interviews and focus group discussions, providing a comprehensive understanding of the energy landscape. The primary objective of the data collection process was to understand the energy needs and priorities of different regions and communities, assess current energy practices, facilitate stakeholder collaboration, and gather insights for policy recommendations. Quantitative surveys provided a statistical basis for understanding common trends and issues related to energy needs and priorities. These surveys were complemented by qualitative interviews and focus group discussions, which offered deeper insights into specific challenges and opportunities faced by different stakeholder groups. The discussions, as well as the process of filling out the survey, were held during the workshops in all three countries that were selected as case studies. Workshop in Mozambique took place on 24th of April 2024, workshop in Morocco was held on 25th of May 2024, while the workshop in Mali on 12th and 13th of June 2024.

The initial survey, which can be found in Annex, was conducted to gather detailed insights into the needs, expectations, and concerns of the identified stakeholders. This survey aimed to capture a broad range of inputs from stakeholders and was made of 6 different 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. The survey results provided a valuable foundation for understanding the specific challenges and opportunities that stakeholders face, informing the development of both the Knowledge Base and the engagement methodology.

The results highlight 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 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 Mali indicates a pressing need to involve communities in the decision-making process, addressing issues of equity and social justice.

The results also reveal 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. In terms of capacity building, the results identify 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

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a more advanced stage in its energy transition, where the enhancement of existing systems is critical. Conversely, Mozambique and 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 Mali 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 also 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.

A tabular presentation of results and discussion is presented below for every section of the survey.

1.1 Data collection for energy modelling stakeholder views

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. 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 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. These main results as well as topics for discussion are shown in Figure 1.

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RESULTS

1. Involvement in energy system modelling: Research; Consulting; Government initiatives
2. Data collection methods: Government databases; Public sources; IoT devices
3. Crucial data types: Energy production; Infrastructure information; Weather; Market prices; Policy regulations
4. Challenges in data acquisition: Limited access; High costs; Reluctance of suppliers
5. Key needs and wishes: Reliable data access; R&D funding; AI/ML integration; Stakeholder collaboration; Standardization of methods
6. Data sources: International (IEA, RETScreen) and national databases

DISCUSSION

1. Consistent involvement across regions, indicating strong collaboration emphasis
2. Reliance on public data sources could pose risks if sources are limited or outdated; Improved data governance and infrastructure needed across Africa
3. Essential data types are similar but regional needs vary (e.g., Mozambique's higher priority on policy data); Regional priorities reflect specific local needs and regulatory contexts
4. Addressing data access and cost issues is crucial for overcoming barriers; Solutions must account for regional technological and economic conditions
5. Across regions, there's a shared vision for advancing energy modelling, while Mozambique and Mali emphasize stakeholder collaboration
6. Regional Approaches: Morocco's reliance on global data vs. Mozambique and Mali's focus on local data; Indicates the need for region-specific models

Figure 1 Main conclusions for the data collection in energy modelling

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. 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. In summary, while the regions face similar challenges and share common goals, there are important differences in their approaches to energy modelling. Morocco's reliance on global data systems contrasts with Mozambique and Mali's focus on local data, highlighting the need for region-specific models and greater collaboration to overcome shared challenges.

1.2 Energy markets for energy modelling stakeholder views

Stakeholders in all three regions agree on the importance of incorporating several market trends into energy system models and the main results and topics for discussion are presented in **Figure 2**. 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.

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RESULTS

1. Influence of energy markets: Energy markets influence models by providing critical data on supply, demand, and price dynamics; Market regulations and policies are key factors shaping the inputs and outputs models
2. Key market trends: Energy price fluctuations driven by supply-demand dynamics are crucial; Technological developments in energy production and distribution are essential to incorporate
3. Adapting to market dynamics: Integration of ML for dynamic model calibration and updating; Use of real-time data to mirror current market conditions; Scenario analysis to anticipate and respond to market fluctuations
4. Optimizing market operations: Models forecast energy demand and supply, aiding in efficient resource allocation; They identify cost reduction and revenue generation opportunities through optimization

DISCUSSION

1. Across all regions, energy markets significantly shape the inputs and outputs of energy system models. However, Morocco's more established market structures may allow for more detailed and dynamic modelling compared to Mozambique and Mali, where regulatory influences and market inefficiencies play central role
2. Technological advancements and consumer behavior shifts are universally recognized as critical; Morocco's focus on integrating these trends may be more advanced due to its more mature energy market; Mozambique and Mali, while also recognizing these trends, may be more constrained by infrastructural and market maturity challenges
3. Morocco appears to be leading in integrating machine learning and real-time data, which could indicate a more advanced approach to dynamic market adaptation; Mozambique and Mali are also adapting, but may face greater challenges due to less developed data infrastructure and market dynamics
4. All regions focus on forecasting and cost optimization, but Morocco's more developed grid infrastructure likely allows for greater emphasis on improving network stability; Mozambique and Mali, while equally concerned with efficiency, may prioritize resource allocation due to more pressing infrastructural needs

Figure 2 Main conclusions for the energy markets in energy modelling

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. 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. 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.

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

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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.

1.3 Regulatory, administrative and legal support for energy modelling stakeholder views

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 shown in Figure 3. 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. Additionally, unclear regulatory guidelines for integrating renewable energy sources into models were identified as a challenge, pointing to the need for more precise and supportive regulations in this area.

Administrative hurdles, such as lengthy permit and approval procedures for data acquisition, were consistently cited as obstacles across all regions. The lack of standardized protocols for sharing data between organizations further complicates efforts, as does the complexity of bureaucratic requirements for securing project funding and grants. These challenges highlight the need for streamlined administrative processes to facilitate smoother project implementation. 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. This collaboration would help bridge the gap between regulatory needs and industry capabilities. Implementing flexible regulations that can adapt to evolving technology was also seen as crucial, ensuring that the regulatory environment remains conducive to innovation. 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.

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RESULTS

1. Necessary support for modelling: All regions emphasize the need for clear regulatory processes for data acquisition and sharing; Adequate funding mechanisms are considered crucial; Collaboration between regulators and industry stakeholders is necessary
2. Regulatory barriers encountered: Limited access to essential data due to regulatory constraints; Complex licensing requirements for using proprietary software tools
3. Administrative Challenges: Lengthy permit and approval procedures for data acquisition are major obstacles across all regions; Complex bureaucratic requirements for project funding slow down progress
4. Improving regulatory frameworks: Increased collaboration between regulators and industry players is key to overcoming current regulatory barriers; Implementing flexible regulations that can adapt to evolving technologies is a shared priority innovation

DISCUSSION

1. All regions recognize the need for clear regulatory processes and funding; Morocco, with a more mature legal framework, may experience fewer barriers compared to Mozambique and Mali, where regulatory gaps and funding challenges are more pronounced
2. Data access and licensing issues are common across regions; However, Morocco's relatively more developed infrastructure may mitigate these challenges slightly compared to Mozambique and Mali, where bureaucratic hurdles might be more significant
3. Bureaucratic hurdles and permit processes are widespread, with Morocco potentially having a slight edge due to better-established protocols; Mozambique and Mali may face more significant delays and complexities due to less streamlined administrative systems
4. Intellectual property and data confidentiality are universally important, but Morocco's more developed legal frameworks may provide better protections compared to Mozambique and Mali, where legal infrastructure might still be evolving

Figure 3 Main conclusions for the regulatory, administrative and legal support in energy modelling

In summary, while stakeholders in Morocco, Mozambique, and the Niger River Basin in Mali face similar challenges in terms of regulatory, administrative, and legal support, there are subtle differences in emphasis. Morocco's focus on legal collaboration and transparency, Mozambique's concern with data privacy, and the Mali's issues with complex licensing requirements suggest that tailored approaches may be necessary to address these regional nuances effectively. However, the overall consistency in the challenges and needs indicates that broader, continent-wide reforms could also be beneficial in supporting energy system modelling across Africa.

1.4 Infrastructure aspects for energy modelling stakeholder views

In the realm of energy system modelling, Morocco, Mozambique, and the Niger River Basin in Mali all identify critical infrastructure needs (Figure 4), though their priorities differ somewhat. 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.

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RESULTS

1. Important infrastructure considerations: High-performance computing; Data storage & management; Collaborative platforms; Integration with existing infrastructure; Cybersecurity measures
2. Challenges in infrastructure compatibility & integration: Diverse data formats & standards; Complex stakeholder coordination; Scalability issues
3. Technological advancements for scalability & accuracy: Advanced sensors & IoT devices; Cloud computing & big data analytics; Smart grid technologies; ML integration
4. Innovative approaches & technologies: AI & ML: Recommended for analysing large datasets, providing deeper insights and predictions; Big data technology; Resilient infrastructure development

DISCUSSION

1. High-performance computing and data management are critical across all regions, but Morocco's more advanced infrastructure may facilitate better integration and cybersecurity; Mozambique and Mali may face greater challenges due to less mature infrastructures, making collaboration and data management more difficult
2. All regions face issues with diverse data formats and scalability; Morocco may have an advantage due to better coordination mechanisms and infrastructure maturity, while Mozambique and Mali may struggle more with integrating complex systems and ensuring security
3. AI, IoT, and blockchain are seen as critical across all regions, but Morocco may be better positioned to implement these due to more advanced infrastructure; Mozambique and Mali, while recognizing the importance of these technologies, may face slower adoption due to existing infrastructural and financial constraints
4. Morocco's focus on cutting-edge technologies like AR/VR and machine learning suggests a forward-looking approach, possibly driven by better access to resources; Mozambique and Mali emphasize resilience and long-term infrastructure development, reflecting their need to build foundational systems before adopting more advanced innovations

Figure 4 Main conclusions for the infrastructure aspects in energy modelling

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.

1.5 Methods and Technical & Financial tools for energy modelling stakeholder views

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 5**).

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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 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 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.

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 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.

The analysis of technical and financial tools for energy system modelling across Morocco, Mozambique and the Niger River Basin in Mali reveals both shared priorities and distinct regional preferences. All three regions recognize the importance of optimization algorithms, financial modelling software, and simulation tools as foundational elements for developing cost-effective and accurate energy models. The consistent emphasis on these tools highlights a universal need for robust solutions that can handle the complexity and scale of modern energy systems.

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RESULTS

1. Valuable technical & financial tools: Optimization algorithms; Financial modelling software - Important for assessing project viability and investment returns; Simulation software; Geographic information systems (GIS)
2. Preferred software tools:
    - Morocco: Plexos, HOMER Pro, EnergyPlus, MATLAB/Simulink
    - Mozambique: MAED, LEAP, FINPLAN, WASP, SIMPACTS
    - Mali: MAED, MESSAGE, HOMERE, ESST
3. Assessing financial feasibility: Cost-benefit analysis; Investment cost estimation; Net present value (NPV) & Internal rate of return (IRR); Risk assessment
4. Anticipated technological advancements: Artificial intelligence (AI) & Machine learning; Internet of Things (IoT); Blockchain technology; Quantum computing; Augmented reality (AR) & Virtual reality (VR)

DISCUSSION

1. Optimization algorithms are fundamental to ensuring that energy systems are cost-efficient; Their integration with financial modelling tools allows for a comprehensive evaluation of project viability; The use of simulation software is essential for understanding and predicting the behaviour of energy systems under various scenarios; GIS tools are particularly valuable in regions like Mozambique and Mali, where spatial analysis is critical for planning and managing energy resources
2. Regional Tool Preferences: The preference for specific software tools in different regions reflects varying local needs and conditions
3. All regions employ a comprehensive financial assessment approach, but Morocco shows a particular emphasis NPV and IRR calculations, reflecting possibly more complex energy projects; Mozambique and Mali also use these calculations but seem to integrate them more within broader strategic frameworks
4. AI and ML are universally recognized as game-changers, but Morocco appears to be more forward-looking in integrating IoT with these technologies, indicating a move towards more integrated and responsive energy systems; Mozambique and Mali also see these technologies as critical but may face more immediate infrastructure challenges that could delay their adoption

Figure 5 Main conclusions for the methods and technical & financial tools in energy modelling

1.6 Values and needs of citizens and communities on a social level for energy modelling stakeholder views

The analysis of social-level values and needs in energy system modelling across Morocco, Mozambique, and the Niger River Basin in Mali (**Figure 6**) 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. 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. Mozambique also highlights the importance of gender equity in energy strategies, reflecting broader social justice considerations in its energy planning.

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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. 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. Mozambique highlights the importance of outreach programs to engage underrepresented groups, ensuring that energy system models reflect diverse perspectives. 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 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.

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RESULTS

1. Social values beyond financial aspects in energy system models: Environmental sustainability and carbon reduction; Energy resilience and reliability; Equity in energy access; Public health and safety; Community engagement in decision-making
2. Environmental and social justice considerations: Greenhouse gas emissions, water usage, and ecosystem impact; Gender equity and community awareness; Local authority involvement and data use
3. Community needs and public participation: Engage communities in modelling; Awareness and education programs; Collaboration with local organizations; Transparency in information
4. Promotion of equity, inclusivity, and long-term societal benefits: Community needs assessments; Training for marginalized groups; Partnerships for inclusive energy solutions; Long-term benefits: emission reduction, energy access, green jobs, and public health
    - Health concerns: Air quality, health impacts, public health initiatives
    - Communication channels: social media, radio, television
    - Public participation: Surveys, public forums, advisory committees
5. Long-term societal benefits: Reduction of greenhouse gas emissions; Increased energy access; Green jobs creation; Enhanced energy resilience

DISCUSSION

1. All regions emphasize environmental sustainability and equity; Some regions prioritize energy resilience, while others stress community engagement; Health and safety considerations are crucial in specific regions, highlighting varied impacts of energy systems
2. Advanced regions address multiple environmental and social justice factors; Some regions focus on gender equity and raising awareness, reflecting different stages of development; Emphasis on local authorities and economic development shows targeted regional priorities
3. Advanced regions create solutions tailored to specific community needs; Strong focus on transparency and collaboration in areas where community trust is critical
4. Consistent emphasis on equity and inclusivity across regions; Common long-term goals include sustainability, economic development, and improved health outcomes
5. Emphasis on air quality and health impacts is consistent across regions, reflecting common concerns about energy production and consumption
6. Effective communication channels and public participation mechanisms are critical; Variations in preferred channels and methods reflect different regional priorities
7. All regions agree on the importance of reducing emissions, increasing access, creating green jobs, and improving resilience; The emphasis on specific benefits may vary, with some regions focusing more on economic development while others prioritize resilience or access

Figure 6 Main conclusions for the Values and needs of citizens and communities on a social level in energy modelling

1.7 Conclusion for energy modelling stakeholder views

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

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process, addressing issues of equity and social justice. The survey 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.

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 survey 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.

The analysis also highlights that while there are common goals, such as environmental sustainability and social equity, the pathways to achieving these goals vary significantly based on local contexts. For Morocco, the emphasis on energy resilience and comprehensive environmental considerations suggests that energy models should focus on enhancing existing infrastructure while maintaining sustainability. In Mozambique and the Niger River Basin in Mali, where community empowerment and equity are paramount, energy models must prioritize inclusive decision-making processes and capacity-building initiatives that engage local communities and address social disparities.

In conclusion, a successful energy transition in the African Union will depend on the ability of energy system models to adapt to the unique social, environmental, and economic conditions of each region. By leveraging the Quadruple Helix framework, stakeholders can ensure that energy models are not only technically robust but also socially inclusive, environmentally sustainable, and responsive to the needs of all communities. This tailored approach will be crucial for achieving a just and equitable energy transition across the African Union.

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