

## Empowering Sudan: Transforming the Energy Landscape for Equitable Access and Sustainable Development

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### Abstract

The study examines Sudan's electricity deficit and its impact on economic growth, social welfare, and the environment. It identifies challenges such as conflict, underinvestment, and unequal energy access, particularly in rural areas. To address these issues, the study advocates for innovative, decentralized renewable energy solutions that emphasize social justice, sustainability, and community involvement, ultimately aiming to create a resilient future that benefits all segments of society.

**Keywords:** *Environmental Sustainability, Outdated Electricity Infrastructure, Inadequate Energy Supply, Need for Renewable Energy Solutions.*

## 1. Introduction

Historically, wood and charcoal have been vital fuels for cooking and heating in many regions and have also played significant roles in industries such as baking and brick-making. Additionally, biomass sources like sugarcane bagasse and cotton stalks have met energy needs, particularly in sugar mills and households, [1] and [2]. Figure 1 below illustrates the wood and charcoal trade in Sudan.



Figure 1: Wood and Charcoal Trade in Sudan

The rapid growth of the population in Sudan has resulted in a significant increase in the demand for wood and charcoal, which are primary sources of energy for many households. This rising consumption has dire consequences, notably leading to deforestation, where vast areas of forested land are cleared for fuel, exacerbating environmental issues such as desertification. As forest cover diminishes, the natural barriers that protect land from erosion and degradation weaken, furthering the encroachment of desert-like conditions.

Figure 2 below provides a visual representation of the struggle faced by farmers in Sudan, as they grapple with the dual challenges of climate change and food insecurity. With the desert advancing towards arable land, agricultural productivity is threatened, compounding hunger and malnutrition issues within vulnerable communities.

In terms of energy resources, Sudan made a significant discovery of natural gas deposits during the period from the 1960s to the 1980s. However, the extraction and production of these resources did not become feasible until 2010, demonstrating a lag in harnessing potential energy supplies to meet national needs. Despite these natural gas reserves, Sudan continues to face an ongoing energy crisis. Alarmingly, about 60% of the population lacks reliable access to electricity, which severely hampers both economic and social development. This lack of energy access inhibits businesses from operating efficiently, limits educational opportunities, and negatively impacts healthcare delivery, creating a cycle of poverty and underdevelopment that is difficult to escape. Consequently, addressing these energy challenges is critical to improving the overall quality of life for millions of Sudanese citizens, [1] – [10].



Figure 2: Farmers in Sudan Battle Climate Change and Hunger as Desert Creeps Closer

### 1.2 Solution Strategies

The review addresses urgent challenges in electricity infrastructure, highlighting the necessity for diverse, sustainable, and practical solutions. It points out the need for significant upgrades to aging power facilities and advocates for investments in new generation plants, particularly renewable sources like solar and wind. This transition aims to reduce greenhouse gas emissions while providing off-grid solutions for underserved communities, thereby enhancing energy security and creating a more resilient energy portfolio.

A comprehensive framework for integrating renewable sources into the existing grid is essential, necessitating upgrades to transmission lines and the implementation of smart grid technologies for efficient energy distribution. Prioritizing these infrastructure investments will foster a stable energy system that meets current and future demands while addressing environmental challenges and promoting economic growth.

The study outlines various strategies for advancing the energy sector through:

1. **Policy Reform and Regulation:** Establishing a robust regulatory framework is crucial for attracting renewable energy investments. This should include incentives such as tax breaks, streamlined regulatory processes, and continuous dialogue with investors to adapt policies.
2. **Community-Based Solutions:** Engaging local communities in energy initiatives fosters ownership and sustainability. Decentralized energy systems, like microgrids and solar home systems, can empower communities, boost local economies, and improve energy access.
3. **Capacity Building and Training:** Investing in human capital through targeted training programs is vital for long-term success. This will develop skilled technicians capable of managing modern energy technologies, fostering job creation and resilience.
4. **International Partnerships:** Collaborating with global organizations can provide critical resources and knowledge for large-scale energy projects. Such partnerships promote innovation and the exchange of best practices, enhancing local energy management.
5. **Public Awareness and Engagement:** Raising awareness about sustainable energy is essential for promoting conservation and citizen participation. A multifaceted approach that combines awareness with community engagement can improve access to reliable energy and support economic development.

Together, these efforts aim to create a sustainable, equitable, and resilient energy future that benefits both the economy and the environment, [11], [12], [13], [14] and [15].

### **1.3 Objectives of the Present Study**

The study explores Sudan's electricity deficit and its negative impact on economic development, social welfare, and environmental sustainability. It aims to analyze the historical evolution of Sudan's electrical infrastructure, identify key factors contributing to the energy crisis, and assess the socio-economic consequences of inadequate energy supply. Challenges such as conflict, insufficient investment, and outdated systems have obstructed progress, resulting in unequal energy access, especially in rural regions. The literature review synthesizes existing research to enhance understanding of the issue, explore innovative solutions, and inform policies aimed at improving energy access and sustainability. This foundational analysis is vital for guiding policymakers and stakeholders involved in energy planning to support Sudan's socio-economic development initiatives.

### **2. Historical Background of Electricity Generation in Sudan**

Electricity generation in Sudan began in 1908 with the establishment of the first power station near Khartoum. In 1925, the Sudan Light and Power Company was formed, later becoming the National Electricity Corporation (NEC) after being nationalized in 1952. The NEC played a vital role in expanding the country's electrical infrastructure, with significant developments including the Sennar Dam (1925) and the Roseires Dam (1966). While these dams were primarily built for irrigation, they also improved agricultural productivity and facilitated the establishment of Sudan's first hydropower station at Sennar in 1962. A strategic assessment of hydroelectric potential along the Nile River followed. Despite these advancements, electricity supply has remained inadequate, averaging about 500 megawatts from 2000 to 2010, leading to frequent outages. The National Electricity Corporation and the Ministry of Energy oversee two grids that mainly serve Khartoum and its surroundings. However, the continued reliance on diesel power and private generators highlights the ongoing challenges in Sudan's energy sector. Figure 3 below depicts the Sennar Dam, which stores water from the Blue Nile, located 300 km north of Khartoum, [1].

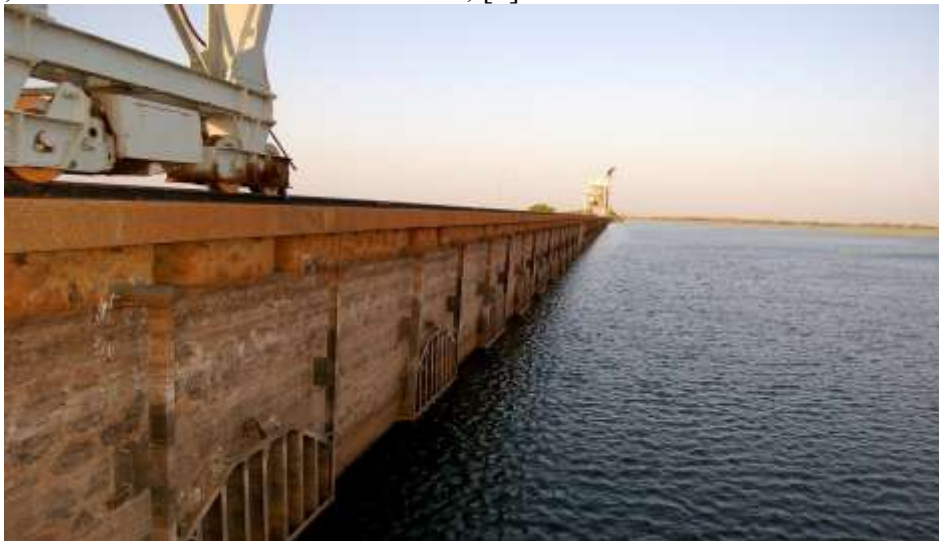


Figure 3: Sennar Dam – Sudan

Sudan's energy infrastructure heavily relies on hydroelectric power, which accounts for 41% of its 4,520 GWh installed capacity. This dependence makes the country vulnerable to fluctuations in the Nile River's flow due to seasonal changes and rainfall patterns. To mitigate this risk, Sudan is diversifying its energy sources and enhancing resilience to climate impacts. Key initiatives include partnerships with Ethiopia to connect power grids and facilitate electricity exports, a contract with a Norwegian firm for designing three new power stations on Ethiopian tributaries of the Nile, and collaborations with Asian companies, including those from China, to develop new energy infrastructure and improve regional integration.

These efforts aim to enhance energy access and reliability, contributing to sustainable economic growth and development in Sudan and its surrounding region.

Established in 2005, the Dams Implementation Unit (DIU) manages the Merowe Dam's construction, with the China International Water and Electric Company as the primary contractor. The project, which involved civil works estimated at \$1.9 billion, was supported by \$600 million in concessional funding from various Arab sources. The dam is projected to more than double Sudan's energy production and create new agricultural land, although it necessitated the relocation of tens of thousands of residents, leading to social challenges. Additionally, the project included infrastructure upgrades, such as an airport and railway enhancements. By 2010, the Merowe Dam became crucial to Sudan's power generation, producing over 7,600 GWh annually, primarily from hydropower, [1]. Figure 4 illustrates the Merowe Dam located in Sudan.



Figure 4: Merowe Dam in Sudan

Sudan's electricity enhancement program comprises several initiatives, including the following: doubling the capacity of the Khartoum North power plant, constructing a new 500 MW power station in Kosti, building a dam on the Setit tributary, and increasing the Roseires Dam's capacity to 560 MW. Additionally, water-harvesting initiatives are planned in North Kordofan to improve water access and agricultural viability.

As of 2010, Sudan struggled with significant power generation deficiencies in its southern and western regions. Plans included future hydroelectric projects and localized diesel-powered grids to provide electricity to 20 towns, as well as efforts to extend the national electrical grid into areas such as Darfur and Kordofan. In January 2010, a joint venture formed by Taqa Arabia, ASEC Cement, and the Sudanese Pension Fund aimed to build a 42-megawatt power station to supply electricity to the Takamol cement plant in Atbara, addressing the increasing construction demands driven by rapid urbanization in Khartoum. This project marked a significant investment in infrastructure and reflected a broader trend of regional partnerships to foster economic growth in Sudan, [1], [16] and [17].

In 2019, the Sudanese Thermal Power Generation Company expanded the Garri power station to increase its capacity, initially using light distillate oil with plans to transition to heavy fuel oil later. At the same time, the company commenced construction of a new power station near Port Sudan to enhance regional energy production and meet rising demand. This initiative demonstrates a commitment to improving Sudan's power infrastructure and diversifying fuel sources for a more reliable energy supply, [18].

### **3. Overview of the Electricity Crisis in Sudan**

Sudan's electricity sector is in crisis, with 60% of the population lacking reliable access to power due to insufficient generation capacity and high electricity tariffs. This disproportionately affects low-income families, making it an issue of great social concern.

A comprehensive study aims to analyze the long-term changes in Sudan's energy sector, exploring past policies, economic changes, and socio-political factors, as well as environmental challenges. The goal is to propose sustainable and equitable solutions that address the current electricity crisis and

align with the democratic aspirations of the Sudanese people, promoting a resilient energy future that balances social equity, environmental stewardship, and economic development, [19].

Sudan relies on hydroelectric and thermal power for electricity, with a total capacity of 3.5 gigawatts. However, only 32% of the population has access to electricity, with rural areas being disproportionately affected, highlighting a need for improved energy infrastructure to ensure equitable access, [20].

The uneven distribution of electricity in Sudan, particularly affecting Darfur and South Kordofan, poses significant challenges as residents often have access to power for only six hours a day. This limited access hampers daily activities and economic development, exacerbated by ongoing conflicts and historical neglect from central authorities. The text emphasizes the urgent need for comprehensive reforms in the energy sector to improve electricity supply and promote long-term stability and sustainable development across all regions. Ultimately, the goal is to ensure equitable access to electricity for all citizens, addressing both immediate needs and future growth, [21].

Figure 5 illustrates Sudan's electricity network, featuring transmission lines that distribute power across the country. The network is divided into medium-voltage lines (blue) and high-voltage lines (green). This diagram provides an overview of Sudan's infrastructure, highlighting its importance in managing electricity distribution and revealing the complexities and challenges within the energy sector and governance.

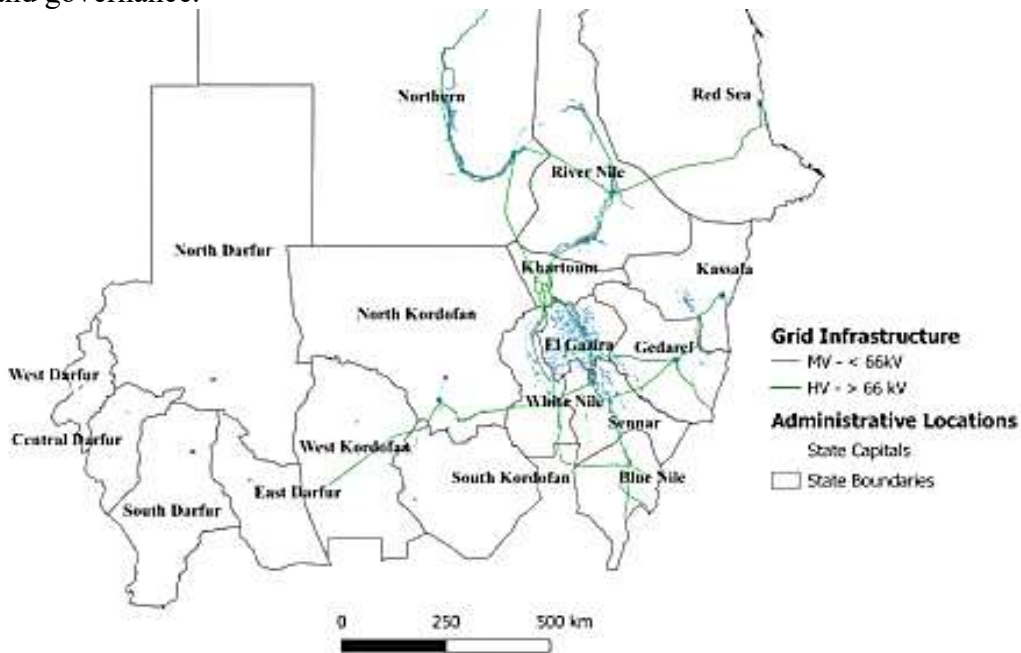


Figure 5: Sudan’s Electricity Network

Sudan's socio-economic disparities stem from its colonial history and cultural diversity, resulting in significant inequalities between the developed northern regions and the impoverished southern areas, such as Darfur, Kordofan, and the Blue Nile. Inadequate infrastructure, limited access to education and healthcare, and ongoing conflict further exacerbate these inequalities. Historical grievances and political marginalization have widened the divide, impacting daily life and national unity. Colonial policies, particularly the 'closed districts' regulation, isolated certain regions from development until 1946, leading to long-lasting inequities that continue to affect the country today.

The struggle for power and resources, rooted in this colonial legacy, has resulted in civil war and ongoing violence, contributing to a humanitarian crisis. This historical context influences Sudan's socio-political landscape, creating persistent tensions that complicate national unity and equitable development. These disparities hinder reconciliation efforts and pose significant challenges to achieving stability and a cohesive national identity, which are essential for Sudan's future growth, [22].

Colonial policies in Sudan have left enduring effects that continue to influence the country post-independence, as unresolved conflicts from that time have become more intricate. Initially fueled by limited political involvement, these tensions escalated following the 1958 military coup, which added a significant religious dimension. The military regime from 1989 to 2010, the National Salvation Government, further employed colonial strategies to impose a unified national identity, deepening societal divisions and ongoing unrest. Understanding these historical contexts is crucial for addressing current challenges in Sudan, [23].

In Sudan, amid turbulent conditions, the military leadership concentrated development efforts on the "Hamdi Triangle," targeting regions like Dongola, El Obeid, and Sennar to promote economic growth. However, this strategy reinforced Arab and Islamic identities, aiming for a unified state, yet revealing ongoing social fractures and disparities that raised questions about inclusivity in the government's vision for national unity. While the development policies aimed to foster growth, they obscured deeper ideological motives and marginalized various communities, worsening cultural and religious exclusions. Additionally, the military utilized energy distribution as a means to maintain control and perpetuate inequality, further destabilizing the social fabric of Sudan, [24].

The review discusses Sudan's energy challenges, which are rooted in its colonial past. Historical projects, such as dam constructions, prioritized foreign interests over local needs and environmental sustainability. This legacy continues to impact Sudan's energy policies and water resource governance, often harming local communities and the environment. The analysis calls for a re-evaluation of current initiatives to incorporate local perspectives and sustainable practices, and highlights the need to consider historical contexts when addressing contemporary energy and resource management issues in Sudan, [25].

The British colonial administration in Egypt, influenced by Garstin, concentrated on managing water resources to control the economy and agriculture. His innovative irrigation and water storage proposals increased agricultural productivity while asserting dominance over Egyptian agriculture. Garstin's efforts significantly impacted the relationship between Egypt and the Nile River and laid the groundwork for future water conservation initiatives, such as building reservoirs to manage the Nile's waters, [26].

A 1953 report titled "Control of the Nile Waters" assessed Nile management, focusing on hydropower generation potential. Insights from irrigation advisor H. A. Morris highlighted the possibility of using the river for both irrigation and energy production, promoting a sustainable future and enhancing the region's economic viability, [27].

The text describes a study on Egypt's management of its water resources, focusing on agricultural, environmental, and energy needs. It highlights how historical colonial influences have shaped this management, favoring Egypt since the 1940s. The study specifically compares Egypt's development of the High Dam to Sudan's Merowe Dam, illustrating complex colonial water governance and its lasting impact on regional relations and resource management, [28].

The World Bank's 1983 report led to a shift in the focus of dam construction from solely irrigation and power generation to also considering environmental sustainability and social impacts. This change prompted policymakers to re-examine the justifications and implications of dam projects, leading to a more inclusive approach in water resource management, [28].

A report highlights a shift in dam use, moving from water preservation to energy production from 1989-2019. This focus on energy generation has led to concerns about the sustainability of water resources and local ecosystems, despite efforts to harness dams for electricity, [29].

The current management of the Nile River's waters has been shaped by colonial powers' focus on Egyptian agricultural development. Their legacy of prioritizing water storage for agriculture persists in modern initiatives, raising questions about the effectiveness of current water management strategies, [30].

The text explores the enduring similarities between historical colonial water management and modern initiatives surrounding the Nile River, focusing on issues of sovereignty, resource distribution, and community impact. It criticizes contemporary proposals for prioritizing large-scale agricultural and

infrastructure projects while neglecting local needs and ecological sustainability. The narrative shifts from agricultural water storage to hydroelectric power generation, which has obscured colonial interests under the guise of progress and led to unmet socio-economic promises.

It also delves into Sudan's context under Omar Al-Bashir regime (1989-2019), highlighting the interplay between international isolation and economic challenges, along with a boost from oil discoveries in the early 2000s which facilitated infrastructure advancements. However, these developments were used to strengthen political control and promote political Islam, with the Merowe Dam serving as a symbol of development intended to consolidate power while disguising political motives. Although initially seen as a solution to energy shortages, public disappointment grew due to persistent electricity issues and high costs, revealing a disconnect between government claims and citizen experiences. The text ultimately calls for genuine development practices that address community needs amidst the complexities of Nile resource management and historical legacies, [31] and [32].

The Sudanese government's construction and marketing initiatives have led to a surge in costs due to corruption and nepotism. This has resulted in a \$3 billion debt tied to the Merowe Dam project, which has failed to meet its promised electrical generation capacity. The dam produces only 600 megawatts, instead of the promised 1,250 megawatts. This has led to financial burdens, economic strain, and questions about resource management and government effectiveness, [33].

The dam project's lack of transparency led to heightened environmental impacts and stakeholder concerns about sustainability and local ecosystems. The engineering firm involved, Lahmeyer International, has a controversial past, including a corruption conviction that resulted in a seven-year suspension by the World Bank. This situation highlights the need for accountability and ethical standards in development projects, particularly in ecologically sensitive areas, [34].

Lahmeyer has obtained financial backing from various stakeholders in Sudan, sometimes prioritizing their interests over transparency. Despite its controversial past, the company remains active as an engineering consultant for dam projects and has expanded its operations during a politically sensitive time. This has raised concerns about regulatory oversight and accountability, particularly regarding the ethical implications and potential impacts on local communities and the environment, [35].

The Merowe Dam project has encountered significant environmental issues due to a failure to follow proper protocols, with environmental impact assessments delayed for three years after construction began. This oversight has caused lasting harm to the local ecosystem and eroded public confidence in infrastructure management. Additionally, a report noted that the Sudanese government consistently rejected environmental studies, highlighting a lack of adherence to environmental standards. This situation threatens financial backing for related projects and underscores the necessity for improved compliance and transparency in environmental governance. An investigation is deemed crucial to ensure accountability and prevent similar future oversights, [36].

The Sudanese government removed the environmental minister and expedited approvals for the Merowe Dam project, prioritizing infrastructure development over environmental and social concerns. The dam's construction has severe environmental impacts, including high evaporation rates and disruptions to local ecosystems, leading to the displacement of tens of thousands of residents and raising concerns about the sustainability and equity of such development initiatives, [37] and [19].

In 2013, Sudan upgraded the Roseires Dam to improve its water storage and hydroelectric power generation, contributing to energy infrastructure and economic growth. This was followed by the completion of the Upper Atbara and Setit Dams in 2017, which collectively produce about 600 megawatts of electricity to meet rising domestic energy demands and foster agricultural productivity. Funding for these projects primarily comes from loans by Gulf nations and Chinese state-owned enterprises, raising concerns about the strategic motives behind China's investments, which may prioritize its own interests and compromise Sudan's autonomy. Additionally, Gulf states aim to secure access to Sudan's fertile land for agricultural projects, potentially undermining Sudan's control over its resources. This situation highlights the complex dynamics between international investments, national sovereignty, and economic development in Sudan, [38].



The study discusses the challenges associated with financing energy production through loans for dam construction, highlighting concerns over national sovereignty, increased debt, and the diversion of funds from essential services like education and healthcare. This reliance on external financing can lead to unfavorable terms that conflict with national interests, risking environmental degradation and social inequality. To address these issues, the study advocates for alternative financing models that utilize local resources and engage communities in decision-making. It emphasizes the benefits of grants and direct investments over loans, promoting ownership and accountability. The text also explores infrastructure projects, such as dams in Sudan, and their links to international investments and land acquisitions. Ultimately, it calls for a comprehensive approach to energy development that prioritizes local involvement, national goals, and sustainable practices for enhanced economic resilience, [39].

The agricultural initiative designed to spur economic growth has caused significant harm to local residents, including forced displacement from their ancestral lands, impacting their cultural heritage and community ties. Compensation for those displaced has been insufficient and unequal, with small landowners receiving only modest residential plots in exchange for larger properties, while larger landowners face minimal compensation. This situation reflects a disregard for local needs and rights in favor of economic interests, leading to social injustice and alienation in affected communities. Urgent action is needed to ensure fair compensation and recognition of local rights, [40].

A study found that approximately 700,000 people have been displaced due to land acquisitions, affecting local communities, especially pastoral groups, who have lost access to agricultural land and face threats to food security and their cultural way of life. It highlights the need for fair land management practices that prioritize the rights and well-being of local residents, and promotes sustainable methods to prevent foreign investments from undermining local communities, [41].

Hydroelectric projects, despite their renewable energy potential, often cause significant social and economic harm, deepening existing inequalities and displacing communities. These projects primarily benefit wealthier regions, while leaving vulnerable populations behind. To address this issue, there is a need for inclusive and sustainable energy practices that prioritize the welfare of all stakeholders and ensure that progress is fair and equitable.

#### **4. Impulsive Measures in Sudan's Energy Sector**

Sudan is facing a major energy crisis, with over 60% of its population lacking access to electricity. The demand for energy is growing by about 10% annually, exacerbating supply shortages and impacting essential services like education and healthcare. The government has attempted to address this by building thermal power plants, which added over 1,500 megawatts of capacity from 2008 to 2019. However, this has increased reliance on imported fuels, straining the national budget—fuel costs rose to \$1.3 billion by 2017, accounting for 15% of total energy spending. To resolve the crisis sustainably, Sudan needs to diversify its energy sources and develop a self-sufficient energy strategy, especially by incorporating renewable energy, [42].

The review highlights the environmental consequences of thermal power plants in Sudan, which predominantly use fossil fuels and emit around 6.25 million tons of carbon dioxide each year. Due to the loss of oil reserves after South Sudan's secession in 2011, Sudan has become increasingly reliant on imported fuels, leading to economic instability and vulnerability to price changes. The text advocates for a shift towards renewable energy sources, such as solar, wind, and hydroelectric power, to reduce environmental harm, stimulate economic growth, and enhance public health. It stresses the importance of investing in sustainable energy alternatives to combat energy poverty and develop a resilient energy infrastructure. Although thermal power plants provide short-term electricity benefits, they carry long-term economic and environmental risks. Sudan's current focus on hydroelectric power includes plans to build dams on the Nile River to generate 990 megawatts, aiming to enhance energy infrastructure, promote sustainability, and support economic development, [19].

Proposed smaller-scale hydroelectric projects in Daqash, Mukrat, Sheri, and Sablouka are encountering significant opposition from local communities due to concerns about flooding, displacement, and the loss of cultural heritage. Critics argue that the social, economic, and

environmental costs outweigh the potential benefits, particularly in light of the anticipated impacts from the Grand Ethiopian Renaissance Dam (GERD) on the Nile River's flow. This situation underscores the need for dialogue between stakeholders to balance development with environmental sustainability.

The GERD complicates Sudan's water management and energy plans, casting doubt on the viability of new dams intended to address energy challenges. High development costs, technical difficulties, and local resistance pose obstacles to achieving ambitious energy goals, such as supplying 80% electricity by 2031. The uneven distribution of electricity across Sudan exacerbates social and economic disparities, with many communities lacking reliable access. A comprehensive strategy addressing infrastructure, finance, and policy issues is critical for ensuring equitable energy access and fostering sustainable development to improve living standards for all Sudanese citizens [43] and [44].

Sudan struggles with low electrification rates and high population density, facing challenges similar to other sub-Saharan African nations. However, its issues are worsened by long-term U.S. sanctions, which restrict trade, foreign investment, and access to renewable energy technology, stunting the growth of its renewable energy sector. In comparison, Tanzania has developed a strong solar energy infrastructure with 109 solar plants generating 158 megawatts, while Sudan has only one solar plant producing 5 megawatts. This stark contrast emphasizes the pressing need for comprehensive strategies to promote sustainable energy solutions in Sudan, [45].

The nation's solar energy journey began in 2014 with an initiative aimed at implementing solar home systems in households through affordable installment payment plans with local banks. Initially targeting 100 households with 100-watt solar systems, the program promotes energy independence and serves as a model for future growth. Looking ahead, the initiative aspires to reach a total solar capacity of 110 megawatts by 2031, significantly enhancing the country's energy landscape and supporting sustainability efforts for a greener future, [46].

A recent report highlights progress in Sudan's solar initiative, noting that by 2018, about 1,500 households had accessed solar energy services. While this indicates potential for solar energy in transforming the region, significant challenges remain, including historical barriers related to economic, political, and infrastructural issues that hinder energy development. Sudan needs a strategic approach to expand solar services and implement policies that encourage investment and innovation in renewable energy technologies. This effort aims to create a more equitable and sustainable energy future, improving electricity access for all citizens. Although ambitious, consistent effort and collaboration can drive progress, [47].

In 2020, Sudan inaugurated its first solar power plant in El Fasher, the capital of North Darfur State, marking a significant advancement in the country's pursuit of renewable energy. This facility is expected to considerably influence the local energy landscape. Figure 6 below shows El Fasher solar power plant which is the first solar power plant to be built in Sudan.



Figure 6: El Fasher Solar Power Plant

A 5-megawatt solar power plant in Sudan is providing a reliable and sustainable energy source to a community that previously struggled with power shortages, supporting development and improving quality of life, [48].

The development of a second solar energy facility in El Daein, Darfur, is facing significant challenges, including financial constraints, delays in essential materials, and theft of project components. These issues highlight the complexities of establishing renewable energy infrastructure in regions lacking adequate logistical and institutional support. Despite these setbacks, the Sudanese Hydro Generation and Renewable Energy Company (SHG and REC) is financially backing both solar projects, managed locally by Top Gear, promoting community involvement and local expertise. These initiatives represent a shift towards renewable energy in Sudan, aiming to improve energy accessibility and reduce reliance on fossil fuels, ultimately contributing to a more sustainable future for the country, [49].

The electricity sector's ongoing challenges are largely rooted in the corruption and mismanagement of the al-Bashir regime. However, the transitional government established after the 2018 revolution has also exacerbated these issues through its economic reforms, heavily influenced by neoliberal frameworks from institutions like the World Bank and IMF. Although intended to stabilize the economy, these reforms have neglected the specific needs of the electricity sector and public welfare, leading to austerity measures that hinder essential investments. This combination of inherited problems and ineffective policies has worsened the electricity crisis, impacting the economy and citizens' daily lives. A more targeted approach to economic reform is necessary to address the energy needs of the population, [50].

Abdalla Hamdok, the former Prime Minister of Sudan, largely supported neoliberal economic reforms during his tenure, viewing them as essential for securing debt relief and attracting foreign investment. His administration prioritized market-driven solutions and austerity measures, which aimed to stabilize the economy but faced significant criticism for exacerbating inequality and neglecting vulnerable populations. A notable policy change was the decision to float the Sudanese pound and eliminate subsidies on essential goods, resulting in severe currency depreciation and skyrocketing fuel prices. These changes significantly strained the finances of ordinary Sudanese citizens, increased inflation, and contributed to economic instability, leading to widespread public discontent regarding rising living costs, [51].

Recent economic reforms in Sudan have drastically impacted citizens' daily lives, primarily due to significant cuts in subsidies that have led to soaring costs of essential goods and services. This has eroded purchasing power and heightened poverty rates, exacerbating existing hardships as households

struggle to meet basic needs like food, healthcare, and education. The transitional government's economic policies, intended to resolve long-term economic issues, have instead worsened the crisis, causing concerns about the electricity sector's viability amid power outages and inefficiencies.

The poorly executed, neoliberal reforms have created a lack of transparency and accountability, leaving citizens feeling disempowered. The situation deteriorated following a coup on October 25, 2021, which halted crucial foreign aid and pressured the government to hastily implement flawed reforms. The convergence of political instability and economic mismanagement now poses significant challenges for ordinary Sudanese, leading to widespread frustration and a sense of disillusionment. A more inclusive and transparent approach is urgently needed to address these issues and foster a sustainable future.

### **5. Trends in Electricity Consumption**

Between 1999 and 2011, Greater Khartoum became an essential urban hub for Sudan's middle class, accommodating approximately 9 million people, which accounts for 20% of the country's population. This metropolitan area plays a critical role in the national economy, utilizing 60% of Sudan's electricity, predominantly for residential needs. The accessibility and cost of energy directly influence living standards, as dependable electricity is vital for everyday household functions. During this period, significant demographic and economic shifts occurred, altering lifestyles and living conditions. This transformation underscores the connection between urbanization, energy consumption, and quality of life in this fast-growing city, [19].

The study discusses the transformation of residential architecture in Greater Khartoum, highlighting a historical reliance on natural earth materials that created well-ventilated homes suited to the harsh desert climate. Recently, there has been a shift towards modern "concrete jungle" structures influenced by global architecture, particularly from affluent cities like Dubai. These new buildings often neglect environmental adaptation, resulting in poor ventilation and uncomfortable living conditions for residents. This architectural evolution raises concerns about sustainability, environmental adaptability, and cultural identity in the region, emphasizing the need to analyze the balance between tradition and modernity in Sudanese housing.

The rise of vertical living spaces, particularly in urban areas, has significantly increased energy consumption, especially due to higher reliance on air conditioning in densely populated high-rises. This surge in electricity demand, particularly during summer months, has strained energy infrastructures, leading to issues such as power outages, higher costs for consumers, environmental concerns from increased fossil fuel use, and health risks from heat exposure. To address these challenges, innovative solutions like energy-efficient buildings, renewable energy promotion, and smart grid technologies are essential. Unlike cities with strong regulations like Dubai, Sudan faces significant energy management issues due to a lack of robust regulatory frameworks, resulting in inefficient energy usage. Households in Greater Khartoum consume much more electricity than the sub-Saharan average, highlighting the need for improved energy policies and infrastructure in the region, [52].

Sudan's current high demand for energy presents both challenges and opportunities for its energy sector. While the increased consumption highlights existing inefficiencies and the need for modernization, there is also significant potential for improvement through stricter building regulations that promote energy efficiency. A recalibrated energy strategy is essential for Sudan's future, fostering sustainable practices and setting a precedent for the entire nation.

The rising electricity demand, particularly in urban areas, strains the existing infrastructure, risking outages and reliability issues. This situation pressures government authorities to ensure a stable energy supply, emphasizing the need for infrastructure upgrades, regulatory reforms, and investment in new technologies. Additionally, the push for sustainable energy sources complicates these challenges, as governments must balance energy needs with environmental considerations. Overall, addressing these dual pressures requires innovative solutions and collaborative efforts across sectors. The current energy crisis has prompted the sector to implement rapid, short-term solutions, particularly through the substantial expansion of thermal energy production. This initiative is part of

a comprehensive five-year plan initiated in 2018 under Al-Bashir leadership, aiming to add 8.7 gigawatts of electricity capacity, with 60% expected from thermal power plants. This expansion addresses immediate energy demands and stabilizes supply, while also serving as a temporary measure as longer-term, sustainable solutions are pursued. The focus on thermal energy reflects the urgent need to meet current energy needs while exploring diverse energy sources for the future.

## **6. Summary of the World Bank Report on Sudan's Electricity Sector**

The World Bank's report on Sudan's electricity sector recommends the following reforms:

Eliminate tariff subsidies to create an equitable pricing system.

Optimize the energy mix by diversifying sources, meeting current/future demands, and integrating renewable energy.

Encourage private sector involvement to drive innovation and efficiency in energy generation and distribution.

### **6.1 Elimination of Electricity Tariff Subsidies**

The report highlights Sudan's extremely low electricity tariffs, which are among the lowest in sub-Saharan Africa, accounting for only 1 to 3 percent of household income, e.g. well below the World Bank's recommended threshold of 5 percent. However, the informal labor market creates income instability for many families, complicating financial planning and raising concerns about their ability to manage these costs. Additionally, government subsidies that aim to reduce electricity expenses disproportionately benefit higher-income groups, suggesting that these subsidies are unsustainable.

To address fiscal deficits and promote equitable resource distribution, the report recommends a gradual five-year phase-out of these subsidies. Between January 2021 and January 2022, Sudan experienced dramatic tariff increases, with household rates rising over 3,000 percent and commercial rates climbing up to 13,000 percent, leading to increased production costs and exacerbating inflation. Therefore, the report advocates for a comprehensive reform plan for the electricity tariff system to balance fiscal accountability with the socio-economic needs of the population, [53], [54] and [55].

#### **6.1.1 Reactions and Concerns Regarding Reform Approaches**

The report emphasizes the urgent need for reforms in the electricity tariff system, focusing on its varying effects on different socioeconomic classes. It advocates for stable tariffs for low-consumption households while proposing adjusted rates for high-consumption users to promote fairness and energy efficiency. This approach seeks to improve the financial sustainability of the electricity sector and encourage responsible usage among the top 1% of consumers. Additionally, the report highlights recent protests by smallholder farmers in northern Sudan against soaring agricultural tariffs, which have significantly impacted their livelihoods. The 'North Barricades' movement successfully lowered electricity tariffs for farmers, demonstrating the effectiveness of grassroots activism in influencing policy change. Ultimately, the protests underscore the broader effects of economic policies on rural communities and the need to address existing disparities, [56].

#### **6.1.2 The Need for Comprehensive Economic Management**

Effective management of Sudan's macroeconomic indicators is essential for maximizing the benefits of subsidy reductions while avoiding severe inflation, which exceeded 260% in March 2022. With over half of the population living below the poverty line and experiencing diminished purchasing power, there are valid concerns regarding how liberalizing price structures might affect the country's electrification goals for 2031. Lessons from Ghana and South Korea demonstrate that successful electrification hinges on strategic government planning and tariff systems that consider citizens' financial difficulties. Consequently, Sudan needs to develop a comprehensive economic strategy that aligns fiscal policies with social equity, ensuring a successful and equitable energy transition that supports long-term growth and stability, [57], [58] and [59].

In mid-2019, the World Bank conducted a comprehensive review of its five-year strategic plan for the electricity sector, assessing its effectiveness and identifying ongoing challenges. The resulting report offers valuable insights into operational and structural issues while proposing targeted solutions for reform. It serves as a vital resource for policymakers and industry leaders, enabling them to align strategies with the sector's needs to foster sustainable development and improve energy efficiency.

Overall, the report has played a significant role in shaping the future of electricity sector reforms, with the goal of enhancing service delivery and ensuring reliable energy access worldwide.

### 6.2 The Future Energy Mix for Capacity Development

Sudan's future energy capacity development faces significant challenges due to a legacy of fragmentation and poor coordination among governmental agencies stemming from former president Omar Al-Bashir administration. This inconsistency complicates the assessment of the 2018 energy strategy in relation to the Nationally Determined Contributions (NDCs) established during the 2015 COP21 conference and revised in 2021. To move forward, Sudan must align its energy policy with its NDC commitments. This requires fostering collaboration among government bodies, engaging local stakeholders and the private sector, and promoting transparency and accountability. A cohesive strategy focusing on renewable energy and infrastructure improvements will enhance energy access, enabling Sudan to meet domestic needs while also addressing global climate goals, [60].

The 2018 energy strategy aims to construct new power plants with a total capacity of 3,000 megawatts by 2031, primarily from renewable sources like wind and solar. However, government recommendations suggest that 60% of this capacity should originate from thermal power plants, a move that raises concerns in light of the global shift towards cleaner energy. A World Bank assessment advocates for reducing thermal generation to 50% and increasing renewable capacity by an additional 800 megawatts. This shift highlights the necessity of aligning energy policies with sustainability goals, emphasizing a transition from fossil fuels to a more balanced energy mix.

The accompanying figure (Figure 7) illustrates the projected energy mix for future capacity and underscores the necessary changes for a sustainable energy future.

In Sudan, the energy planning process mainly focuses on cost minimization, often overlooking the social and environmental impacts. This approach raises questions about the lack of prioritization for renewable energy, despite the country's rich natural resources for solar and wind energy. With high solar radiation and strong wind speeds, Sudan has significant potential for renewable energy production, which could bolster energy independence. Furthermore, declining costs of renewable technologies make solar and wind increasingly competitive with fossil fuels. As a result, incorporating renewable energy into Sudan's energy strategy is both ecologically responsible and economically advantageous for the country's development and resilience, [60].

Sudan's centralized energy planning approach has proven less effective compared to countries like Kenya, which achieved a significant increase in electrification rates by adopting a decentralized strategy. Micro-grid systems, with decreasing expenses, offer advanced capabilities to operate autonomously and connect with other systems, improving energy distribution efficiency and reliability. This emerging technology is expected to play a crucial role in sustainable energy management and addressing increasing energy demands.

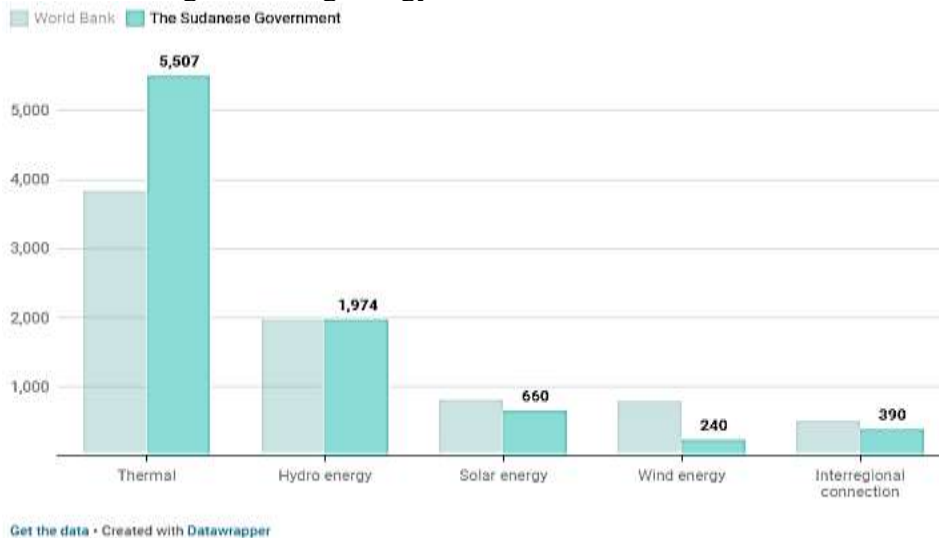


Figure 7: The Energy Mix for Future Capacity

In Sudan, micro-grids can help achieve universal electrification, particularly in remote and rural areas, where 60% of the population lacks access to electricity. The current energy policies, however, focus on enhancing supply for areas connected to established grids, neglecting off-grid communities. To address this issue, a comprehensive reassessment of energy policy is necessary, one that recognizes electricity as a fundamental human right and embraces renewable energy sources and decentralized solutions, ensuring equitable access to reliable electricity for all citizens and promoting sustainable development, economic growth, and improved quality of life, [56].

### **6.3 Engagement of the Private Sector in Electricity Liberalization**

The study underscores the significance of liberalization and private sector participation in the global economy, especially within the electricity sector. Despite reforms initiated in 2010 to enhance efficiency and attract investments, the outcomes have fallen short of expectations. It highlights the necessity for collaboration between public policy and private enterprise to modernize essential services like electricity and achieve sustainability.

Currently, private sector involvement in the country's electricity generation capacity is limited to just 3%, presenting a significant barrier to growth. This situation indicates potential regulatory and market-related issues. According to the World Bank report, stimulating investment and developing a dynamic electricity market requires clearer regulations, revised tariff systems, and improved financial incentives. The emphasis should shift from merely increasing capacity to enhancing profitability; however, there are concerns regarding the sustainability of prioritizing profit, which may undermine the sector's stability.

Additionally, the report advocates for comprehensive strategies that harmonize innovation with stability while addressing economic goals, service reliability, energy security, and environmental impacts. To draw essential investments, it recommends following international best practices, including transparency and competitive bidding processes. Nonetheless, Sudan's energy sector faces significant challenges, including an unfavorable investment climate and political instability, which impede progress and necessitate reforms to align with global standards for a sustainable energy future, [19].

Turkish independent power producers in Sudan are encountering significant challenges, such as unreliable fuel supplies and delayed government payments, which contribute to electricity outages that disrupt daily life and economic growth. Urgent reform in Sudan's energy sector is necessary to attract investment and modernize infrastructure.

The text advocates for reducing private sector involvement and redirecting development loans toward public enterprises to better support marginalized communities and enhance equitable access to electricity. It highlights the importance of empowering state-owned enterprises to provide affordable and reliable electricity, particularly in underserved areas, while promoting social responsibility through initiatives such as Lifeline Tariffs and cross-subsidization.

Additionally, the study critiques private sector financing in the Global South, suggesting it fosters dependency rather than sustainable solutions. It stresses the need to reevaluate development strategies to prioritize local empowerment. The assumption that local companies lack the expertise to manage energy projects is challenged, as past successes during Sudan's oil production phase demonstrate their capabilities. Recent initiatives aimed at boosting local manufacturing in the energy sector, like transformer assembly plants and pre-payment meters, further highlight the potential of local firms to contribute to economic development and create a sustainable energy future.

Overall, the study calls for a balanced approach that enhances local capacities while prioritizing the needs of vulnerable populations in energy development.

### **7. Concluding Remarks**

Sudan's energy sector faces significant challenges, particularly for rural and disadvantaged communities who struggle to access reliable electricity, exacerbating poverty and inequality. This gap offers an opportunity to transform energy generation and distribution through innovation and alternative sources, ensuring a sustainable and equitable energy landscape.

The study emphasizes the need for gradual, inclusive actions that prioritize long-term societal benefits, particularly for marginalized groups. Policymakers are urged to engage with underrepresented communities to ensure that infrastructure goals are balanced with community welfare. This includes addressing forced displacements and cultural erosion caused by large-scale energy projects.

Currently, Sudan's reliance on outdated, thermal power plants complicates the energy crisis. A reassessment of energy policies is necessary to focus on domestically sourced, sustainable solutions. The study recommends community-based, decentralized energy strategies and innovative financing mechanisms to promote socio-economic development without increasing debt.

A comprehensive approach is needed to integrate technical solutions with equitable strategies, enabling Sudan to transition towards renewable energy and promote social justice. This approach will help build a resilient and inclusive future where the diverse challenges of various social groups across regions are addressed through collaboration across sectors.

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