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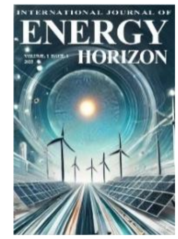

Review Article

Advancing universal energy access: data-driven solutions, and critical importance of interdisciplinary collaboration

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A B S T R A C T

This critical review paper presents a general overview of the challenges to attain universal energy access and the promise of emerging potential solutions. The barriers to deployment of energy access are described followed by pathways to towards potential solutions. Recommendations include a primary focus on an interdisciplinary approach supported and introduce a novel concept: the "Data in Energy Platform," which leverages data and artificial intelligence (AI) to improve energy access solutions.

1. INTRODUCTION

Energy access is a fundamental component of Sustainable Development Goal (SDG) 7, with the aim to "ensure access to affordable, reliable, sustainable, and modern energy for all" [1]. Key indicators of SDG 7 include Indicator 7.1.1, which measures the proportion of the population with access to electricity, and Indicator 7.1.2, which tracks the proportion of the population primarily relying on clean fuels and technologies for cooking [2]. In 2015, approximately 957.5 million people lacked access to electricity [2]. While significant progress has been made in recent years, energy access remains a pressing issue. The most recent data from 2022 indicate that 685 million people still live without electricity [2]. The challenge extends beyond electricity access. Approximately 2.1 billion people-nearly one-third of the global population-lack access to clean cooking facilities [2]. As a result, many households rely on smoky solid fuels or kerosene, which expose them to harmful indoor air pollution [3]. This pollution is a significant health hazard, contributing to millions of premature deaths annually [4]. Women and children, who spend more time near traditional cooking stoves, are disproportionately affected. Energy access is particularly critical in Sub-Saharan Africa, where many countries face severe challenges in providing modern energy services to their populations. For instance, as of 2022, only 21% of the population in the Democratic Republic of Congo (DRC) had access to electricity, while in Malawi, this figure stood at just 14% [5]. The situation is even more concerning regarding clean cooking access-only 4% of the population in the DRC and a mere 1% in Malawi had access to clean cooking facilities [5]. This lack of access is not unique to these two nations; many other countries in Sub-Saharan Africa experience similar disparities [5,6], highlighting the urgent need for targeted interventions and sustainable solution. While energy access challenges are most severe in less developed regions, they are not confined to these areas. Even in high-income countries, certain communities face significant barriers to reliable energy access, and emerging situations such as natural disasters can further exacerbate these challenges. For instance, Canada struggles with energy access issues in its Indigenous, rural, and remote communities [7, 8]. Approximately 178

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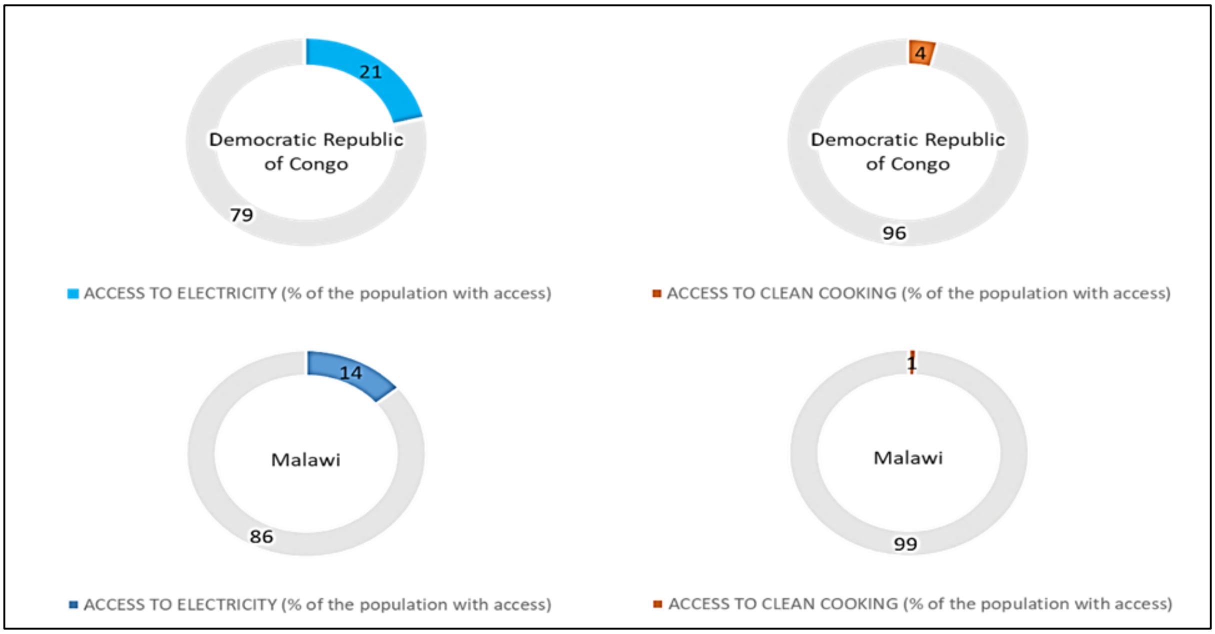

Figure 1. Percentage of the population with access to electricity and cooking in the Democratic Republic of Congo and Malawi (2022). Data sourced from Ref. [5]. For access rates in other countries, refer to Ref. [5]

remote Indigenous and Northern communities remain disconnected from the North American electricity grid and natural gas infrastructure [9]. As a result, these communities primarily rely on diesel fuel for electricity generation and heating, leading to high energy costs, supply vulnerabilities, and environmental concerns [9]. Furthermore, energy access becomes even more critical during emergency situations, such as natural disasters (e.g., earthquakes, wildfires, and extreme winter conditions). These events can disrupt energy infrastructure, leaving affected populations without reliable power and heating. Therefore, strategies to improve energy access must go beyond developing nations and incorporate resilience planning for high-income countries and emergency scenarios. Most existing solutions for energy access have focused on off-grid and decentralized energy systems, which play an increasingly vital role in addressing energy challenges [10]. Hybrid renewable electricity systems have emerged as key components of these solutions, offering flexibility and sustainability. Research in this field has primarily concentrated on three key areas [11]: (i) Deploying off-grid and mini-grid energy systems to support various SDGs; (ii) Assessing the impact of decentralized energy solutions on gender inequalities and disadvantaged communities; (iii) Advancing technologies to enhance the efficiency and scalability of off-grid and mini-grid systems. Beyond electricity access, research on energy access also addresses two critical dimensions [11]: alternative energy options for cooking and new approaches to energy planning, including political and decision-making challenges within energy systems. However, despite these advancements, several key challenges persist. Financial sustainability remains a significant concern, requiring a careful balance between capital expenditure and operational costs to ensure long-term viability [12, 13]. Furthermore, the design of off-grid systems must account for diverse geographical conditions, performance standardization, and modeling limitations [10]. Data is crucial in addressing energy planning, decision-making challenges, and modeling limitations in off-grid decentralized systems. Accurate and reliable data facilitate demand forecasting, storage optimization, and efficient supply management for energy access projects [14]. Additionally, data-driven approaches improve decision-making, reduce risks, and enhance energy projects' scalability and financial viability in underserved communities [14]. For instance, Miles et al. [15] highlight the importance of data in healthcare electrification as a solution to energy access challenges, particularly in the unique demand context of North Kivu. Beyond data, AI is emerging as a powerful tool for designing energy systems in regions lacking access to electricity. AI applications include feature extraction, classification, demand-side management, optimization for energy management, and fault detection [16]. While data and AI offer valuable tools for energy access solutions, the multifaceted nature of energy access challenges necessitates effective interdisciplinary collaboration. Addressing energy access requires integrated engineering, economics, policy, and social sciences efforts to develop holistic and equitable solutions [17]. Numerous technical reports and review papers have examined different aspects of energy access. Kammen et al. [18] analyzed the current energy mix in East Africa and assessed the energy planning efforts of the East African Power Pool (EAPP) within sustainable growth. Their study highlights the EAPP's potential to attract investment and influence both on-grid and off-grid energy initiatives. It demonstrates that East Africa has substantial potential for clean energy development to support economic, social, and environmental goals. Similarly, Corfee-Marlot et al. [19] compiled a report on the challenges and opportunities for delivering clean energy access in Sub-Saharan Africa, focusing on technological advancements, policy reforms, and financing mechanisms. Reviews on off-grid systems are provided in Ref. [20], while sustainable energy access and relevant technologies are highlighted for healthcare facilities in Ref. [21]. However, despite the breadth of existing literature, a significant gap remains in understanding how different disciplines can collaborate to address energy access challenges effectively. Additionally, no dedicated data platform has been designed to integrate interdisciplinary approaches for energy access solutions. This review aims to bridge these gaps. First, we review current energy access solutions. Next, we explore how different disciplines can collaborate to enhance energy access initiatives. Finally, we propose a novel concept: the "Data in Energy Platform," which leverages data and AI to improve energy access solutions. This paper is a guide and foundational resource for organizations and research groups focused on energy access challenges.

2. CURRENT STUDIES AND POTENTIAL SOLUTIONS FOR THE ENERGY ACCESS ISSUE

The research on energy access targets five main areas [11]: decentralized electrification for SDG delivery; equity impacts of distributed services, especially along gender lines; innovation that hardens and scales mini/off-grid systems; pathways to clean cooking; and rethinking planning institutions and the politics that shape energy decisions. Due to their significant advantages, many studies focus on renewable-based, off-grid, and decentralized systems. These advantages include efficient end-use appliances and the potential for significantly reduced costs through low-cost photovoltaics (PVs) [22, 23]; support from available information technologies, particularly mobile phones, and virtual financial services [22]; a substantial decrease in greenhouse gas emissions when replacing diesel generators in regions suffering from inadequate energy access [24]; and a reduction in energy vulnerability in remote, low-income areas lacking sufficient energy access [25]. Of course, the systems' conceptual design, thorough testing, and careful technology selection are critical for fully utilizing renewable-based decentralized systems as solutions for traditional energy access. Building on this foundation, the main efforts of studies on renewable-based off-grid systems have been to develop methodological frameworks and tools that enhance the full utilization of these systems, considering these essential factors. The diversity of global geographies poses significant challenges for the conceptual design and comparison of different off-grid systems. Additionally, energy storage technologies are a key component of solar and wind-based off-grid systems; thus, evaluating the performance of various energy storage technologies is critical for designing cost-effective, optimal off-grid systems. Considering these factors, Elkadragy et al. [10] developed a data analysis platform and irradiance forecasting models for an off-grid hybrid renewable energy conversion system. The system comprises solar and wind turbine power generators, non-renewable source backup generators, and hybrid battery storage systems consisting of lead-acid and lithium-ion batteries. This system was tested in Sub-Saharan Africa (Uganda) and Nemiah Valley, British Columbia, Canada [10, 26]. Therefore, the studies [10, 26] elucidate the techno-economic challenges of off-grid systems in various global locations. These studies [10, 26] also demonstrate the economic benefits of using hybrid lead-acid and lithium-ion batteries in off-grid systems. Solar off-grid systems have also been investigated in the literature for energy access solutions. Gill-Wiehl et al. drew on a large dataset to examine the scalability and impact of Rwanda's container-based solar PV systems in practice [27]. They assessed how a rapid rollout of these flexible, modular units might serve fast-growing yet resource-constrained communities, combining modeled results with field data across three application areas—water, food, and health—under optimistic and more conservative assumptions. In the optimistic scenario, a single unit could supply daily drinking water for 2,083 people and meet the daily milk consumption of 1,674 people, or fully cover a health clinic's electricity demand. The system itself is a 2 x 2 x 2 m container outfitted with 12 PV modules totaling 3.36 kWp, four 90-Ah GEL/AGM lead-acid batteries, and a 3,000-W charge controller/inverter. Compared to incumbent technologies, this configuration exhibited lower cost variability while minimizing pollutant and greenhouse-gas emissions, indicating a more sustainable option. The researchers have also conducted numerous studies that cover various aspects of off-grid and decentralized systems for regions that lack energy access. One notable investigation by Lee and Callaway [28] investigates the economics and reliability of decentralized solar systems across large spatial scales. Their research focused on stand-alone household solar systems with battery storage in sub-Saharan Africa. They examined how different designs aimed at varying levels of reliability impact system costs and compared these costs to those of national grids designed for equivalent reliability. Moreover, their study considered the effects of changing commodity prices on these cost relationships. Using a fraction of demand served as a measure of reliability, Lee and Callaway developed a multistep optimization process to efficiently compute the least-cost system, considering daily variations in solar resources and the costs of solar and storage components. Furthermore, Szabo et al. [29] provide compelling evidence regarding the cost-effectiveness of solar PV systems compared to diesel-powered electricity generation. Their analysis, covering East Asia, South Asia, and sub-Saharan Africa, reveals that solar systems are more affordable for at least 36% of the unelectrified populations in these regions. By developing geo-referenced estimates of affordability with a high level of resolution, their study identifies unelectrified communities across 71 countries where solar power is a viable alternative, even in competition with low-priced diesel. In addition, Kebir et al. [30] explore the innovative use of second-life batteries combined with solar PVs to provide affordable energy access to primary schools in Kenya. Based on interviews with 12 East African schools, their study assesses various system sizes and configurations. They conducted a techno-economic analysis comparing new and second-life batteries across 48 system scenarios, finding that second-life batteries could reduce the levelized cost of electricity by 5.6–35.3% in 97.2% of the scenarios compared to new batteries and by 41.9–64.5% compared to grid-supplied electricity. Their results show that the small system with a 5 kW solar array and a 5 kWh storage system using second-life batteries has a payback period of 2.9 years. These results in [30] highlight the viability and competitiveness of using second-life batteries for school electrification, significantly reducing costs and waste. The studies mentioned above predominantly focus on renewable-based (mainly solar and wind energies) off-grid systems for energy access. However, Her et al. [31] (2024) conducted a comprehensive study to explore the feasibility of small and micro-modular nuclear reactors for energy access in developing countries. They presented a global analysis assessing regions suitable for nuclear reactor deployment based on physical siting criteria, security, governance, and economic competitiveness. Their findings indicate that technically, reactors in the 1-50 MWe range could serve 70.9% of the populations in developing regions. However, economically, microreactors would not be competitive with renewables and energy storage for 87% of this population due to cost factors. Further diversifying the perspective on energy solutions, another study by Gill-Wiehl et al. [32] focuses on the crucial aspect of the gender-differentiated impact of off-grid solar energy in rural Tanzania. This study uses quantitative surveys and qualitative interviews to investigate the energy justice implications of off-grid solar systems. It critically evaluates and compares the primary goods and capabilities approaches to assess how the distributional benefits of off-grid solar are mediated by gender and class. Interestingly, their case study does not find clear benefits specifically for women or low-income households, suggesting that while off-grid solar usage may be equal, it is not necessarily equitable. The findings highlight the importance of considering gender and class in energy justice, filling a crucial gap in the literature on off-grid solar's impact. The above cited studies focus primarily on power generation from off-grid renewables. However, clean cooking sources and stove technologies are critical to eliminating particulate and carbon monoxide emissions from cooking and preventing several health risks, such as cancer, respiratory infections, and heart disease [33]. Therefore, the literature also addresses the crucial aspect of clean cooking sources and stove technologies for regions, specifically African countries struggling with comprehensive energy access. Gill-Wiehl et al. [34] analyzed the research on the hindrances related to the adoption and consistent use of clean cooking stoves and fuels due to affordability. They examined various affordability aspects of the adoption and regular usage of stoves and fuels, such as initial costs and regular expenses discussed in the clean cooking literature. Their findings revealed various frameworks, definitions, and measurements used in the discussions, with frequent focus on stove prices, fuel expenses, microfinance, and smaller purchase quantities. The researchers suggest financing strategies to address unaffordability should consider how low-income families earn, spend, and save money. They also recommend expanding affordability frameworks to encompass gender, rural/urban disparities, and stove-stacking behavior. Using liquified petroleum gas (LPG) as a clean cooking source as a solution for energy access has also been widely studied. Gill-Wiehl et al. [35] highlight the potential of a community engagement model for public health in promoting the adoption of clean cooking fuels. They propose that this type of community infrastructure model can substantially increase LPG usage when augmented with financial mechanisms like a micro-savings program. This is particularly true in rural, low-income regions. In another study [36], Gill-Wiehl et al. revealed that despite the widespread use of firewood and charcoal, 82% of households preferred LPG. Moreover, their findings suggest that integrating household preferences into clean cooking policies is essential, especially as their data indicates that LPG is preferred and more economical than traditional fuels. When exploring off-grid and clean cooking solutions, researchers have also investigated alternative community-based approaches and critically assessed the limitations of corporate-led market strategies for achieving energy access. Kemabonta and Kammen [37] investigated an alternative approach to addressing energy poverty, focusing on private and community ownership of electricity production factors and emphasizing the importance of economics over mere technical calculations. They argue that traditional interventions often fail by treating energy access as merely a technical issue, neglecting the economic aspects that can empower communities. Their study includes case studies like the Nigerian off-grid mini-grid industry and the Ecoblock pilot project in California, demonstrating how community-based approaches can effectively tackle energy access issues. By prioritizing economic calculation and leveraging community and private property rights in electricity production, their approach suggests a more sustainable and participatory model for addressing energy poverty, moving beyond the limitations of current paradigms that focus primarily on technical solutions. While Kemabonta and Kammen [37] highlight the effectiveness of community-based approaches in empowering local populations and enhancing energy access, Groenewoudt and Romijn [38] provide a contrasting perspective by critically evaluating the corporate-led market approach, which predominates in the Global South. Their review [38] critically assesses the limitations of the corporate-led market approach to off-grid energy access, particularly in the context of the Global South. Their study highlights that while markets facilitate technology diffusion, they prioritize profit over people and the planet, leading to sustainability trade-offs. The authors argue that this market model fails to achieve equitable and sustainable energy access and perpetuates structural injustices by not effectively reaching the poorest or most isolated populations. They propose a more inclusive approach that involves local entrepreneurs, non-profits, and public sectors to negotiate these trade-offs better, suggesting that a pluralistic route might offer a more just and sustainable framework for energy access. This perspective challenges the reliance on foreign-affiliated corporate enterprises and underscores the need for a diversified strategy emphasizing community and local capacities. Reflecting the earlier studies in the literature, various successful energy access projects have been initiated in regions lacking reliable energy sources. These projects generally focus on renewable energy-based decentralized and off-grid systems. Some important activities of these energy access projects [39] can be categorized as follows:

1. **Regional Development and Technical Assessments:** Projects typically focus on identifying energy demand and designing mini-grid systems for diverse communities. This involves comprehensive assessments addressing the water, telecommunications, and energy nexus to enhance productive energy uses.

2. **Strategic Planning and Capacity Building:** These initiatives often include creating platforms for universal electrification that involve developing national and regional plans, extensive training for technical staff, and support for ongoing electrification efforts.

3. **Georeferenced Planning for Universal Access**: Projects aim to develop georeferenced plans to facilitate universal access to electricity, especially targeting remote and isolated areas, to identify and characterize potential consumer units for community and productive usage.

4. **Hybrid Power Systems Design and Evaluation:** These involve designing hybrid power systems that integrate renewable energy generation with battery storage solutions, focused on reducing reliance on traditional diesel generators.

5. **Feasibility Studies and Technical Specifications**: Comprehensive feasibility studies and technical specifications are conducted to review energy options and develop concrete project concepts. These include detailed budgeting and implementation schedules tailored to each community's needs.

3. RECOMMENDATIONS

Traditional studies on energy access have often focused on isolated, siloed solutions, as shown in Sections 2 and 3. However, the energy access challenge is inherently multidimensional, involving aspects such as energy sector governance, technological integration, stakeholder engagement, data collection and analysis, configuration of technology solutions, linkages with other sectors, region-specific customization, financing, social and cultural barriers, planning deficiencies, and limited data availability [13, 40, 41]. Addressing these complexities requires interdisciplinary collaboration [13, 40, 41] and the active participation of diverse stakeholders [42-44]. Figure 2 summarizes traditional and integrated approaches for energy access solutions.

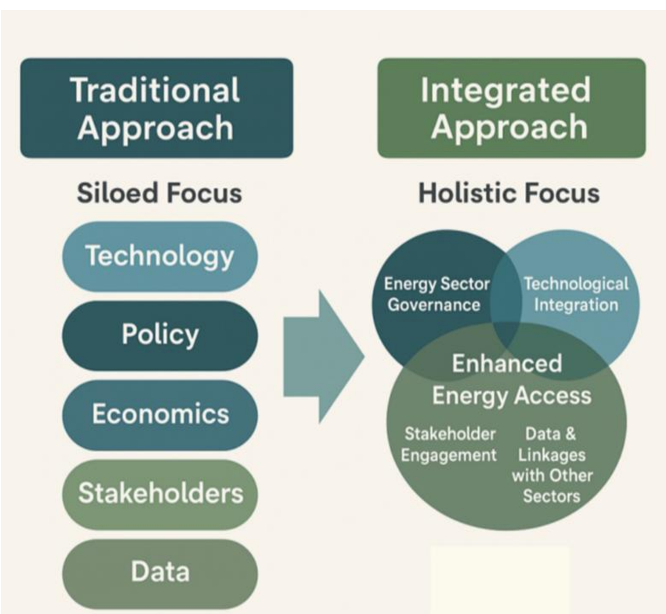

Figure 2. Overview of traditional and integrated approaches to energy access.

In this paper, we propose a preliminary framework to promote an interdisciplinary approach. Additionally, we introduce the concept of a data-driven energy platform to facilitate cross-disciplinary collaboration and foster stakeholder engagement. Such a platform can support the development of innovative, regionally tailored solutions to overcome energy access challenges. Before proceeding

3.1 Interdisciplinary Approach to Solving the Energy Access Problem

The current literature highlights the importance of interdisciplinary collaboration to address the primary challenges of energy access and develop sustainable solutions. Key disciplines identified for their contributions include [40]: Engineering; Economics and Finance; Political Science and International Relations; Environmental Science; Legal Studies; Sociology and Anthropology; Spatial Analysis; Business; Psychology; and Public Health. In our interdisciplinary approach to energy access, we focus on two guiding questions: 1. How can different disciplines be classified into collaborative domains to create a more inclusive governance model? 2. How can these domains manifest across key areas essential to solving the energy access challenge? The global energy access issue is inherently complex, influenced by a wide array of interconnected factors that shape the viability and effectiveness of potential solutions. To tackle this, we propose four primary domains: D1 (Energy Generation, Devices, and Advanced Materials), D2 (Microgrids for off-grid solutions), D3 (Internet and Communication Technology (ICT) for energy system optimization), and D4 (Environmental and Human Dimensions of energy use). This interdisciplinary framework is vital for creating comprehensive solutions that address the various aspects of energy access. Bringing together expertise from STEM fields, social sciences, and humanities is crucial for driving the sustainable development of energy systems. The literature stresses the need to integrate financial, technical, and social insights to create lasting solutions for energy access challenges [22, 41, 45-47]. Overcoming barriers such as remote monitoring, market identification, logistics, resource management, and addressing user needs requires collaboration from researchers across these disciplines [22, 41, 47]. Such interdisciplinary cooperation not only fosters idea exchange but also enhances the effectiveness of the solutions proposed. At the core of this approach is the integration of innovations in energy generation and storage (D1) with advancements in microgrid technology (D2) to improve energy system efficiency and cost-effectiveness. Additionally, incorporating AI and data science (D3) with insights into social and environmental factors influencing energy usage (D4) results in systems that are not only effective but also responsive to community needs. This approach ensures solutions that are both theoretically sound and practically feasible, particularly in remote or underserved regions.

This interdisciplinary approach manifests across several critical areas:

1. **Integration of Technical, Economic, and Social Factors:** Using data science and AI to design, create, and implement microgrids in remote, off-grid regions demonstrates the importance of aligning technical strategies with social and economic considerations. Factoring in community-specific socio-economic, behavioural, and cultural elements enhances the acceptance and sustainability of these solutions. Data-driven decision-making tools, tailored to the unique characteristics of renewable energy sources and demographic needs, provide reliable, contextually appropriate energy solutions [48].

2. **Socio-economic and Environmental Intersection:** In the contemporary business environment, creating sustainable business models that balance economic viability with sociocultural values is essential. This requires embedding environmental stewardship, equity, diversity, and inclusion into operational strategies. Interdisciplinary collaboration, drawing on insights from cultural anthropology and sociology, ensures that solutions align with local cultures and are socially responsible and sensitive to diverse community needs.

3. **Policy, Governance, and Community Engagement:** Expertise in public policy, governance, and law is critical for addressing the multifaceted challenges of energy access initiatives. Insights from these disciplines contribute to developing comprehensive strategies that account for legal and regulatory frameworks, public administration, and the social impacts of energy policies. Prioritizing community involvement and participatory methods in planning and implementation ensures that energy access solutions meet local needs and expectations. Involving local communities, stakeholders, and relevant organizations in decision-making provides a more holistic understanding of specific obstacles and opportunities for energy access. Additionally, incorporating educational, psychological, and social principles into community development strategies is essential for fostering sustainable and inclusive energy access. By considering the diverse needs and aspirations of various communities, programs can be designed to improve access to energy resources and contribute to broader societal development and well-being. Drawing on expertise from multiple fields and emphasizing community involvement and holistic development approaches enable more effective design and implementation of energy access initiatives, promoting equity and sustainability.

Addressing logistical and security challenges related to delivering energy equipment to remote areas is essential for strengthening private-sector investments in energy access across the Global South. Shifting from a focus on “capital intensity” to “data intensity” is a key strategy for overcoming financial obstacles, supporting the creation of sustainable business models, and promoting the widespread adoption of clean energy solutions. This multifaceted approach not only advances energy access in underserved communities but also contributes to poverty alleviation, socio-economic development, and environmental sustainability within the region.

3.2 Data in Energy Platform

Different stakeholders should collaborate on the energy access issue to create innovative solutions. Sharing data and knowledge between different players is one of the most critical factors in effective collaboration. Sulzer et al.[49] suggest a platform-based design for an energy system, and Fioriti et al. [48] discuss data platform guidelines and a prototype for microgrids and energy systems. Sulzer et al. [49] suggest a platform-based design (PBD) for effectively integrating renewable energy sources. In the context of energy systems, PBD (Platform-Based Design) is a methodology that streamlines the complex design of integrated systems by separating functions from architectures, identifying different levels of abstraction, and repurposing components. The semiconductor and automotive industries inspire the platform. The core of PBD is the development of modular components that can be reused and combined in various ways, ultimately aiding in faster market entry and lowering implementation risks. It improves interoperability, stimulates innovation, enhances reliability, and increases the flexibility of energy system designs. When PBD is aligned with the energy hub concept, it facilitates a holistic strategy for design and operation that spans various sectors, disciplines, and domains. The integration of these concepts leads to the creation of energy systems that are sustainable, affordable, and robust. Digital Twins and Building Information Modeling (BIM) are essential in the PBD, enabling efficient data sharing among diverse stakeholders. Digital twins integrate multiple datasets and are frequently refreshed with real-time measurement data. Moreover, PBD utilizes BIM to enhance and automate the design workflow. BIM establishes an extensive data framework that facilitates information sharing among various stakeholders and disciplines within the building sector. Fioriti et al. [48] also suggest data platform guidelines and develop a prototype for microgrids and energy access to overcome the key challenges in energy access. These challenges are listed in [48] as resource constraints, lack of granular data, high cost of traditional approaches, complex data collection, data inconsistency, stakeholder diversity, poor data quality, and uncertain demand. These challenges make it difficult to plan and deploy energy access projects in rural and underserved areas [48]. Therefore, Fioriti et al. [48] propose a platform to overcome these issues. Specifically, the platform addresses data quality issues in energy access projects through several mechanisms, including a two-fold approval process, moderator validation, reward point system, user roles and permissions, data licensing and attribution, and flexible data structure. In this work, we suggest a Data-in-Energy Platform for Energy Access projects as a preliminary idea inspired by [49] and [48]. Figure 3 illustrates a general framework of this platform. This platform should include valuable features suggested in [49] and [48]. Additionally, the Data-in-Energy Platform should consist of the features below, unlike the suggested platforms in [49] and [48]:

- **AI Integration and Disaster Response:** Unlike the platforms in [49] and [48], the Data-in-Energy Platform should leverage AI for rapid, on-demand configuration and response capabilities. For instance, its "Rapid Response Capability" could address natural disasters, providing immediate, location-specific energy system designs.

- **Global 'Energy Extension Service' and Dynamic Business Models:** The Data-in-Energy Platform should support emerging business models by providing data-rich decision-making resources, which would dynamically support entrepreneurs and small and medium-sized enterprises in the energy access sector. The inclusion of this type of data infrastructure can help lower financial and logistical barriers, specifically in under-resourced regions.
- **AI-Driven Custom Energy Solutions:** Unlike the platforms in [49] and [48], the Data-in-Energy Platform should include generative AI to develop and visualize custom energy solutions in real-time. By enabling users to input specific parameters, it can adapt the energy system design to local needs, making it a powerful tool for marginalized or remote communities.
- **Data-in-Energy Platform as a Tool for Universal Energy Access and Policy:** The Data-in-Energy Platform should aim to contribute to SDGs by shaping equitable policies and governance models, benefiting energy access at local, national, and international levels. Its AI-driven insights can help policymakers align local regulations with real-time data, strengthening its potential for influencing policy.

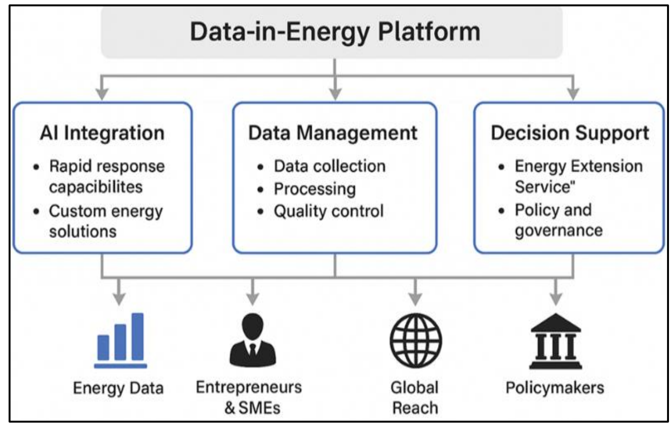

Figure 3. Simplified superstructure of the Data-in-Energy Platform.

We suggest the Data-in-Energy platform as an early idea in this paper. In future works, we aim to improve this idea in detail by collaborating with researchers from different disciplines.

4. CONCLUSION AND FUTURE WORK

As the global energy landscape is shaped by rapid geopolitical shifts and diverse challenges around priorities, the urgency of the energy access issue becomes increasingly apparent. Here we have reviewed the potential solutions to meet the challenges of for energy access highlight the positive the role of data in energy access issues. The literature shows we have different technological solutions for the energy access issue. However, the problem has multidimensional challenges. To overcome these challenges, an interdisciplinary approach is critical and our capacity to exploit and utilize data with digital technologies and AI techniques. We provide our perspective the importance and strengths of a multidisciplinary approach and propose a novel ‘data-in-energy’ platform.

In future work, we will focus on using data to address the energy access issue and the main features of the data-in-energy platform. Moreover, we want to improve our interdisciplinary approach to energy access issues.

Decleration

The first author used Grammarly, Grammarly AI, and ChatGPT-4o to assist with language editing. After using these tools, both authors reviewed the manuscript thoroughly and take full responsibility for its content.

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