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Electricity and its discontents: Unreliability and the struggle for an African energy transition—from Nigeria's frontlines

by

Oluwagbemisola Deborah Akinsipe

A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

in

Energy and Resources

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Professor Daniel M. Kammen, Chair
Professor Duncan S. Callaway
Associate Professor Jay Taneja

Spring 2025

Electricity and its discontents: Unreliability and the struggle for an African energy transition—from Nigeria's frontlines

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by

Oluwagbemisola Deborah Akinsipe

Abstract

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Professor Daniel M. Kammen, Chair

Climate change is the over-arching existential threat of our time, with clear risks and mounting evidence of extreme weather events demanding urgent action. The dominant global strategy for mitigating climate change centers on low-carbon electricity generation and widespread electrification of end-uses, positioning electricity as the backbone of decarbonization. Yet, in many African nations, this vision is complicated by fundamental discontents—particularly the lack of electricity access and unreliable supply, both of which severely constrain socioeconomic development and limit opportunities for a just transition.

This works dives into this tension, investigating how electricity unreliability shapes energy transition pathways in Nigeria, Africa's largest economy by population and the country with the world's largest energy access deficit. Using a mix of theoretical frameworks—including the dependency theory, the multi-level perspective on socio-technical transitions, the energy stacking model, and the symbolic logic of infrastructure—alongside quantitative and qualitative methods, this research provides a data-driven, theoretically grounded analysis of Nigeria's energy transition. Motivated by an aspiration toward scholar-practitioner praxis, I engage with both academic and policy perspectives to interrogate the complexities of electrification for decarbonization in a country where unreliable power is the norm and energy access remains a persistent challenge. My work contributes to the literature and practice on energy transition in Africa, household energy decision-making, electricity access (SDG7), and the broader energy-climate-development nexus. More than an academic exercise, this dissertation represents my commitment as a young African scholar to producing rigorous, evidence-based research that centers the lived realities of those most affected.

In brief:

- **Chapter 1: Electricity for What? Decarbonization, Development and the African Energy Dilemma**—introduces the global energy transition, focusing on the "mega-trend of electrification" and its role at the nexus of climate action and development. It explores how electrification has been positioned as both a decarbonization strategy in industrialized nations and an energy access imperative in developing regions. By framing electrification as central to both climate mitigation and socioeconomic development, this chapter highlights the core tension analyzed in this dissertation—particularly the struggle in Africa to balance electrification for energy access with electrification for energy transition.

- **Chapter 2: Electricity for Whom? Africa's Growth, Emissions, and the Politics of Transition**—provides a data-driven examination of Africa's historical emissions trends, development trajectories, and climate responsibilities. This chapter critically evaluates competing narratives on Africa's role in the energy transition, highlighting the financial and technological dependencies shaping its future. These insights provide a critical empirical foundation for the rest of the dissertation, framing the analysis of national-level energy transitions.

- **Chapter 3: Electricity for Nigeria: Past, Present, and the Transition Ahead**—explores the historical evolution of Nigeria's electricity sector and its implications for the country's energy transition. This chapter contextualizes Nigeria's Energy Transition Plan (ETP), analyzing its core strategies and emerging challenges—particularly the tension between electrification for energy access and electrification for energy transition. It then interrogates the shaping role of electricity unreliability in Nigeria's energy transition pathway, setting up the empirical analyses that follow.

- **Chapter 4: Electricity for the Gaps: Household Energy Transitions in an Unreliable System**—examines how electricity unreliability drives decentralized fossil-fuel generation, complicating Nigeria's renewable energy expansion. Using survey data from over 7,000 Lagos households, this chapter provides empirical evidence linking grid unreliability to genset adoption and explores economic, infrastructural, and social factors shaping household energy choices. It also investigates early solar adoption trends and the prevalence of genset-solar stacking. These findings highlight key barriers to Nigeria's energy transition and inform strategies for displacing gensets with cleaner alternatives.

- **Chapter 5: Electricity for the End-Uses: Temporal Availability and the Viability of End-Use Electrification in Nigeria**—examines how the timing and reliability of electricity supply constrain the adoption of electric cooking and vehicle charging in Nigeria. Using daily outage data from 50 feeders (2019–2024), it analyzes whether electricity is available during peak demand windows. Expert interviews complement the analysis, highlighting how affordability, politics, technical capacity, and cultural preferences interact with reliability to shape end-use feasibility. The findings show that unreliability limits usage at the point of need, but targeted strategies—such as fleet electrification or mini-grid EV pilots—may offer viable entry points.

- **Chapter 6: Electricity for the People: Diagnosing the Multi-Level Causes of Nigeria's Grid Unreliability**—investigates the root causes of electricity unreliability in Nigeria using feeder-level outage data and expert interviews. It introduces a six-level causal framework spanning proximate technical issues—such as load shedding, infrastructure failures, and planned maintenance—to deeper financial, institutional, and sociocultural drivers. The chapter offers a structured roadmap for understanding and addressing grid unreliability, arguing that durable solutions must be as multilayered as the problems themselves. Without coordinated, system-wide reform, emerging models of reliability based on ability to pay risk deepening energy inequality and entrenching a system where reliable supply exists only "for the rich."

- **Chapter 7: Electricity for the Future: Confronting the Tensions of the Energy Transition in Nigeria**—reflects on the core tension explored throughout the dissertation: the simultaneous pursuit of electrification for energy access and energy transition. Drawing on empirical insights and practitioner experience, it argues that while electricity unreliability remains a significant constraint, the deeper challenge lies in the lack of political will and implementation capacity. Nonetheless, Nigeria's transition is already unfolding—albeit unevenly, and primarily for the wealthy. Therefore, this concluding chapter calls for honest reckoning and renewed commitment to a just, inclusive energy future.

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Chapter 1

Electricity for What? Decarbonization, Development and the African Energy Dilemma

Preface

Over the past century, electricity has become the backbone of modern economies, driving industrialization, technological innovation, and quality of life improvements. More recently, within the context of the "mega-trend of electrification"—the shift toward low-carbon electricity generation and widespread electrification of end-uses—it has been reimagined as a key climate mitigation tool. Yet, while advanced economies focus on electrification for decarbonization, vast populations—particularly in Africa—still lack reliable electricity access. In these regions, electrification remains a developmental necessity rather than a climate solution. These diverging realities underscore a fundamental tension: electrification is simultaneously a strategy for global decarbonization and an unfinished project of socioeconomic development.

This chapter lays the foundation for the dissertation by examining this duality. It begins with an overview of climate change mitigation strategies, situating the energy transition within global climate governance. It then explores electrification as both a mitigation tool and a developmental necessity, emphasizing regional disparities. After this, the chapter turns to the African context—where electrification primarily remains an urgent developmental priority—and highlights how nations in the region must expand energy access while navigating global decarbonization pressures.

By the end of this chapter, the stage is set for the dissertation's core research agenda: bridging knowledge gaps in Africa's contested energy transition. Through an interdisciplinary and data-driven approach, this research examines the evolving role of electrification in shaping the continent's energy future—interrogating whether electrification efforts can simultaneously advance climate goals and development imperatives.

> "Our climate challenge is a shared global challenge—and it is largely an energy challenge. Energy accounts for over two-thirds of global greenhouse gas emissions. This means energy must be at the heart of any solution." –Dr Hoesung Lee, Former Chair of the Intergovernmental Panel on Climate Change (IPCC) [1]

Introduction

Climate change has been described as the *"greatest threat to human health in history"* [2], the *"greatest threat to global security"* [3] and the *"greatest existential threat of our time"* [4–5]. Due to massive negative feedbacks inherent in the Earth's system, it is also considered the ultimate threat multiplier [6]. There is increasing evidence of more frequent and intense extreme weather events—such as heatwaves, heavy precipitation, droughts, and cyclones—alongside growing clarity in their attribution to human influence [7-8]. CO_2 and other greenhouse gases (GHGs), primarily from fossil fuel consumption in sectors including transportation, electricity, and industry, are definitively recognized as the main drivers of anthropogenic climate change [9]. Consequently, global efforts to mitigate climate change—by reducing GHG emissions—have accelerated, particularly since the mid-2000s. International climate frameworks, mitigation policies, and national commitments have proliferated, first among developed economies and, more recently, across the world [8, 10-11].

Climate science, mitigation, and adaptation strategies summarized by the IPCC indicate that limiting warming to 1.5°C above pre-industrial levels would significantly reduce the most severe climate-related impacts [12]. Accordingly, the 2015 Paris Agreement established the long-term temperature goal of *"holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels"* [13, p. 3]. Under this framework, governments committed to Nationally Determined Contributions (NDCs), outlining their targets to curb warming [13]. Nearly all parties to the agreement have submitted NDCs for tracking and verification, collectively covering approximately 95% of global emissions in 2019 (~52.6 $GtCO_2eq$ without LULUCF[1]) [14, 15]. However, even with the latest NDC updates, projected emissions remain well above the pathways required to limit warming to 1.5°C and are approaching the upper threshold of scenarios that aim to stay below 2°C [9]. This indicates that without more ambitious and immediate action, these targets are unlikely to be met [9].

Although substantial emissions reductions are required across all sectors, it has been noted that *"warming cannot be limited to 2°C or 1.5°C without rapid and deep reductions in energy system GHG emissions"* given that the energy sector is the single largest contributor to global emissions [9, p.89 (quote), 16]. In scenarios limiting warming to 1.5°C (>50%[2]) with no or limited overshoot (likely below 2°C), net energy system GHG emissions fall by 38–52% in 2030, and net CO_2 emissions fall by 87–97% in 2050 [9]. While national approaches will vary, Pathak *et al.* [9] provide the following common characteristics of net-zero energy systems:

i. electricity systems that produce no net CO_2 or actively remove CO_2 from the atmosphere;

[1] LULUCF: Land Use, Land Use Change and Forestry

[2] In Pathak et al. (2022), the assessed likelihood of an outcome or a result is described as: virtually certain (99–100% probability); very likely (90–100%); likely (66–100%); about as likely as not (33–66%); unlikely (0–33%); very unlikely (0–10%); exceptionally unlikely (0–1%).

ii. extensive low-carbon electrification of end uses such as buildings, industry, and transport;
iii. significant reduction in fossil fuel reliance;
iv. use of alternative energy carriers such as hydrogen, bioenergy, and ammonia to replace fossil fuels in sectors less amenable to electrification;
v. adoption of more efficient energy practices surpassing current standards and reduced activity to reduce energy demand;
vi. enhanced integration within and between regions, as well as across different components of the energy system; and
vii. deployment of CO_2 removal technologies like Direct Air Carbon Capture and Storage (DACCS) and Bioenergy with Carbon Capture and Storage (BECCS) to offset residual emissions.

While the technoeconomic and sociopolitical feasibility of these characteristics varies across regions, they are also perceived differently by scholars and experts. For example, some advocate for solutions like carbon capture and storage, while others question their viability [17-20]. Nonetheless, there is broad consensus that, at least in the short to medium term, the most critical pillars of the energy transition are the rapid expansion of renewable electricity generation and the widespread electrification of end-uses.

Electrification as energy transition: The "mega-trend of electrification"

Extensive literature affirms that rapid energy decarbonization hinges on large-scale electrification, enabled by low-carbon power generation [9, 15, 21-22]. By 2050, electricity is projected to supply 48–58% (36–47%[3]) of final energy—up from 20% in 2019—while net CO_2 emissions from electricity are expected to reach zero globally between 2045 and 2055 [9]. Tsao *et al.* [22] explain that the world is transitioning from containing a diversity of energy *"currencies"* to one predominant currency: electrical energy[4]. This trajectory positions electricity as the *"new oil or the new backbone of energy systems globally"*, the *"main format for delivering energy services"*, and the *"primary commodity of the energy trade"* [21, p.3; 23, p.289]. Climate change considerations aside, this transition is due to electricity being easily transportable over both long-distance 'trunk' lines as well as point-of-use 'last meter' lines, low-cost, and readily usable/exchangeable into other forms of energy with near-total efficiency [21-22, 24].

In describing this shift, termed the *"mega-trend of electrification"*, Aalto *et al.* [21, 23] outline three main phases which are analytically separable but may overlap in practice:

1. **Expanding Renewable Power Generation:**
   This first phase involves the accelerated deployment of renewable energy sources, particularly wind and solar, as their levelized costs of electricity (LCOE) continue to decline. Hydropower and bioenergy remain key contributors, while emerging technologies such as marine and

[3] See note 2 above.
[4] It is worth mentioning that certain authors warn against the replication of *"the same risky dynamic of lack of diversification"* by relying on electricity as the *"single transport modality"* [10].

geothermal energy have potential in select regions. Nuclear power—particularly Small Modular Reactors (SMRs)—remains an actively considered but contested option due to concerns over factors like environmental sustainability. Additionally, natural gas continues to be regarded as a transitional energy source in some countries.

2. **Enhancing Grid Flexibility and Storage:**
   The second phase involves increasing flexibility with storage and backup solutions to address the variable nature of renewable energy supply. Beyond a 10–20% share of variable output power, power grids typically require additional flexibility options to continuously balance supply and demand. However, the necessity and form of these backup and storage solutions vary across contexts, depending on factors such as available energy resources, required response times, energy volume needs, and the level of interconnection with neighboring countries. For example, nations like Norway and Iceland, with abundant hydropower resources, face minimal short -term flexibility challenges, making this phase perhaps less critical for them. Conversely, countries such as the UK and Japan, with limited access to hydropower, geothermal, and biomass, must actively address this challenge—considering options like lithium-based batteries and hydrogen-based solutions to enhance system flexibility.

3. **Sector Coupling and Smart Grids:**
   The third phase involves sector coupling—integrating the power, transport, building, and industrial sectors through electricity flows and smart grids to optimize energy use. In systems with high shares of renewable energy, both direct and indirect electrification pathways are encouraged across various sectors. Direct electrification includes the adoption of electric vehicles (EVs) in transport and the replacement of fossil fuel-based heating systems with electric heat pumps in residential and commercial buildings. Indirect electrification, facilitated by electrolysis, enables the conversion of electricity into hydrogen and hydrogen-derived fuels such as ammonia and methanol, collectively known as 'power-to-X' technologies. At this stage, energy systems require advanced grid infrastructure to efficiently manage diverse energy sources at both utility and distributed scales. This necessitates the development of smart grids with integrated ICT systems—comprising energy hubs, real-time data acquisition and processing, and networked control technologies—for ensuring efficient energy distribution and system stability.

However, across the three phases listed above, *"electrification is about much more than the end product of electricity itself"* [21, p.9]. It is a *"thoroughly material"* process that encompasses not only physical energy flows but also the actors, networks, and institutional structures that underpin, facilitate, and benefit from these flows [21, p.9]. As such, the electrification-based transition is not merely a technological shift; it entails *"major changes, disruptions, and creative destruction"* across energy systems and economies [21, p.9].

For instance, this transformation will drive the emergence of new business models, particularly with the rise of small-scale producer-consumers (prosumers) enabled by distributed renewable energy resources [25-26]. It will necessitate greater energy efficiency across end-use sectors such as transport, buildings, and industry while also demanding advanced ICT infrastructure and digital platforms, including smart grids and the more expansive *"internet of energy"*, to optimize energy flows [23, p.289].

At the same time, this transition will involve both leveraging existing transmission and distribution networks and undertaking widespread grid modernization and expansion efforts. From an economic angle, renewable energy deployment and increasing demand across electrified end-use sectors will contribute to electricity price fluctuations—initially driving costs down due to declining levelized costs of renewables but also introducing upward pressures through investment needs in grid reinforcement and storage solutions [23].

Given the breadth of changes required and the high inertia inherent in energy systems, this transition is unlikely to occur uniformly or instantaneously. Political, economic, and technical barriers—ranging from entrenched fossil fuel interests and regulatory complexities to financing constraints and grid integration challenges—pose significant hurdles to large-scale electrification [22-23]. Consequently, while some regions have advanced to later stages of the mega-trend of electrification, many parts of the world are still awaiting even its first phase, which primarily involves the transition to renewable energy [23].

Yet, several nations are even further behind—where the challenge is not decarbonizing electricity systems but providing first-time access to modern electricity services**.** In these contexts, electrification more closely resembles the historical trajectory started over a century ago, with milestones such as the launch of the direct current (DC) Pearl Street Power Station in New York City in the 1880s [23]. This stark divide underscores the need to examine electrification's geographical disparities and competing priorities.

The Geography of Electrification

The mega-trend of electrification has gained the most momentum—and by extension, the most scholarly attention—in developed economies, particularly in Europe [23, 27]. This pattern is also evident in broader climate change mitigation research, which remains disproportionately focused on the Global North, despite the expectation that all nations must contribute to limiting global warming [8, 27-29]. As Goldthau *et al.* [30, p.319] observe, *"the scholarly literature has been surprisingly silent on what the low-carbon shift means for the Global South."*

This bias aligns with historical climate policy approaches, which initially concentrated emission reduction efforts in industrialized nations due to their historical responsibility for climate change and their greater financial and technical capacity. For instance, the principle of common but differentiated responsibility and respective capabilities (CBDR-RC)—enshrined in the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol—explicitly acknowledged this disparity [31-32]. However, international climate policy has gradually shifted away from emphasizing historical responsibility. Instead, advanced economies have sought to reframe the discussion around the *"future responsibility"* of emerging economies, particularly large emitters like China and India, whose emissions continue to rise due to increasing energy consumption and industrial expansion [32].

The Energy Transition in Emerging Economies: Development vs. Decarbonization

Energy development—the increased availability and use of energy services—has long been recognized as fundamental to economic growth [33]. Empirical evidence consistently demonstrates a strong correlation between income levels and energy consumption across all regions and historical periods [34]. While wealthier populations naturally consume more energy services, research increasingly affirms that energy consumption is not merely a byproduct of economic growth but also a necessary driver of development, as energy is a critical input in virtually all economic activity [33-34].

Moreover, energy use is deeply linked to multiple dimensions of human development. Studies show strong correlations between per capita energy consumption and key development indicators, including wealth, health, nutrition, water access, infrastructure, education, gender equality, and life expectancy [34-35]. Given this relationship, energy demand in emerging economies is expected to rise significantly as countries pursue socioeconomic transformation [16, 30, 36].

However, the projected increase in energy consumption raises concerns about future emissions trajectories, as both per capita and absolute emissions have historically risen alongside industrialization. Even in the past decade, GDP per capita and population growth have remained the dominant drivers of global CO_2 emissions from fossil fuel combustion [8-9, 28]. While there is some evidence that countries can decouple economic growth from emissions, this trend has mainly been observed in high-income countries with already high per-capita emissions and typically refers to territorial emissions rather than consumption-based emissions [9]. In contrast, for most developing economies, emissions continue to rise due to increased energy consumption and investment [9].

This challenge—balancing economic growth with climate mitigation in emerging economies—has thus become a central tension in energy transition debates, both in international climate negotiations and, increasingly, in academic literature. For instance, Babayomi *et al.* [27] emphasize that *"the pathway to economic growth for the Global South under the clean energy transition remains an open topic."* Ideally, developing countries would bypass fossil-fuel-intensive development pathways and instead adopt low-carbon energy sources to drive economic growth and universal energy access [27, p.5]. However, this approach presents substantial technical, financial, and political challenges.

Greater research on energy transitions in these regions is therefore necessary to examine the feasibility of rapid industrialization and economic development driven primarily by renewable energy sources—a consideration often overlooked in Global North-focused mitigation strategies [27-30, 37]. Accordingly, Pathak *et al.* [9, p.138] stress the importance of *"validating current results and generating insights from theoretical frameworks and empirical studies for developing countries' contexts."*

Electricity sits at the heart of this tension, as it is the most advanced form of energy use and remains the core focus of energy development efforts globally [38-39].

Electrification as energy access: Sustainable Development Goal (SDG) 7

While electrification is increasingly viewed as a climate mitigation strategy in advanced economies, in many developing countries, it refers primarily to expanding electricity access—particularly to underserved rural communities—for socioeconomic and human development [21, 39 – 45]. Burgess *et al.* [46] highlight that *"Electricity consumption in low-income countries is a negligible 1 percent of that in the United States; thus, world inequality in electricity is larger than income inequality."* Accordingly, Aalto *et al.* [21, p.9] explain that, unlike in developed nations, *"In developing countries, electrification is often inseparable from issues of energy access, energy justice, and poverty alleviation, and indeed, from many other issues on the Sustainable Development Goals (SDGs) agenda of the United Nations."*

Electricity is widely recognized as foundational to economic and human development. It is *"in many respects the fundamental apparatus upon which the experience of modernity has been constituted"* [47, p.532, cited in 48, p.61], and no country has achieved high living standards without significantly increasing per capita electricity consumption [46]. Among other things, electrification expands economic opportunities, enhances educational outcomes, and improves health and gender equity [24, 27, 42-43, 45, 49-50]. Universal electricity access is therefore considered the *"indispensable starting point for improving the lives of the poorest populations of the world"* [51, p.2 (quote)]

Given its direct correlation with GDP, income, and human development indices, electricity access has become central to global development efforts [24, 42, 46, 49, 52]. As a key example, the United Nations established Sustainable Development Goal (SDG) 7, which aims to *"ensure access to affordable, reliable, sustainable, and modern energy[5] for all"* by 2030 [53]. However, the source of this electricity—whether predominantly fossil-fuel-based or renewable—will significantly shape global climate trajectories.

This issue is particularly relevant in Sub-Saharan Africa (SSA), home to the largest share of the world's extreme poor and energy-deprived [10, 37, 55-57]. As of 2022, SSA accounted for 83% of the 685 million people worldwide without electricity access [56]. Even for those with electricity connections, typically on a national grid, chronic shortages persist, with widespread blackouts and brownouts imposing severe socioeconomic consequences [43, 48, 51, 54].

Given these realities, Mulugetta *et al.* [58, p.1016] assert that, *"what is unequivocal is that African countries desperately need more energy supply to unlock social and financial opportunities for national development"*. This urgent need for energy supply is central to ongoing debates about the role of electrification in Africa's development trajectory and its positioning within global climate policy frameworks.

Africa's Electrification Dilemma: Between Transition and Access

Historically, Africa has contributed the least of any global region to fossil fuel emissions, totaling 3.8% in 2022 and approximately 2% of cumulative CO_2 emissions since 1850 [59]. Yet, paradoxically, the continent faces disproportionate vulnerability to climate change impacts [60]. This outcome is partially geographic but mainly due to the preponderance of low-income and at-risk populations. Climate change threatens Africa's economic development, food security, labor productivity, health, rural-urban balance, and security, among other factors [61-65]. The region is already warming faster than the global

[5] This includes both access to electricity as well as clean cooking technologies.

average and experiencing heightened sea-level rise, leading to devastating impacts across the continent [66-68]. The African Development Bank estimates that climate change costs Africa between 5–15% of its annual GDP per capita growth [69].

Given Africa's minimal emissions and high vulnerability to climate change impacts, climate discussions regarding the continent have historically emphasized adaptation over mitigation [10, 70]. However, this focus is shifting as some authors warn that rapid development in the region could challenge global decarbonization efforts [10, 28, 70]. Projections suggest that emissions from fossil fuel combustion in Africa will increase in the near future due to urban expansion, industrial growth, and population density [28, 71-72].

Although Africa has the fastest-growing population and urbanization rates in the world, it remains the least energy-consuming region per capita [30]. Research indicates that an annual energy consumption of approximately 2 tons of oil equivalent (toe) per capita is a rough threshold for achieving a sufficient global average level of welfare and happiness [73]. In 2020, the USA's per capita energy consumption stood at 7.1 toe—the lowest since 1965 [74]. In contrast, South Africa and Nigeria had 2.3 toe/capita and 0.8 toe/capita, respectively, while most other Sub-Saharan African nations averaged just 0.4 toe/capita, primarily from inefficient biomass use [75]. Addressing this energy deficit is essential for economic development, and substantial increases in energy consumption across the continent are anticipated in the coming decades [28, 58, 76-77].

Electrification is central to these discussions, with many scholars and policymakers advocating for Africa to prioritize renewable energy—mainly wind and solar—over fossil fuels for electricity generation, thereby avoiding the carbon-intensive development trajectory of industrialized nations [30, 70, 78]. Proponents argue that beyond their environmental and climate benefits, these sources offer significant economic advantages given their declining costs relative to the long-term expense of predominantly imported oil and gas. Additionally, renewables hold substantial potential for broader socioeconomic gains across the continent. For instance, modeling by the International Renewable Energy Agency (IRENA) suggests that, when accompanied by appropriate policies, a transition from fossil fuels to a renewable energy-based system could yield a 6.4% increase in GDP, 3.5% more economy-wide jobs, and a 25.4% improvement in the welfare index over the period from 2020 to 2050 [79]. Advocates further highlight that prioritizing renewables would reduce the risk of stranded assets, enhance energy independence, support economic diversification, and contribute to long-term fiscal stability [78-80]. In line with these arguments and broader global climate strategies, key developed nations have begun restricting financing for fossil fuel-based energy projects in developing economies, including those in Africa.

However, this approach has drawn sharp criticism. Some experts argue that concerns over Africa's potential future emissions are unjustified given the region's low starting point [81-82]. For example, Moss and Kincer [82] estimate that even if SSA's 1 billion people were to triple their electricity consumption using natural gas—the most abundant fossil fuel on the continent—the additional emissions would still amount to just 0.62% of global CO_2 output today. This perspective underscores the argument that Africa's immediate priority should be economic growth and energy access rather than aggressive decarbonization [81].

This divergence in perspectives has sparked ongoing debate, particularly following policy measures such as the joint commitment at COP26 by 39 countries and institutions—including the United

Kingdom, the United States, and Germany—to end international public support for unabated fossil fuels by the end of 2022[6] [83-84]. Similar commitments have been made by G7 nations, along with proposals for carbon border adjustment mechanisms [85-86]. Critics of these measures argue that they impose disproportionate constraints on African nations while failing to account for the energy needs of their growing populations. For example, Moss and Ramachandran [81] contend that *"Africa's economic and energy ambitions are not going to ruin the West's climate plans. Cutting off financing for gas to the world's poorest nations is unfair and inhumane…Western climate policy must stop blaming the victims."*

Several authors have framed these restrictions as a form of 'climate/green/energy colonialism', 'environmental racism', and 'climate redlining', suggesting that they reinforce global inequalities and deny African nations access to the same energy resources that industrialized countries relied on for their own development [81, 87-89]. This argument draws from the broader critique that climate policies preventing African nations from utilizing their own fossil fuel reserves resemble a form of *"kicking away the ladder"* ([90] cited in [91]).

In response, many African leaders continue to advocate for greater flexibility in energy policies, emphasizing the necessity of fossil fuels—especially natural gas—as a transitional fuel to support industrialization and energy security [92-95]. This position is reinforced by perceived hypocrisy from the West, as many advanced economies continue to rely on fossil fuels while restricting financing for similar projects in Africa [96-97].

Consequently, although South Africa and Nigeria have both announced net-zero targets, their respective energy strategies still incorporate substantial natural gas use, with South Africa also maintaining room for continued coal utilization [92, 98-100]. Beyond these policy commitments, new fossil fuel developments continue to shape Africa's energy landscape. Senegal, for instance, officially became an oil-producing country in 2024 following the extraction of oil from the offshore Sangomar field [101]. The country is also set to become a major gas exporter alongside Mauritania in 2025, with the full commissioning of the Greater Tortue Ahmeyim LNG project [102]. The Senegalese government, particularly under former President Macky Sall, has aggressively promoted fossil fuel extraction as a pathway to economic growth and energy access [95, 101, 103]. Similarly, the governments of Uganda and Tanzania have defended their right to exploit domestic fossil fuel resources, asserting that they *"cannot afford not to exploit their natural resources while the world still runs on fossil fuels"* [94]. As Douet [104] highlights, *"in Uganda, the dream of oil billions overshadows climate concerns."* Some stakeholders argue that fossil fuels are not just important for sufficient energy supply and economic development [37] but essential for survival [105] and *"lifting people out of poverty"* [93]. Even within academic energy transition models, fossil fuels remain a dominant feature of projected energy pathways for the continent [106].

This ongoing debate illustrates the competing imperatives of electrification as a climate mitigation strategy versus electrification as an enabler of economic development**.** These issues continue to shape Africa's energy transition discourse, influencing policy decisions at both national and regional levels. As Mulugetta *et al.* [58] highlight, current debates over Africa's energy future—particularly the role of natural gas versus renewables—reflect deep-seated tensions between development aspirations and global climate commitments.

[6] The following African countries were signatories: Burkina Faso, Ethiopia, Gabon, Mali, South Sudan, The Gambia and Zambia.

However, despite these divisions, most African countries have signed the Paris Agreement and submitted NDCs that signal their intention to transition toward low-carbon energy systems [10, 37, 58]. Even South Africa and Nigeria's net-zero targets align closely with those of more advanced economies, despite both countries, as mentioned earlier, continuing to advocate for fossil fuel use. Furthermore, within Africa, there is strong civil society resistance to fossil fuel expansion, with grassroots movements and advocacy groups actively campaigning for a just and sustainable energy transition [107-110].

Ultimately, the pathways for Africa's energy transition remain diverse and uncertain, influenced by a complex mix of economic, political, and technological factors [58]. Africa's energy system is shaped by several structural challenges that differentiate its energy transition trajectory from that of more advanced regions. These include size-constrained and unreliable electricity infrastructure, persistent energy poverty, and the continued predominance of traditional biomass as a primary energy source. Additionally, inadequate investment and economic sustainability in the power sector, weak democratic institutions, limited citizen participation in energy governance, and significant foreign influence—often manifesting as neo-colonial financial and technological dependencies—further complicate the transition [10, 27, 29, 58].

At the same time, the continent presents distinct opportunities that could shape an alternative energy transition pathway. Africa has a high youth population and a potential demographic dividend, which could drive innovation and labor force expansion. Emerging technology and business model innovations—such as 'smart payment' or 'pay-as-you-go' systems—are rapidly transforming energy access, particularly in decentralized renewable energy markets. Additionally, cultural values that emphasize communalism and shared purpose may foster collective action and resilience in energy transition efforts [10, 27, 36, 111]. These characteristics present significant challenges to mainstream energy transition narratives. Yet, their implications remain underexplored in the literature [27].

In this context, Africa is *"incredibly under-researched"* [106, p.6], and the trajectories of its energy transitions are poorly understood [112]. Indeed, the global energy transition debate has largely overlooked the continent's distinct constraints and opportunities [27, 37]. Although energy transition modeling for African countries is expanding, country-specific analyses remain limited, constraining the development of a comprehensive climate action framework [106]. Moreover, most existing research relies on techno-economic modeling, often neglecting development outcomes and the sociopolitical constraints critical to policy implementation [21, 106, 113]. This omission is particularly concerning given that, *"especially in the African context, cultural perceptions, beliefs, preferences, and political actions play an important role in social decision-making"* [106, p.5].

Consequently, at the core of my research, is a strong interest in bridging these knowledge gaps by examining Africa's electrification-based energy transition from both a climate and development perspective, while centering the sociopolitical and economic realities that shape energy policy decisions. As Pistelli [10, p.171] observes, it is important to problematize the energy transition in Africa *"instead of taking for granted that a transition is well received and occurring."*

My overarching research agenda

This dissertation contributes to the growing but still limited body of research on Africa's energy transition, particularly through the lens of electrification. As discussed, global efforts prioritize renewable electricity and end-use electrification, positioning the mega-trend of electrification as the linchpin of the energy transition. However, in the African context, electrification carries dual significance—not only as a climate mitigation tool but also as a fundamental driver of economic and human development, as reflected in SDG 7. This dissertation engages with this tension between electrification as energy transition and electrification as energy access.

This work addresses the intensifying debates over the energy transition in Africa, where structural injustices, broken promises of financial and technological support from the Global North, and perceived hypocrisy in global climate action intersect with economic pragmatism and the stark reality of energy poverty [96-97, 114-116]. This dissertation engages with the tension between development needs and climate commitments that is increasingly evident as African nations assert their right to define their own energy future—though emerging divisions exist both internationally and within these countries over appropriate pathways forward [117-120]. Relatedly, this research also directly responds to recent calls in the literature to better integrate African development, economic growth, and poverty reduction into global climate discussions. As Blimpo *et al.* [106, p.2] emphasize, *"It is, therefore, urgent that discussion about African development, economic growth, and poverty reduction is tightly linked to the climate discussion, especially regarding structural transformation"*

Thus, at its core, this work contributes to the climate-energy-development nexus, a framework that underscores the interconnected challenges and opportunities Africa faces in simultaneously addressing climate change, expanding energy access, and promoting sustainable development [121-122].

Through an interdisciplinary approach, I explore electrification as it relates to the dual pursuit of climate goals and development imperatives on the continent. Rather than accepting prevailing narratives at face value—such as the idea that African nations must exploit fossil fuels for economic development or that renewables are already cheap enough to enable a clean energy transition—this dissertation interrogates these claims using empirical data from the region [70, 79, 95, 117]. Empirical analysis serves as a tool not only to evaluate these competing perspectives but also to offer a nuanced, data-driven understanding of Africa's evolving energy landscape.

Finally, recognizing that African energy conversations have long been dominated by external actors, this dissertation is deeply motivated by the need to amplify African perspectives on the continent's energy future. As Mulugetta *et al.* [58, p.1016] note: *"the global north has dominated African energy conversations for decades, directly influencing the configuration of countries' techno-economic rationale and policy choices."* By integrating insights from African scholars, policymakers, and local energy practitioners, this research seeks to provide a more contextually grounded and equitable contribution to the discourse on Africa's energy transition.

Additionally, with nearly 80% of Africa's population under 35 and a median age of just 19, youth engagement is critical in shaping the continent's climate and energy future [123]. Recognizing this, policymakers and scholars are increasingly emphasizing the role of young Africans in defining sustainable energy pathways [116]. As a young African scholar, I am deeply motivated to contribute

an evidence-based, theoretically rich, and data-driven perspective to these debates. This dissertation is therefore not just an academic exercise—it is a commitment to shaping Africa's energy future with rigor, nuance, and a firm grounding in the lived realities of those who stand to be most affected by the region's energy transition.

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Chapter 2

Electricity for Whom? Africa's Growth, Emissions, and the Politics of Transition

Preface

In Chapter 1, I highlighted the intensifying debate about Africa's role in the global energy transition. One camp argues that Africa has historically contributed little to the climate crisis and, given its pressing development challenges—notably energy poverty—it should not be burdened with stringent climate mitigation restrictions. From this perspective, rapid economic growth should be prioritized, even if fossil fuel resources are necessary to support it. The opposing camp acknowledges that Africa's historical and current emissions are negligible but warns that if the region develops through unchecked fossil fuel expansion, its future emissions could erode hard-won global mitigation gains and lead to other environmental consequences such as habitat loss and air pollution.

As is central to my approach in this dissertation, this chapter interrogates these claims using available quantitative data from the region. Many research endeavors begin with a literature review, and in a sense, this chapter represents a 'data review' that grounds the discussion in empirical evidence. Indeed, data-driven analyses like this are often absent in the passionate, opinion-based debates on Africa's climate role. Furthermore, given the limited literature on the climate-energy-development nexus in Africa (as discussed in Chapter 1), a quantitative approach was chosen to provide a clearer understanding of potential emissions trajectories for the continent.

The research in this chapter seeks to establish how Africa's emissions trajectory should be understood in light of historical and current patterns. What does the data say? Which prevailing narratives hold up to empirical scrutiny? Has economic development in Africa led to increased emissions, as is often assumed? Is the region growing fast enough for its future emissions to significantly hinder global decarbonization targets?

To address these questions, this chapter develops emission growth scenarios and estimates the potential trajectory of Africa's energy-related emissions based on historical growth patterns in key drivers, including population, economic growth, energy intensity, and carbon intensity of energy use. It then examines the conditions under which Africa's future emissions could meaningfully offset planned global mitigation efforts.

The findings suggest that Africa's contribution to global emissions targets will likely remain small, particularly in the short term. However, a deeper interrogation of the data reveals nuances that are frequently overlooked in the ongoing discourse. For instance, low emissions growth in many African countries is primarily a reflection of low economic growth. This means that if economic growth accelerates—an outcome many advocate for—emissions will also rise unless carbon and energy intensity trends are actively managed through mitigation efforts. This insight carries important implications:

- For developed nations: Policies restricting financing for critical energy projects in Africa could stifle economic development without delivering meaningful climate benefits.

- For proponents of rapid economic development in Africa: Those truly committed to advancing the region's prosperity should be equally concerned with ensuring climate mitigation efforts remain central to that growth strategy. Beyond rhetoric, nations strategically pursuing economic development—evidenced, for example, by national economic development plans—are the ones who must ensure that climate mitigation efforts remain front and center.

The results also show that a small subset of African nations is responsible for the vast majority of emissions. The data indicates that just 10–19 countries account for 80–90% of the continent's total emissions. This insight holds critical implications for climate policy: broad, continent-wide restrictions are inefficient, and a more targeted, country-specific approach is necessary. Sweeping policies applied indiscriminately across the region could hamper development goals without meaningful climate benefits, specifically in the ~28 countries whose emissions pose minimal risk to global targets.

The addition of a qualitative review of Nationally Determined Contributions (NDCs) further contextualizes Africa's climate ambitions and highlights the continent's financial and technical dependence on external actors. Africa's growing presence in climate discussions—alongside international concerns about its future emissions—may, at first glance, appear paradoxical given the region's currently low contribution to emissions. One explanation is that Africa's heightened engagement is a necessary response to its extreme climate vulnerability, compelling it to push for stronger global action. However, the West's focus on Africa's future emissions, associated financing restrictions, and even Africa's own increasing climate initiatives and debates seem to be largely driven by international politics and structural dependencies. Indeed, the reviewed NDCs—many of which emphasize electrification as a cornerstone of Africa's energy transition (discussed in Chapter 1)—all underscore the need for substantial external financial and technical assistance. The reality is that most major climate projects in Africa are externally funded, and even fossil fuel projects are largely backed by foreign governments and corporations. This means that Africa's energy transition is already being shaped—and could continue to be further influenced—by external actors.

The insights obtained from this chapter provide a critical foundation for the rest of the dissertation. They offer an empirical baseline for exploring the interplay between Africa's development goals and climate imperatives, laying the groundwork for the in-depth case study of Nigeria's energy transition in the following chapters.

This research was previously published in Environmental Research Communications in 2024 as an article titled "The African Fulcrum to Bend the Curve of the Climate Crisis to a Just Transition." It is included in this dissertation with the permission of my co-author, Daniel M. Kammen. Supplementary materials can be found in the Chapter 2 Appendix at the end of this dissertation.

> "We [Africa] are all, in relation to the developed world, dependent—not interdependent—nations. Each of our economies has developed as a by-product and a subsidiary of development in the industrialized North and is externally oriented. We are not the prime movers of our own destiny."– Julius Nyerere, first President of Tanzania ([1] cited in [2])

Abstract

From a current impact of under 4% of global greenhouse gas emissions, rapid industrialization and population growth in Africa could dramatically alter the continent's emissions profile. This chapter develops an analytic framework to quantify future scenarios, with results suggesting that, in mid- and green-growth scenarios, Africa's emissions would account for just 4-13% of the planned carbon savings in major economies. However, in a high-growth scenario without climate-conscious development, African emissions could jeopardize global mitigation efforts. Fewer than 20 nations could contribute 80-90% of the continent's emissions, emphasizing the critical role of green growth pathways centered on rapid clean energy adoption in a select group of countries to transform Africa's energy landscape. Meeting the renewable energy targets outlined in these nations' Nationally Determined Contributions (NDCs) requires a 20-fold increase in investment and project completion rates. Yet, Africa's energy transition is shaped by long-standing structural dependencies and external financing constraints, raising critical questions about equity, agency, and power in the global climate discourse. The analysis in this chapter underscores the need for nuanced, country-specific strategies that prioritize equity—along with financial and technical support—to achieve both climate and developmental goals in Africa, while also addressing the broader political economy of the energy transition.

Introduction

In response to the ongoing debate over whether Africa's future emissions will derail global progress on the energy transition, this chapter provides an analytical framework to quantify and contextualize the potential impact of energy-driven growth in Africa on global climate mitigation efforts [3-4]. Despite the saliency of emissions from fossil fuel-based energy systems to these debates, few studies have specifically analyzed such emissions in African countries [5]. Relatedly, with the noteworthy exception of recent work by Mulugetta and colleagues [6], most studies on the growth in African emissions have not critically engaged with ongoing debates in the international climate policy regime, which have important ramifications for how transition efforts are being shaped and stalled in the region. Moving these discussions beyond policy circles and into academic literature is essential, as more rigorous methods and critical analyses can be applied. Thus, this chapter aims to fill a notable gap in the research by establishing a foundation for substantive methods to move beyond rhetoric and enable informed, data-driven dialogue about Africa's role in the global climate system.

Furthermore, in recognition of the seeming geopolitical divide in these discussions—for example, African leaders versus those from Europe and North America (see [7])—this chapter draws on international political economy theory to enrich the quantitative analysis [8-10]. This is a key contribution to the literature, given the limited exploration of the current energy transition from a critical international political economy perspective [9, 11].

Using the Kaya Identity, which breaks down fossil fuel CO_2 emissions into four factors—carbon intensity of energy use, energy intensity of Gross Domestic Product (GDP), economic rent, and population—this chapter examines Africa's historical emission patterns and explores potential future scenarios for energy-related emissions [5]. The results are then assessed in relation to the expected carbon savings from more advanced economies in the coming decades. This approach contrasts the typical projections about the region's emission growth, which often overlook historical patterns and current realities. By failing to ground such projections in the continent's past achievements, authors often miss that their predictions represent significant deviations from ongoing trends and would likely require concerted efforts to become feasible. For instance, while one hopes to see exceptional economic and human development in Africa, which could drive higher energy consumption and emissions, it is important to acknowledge that the region has frequently fallen short of forecasts that predicted unprecedented growth [2, 12].

Accordingly, this chapter draws on historical trends to investigate under what growth scenarios/assumptions an increase in African emissions is sufficient to negate hard-won global mitigation targets. Furthermore, in line with recommendations from a growing number of scholars, this analysis recognizes that Africa is not monolithic and, therefore, highlights country-level trends[7] [5-6, 11, 13-15]. The continent exhibits significant variation in economic development, energy mix, and population, meaning that continent-wide generalizations or the use of average values often produce misleading conclusions. Instead, a bottom-up approach is applied, estimating emissions for each African country based on its own historical patterns. The results indicate that a nuanced approach that favors country-specific strategies, rather than continent-wide policy prescriptions, would likely to be more effective in advancing climate and development goals.

In line with this dissertation's focus on the mega-trend of electrification as the linchpin of the energy transition, renewable electricity generation—the first phase of this transition—is examined as a case study to explore climate mitigation trends on the continent, and this highlights the role of international support in shaping Africa's transition pathways. Finally, with the dependency theory as a critical lens, results from the analysis are discussed and some recommendations are provided.

Methods

Among other things, this dissertation engages with debates on the potential impact of Africa's future emissions on global climate mitigation efforts. As an illustrative measure, the analysis in this chapter examines the plausibility of the hypothesis proposed by authors such as Goldstone [3] and implied in recent strategies [16] that Africa's emissions growth in the coming decades could offset emissions savings from major economies that have pledged significant reductions.

Methodology to forecast future emissions in Africa

To determine the growth of emissions from the continent in the coming years, it is assumed that future growth can be estimated based on historical patterns. Furthermore, this analysis adopts the position that these patterns indicate plausible trajectories in African countries. In line with this, the

[7] See Table A-1 in the chapter's appendix for the list of countries included in the study.

Kaya Identity, as used by Ayompe *et al.* [5], is employed with a focus on historical fossil fuel CO_2 emissions due to data availability and relevance.

The Kaya Identity has been widely used to quantify the contribution of different factors to emissions and to assess the effectiveness of technology and policy measures [5]. The Kaya Identity, similar to the IPAT equation, attempts to describe the impact of human activity on the environment with a focus on measures of population, affluence, and technology[8]. It helps to split fossil fuel CO_2 emissions into four factors: carbon intensity of energy use (CO_2 emissions per unit of energy consumed), energy intensity of GDP (total energy consumed per unit of GDP), economic rent (represented as per-capita GDP), and population. As the debates around Africa's future energy emissions typically center on growth assumptions for these specific components, the Kaya Identity is considered fitting for this analysis[9]. It can be expressed as follows:

$$CO_2\ emissions = \frac{Emissions}{Energy} \times \frac{Energy}{GDP} \times \frac{GDP}{capita} \times Population$$

Given data limitations in the African context, the Kaya Identity, which is a simpler and less data-intensive approach, is very helpful compared to, for example, structural decomposition analysis (SDA) [5]. Additionally, the simplified approach enables a clear understanding of the assumptions underpinning this analysis.

To build the model, data on emissions [17], GDP [18], and population [19] from the World Bank Databank and total primary energy consumption data from the U.S. Energy Information Administration (EIA) [20] are combined for the period 1990–2020[10]. Each term in the Kaya identity is disaggregated for individual African nations to explore country-level trends and enable bottom-up estimations of future African emissions. Due to data availability, this study includes 47 of the 55 African countries organized into geographic regions per the African Union[11,12] [21].

To estimate the future growth of fossil fuel emissions (2030–2050) in Africa using the Kaya Identity, a bottom-up approach is adopted and explores four scenarios based on the observed historical patterns across the continent. These patterns reveal that the recorded growth rates of the different factors within the Kaya Identity varied across the three decades under consideration (1990–2000, 2000–2010, and 2010–2020)[13]. While a detailed analysis of the underlying drivers of these trends is beyond the scope of this chapter, it presents an avenue for future research. For instance, a preliminary review of the emissions/energy term highlights that the growth rates tallied with trends in the share of electricity generated from renewable sources (including hydro and biomass) for several countries, including Burundi, Chad, Côte d'Ivoire, Eswatini, Ghana, Mozambique, Rwanda, Tanzania, Uganda,

[8] I(Impact) = P (Population) x A (Affluence) x T (Technology)

[9] While we use GDP per capita as a measure of progress and economic development in the analysis, in alignment with similar studies and mainstream conventions, we recognize the importance of other comprehensive measures and indicators of the actual quality of growth and prosperity. We acknowledge that *"it is possible that output may be growing, and yet that the mass of the people may be becoming poorer"* (See [2]).

[10] The emissions dataset from the World Bank spans the years 1990 - 2020.

[11] Djibouti, Eritrea, Liberia, Libya, São Tomé and Príncipe, Somalia, South Sudan, and Sahrawi Republic (Western Sahara) did not have complete panel data for the 1990 – 2020 period considered in this study.

[12] See Table A-1 and Figures A-1–A-2 in the chapter's appendix.

[13] These findings can be seen in Figures A-3–A-7 in this chapter's appendix, which show the annual growth rates of the four terms in the Kaya Identity during each decade considered and across the entire 30-year period for the African countries.

Zambia, and Zimbabwe[14]. However, in other cases, no correlation was observed, suggesting the presence of different influencing factors/sectors. High economic growth rates appeared to coincide with the discovery and exploitation of valuable commodities (like the discovery of large oil reserves in Equatorial Guinea in the 1990s) and patterns in commodity markets, among other things [2, 12, 22-24].

Generally, while population has consistently recorded growth over the past three decades, carbon intensity (emissions/energy), energy intensity (energy/GDP), and economic growth (GDP/capita) have experienced swings from decade to decade. Therefore, four scenarios are defined based on possible changes in carbon intensity, energy intensity, and economic growth to obtain a range for Africa's future emissions. For population, the medium variant of the UN population projections is adopted and kept constant across all scenarios [25]. However, it is important to note that similar growth rates in at least two decades were observed across all four terms of the Kaya Identity in several African countries, which supports the hypothesis that future growth can be estimated based on plausible trajectories from historical patterns[15].

A **low-growth** scenario is defined to estimate a potential lower limit for the continent's future fossil fuel emissions. In this scenario, African countries are assumed to maintain the lowest growth rates recorded for carbon intensity, energy intensity, and economic growth over the past three decades. For example, the low-growth scenario for Angola in Southern Africa (Figure A-3 in the chapter's appendix) combines the low emissions/energy growth rate of -5.82% recorded between 2000 and 2010 with the energy/GDP growth rate of -1.08% recorded in the same decade and the GDP/capita growth rate of -0.34% recorded between 2010 and 2020. On the other hand, to establish an upper limit of the continent's future emissions, a **high-growth** scenario—in which African countries are assumed to sustain the highest growth they recorded for carbon intensity, energy intensity, and economic growth over the past three decades—is defined. Using the same example, Angola's high-growth scenario combines the emissions per energy growth rate of 5.91% from 1990 to 2000, with the energy per GDP growth rate of 0.25% recorded between 2010 and 2020, and the GDP per capita growth rate of 7.20% from 2000 to 2010.

Since sustaining significantly high growth rates over three decades is infeasible, an emissions cap is introduced to keep emission estimates within realistic limits. Without this cap, estimated emissions for certain countries would increase rapidly due to their high growth rates. Equatorial Guinea, for example, has shown significant growth with GDP per capita and emissions per energy growth rates of 29% and 16%, respectively (Figure A-5). To set the cap, the highest average annual emissions per capita recorded globally from 1990 to 2020, which was Qatar's 38.4 tCO_2e/capita, is used [3, 26]. For comparison, during the same period, the USA averaged 18 tCO_2e/capita, China 5 tCO_2e/capita, and India 1 tCO_2e/capita, while South Africa, the highest emitter in Africa, averaged about 7 tCO2e/capita [26]. Across the 47 countries in this study, the average emissions per capita was 1 tCO_2e/capita. Given this range, the cap of 38.4 tCO_2e/capita is notably high, and it is unlikely any country will exceed this value due to increasing climate action and advancements in clean technologies. Under the high-growth scenario, each country's emissions cap is calculated by multiplying 38.4 tCO_2e/capita by the projected population for 2030, 2040, and 2050. For each country, the lower of the emissions estimated using the Kaya Identity and the emissions cap is used. As expected, the cap is only applied for Equatorial

[14] See Table A-3 in the chapter's appendix.

[15] See Section 2 in the chapter's appendix for a detailed discussion of these trends.

Guinea across the three decades. However, even with the cap, Equatorial Guinea's high-growth scenario still shows substantial growth, given the nation's average emissions per capita of 3.8 tCO_2e/capita over the past three decades. In 2040 and 2050, emissions from the Republic of Congo are capped due to high emissions per energy and energy per GDP growth rates of 7.14% and 10.03%, respectively[16] (Figure A-5 in the chapter's appendix). Additionally, in 2050, high-growth emissions from Algeria, Benin, Chad, Mozambique, Seychelles, and Tunisia are also capped[17].

In addition to the low- and high-growth scenarios, the analysis explores a **green-growth** scenario in which African nations are assumed to maintain the highest economic growth rate experienced in the 3-decade period under consideration while retaining the lowest growth rates recorded for energy intensity and carbon intensity. Angola's green growth scenario combines a GDP per capita growth rate of 7.20% from the 2000–2010 decade with the emissions per energy growth rate of -5.82% and energy per GDP growth rate of -1.08% from the same decade. It is worth noting that this match in the decade for the green-growth scenario is inconsistent across Africa. For example, the green-growth scenario for Algeria in Northern Africa combines the GDP per capita growth rate of 4.44% from 2000 to 2010 with the emissions per energy growth rate of 0.14% from 2010 to 2020 and the energy per GDP growth rate of -3.35% from 1990 to 2000 (Figure A-4 in the chapter's appendix).

Finally, the study also includes a **mid-growth** scenario in which it is assumed that African nations record the average growth rate observed across the 30-year period for carbon intensity, energy intensity, and economic growth. For Angola, the mid-growth scenario combines an emissions per energy growth rate of -1.70%, an energy per GDP growth rate of -0.27%, and a GDP per capita growth rate of 2.23%. Table 2-1 summarizes the assumptions for the four growth scenarios considered in this study. Using these scenarios, future African fossil fuel emissions over the next three decades are estimated[18].

Likelihood of Study Scenarios

While the Kaya Identity does not offer precise predictions of future emissions, it provides a framework for exploring potential trajectories. To contextualize the projections, this section assesses the likelihood of the **low-growth, high-growth, and green-growth scenarios**[19] across African countries, focusing on observed trends in the decade **2010-2020**. It is assumed that the growth rates in this period are the most reliable indicators of future patterns and are particularly significant since several African countries ratified the Paris Agreement and submitted NDCs in this decade.

For each nation, the analysis determines whether the growth rates in emissions per energy, energy per GDP, and GDP per capita during 2010-2020 are the highest recorded or at least higher than in previous decades.

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[16] Similar to Equatorial Guinea, the capped emissions indicate considerable growth for the Republic of Congo, which maintained an average emissions per capita value of 1.1 tCO_2e/capita between 1990 and 2020.

[17] This also represents marked growth for these countries given their historical emissions per capita values: Algeria – 3.1 tCO_2e/capita, Benin – 0.34 tCO_2e/capita, Chad – 0.08 tCO_2e/capita, Mozambique – 0.13 tCO_2e/capita, Seychelles – 4.3 tCO_2e/capita, and Tunisia – 2.3 tCO_2e/capita.

[18] As a sense check, we also estimate future emissions from the continent using the mean and median values of the emissions/energy, energy/GDP, and GDP/capita metrics from 1990 to 2020. For results, see 'Africa's Potential Future Emissions Based on Mean and Median Values' in Section 2 in the chapter's appendix.

[19] The adopted methodology is not applicable to the mid-growth scenario.

- A high-growth scenario is likely if all three terms have shown an increasing trend. If two of the three terms have increased, the country is also considered inclined toward the high-growth scenario.
- A low-growth scenario is indicated if all three terms show a decreasing trend or if two of the three decline.
- A green-growth scenario is identified when a country exhibits declining carbon and energy intensity alongside rising economic rent, signaling, even if briefly, a capacity to decouple growth from emissions.

Figure 2-1 illustrates the anticipated scenarios for the 47 countries in this study. Only Democratic Republic of Congo (DR Congo), Kenya, Seychelles and Zimbabwe are projected to follow a green-growth pathway. 21 countries lean toward high-growth, while 22 countries are more aligned with a low-growth trajectory, primarily due to declining economic rent trends. If African countries begin to experience rising economic rent while maintaining recent carbon and energy intensity trends, most—except for DR Congo, Kenya, Seychelles, South Africa, and Zimbabwe—are likely to follow a high-growth emissions path. Across the study sample, 70% of countries exhibit an increasing trend in carbon intensity, 55% in energy intensity, and only 26% in economic rent.

Table 2-1: Scenarios Considered for Growth in Africa's Emissions and Economic Output

	Carbon Intensity of Energy Use (Emissions/Energy) [17, 20]	**Energy Intensity of GDP (Energy/GDP)** [19, 20]	**Economic Rent (GDP/capita)** [18, 19]	**Population** [25]
Low-growth	The lowest growth rate across the three decades considered	The lowest growth rate across the three decades considered	The lowest growth rate across the three decades considered	Medium variant of the UN population projections
High-growth	The highest growth rate across the three decades considered	The highest growth rate across the three decades considered	The highest growth rate across the three decades considered	Medium variant of the UN population projections
Green-growth	The lowest growth rate across the three decades considered	The lowest growth rate across the three decades considered	The highest growth rate across the three decades considered	Medium variant of the UN population projections
Mid-growth	Average growth rate across all three decades	Average growth rate across all three decades	Average growth rate across all three decades	Medium variant of the UN population projections

Country	Carbon Intensity (Emissions/Energy)	Energy Intensity (Energy/GDP)	Economic Rent (GDP/Capita)	Most likely scenario
Algeria	Low	High	Low	low-growth
Angola	High	High	Low	high-growth
Benin	High	Low	High	high-growth
Botswana	High	High	Low	high-growth
Burkina Faso	High	High	Low	high-growth
Burundi	High	High	High	high-growth
Cabo Verde	High	Low	Low	low-growth
Cameroon	High	Low	Low	low-growth
Central African Republic	High	High	Low	high-growth
Chad	Low	High	Low	low-growth
Comoros	High	High	High	high-growth
Congo, Dem. Rep. (DR Congo)	Low	Low	High	green-growth
Congo, Rep.	High	Low	Low	low-growth
Cote d'Ivoire	High	High	High	high-growth
Egypt	High	Low	Low	low-growth
Equatorial Guinea	High	Low	Low	low-growth
Eswatini	High	High	Low	high-growth
Ethiopia	High	High	High	high-growth
Gabon	High	Low	Low	low-growth
Gambia	High	Low	Low	low-growth
Ghana	Low	High	Low	low-growth
Guinea	High	Low	High	high-growth
Guinea-Bissau	High	Low	High	high-growth
Kenya	Low	Low	High	green-growth
Lesotho	High	Low	Low	low-growth
Madagascar	High	High	Low	high-growth
Malawi	High	High	Low	high-growth
Mali	High	Low	Low	low-growth
Mauritania	Low	High	Low	low-growth
Mauritius	Low	High	Low	low-growth
Morocco	High	High	Low	high-growth
Mozambique	High	High	Low	high-growth
Namibia	Low	High	Low	low-growth
Niger	High	Low	Low	low-growth
Nigeria	Low	High	Low	low-growth
Rwanda	High	High	Low	high-growth
Senegal	Low	High	Constant (but on the higher end)	high-growth
Seychelles	Low	Low	High	green-growth
Sierra Leone	High	High	Low	high-growth
South Africa	Low	Low	Low	low-growth
Sudan	High	Low	Low	low-growth
Tanzania	High	Low	Low	low-growth
Togo	High	Low	High	high-growth
Tunisia	Low	High	Low	low-growth
Uganda	Low	High	Low	low-growth
Zambia	High	High	Low	high-growth
Zimbabwe	Low	Low	High	green-growth

Figure 2-1: Most Likely Scenarios across African Countries in the Study. Senegal recorded the same growth rate in the 2000-2010 and 2010-2020 periods (2.9%), the preceding decade saw a growth rate of 2.7%.

Methodology to estimate emission savings from 'large economies'

To test the hypothesis that growth in African emissions can nullify savings from advanced economies in future decades, the increase in emissions based on the predicted range of future African emission values is compared with the expected savings from key 'large economies'.

For this study, 'large economies' are defined as the top 10 countries with the highest annual fossil fuel CO_2 emissions [17] and highest GDP rankings [27]. Combining both criteria results in a list of 13 countries: the USA, China, India, Russia, Japan, Iran, Germany, Indonesia, South Korea, the United Kingdom, France, Canada, and Italy (Table A-4 in the chapter's appendix). Emissions savings from these countries are estimated based on their submitted Nationally Determined Contributions (NDCs) and announced net-zero targets. For Germany, France, and Italy, there are no individual NDCs, therefore, the European Union NDCs are used. Iran was excluded from the list because the country has neither ratified the Paris Agreement nor submitted NDCs.

The expected emissions savings from the 'large economies' between 2030 and 2050 are calculated as the difference between their predicted emissions under NDCs and net-zero targets, and their 2020 emissions. The climate targets are listed in Table A-5 in the chapter's appendix. To estimate 2040 and 2050 emissions for economies without a net-zero pledge or recorded target for those years, it is assumed that they will reduce their emissions by an equal amount every year from 2030 to reach zero at their pledged net-zero targets. For nations with emission intensity targets, estimated future GDP values are taken from the World Economic League Table 2021 by the Center for Economics and Business Research (CEBR) [27]. The resulting estimates of future emissions from these economies, especially for 2030, are matched to those provided by the Climate Action Tracker [28] and where there are clear discrepancies, the lower emission values are adopted. Consequently, this analysis skews towards a more ambitious mitigation scenario for the 'large economies'.

Table 2-2: Scenarios Considered for Growth in Africa's Emissions and Economic Output

	Carbon Intensity of Energy Use (Emissions/Energy) [17, 20]	**Energy Intensity of GDP (Energy/GDP)** [19, 20]	**Economic Rent (GDP/capita)** [18, 19]	**Population** [25]
Low-growth	The lowest growth rate across the three decades considered	The lowest growth rate across the three decades considered	The lowest growth rate across the three decades considered	Medium variant of the UN population projections
High-growth	The highest growth rate across the three decades considered	The highest growth rate across the three decades considered	The highest growth rate across the three decades considered	Medium variant of the UN population projections
Green-growth	The lowest growth rate across the three decades considered	The lowest growth rate across the three decades considered	The highest growth rate across the three decades considered	Medium variant of the UN population projections
Mid-growth	Average growth rate across all three decades	Average growth rate across all three decades	Average growth rate across all three decades	Medium variant of the UN population projections

Results

Africa's Emissions and Associated Implications

As shown in Figure 2-2, Africa has recorded an average annual increase of ~2.6% in population, ~2.5% in energy consumption, ~5.4% in GDP, and ~2.5% in fossil fuel emissions over the past three decades. Analysis of the continent's CO_2 emissions using the Kaya Identity indicates that emissions

have grown primarily due to simultaneous increases in GDP per capita and population, outpacing reductions in carbon and energy intensity (Figure 2-3). This indicates that the primary drivers of Africa's fossil fuel emissions growth have been economic development and population expansion, as reductions in carbon and energy intensity have not been sufficient to offset these increases.

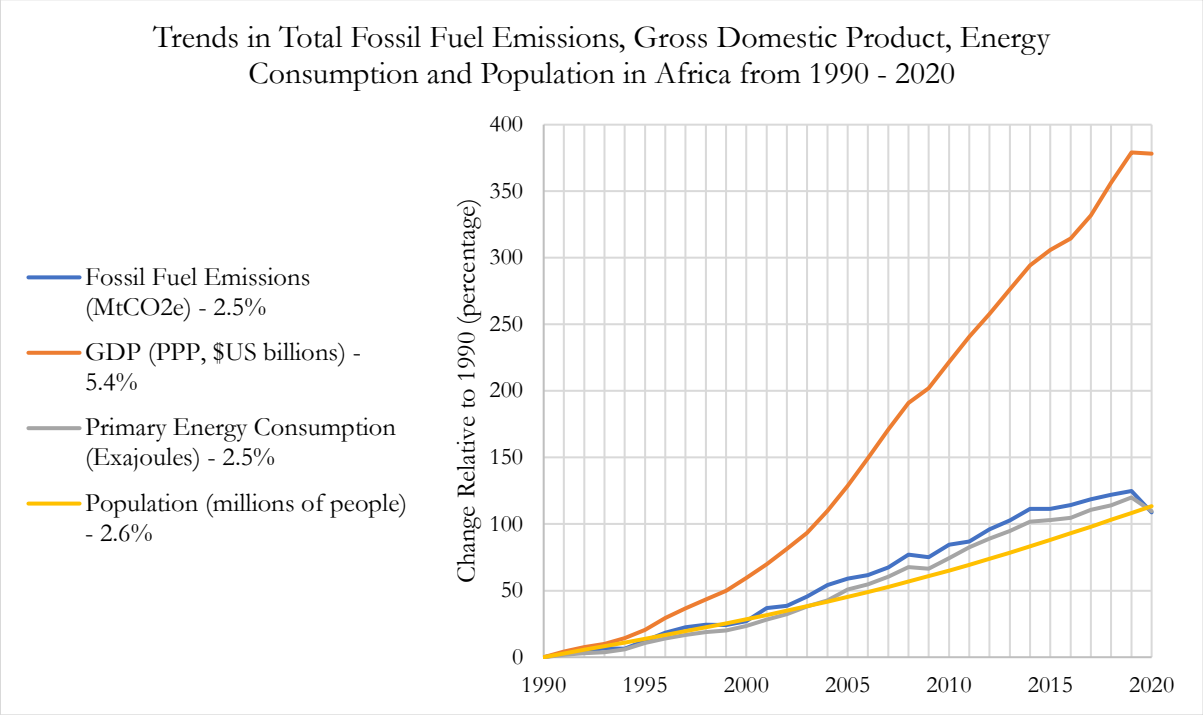


Figure 2-2: Trends in Total Fossil Fuel Emissions, Gross Domestic Product (GDP), Primary Energy Consumption, and Population in Africa from 1990 – 2020. Trends are given as percentage changes relative to 1990. The compound annual growth rate for each metric is included in the legend.

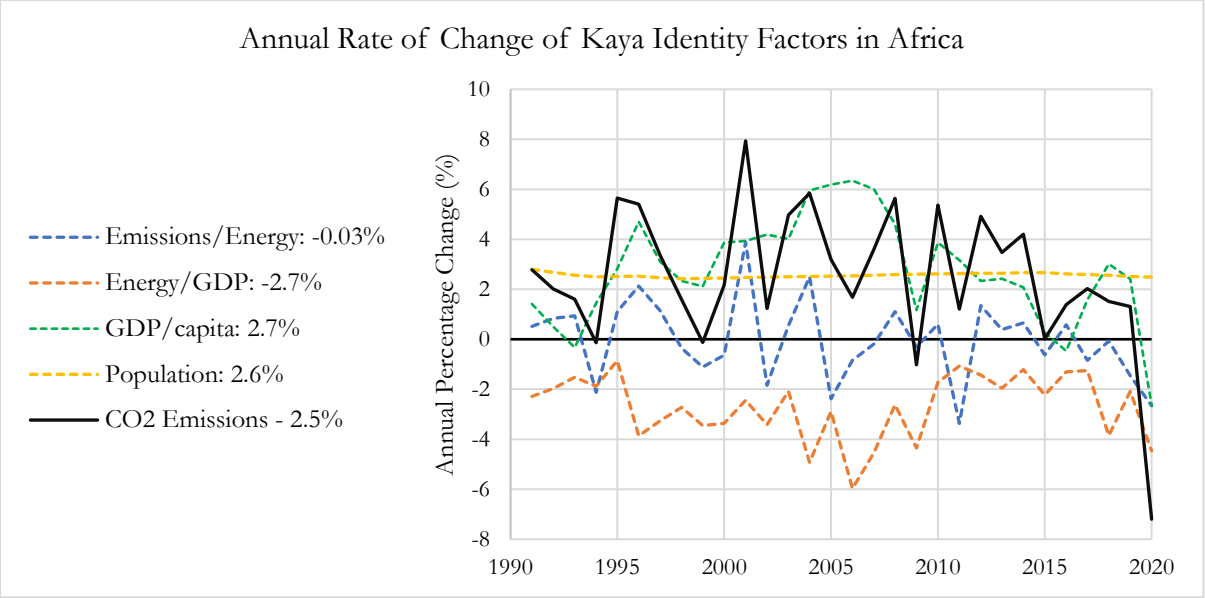


Figure 2-3: Annual rate of change of Kaya Identity factors in Africa. The compound annual growth rate for each factor is included in the legend. Pre-1990 emissions data is unavailable in the World Bank dataset used in this study.

Carbon Savings from the World's 'large economies'

Based on the NDC and net-zero commitments summarized in Table A-5 in the chapter's appendix, the 'large economies' are projected to witness a ~3900 $MtCO_2e$ rise[20] in annual emissions by 2030 compared to 2020, mainly due to increased emissions in China, India, and Indonesia. This increase is equivalent to approximately 90% of the USA's 2020 emissions and exceeds the total annual emissions of all other 'large economies' in that year, except China. Put differently, the 'large economies' could collectively increase annual emissions by the equivalent of an economy the size of the European Union, Japan, and the United Kingdom combined. However, a reversal is anticipated in 2040 and 2050, with the 'large economies' projected to decrease their annual emissions by ~6300 $MtCO_2e$ and ~16000 $MtCO_2e$, respectively.

Low-Growth, Mid-Growth, and Green-Growth Scenarios

In the low-growth scenario, the annual emissions for the 47 African countries in this study decrease from ~1225 $MtCO_2e$ in 2020 to ~930 $MtCO_2e$ in 2030, ~740 $MtCO_2e$ in 2040, and ~610 $MtCO_2e$ in 2050. In this scenario, Africa is not a threat to global mitigation targets for the foreseeable future and instead contributes to emissions reduction even in 2030, when the 'large economies' would still record increasing emissions (Figure 2-4a).

In the mid-growth scenario, it is projected that emissions will rise to ~1600 $MtCO_2e$ in 2030, ~2100 $MtCO_2e$ in 2040, and ~2800 $MtCO_2e$ in 2050, accounting for ~8% of the total growth in annual emissions—across the region and 'large economies'—in 2030. This is similar to the results obtained

[20] Using estimates from the Climate Action Tracker, we find that emissions from the 'large economies' could increase by as much as ~6300 $MtCO_2e$ in 2030 compared to 2020.

by Ayompe and colleagues [5]. In 2040 and 2050, the growth in Africa's emissions would nullify just ~13% and ~10% of the expected savings from the 'large economies', respectively (Figure 2-4b).

While the low- and mid-growth scenarios depict relatively positive outcomes for climate mitigation, they entail a limited realization of economic growth on the continent, which is suboptimal given the imperative for rapid development and the global push for prosperity outlined in the United Nations' Sustainable Development Goals [29]. The green-growth scenario addresses this and indicates that economic development in Africa need not be compromised to curb emissions growth.

In the green-growth scenario, Africa's emissions are projected to rise from ~1225 $MtCO_2e$ in 2020 to ~1400 $MtCO_2e$ in 2030, ~1600 $MtCO_2e$ in 2040, and ~1800 $MtCO_2e$ in 2050. Despite significant economic growth, Africa is expected to contribute only ~4% of the total growth in annual emissions—across the region and 'large economies'—by 2030. Additionally, in the subsequent decades, the impact on savings from the 'large economies' would remain minimal, accounting for only ~ 5% of the expected savings in 2040 and ~4% in 2050 (Figure 2-4c).

High-Growth Scenario

Unlike the low-, mid-, and green-growth scenarios, the high-growth scenario highlights the possibility of an order-of-magnitude increase in Africa's emissions. Under this scenario, emissions from Africa could rise from ~1225 $MtCO_2e$ in 2020 to ~3200 $MtCO_2e$ in 2030, representing a near-tripling within a decade. By 2040, emissions would reach ~10,000 $MtCO_2e$—an eightfold increase—before escalating to ~28,000 $MtCO_2e$ in 2050, nearly 23 times the 2020 level[21]. In the high-growth scenario, the estimated emissions from Africa cancel out savings from the 'large economies' in 2040 and 2050 (Figure 2-4d).

The wide margin between the estimated emissions in the high-growth scenario and the three alternative scenarios suggests that the high-growth projection is likely a clear outlier. The scenario hinges on the assumption that most African countries will sustain growth rates in economic rent, energy intensity, and carbon intensity that surpass those observed in fast-growing emerging economies such as India and China. Given recent trends highlighted in Figure 2-1, maintaining such a trajectory consistently across multiple decades and in numerous countries on the continent seems highly unlikely. Nonetheless, concerns about Africa's future emissions likely stem from such high-growth projections, despite their low probability, and are perhaps conceptually grounded in these extreme scenarios of the continent's future.

While unlikely, this scenario provides an estimated upper boundary for potential emissions growth, underscoring the importance of decoupling GDP and population growth from rising emissions, especially post-2030. On a smaller scale, the mid-growth and green-growth scenarios similarly indicate that Africa's business-as-usual emission pattern is insufficient to curb emissions in light of rapid population growth and economic development. With the urgency of the climate crisis and the constraints of a shrinking carbon budget [30-32], strengthening mitigation efforts in Africa remains imperative—especially in the context of intentional development strategies. As Figure 2-1 illustrates, emissions growth in many African countries has been primarily constrained by low economic growth,

[21] Asia's CO_2 emissions grew 65 times between 1870 and 1900, the highest growth factor recorded in any three-decade period between 1780 and 2020 across Europe, Asia, North America, South America, and Africa, based on available data. See Table A-6.

suggesting that if economic expansion accelerates, emissions will rise unless targeted mitigation measures reverse recent carbon and energy intensity trends.

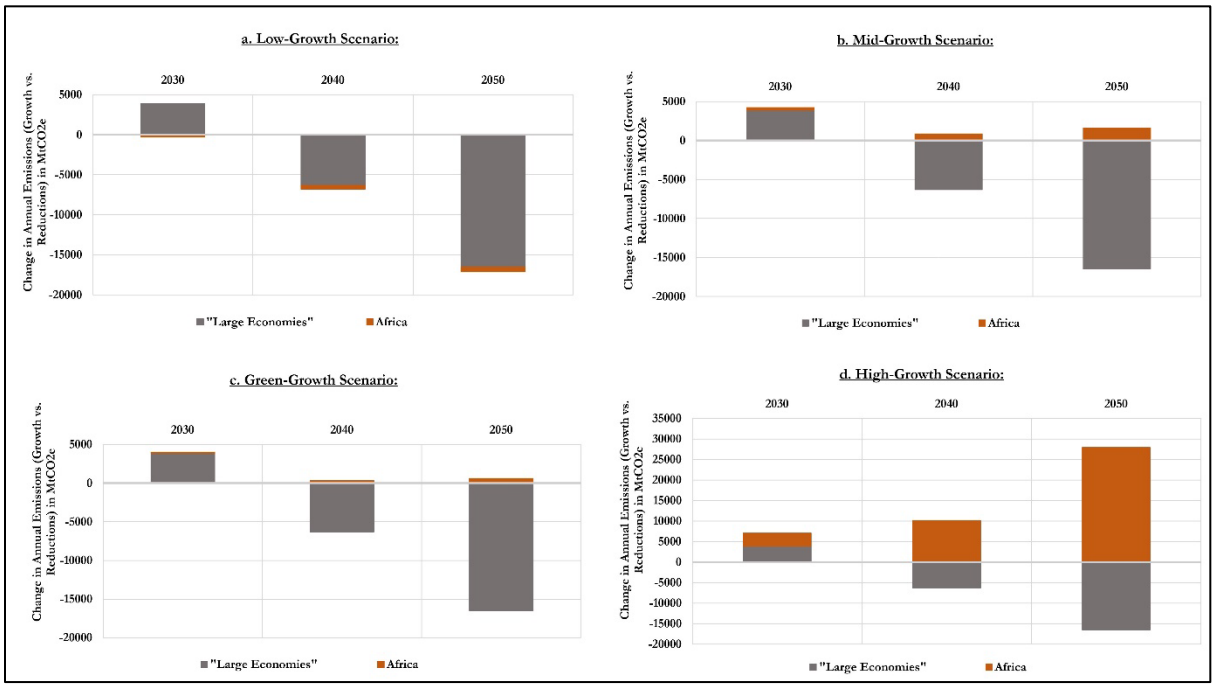


Figure 2-4: Changes in annual fossil fuel GHG emissions from across Africa and 'large economies' in coming decades relative to 2020 emissions across the low-growth, high-growth, green-growth, and mid-growth scenarios.

Country-level Trends

Historical emissions data from Africa underscore that effective mitigation strategies hinge on only a handful of nations because of the uneven distribution of emissions. As of 2020, the top ten emitters in Africa—South Africa, Egypt, Algeria, Nigeria, Morocco, Libya, Tunisia, Angola, Ghana, and Sudan—accounted for approximately 85% of the total emissions from the continent, a pattern consistent over the past three decades (Figure 2-5) [17].

Across the four considered scenarios, the top 10 emitters from 2020 to 2050 account for 80–90% of the annual emissions. Figure 2-6 illustrates the evolving role of the 19 highest-emitting African nations in the coming decades, based on the different scenarios[22,23]. These high-emitting nations are pivotal in determining Africa's role in global climate change mitigation. Indeed, continent-wide emissions can be effectively curtailed by a strategic focus on these countries. As discussed in Chapter 1, South Africa and Nigeria have announced 2050 and 2060 net-zero targets, respectively [33-34]. In 2020, these two countries accounted for approximately 60% of the Sub-Saharan Africa's emissions [17]. Across the

[22] Due to data limitations, certain key countries, such as Libya, were excluded from this study. Additionally, variations in data quality across countries may exist. Complexities, including the widespread use of decentralized energy systems like diesel/petrol generators, might not have been fully captured, potentially leading to underestimated emissions for countries such as Nigeria and the Democratic Republic of Congo. Consequently, the list of the 19 identified nations has some limitations. Nevertheless, the analysis strongly suggests that just a few countries play a pivotal role in achieving rapid and impactful decarbonization on the continent.

[23] The noteworthy shifts in what countries feature in this subgroup across the different decades and scenarios are discussed in Section 5 of the chapter's appendix and displayed in Figures A-8–A-11.

low-, mid-, and green-growth scenarios, if South Africa meets its net-zero target, the total emissions from the continent in 2050 could be reduced by 20 – 30%.

Moreover, identifying these key countries suggests that about 28 African countries[24] pose minimal risk to carbon targets, emphasizing that deep decarbonization efforts need not encompass all nations. Only 10 African countries[25] consistently rank among the top five emitters, further streamlining the scope of decarbonization efforts and policies.

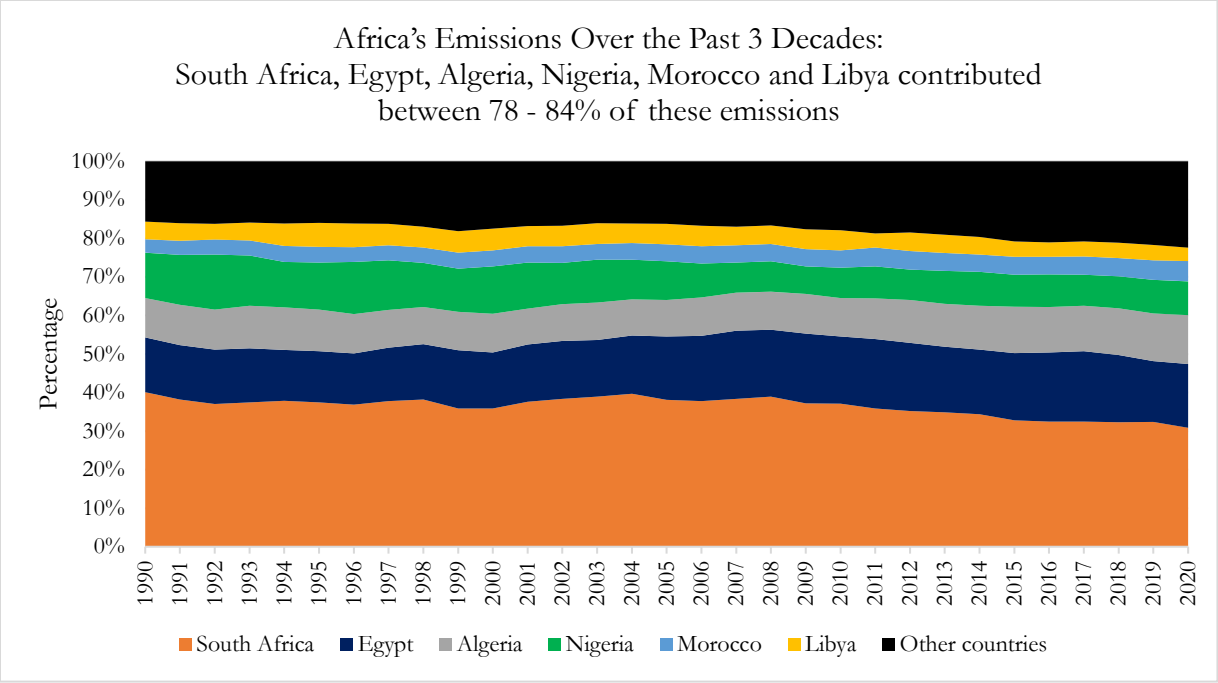


Figure 2-5: Nation-specific percentage contributions to Africa's emissions between 1990 and 2020 highlighting top emitters.

[24] Botswana, Burundi, Cabo Verde, Cameroon, Central Africa Republic, Comoros, Democratic Republic of Congo, Cote d'Ivoire, Eswatini, Gabon, The Gambia, Guinea, Guinea-Bissau, Lesotho, Madagascar, Malawi, Mali, Mauritania, Mauritius, Namibia, Niger, Rwanda, Seychelles, Sierra Leone, Togo, Uganda, Zambia, Zimbabwe.

[25] Algeria, Angola, Benin, Egypt, Ethiopia, Morocco, Mozambique, Nigeria, South Africa and Tanzania. These countries account for 60–80% of annual emissions across the four considered scenarios.

S/N		Country	2020	2030				2040				2050			
				low-growth	green-growth	mid-growth	high-growth	low-growth	green-growth	mid-growth	high-growth	low-growth	green-growth	mid-growth	high-growth
1	Starting Group	South Africa	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2		Egypt	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3		Algeria	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4		Nigeria	✓	✓	✓	✓	✓		✓	✓	✓			✓	✓
5		Morocco	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	
6		Tunisia	✓	✓	✓	✓	✓								
7		Sudan	✓			✓	✓		✓	✓	✓				✓
8		Angola	✓		✓		✓		✓		✓		✓		✓
9		Kenya	✓	✓	✓			✓	✓				✓		
10		Ghana	✓	✓		✓		✓		✓	✓	✓	✓	✓	✓
11	Emerging Group	Ethiopia		✓	✓	✓		✓	✓	✓		✓	✓	✓	
12		Tanzania		✓	✓	✓		✓	✓	✓		✓	✓	✓	
13		Benin						✓		✓		✓	✓	✓	✓
14		Senegal						✓				✓			
15		Burkina Faso										✓			
16		Equatorial Guinea					✓							✓	
17		Mozambique					✓				✓				✓
18		Republic of Congo									✓				
19		Chad									✓				✓

Figure 2-6: Top 10 emitters in Africa based on the different scenarios and decades considered.

Advancing Mitigation in Africa: Renewable Electrification and International Support

A strategic approach to addressing Africa's emissions will require prioritizing paradigms and activities in the 10–19 nations identified in the preceding section, all of which have ratified the Paris Agreement and submitted Nationally Determined Contributions (NDCs) [6]. A detailed content analysis of these NDCs highlights that the most commonly cited mitigation measure is the increased adoption of renewable energy technologies for electricity—aligning with phase 1 of the mega-trend of electrification, as discussed in Chapter 1 (see Figure A-12 in the chapter's appendix). Only Ethiopia's NDCs do not directly include this measure, possibly because the nation already has ~99% of its installed electricity generation capacity based on renewables [35].

Yet, as also highlighted in Chapter 1, this is a hotly debated theme in conversations on the speed, scale, urgency, and trade-offs of the energy transition in Africa. For instance, a key point of contention is whether natural gas can serve as a transition fuel or if the focus should be on a full-scale shift to renewables [6, 36].

Media, think-tank, and advocacy campaigns aside, electricity generation and capacity data from the U.S. Energy Information Administration reveal that several of the key 19 countries recorded faster compound annual growth rates (CAGR) for renewable electricity capacity and/or generation than for fossil fuel in the past decade (Figure 2-7)[26]. Perhaps contrary to the popular sentiments expressed by African leaders, the data does not show a staunch commitment to fossil fuels in the case of electricity supply. Instead of an unchanging predisposition to grow via fossil fuels, these countries appear balanced in their approach and inclined to prioritize renewable energy pathways if the required technical and financial resources are available at the required scale.

[26] For an overview of these trends in absolute terms, see Table A-7 and Figure A-13. While the CAGRs in Figure 2-7 indicate the direction of efforts in the 19 countries over the past decade, the absolute values provided in the chapter's appendix highlight the overall changes in their electricity systems over the past three decades as they pertain to the penetration of renewable sources. Furthermore, they show the wide variations in electricity generation and renewable energy shares across these countries.

Importantly, while all 19 countries discuss increasing the amount of electricity generated from renewable sources, only seven include plans to expand the use of natural gas for electricity in their NDCs. These countries are Benin, Chad, Morocco, Mozambique, Senegal, Tanzania, and South Africa. However, their renewable targets exceed natural gas targets. For example, while South Africa's Integrated Resource Plan proposes installing about 7GW of additional gas capacity by 2030, ~20GW of additional renewable energy capacity (including storage) is expected during the same period [37]. Egypt and Nigeria also mention the use of natural gas for electricity, but only in the context of displacing diesel and gasoline generators and converting existing simple-cycle gas turbine power plants to combined-cycle ones.

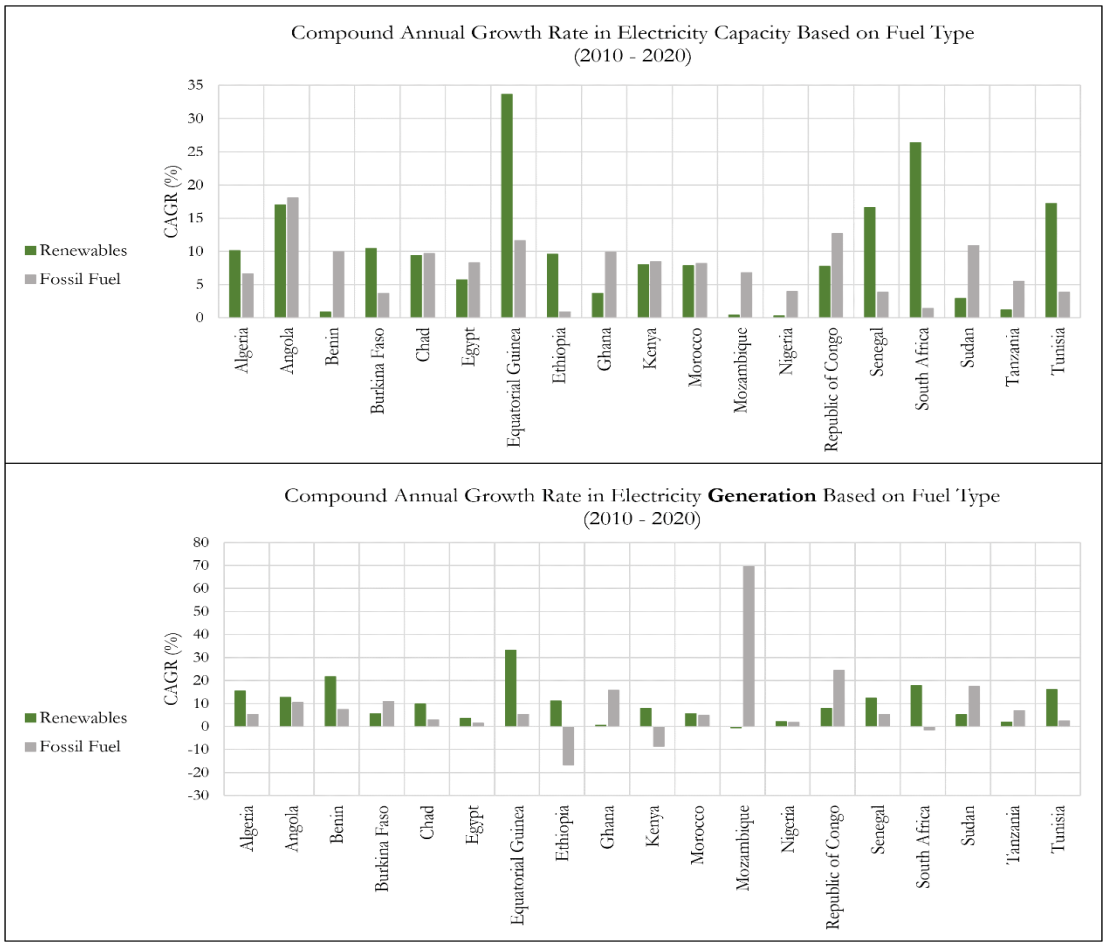


Figure 2-7: Compound annual growth rate (CAGR) for electricity generation and capacity based on fuel type between 2010 and 2020 for the key 19 relatively high-emitting nations. Algeria, Equatorial Guinea, Ethiopia, Senegal, South Africa, and Tunisia recorded higher CAGR for both renewable energy generation and capacity than for fossil fuel. Angola, Chad, Kenya and Morocco recorded faster CAGR for just renewable energy generation. However, their CAGRs for renewable and fossil fuel capacity were "neck and neck". Burkina Faso recorded a higher CAGR for renewable electricity capacity, while Benin, Egypt, and Nigeria experienced faster CAGR for renewable electricity generation. Only Ghana, Mozambique, the Republic of Congo, Sudan, and Tanzania had lower CAGRs for both renewable electricity generation and capacity compared to fossil fuels.

Africa currently accounts for less than 3% of the world's installed renewables-based electricity generation capacity despite its vast renewable energy resource potential, not in the least part due to limited investment flows into the region [38]. Although the continent accounts for approximately 20%

of the world's population, it receives less than 2% of its spending on clean energy on average [39] (Figure A-14 in the chapter's appendix). SSA recorded just $3 per person in 2021 compared to Europe's $127 per person renewable energy investment rate [40]. There is a clear mismatch between capital made available by the West and the emissions the region expects in Africa [30]. The current investments are also misaligned with arguments that renewables offer African countries the opportunity to leapfrog fossil fuel dependence and develop based on a low-carbon model [9]. Furthermore, the cost of capital and perceived investment risk remain significantly higher for African countries than more advanced economies [38, 41]. African nations are unlikely to advance mitigation efforts, even at their proposed pace, without increased financial and technical support to address the underlying causes of risk premiums, such as regulatory uncertainty and weak project preparation. As Babayomi and colleagues highlight, *"the slow rate of the clean energy transition is strongly influenced by ease or difficulty of access to finance, and the cost of available finance"* [42].

Figure 2-8 shows that the CAGR recorded by most of the 19 countries is insufficient to achieve the conditional and, in some cases, unconditional targets set out in their NDCs to expand electricity generation/capacity from renewable sources. On average, clean energy deployment rates must become 20 times faster to achieve their current NDC targets. For 11 of the 19 countries that provide renewable capacity targets, this translates to adding about 70 GW of renewable capacity by 2030. Assuming for simplicity that this capacity is supplied by utility-scale solar systems, ~$10 billion needs to be mobilized annually between 2021 and 2030 to achieve this[27]. Given that this value represents double the annual renewable energy investment recorded for the whole continent between 2010 and 2020 [38], these targets are likely out of reach in the current *"funding squeeze"* era [12]. Intentional efforts and a substantial increase in both local and international investment flows to Africa are needed to deliver the region's energy transition.

Relatedly, the NDCs of the core 19 countries repeatedly emphasize the need for assistance to achieve their mitigation targets and make their more ambitious targets *"conditional on support in terms of external finance, technology development, and transfer and capacity building."* [44]. Below are additional quotes on this point from some of the reviewed NDCs, and these align with the discussion of the continent's dependency in the following section:

> "The actual implementation of these mitigation and adaptation measures are conditional on the provision of adequate, appropriate international finance through highly concessional finance and grants as appropriate."– Egypt [45]

> "As stated in section 1, the implementation of these ambitious mitigation targets will require substantial multilateral support, as provided for in the Paris Agreement. South Africa is updating these mitigation targets in the expectation that such support will be available."– South Africa [46]

> "Subject to national circumstances, Kenya intends to bear 21% of the mitigation cost from domestic sources, while 79% of this is subject to international support in the form of finance, technology development and transfer, and capacity building."– Kenya [47]

[27] We use cost estimates for projects starting construction in 2025 from the National Renewable Laboratory (NREL)'s Annual Technology Baseline [43]

The global community must commit to and follow through on bridging this clear gap to accelerate mitigation efforts in these core countries and across the African continent more broadly. Furthermore, in addition to grants and concessional finance, carbon-pricing mechanisms can potentially be designed to address financing gaps. For instance, a moderate price of ~$14/tCO$_2$e is sufficient to close the upfront financing gap between natural gas plants and even utility-scale solar and storage solutions (Figure 2-9).

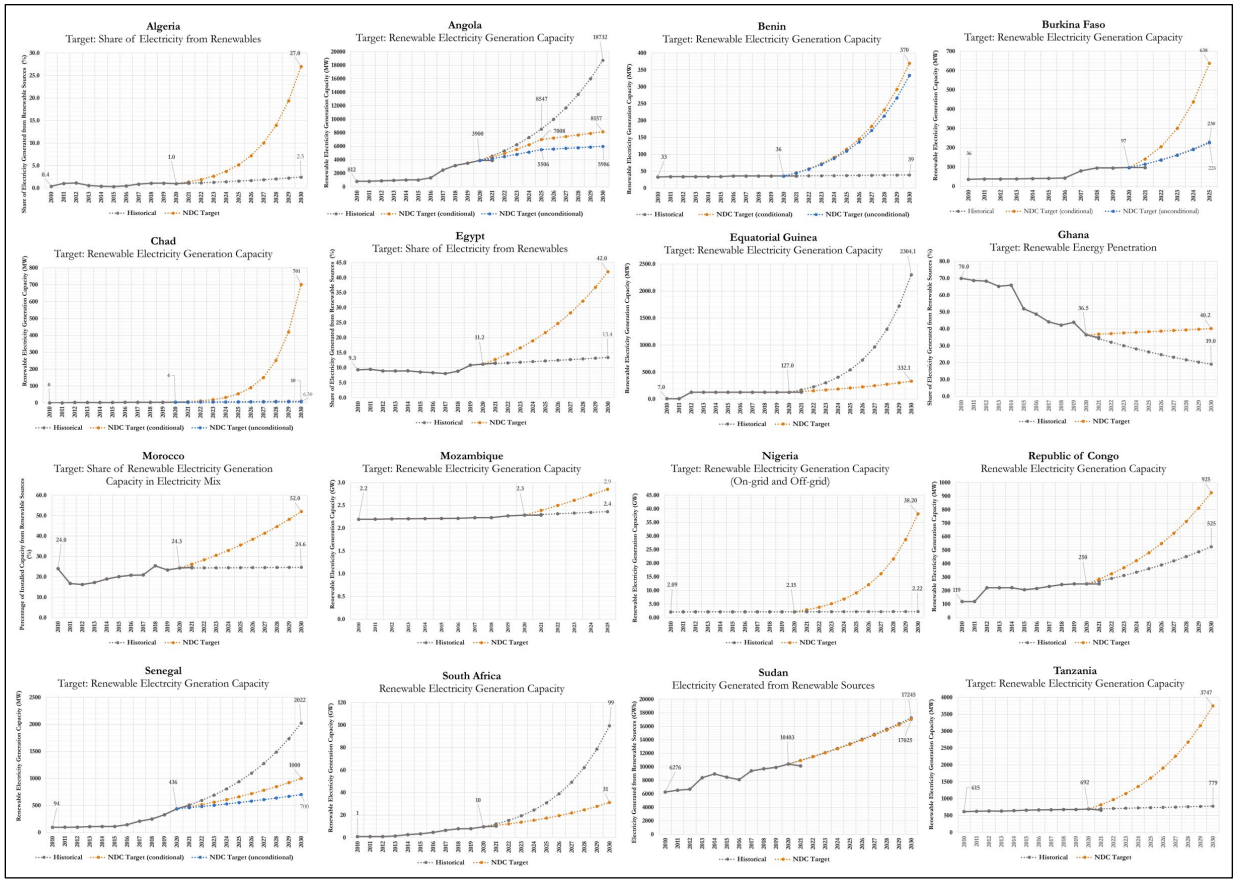


Figure 2-8: Potential growth of renewables-based electricity generation/capacity in certain African countries based on growth rate recorded between 2010 and 2020 compared to the conditional and/or unconditional targets recorded in their NDCs, where available.



Figure 2-9: (a.) Capital Costs of Certain Electricity Generation Technologies. The data were obtained from the National Renewable Laboratory (NREL)'s Annual Technology Baseline [43]. (b.) Required Carbon Price to Close Financing Gap between Utility-Scale Renewable Systems and Natural Gas Plants (See Section 8 in the chapter's appendix for calculation details)

Discussion

The findings presented in this chapter highlight a critical paradox: while Africa's emissions are projected to rise, their impact on global carbon targets remains relatively low, particularly in the short term. Yet, despite this, international climate discussions remain preoccupied with the continent's future emissions, often framing Africa as a potential threat to global mitigation efforts rather than recognizing its urgent development imperatives. This framing stands in stark contrast to the reality

that, even under high-growth projections, Africa's energy-related emissions remain marginal relative to major economies. Moreover, it carries significant implications—not only for Africa's economic trajectory, but also for global climate diplomacy and equity in the energy transition.

At the same time, Africa is becoming increasingly proactive in climate mitigation efforts and global discussions. This growing engagement could be seen as a necessary response to the continent's acute vulnerability to climate change and the need to compel stronger global action for its own sake [48-58]. However, the West's approach to Africa—and even the continent's own response—appear to reflect dynamics and longstanding power asymmetries in the international political economy, particularly those theorized within dependency theory [8, 59]. For instance, Africa's growing participation in climate discussions may be driven less by intrinsic priorities and more by external influence and the prospect of international financial and technical support.

The deep tension between Africa's development needs and external pressures for rapid decarbonization raises fundamental questions about power, agency, and structural dependencies. Building on the findings of this chapter, the following discussion applies dependency theory to critically examine how financial, technological, and policy dependencies continue to shape the continent's energy trajectory.

The dependency theory posits that the capitalist world system has *"two types of states, the dominant and dependent,"* an inherent *"core-periphery duality or 'metropolis-satellite' concept that determines the development potentialities of different countries"* [8, 47], with the industrial/advanced nations being the *"core",* and the developing/non-industrial world as the *"periphery"* [59]. The dependency theory, which emerged in the 1960s/70s from developing countries, *"revolutionized the African thinking about development"* [59] and remains relevant in examining the complex relations between Africa and external actors [2, 8]. Alpha F. Lisimba argues that *"Africa is still exposed to external pressures; its economic development is still conditioned by donor countries' interests, structural weakness, and it is economically dependent to some degree on Chinese and Western loans and credit lines."* [8]

The following quote by Julius Nyerere, the first President of Tanzania, succinctly captures the essence of the dependency theory in Africa:

> "We [Africa] are all, in relation to the developed world, dependent—not interdependent—nations. Each of our economies has developed as a by-product and a subsidiary of development in the industrialized North and is externally oriented. We are not the prime movers of our own destiny." ([1] cited in [2]).

Similar to the sentiment in Nyerere's quote, Newell and Bulkeley [60] note that national action plans on climate change in African countries like South Africa, Mozambique, Rwanda, and Kenya *"are being developed as part of a donor drive to promote 'climate-compatible development.'"* Pistelli [11] argues that for African nations:

> "Adding renewables to their power mix was indeed considered a way to obtain technical and financial support from development finance institutions mandated to support infrastructure enhancement in developing countries and, at the same time, attract investments and capacity building from international energy companies interested in gaining/increasing their foothold in African markets."

Some features of Africa's dependent relationship include:

1. Trade that is based on the export of raw materials in exchange for value-added products and technology, with Africa typically in the role of *"resources supplier and marketplace"* and external actors (Western countries and, increasingly, China) as suppliers of finished products and advanced technology [2, 8, 12].
2. Projects in Africa that are based primarily on the interests of the donor countries and benefit their economies more, with limited participation of local African people in implementation [8].
3. The flow of capital from foreign actors to African countries in the form of loans, cash, or credit lines to provide investment opportunities to companies from their own countries and not Africa [8, 12].
4. Concentration of innovation processes in the core countries, though some transfer of technology occurs following the influx of foreign capital [9].
5. African countries do not necessarily possess adequate resources to design alternative methods of responding to constraints imposed upon them by the international capitalist economic system and the West [8].

The above features, which strongly define fossil fuel exploitation on the continent, are increasingly characterizing the energy transition [9, 11]. Africa still relies on external financial and technological support to develop renewable energy systems [11, 38]. For example, European bilateral donors played an influential role in the development of South Africa's renewable energy industry, *"shaping policy, directing research,"* and establishing the Renewable Energy Independent Power Producers Procurement Agreement (RE-IPPP) program [60]. Unsurprisingly, these countries (Denmark, Germany, Italy, Spain, France), as well as the UK and US, reportedly dominate the development, financing, ownership, and construction of projects within the program with the clean energy technologies originating from their countries [60]. Commercial and geopolitical interests in response to the saturation of domestic markets or desires to establish global supply chains have been cited as reasons for Chinese solar firms' significant interest in investing in SSA [3, 60]. Germany's recent push for the development of a hydrogen ecosystem in Africa seems more geared towards the nation's domestic transition aspirations than Africa's development agenda [61, 62].

Africa is a supplier of critical materials needed for renewable energy technologies but does not lead the manufacturing or innovation of these technologies [9, 11]. For example, compared to China, which had about 150,000 renewable energy patents in 2016, records for Africa indicate a total of merely 657 climate change mitigation-related patents [11]. Worse still, the extraction of these minerals on the continent results in *"backbreaking work"* and deleterious impacts [11, 63].

Furthermore, related to the fifth point outlined above, it has been estimated that Mozambique could lose profits of over 1% of GDP just from aluminum exports because of the EU's Carbon Border Adjustment Mechanism [6]. South Africa, which has the European Union as its largest trade partner, is not poised to fare much better [6].

Applying the dependency theory to the energy transition provides insight into the degree of policy autonomy in African states and their capacity to implement a low-carbon energy system [60]. It highlights why there are such strong responses to the West's climate policies and partially explains why the media campaigns of several African leaders, as mentioned in the preceding section, are not reflective of local energy realities. The West and China appear to be setting the energy transition

agenda in Africa [6], and while this has important developmental implications, it suggests that financial and technical support, as well as policy directions from external actors, can have an extensive impact on the continent's energy trajectory [3]. It is worth highlighting that most fossil fuel projects on the continent are owned by companies mainly headquartered in Europe, the United States, and China [3, 64]. Relatedly, foreign multinational corporations own two-thirds of the projected new gas and oil production in Africa to 2050 [65]. Indeed, it has been noted that a *"new scramble for the continent's oil and gas wealth is being witnessed"* [66]. External actors clearly have a strong influence on whether a renewable or fossil fuel-reliant path will be followed on the continent.

On the other hand, the discussion emphasizes the urgent need for African leaders and societies to commit to securing a more balanced relationship with the West in the ongoing transition. It has long been argued that the dependency theory denies African nations agency and implicitly absolves local actors—who have stunted the region's development through corruption, maladministration, and bad governance—of due blame [8, 58-59]. In line with this, this discussion recognizes that responsible leadership and activism on the continent can indeed help to ensure favorable terms of engagement with more advanced nations [8]. While it is pragmatic to take advantage of available support, African nations must pursue internal reforms, develop local capacity, promote local manufacturing and innovation, enforce domestic content requirements, protect local communities, and ensure equitable distribution of investment benefits [8, 59]. *"A jobless growth"* and *"conspicuous lack of value added on the African side"* must be avoided [2, 67]. Several authors have also suggested that increased regional cooperation on the continent can counteract the dependence on foreign actors [11, 58, 68]. Developments like the African Continental Free Trade Area (AfCFTA) and the Kigali Communique for a Just and Equitable Energy Transition appear as moves in the right direction [69-70].

Conclusions and Recommendations

Based on the analysis and results in this chapter, the key conclusions and recommendations are as follows:

- **Africa's impacts on global carbon targets will likely be low, especially in the short term:** The findings indicate that between 2030 and 2050, Africa's energy-related emissions may offset only 4–13% of the emission reductions achieved by the 'large economies'. Consequently, concerns about immediate mitigation actions and related restrictions in Africa may be overstated—disproportionate to the continent's actual emissions impact. On the other hand, the high-growth scenario suggests the existence of combinations of historically documented trends in carbon intensity, energy intensity, and economic rent that can outstrip global carbon mitigation efforts. Nonetheless, even in this scenario, Africa's impact will remain secondary to that of other emerging economies until 2030. It is true that long energy infrastructure lifespans cause energy system transformation inertia, which necessitates preempting carbon-intensive investments, even today [6, 9]. However, given the likely minimal impact of Africa's future emissions compared with the potential effects of stringent carbon mitigation policies on economic development, perceptions of equity, and global consensus, a heavy-handed approach from Western nations should be avoided. This is particularly important considering growing African concerns about the West's hypocrisy on carbon mitigation and calls for a *"just and equitable energy transition"* [70-71]. As Bond [72] writes, *"Africa*

has, for centuries, been exploited and looted, and hence an extra amount of intellectual, political, and solidaristic care is required when considering climate justice here."

- **Mitigation efforts should be advanced in Africa with nuance:** In three of the four scenarios explored in this study, Africa's energy-related emissions are projected to increase in the coming decades. While the results also indicate that emissions from the continent should not be a first-order priority and that extensive mitigation efforts should be pursued in advanced economies and major emerging countries such as China, India, and Indonesia, there remains a clear need to bolster mitigation efforts on the continent given the shrinking global carbon budget and increasingly alarming climate signals. The nuance suggested here, particularly as it pertains to the international community advocating for such efforts in Africa, revolves around recognizing at least the following:
    - **Africa's limited contribution to historical and, potentially, future global energy-related emissions**
    - **The need to avoid jeopardizing the speed and scale of Africa's development over limited climate benefits because economic growth will not necessarily impede climate mitigation.** As advised by Pathak *et al.* [6], *"The necessary transformational changes are anticipated to be more acceptable if rooted in the development aspirations of the economy and society within which they take place."*
    - **The unequal distribution of emissions across the continent and the plausible inefficiency of 'one-size-fits-all'"solutions and blanket restrictions**: just 10 -19 countries account for the bulk of the continent's emissions and should be prioritized for mitigation efforts. Stringent climate policies imposed on the whole continent by international actors risk hampering development goals for negligible climate benefits, especially in approximately 28 African countries.
    - **Africa's significant financial and technical dependence on external actors:** Perhaps more than any other global region, Africa is highly dependent on external actors. Therefore, providing resources for the region's transition can have an extensive impact. Indeed, given the current dependent relationship, it is somewhat hypocritical to demand an ambitious energy transition in the region without offering commensurate support. African nations, with their limited financial resources and competing demands, need support to finance the cost premiums often associated with clean pathways. Traditional and innovative mechanisms, such as the upfront monetization of expected carbon savings—that could potentially serve as guarantees/de-risking instruments—should be explored to scale up the available assistance. At the same time, African nations must ensure that such support aligns with developmental objectives. Furthermore, the research community can play a crucial role in highlighting equity and justice concerns as they emerge in the energy transition and forestall the replication of unequal exchange relationships.

As a final note, it is worth mentioning that historical trends are not fully indicative of future patterns, and it is possible that countries will follow radically different patterns in the coming decades. However, while historical trends do not fully predict future trajectories, they provide a crucial foundation for analysis. This study, therefore, serves as a launching point for further research that critically examines the climate-energy-development nexus in Africa, particularly through the lens of international political

economy and development [11, 73]. Indeed, this is the function it serves in this dissertation—as a starting point that frames the approach to the rest of the research. The following chapters expand on this foundation by examining Nigeria's energy transition, further interrogating the interplay between electrification, development imperatives, and global climate commitments.

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Chapter 3

Electricity for Nigeria: Past, Present, and the Transition Ahead

Preface

Towards the end of the project detailed in Chapter 2, I had the opportunity to join Nigeria's Energy Transition Office (ETO), where I was tasked with supporting the socialization and implementation of the country's newly unveiled Energy Transition Plan (ETP). Nigeria—the most populous nation on the African continent, the fourth largest economy by GDP, the country with the highest electricity access deficit in the world, the second-largest emitter in Sub-Saharan Africa (SSA), and one of ten African countries consistently ranking among the top five emitters across the four scenarios analyzed in Chapter 2—had become the first country in Africa to develop an energy transition plan and I was part of a four-person team directly supporting the Federal Government of Nigeria in advancing it [1-3].

This experience provided an invaluable opportunity to examine the unfolding energy transition in a developing country grappling with the tensions inherent in the duality of electrification. Scaling down from the regional, high-level analysis in Chapter 2, it enabled me to conduct an in-depth case study that informs the research in the rest of my dissertation. Through this, I was able to test the insights from Chapters 1 and 2 in the context of an active energy transition on the African continent, raising critical questions: What role does the mega-trend of electrification play in Nigeria's proposed energy transition? Is the duality of electrification acknowledged? How does Nigeria intend to balance climate change mitigation with energy-driven development? Equally important is the question of feasibility: can electrification for the energy transition proceed when electrification for energy access remains incomplete? In advanced economies, near-universal access to reliable electricity appears to be a prerequisite for advancing deeper phases of the electrification mega-trend [4]. Is Nigeria, instead, attempting to pursue both simultaneously?

This chapter explores these questions conceptually, providing critical background on Nigeria's electricity supply industry (NESI), the ETP, and the emerging themes—particularly the shaping role of electricity unreliability—that influence the direction of my research and the framing of the studies that follow.

Given the relatively short period of time that has elapsed since the release of the ETP, my research captures only the early days of Nigeria's energy transition. Much will likely change over the coming decades. Nonetheless, studying these early steps provides an indispensable foundation for understanding what lies ahead, both for Nigeria and, potentially, the African continent at large.

> "See them! What is your priority? A country in total darkness is talking of net zero!"– Twitter/X user from Nigeria[28]

Introduction

At the core of my research is a strong interest in problematizing the energy transition in Africa. My experience socializing and implementing Nigeria's Energy Transition Plan (ETP) in the Energy Transition Office (ETO) from March 2022 to January 2024 provided a unique opportunity to do this within a specific national context. To problematize means to view, interpret, or analyze (an issue, discipline, etc.) as a problem or system of problems to be solved in order to find out if it is as simple as people think. This definition encapsulates what I repeatedly found necessary as I engaged with various stakeholders—including government officials, colleagues, everyday citizens, researchers, donors, and even my own assumptions—about what a transition to a low-carbon society entails for Nigeria.

For instance, while some exceptions existed, many foreign actors criticized the ETP for lacking depth and withheld financial support. Nigerian experts complained about inadequate consultation and engagement during the plan's development, and several other Nigerians viewed it as infeasible or detached from reality. Critics questioned the necessity of an energy transition, given Nigeria's negligible historical and present emissions, and rejected what they saw as pressure from the 'hypocritical West.' Others dismissed the plan outright, citing the country's unreliable power supply, which made the idea of an energy transition seem unrealistic. Some skeptics mockingly suggested that the electric cars and buses proposed in the plan would ultimately be charged using backup fossil-fuel generators due to persistent grid instability.

These perspectives underscore the need to problematize the energy transition in Nigeria and Africa, rather than assuming a transition is universally accepted and underway. They shape my work significantly, influencing the central research question guiding much of the remaining analysis in this dissertation: **How does electricity unreliability shape Nigeria's energy transition—as an African case study?** While Nigeria serves as the primary case study, the insights extend to other African countries facing similar challenges. This framing ensures that while the research is grounded in Nigeria's specific context, it contributes to a broader understanding of the energy transition across the continent.

My research is motivated by an aspiration toward pracademician/scholar-practitioner praxis and a commitment to producing knowledge that accelerates action at the climate-energy-development nexus. The projects developed from this inquiry emerged directly from the day-to-day activities of my work within the ETO. The questions I explore stem from the long list of issues that my colleagues and I sought answers to as we worked to drive advocacy and generate momentum for the plan's implementation. These are questions aimed at accelerating the start of a transition. Thus, my hope is that this scholarly research will be of practical use to policymakers, practitioners, and researchers engaged in Africa's energy transition, while also highlighting critical areas for further study that align with efforts to translate policy into action.

[28] A tweet in response to then Vice President Yemi Osinbajo's post on the launch of Nigeria's Energy Transition Plan [5]

Furthermore, in true scholar-practitioner fashion, my research seeks to bridge *"the boundaries between the world of academia and the world of practice, resulting in a more authentic outcome"* [6]. As Hebert [6, p.35] explains, *"additional blurring often occurs between artificial boundaries (i.e., research paradigms, theory and practice, scholars and practitioners, professional and personal, rationality and emotion), or binaries."* Mullen [7] similarly observes that *"these binaries are collapsed as the scholar-practitioner-as-bricoleur utilizes an eclectic mix of inquiry methods and methodologies to better understand the deep and hidden meanings of a phenomenon."* In this spirit, I apply a combination of theoretical frameworks—including the multilevel perspective on socio-technical transitions, the energy stacking model, and the symbolic logic of infrastructure—alongside quantitative and qualitative methods to examine Nigeria's energy transition.

The next section of this chapter provides a detailed history of Nigeria's electricity sector, identifying key actors, technologies, and policies to establish a contextual foundation for the remaining chapters. This is followed by an overview of the ETP and the major themes that emerged during its development and socialization. Finally, I frame the issue of electricity unreliability—a central facet of Nigeria's energy access challenges—as the focal point of my analysis. This persistent challenge complicates the country's transition agenda and serves as the primary lens through which I examine Nigeria's energy transition.

History of Electricity in Nigeria

Nigeria's electricity sector has undergone several transformations/reconfigurations since the first power plant was established in Lagos Marina in 1896[29,30] [8]. Scholars such as Edomah [9] and Pavanelli *et al.* [10] identify three major technological shifts: (1) coal and diesel use until the mid-1900s, (2) the expansion of hydroelectric power from the mid-1900s (slowing by the 1980s), and (3) the dominance of gas-fueled thermal plants from the 1970s onward. However, as Adebayo [11, p.172] highlights *"power networks are not only technical but also 'cultural artifacts' shaped by variations in resources, traditions, economics and politics across societies and over time"*. Consequently, this section examines these technological shifts within their broader sociopolitical context.

Early Electrification

In the early years, electricity was primarily used for lighting, replacing traditional lamps that used oil from food sources [8-9]. Electrical lighting in Lagos was an initiative driven by both colonial administrators—who sought to reinforce their claims that Lagos was the most *"civilized"* colony in West Africa—and the mercantile elite, represented by the Lagos Chamber of Commerce (LCC) [31]—who pushed for improved street lighting to enhance security and crime control [11, p.185].

Electricity was introduced in response to public demand, and its presence further reinforced its value, driving even greater demand. For instance, it has been noted that the *"installation of electric lights became*

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[29] Adebayo [11, p.195] explains that *"contrary to popular narrative, the first electrical equipment that was purchased and installed was not technically suitable. The PWD [Public Works Department] carried out further investigations and put in a working system in December 1897 during the tenure of Henry McCallum as governor (1897-9)"*

[30] About five years later, Lord Lugard completed a similar project for the Niger company, illuminating the government house in Zungeru (a small city in North-Central Nigeria) [8]. Electricity got to Jos in 1923, Port-Harcourt in 1928, Kaduna in 1929, Enugu in 1933, Maiduguri in 1934, Yola in 1937, Zaria in 1938, Warri in 1939, and Calabar in 1939 [12-13].

[31] The LCC (now Lagos Chamber of Commerce and Industries) was established in 1888 and is Africa's second oldest chamber of commerce [11, p.187].

a growth strategy among African churches, and Africans across the class divides submitted applications to the Public Works Department (PWD)[32] *to install electric lights at home."* [11, p.177]. This enthusiasm was fueled by the widespread perception of electric lighting as a symbol of modernity and progress, with oil lamps being dismissed as *"dirty," "expensive," "old-school,"* with *"messy burners"* and *"smell"* [11, p.204].

Beyond household, church, and street lighting, additional demand for electricity emerged from the colonial administration's trade and export-focused efforts, which often necessitated technological shifts. For instance, the replacement of Lagos's steam plants, installed between 1896 and 1909, with diesel engines after 1910 was largely driven by the energy needs of the Lagos railway workshops at Iddo and Ebute-Metta [8-9]. Similarly, in 1923, tin miners in Jos, Plateau State, established a two-megawatt power plant to support their operations [12].

The discovery and increasing availability of primary energy resources—enabled by extensive surveys conducted by British colonial authorities in the first half of the 20th century—also played a crucial role in shaping Nigeria's electricity system [8, 14]. These discoveries influenced the trajectory of power generation in the country, resulting in a primary focus on coal-fired electricity generation and hydropower.

Resource Discoveries and the Shift to Coal and Hydropower

The discovery of coal in Nigeria in 1909 led to its growing use as a heat source for steam engines in manufacturing [8-9]. This industrial application reinforced coal's role in the country's broader energy landscape, ultimately leading to its adoption in electricity generation. For example, a 3.6 MW coal-fired power plant was commissioned in Ijora, Lagos, in 1923, to meet rising demand and expand Nigeria's generation capacity [8]. Although oil basins had been identified in the early 20th century, colonial authorities prioritized coal over oil due to concerns about oil's economic viability at the time [10].

By the 1930s, plans to harness Nigeria's hydropower potential were introduced as part of efforts to diversify the electricity mix in response to growing demand [9, 14]. Between 1917 and 1922, a comprehensive survey of hydropower potential across the British Empire was conducted, followed by detailed hydrological investigations of individual colonies [14]. In 1922, the Nigerian Electricity Supply Company (NESCO) was established as a private firm to manage hydropower generation in Jos and provide electricity to select locations in Northern Nigeria[33] [9, 12, 14-15].

However, hydropower expansion faced several constraints, including high costs, accessibility challenges, and seasonal fluctuations in river flow [8, 14]. As a result, coal remained the dominant energy source for electricity generation until the 1940s and 1950s. During this period, a decline in coal mining activities—partly due to disruptions caused by World War II—combined with early discoveries of crude oil, set the stage for Nigeria's gradual transition away from coal-fired power plants [8].

Nigeria's electricity sector also witnessed several structural transformations in the colonial and early post-colonial period. While the PWD played a role in establishing Nigeria's first electrical power plant in Lagos, electricity provision remained largely a private affair during the colonial era, with Native

[32] The PWD was established by the colonial administration to plan and develop several infrastructural facilities in Nigeria (roads, electricity, ports and harbors, etc.) [9, p.30].
[33] Falola [12] states that the Nigerian Electricity Supply Company was established in 1929 while Oluleye & Koginam [13] claim it was licensed by the government in 1929.

Authorities (NAs)[34] and private companies such as NESCO operating electricity infrastructure [13-14].

However, after World War II, growing electricity infrastructure challenges necessitated increased governmental interventions and coordination [8]. Hasenöhrl [14, p.18] describes this as a period of *"developmental colonialism"*, during which *"Britain committed to spending more metropolitan resources in its colonies."* In response, the Nigerian Government Electricity Undertaking (NGEU) was established in 1946 as a temporary entity, intended to last five years before paving the way for a future corporation. The NGEU developed a 10-year plan (1946–1956) to increase electricity generation capacity by 200% and several manufacturing plants, for example, based their growth projections on the expected expansion of electrical infrastructure [9].

In 1950, electricity supply in Nigeria was centralized under the Electricity Corporation of Nigeria (ECN), while Native Authorities were permitted to continue managing their electricity systems [9, 12]. All electricity generation assets were transferred to ECN, which became the national center for generation, transmission, and distribution [12-13]. This restructuring occurred in parallel with preparations for Nigeria's independence, as British colonial administrators transitioned institutional control to Nigerians [8, 14]. Furthermore, Hasenöhrl [14, p.17] notes that *"technological advances made centralized generation with the transmission of large quantities of electricity over greater distances commercially viable."*

Post-Independence and the Expansion of Hydropower

Following Nigeria's independence on October 1, 1960, the Federal Government prioritized hydroelectricity as part of its broader agenda for rapid industrialization. In 1962, it established the Niger Dams Authority (NDA) to develop the country's hydropower potential [10, 13, 16]. The NDA initiated the construction of the Kainji Dam along the River Niger between 1964 and 1968 with support from international partners [13, 17].

As Hasenöhrl [14, p.18] explains, hydroelectric projects represented,

> "Outstanding symbols of state power, control over the environment, and technological competence. Large dams were not only promoted by newly independent governments but also aided (and funded) by many international organizations and donors (including the UN and World Bank) until well into the 1970s, reinforcing the tendency to 'think big' in terms of energy production and consumption."

This suggests that beyond energy needs, the symbolic significance of large hydropower projects—combined with foreign financing and the influence of similar projects in other newly independent states, such as Ghana's Akosombo Dam on the Volta River—played a key role in shaping Nigeria's post-independence electricity strategy [14].

However, Nigeria's first decade post-independence was marked by political instability, including multiple military coups, counter-coups, and ultimately a civil war. These disruptions had widespread socioeconomic consequences, including severely limiting resources for the expansion of the electricity

[34] Native Authorities were local governance structures created during the colonial period, typically comprising traditional leaders like chiefs and emirs. Recognized by the British colonial administration, these authorities were entrusted with administrative functions, including maintaining law and order, taxation, and public services.

industry [8, 10]. They also led to a highly militarized and centralized decision-making structure, which was *"fostered by the command structure of the armed forces."* [8, 18].

In 1972, the NDA merged with ECN to form the National Electric Power Authority (NEPA), driven by the military government's belief that *"it would be economically efficient and effective for all power assets in the country to be controlled by a single entity"* [13, p.191 (quote); 18]. The national grid connected existing power stations such as the Kainji hydro plant in Niger, and the thermal stations in Lagos (Ijora) and Eastern Nigeria (Oji River and Afam) [18]. NEPA therefore became the government-owned utility responsible for generation, transmission, and distribution nationwide [16]. By 1974, NEPA supplied approximately 98.7% of Nigeria's electricity [18].

The Rise of Oil and Gas in the 1970s and 1980s

While crude oil was discovered in commercial quantities in 1956, significant oil and natural gas production did not begin until after the Nigerian Civil War (1967–1970). Nigeria's entry into the Organization of the Petroleum Exporting Countries (OPEC) in 1971 further spurred domestic production [10]. By the time of the first oil shock in 1973, rising oil prices significantly improved the economic viability of oil production and would be *"a primary cause for natural gas internal abundance, and consequently for the dominance of gas-fueled electricity supply in Nigeria since the 1980s"* [10]. Additionally, gas-fired electricity generation became dominant because natural gas was more cost-effective than coal in the Nigerian context [9]. Consequently, the transition away from coal fired power plants in Nigeria became well-entrenched from the 1970s such that all the coal fired power plants built in the country from the 1920s to the 1950s have been retired [9].

Following the initial boom in hydro power right after independence, drawbacks—such as being cost-intensive leading to significant debt—were exhibited, which alongside the growth in gas production can partly explain why hydro projects have slowed down in Nigeria since the 1980s. Of the 29 grid-connected plants recorded by the Nigeria Electricity Regulatory Commission (NERC) in 2022, 25 were gas-fired and only 4 were hydro-based [19]. However, there appears to be a renaissance of such projects with the recent commissioning of Dadin Kowa hydroelectric power station (40MW), Kashimbilla hydroelectric power station (40MW) and Zungeru hydroelectric power station (700MW) [20-23].

Privatization and Market Reforms (1980s–2020s): Reshaping Nigeria's Power Sector

In response to severe economic challenges in the 1980s, resulting from the collapse of global oil prices, Nigeria sought assistance from the International Monetary Fund (IMF) and the World Bank [10]. This led to the adoption of a Structural Adjustment Program (SAP) in 1986, which, in line with a global trend of electricity market liberalization, encouraged the commercialization and eventual privatization of the power sector [10, 13, 16, 24].

As part of these reforms, the National Electric Power Authority (NEPA) was commercialized in 1991[35] and earmarked for privatization [16]. However, the privatization process was significantly

[35] Following NEPA's commercialization, the organization was expected to *"operate without subventions from the budget, and to fix rates, prices and charges"* [16, pp.305 – 306]. The objectives included improved cost recovery, revenue collection, operational efficiency, financial independence and corporate governance. Unfortunately, the expected results did not manifest. Tallapragada & Adebusuyi [16, p.306] submit that *"the utility viewed commercialization merely in terms of raising its tariffs while the power supply situation worsened."*

intensified from 2000 onwards, following Nigeria's return to democracy [10, 13, 16, 24]. A pivotal milestone in this process was the Electric Power Sector Reform Act (EPSRA) of 2005, which led to the establishment of the Power Holding Company of Nigeria (PHCN) as an interim entity to manage NEPA's assets and liabilities. By November 2013, PHCN was eventually unbundled into 18 successor companies, comprising six generating companies (GENCOs), 11 distribution companies (DISCOs), and one transmission company, the Transmission Company of Nigeria (TCN) [8, 10, 16, 24].

The return to democracy, which accelerated the privatization process, also led to the conception of the National Integrated Power Projects (NIPPs). These projects were designed as a government-funded intervention to revive the ailing power sector after more than two decades of little to no investment during the military era [25]. At the same time, the Federal Government of Nigeria (FGN) engaged extensively with oil joint venture companies, state governments, and private sector players, encouraging them to invest in the power sector and develop independent power projects (IPPs) [16]. The IPPs and NIPPs were structured to increase electricity generation in phases while simultaneously reducing gas flaring in the Niger Delta region by utilizing associated gas for power generation—reinforcing the dominance of gas as the primary electricity generation fuel [26].

The grid-connected power plants recorded by the Nigeria Electricity Regulatory Commission (NERC) in 2022 include:

- 10 plants originally owned by the Federal Government of Nigeria (FGN) that have been privatized, including:
    - Six GENCOs representing seven power plants that were core assets of NEPA/PHCN
    - Two power plants built in the early 2000s under bilateral agreements with Chinese contractors, later privatized under different transaction structures
    - Afam IV-V power plant, privatized in 2020 after long delays since 2013
- 12 independent power projects (IPPs), owned by private energy companies, state governments, and international oil companies
- Six National Integrated Power Projects (NIPPs) initiated, funded, and still owned by the Federal Government through the Niger Delta Power Holding Company (NDPHC). These NIPPs were not part of the 2013 privatization process [19, 27].

While the FGN retained partial ownership stakes in some thermal power plants, the hydropower plants were placed under long-term concession agreements [28]. Additionally, the FGN retained a 40% ownership stake in all 11 DISCOs, while TCN remained fully state-owned [16].

The EPSRA of 2005 also facilitated the establishment of:

- The Nigeria Electricity Regulatory Commission (NERC) as the independent regulatory authority overseeing the sector
- The Nigerian Bulk Electricity Trading Plc. (NBET) as the intermediary in the Nigerian electricity market, responsible for purchasing electricity from GENCOs and reselling it to DISCOs

- The Rural Electrification Agency (REA) and the Rural Electrification Fund, to promote electricity access in rural areas [16].

Following the completion of the privatization process in November 2013, an interim period was introduced to ensure that all Conditions Precedent were met before transitioning to the next stage of Nigeria's Electricity Supply Industry (NESI) market development roadmap[36]. These conditions included:

- Formalization of trading arrangements
- Establishment of the initial Stakeholder Advisory Panel to review market guidelines and approve amendments
- Publication of the initial Transmission Use of System Charge (TUoS)
- Development and testing of systems and procedures for implementing the Grid Code[37] and Market Rules[38], overseen by the System Operator[39] and Market Operator[40] [29].

Additionally, several structural and financial challenges—such as the lack of a cost-reflective tariff, liquidity constraints faced by DISCOs, and gas supply disruptions—necessitated an extended interim period [29].

In February 2015, NERC formally declared the commencement of the Transitional Electricity Market (TEM) [29]. This stage was intended to mark a significant shift by transitioning the Nigerian electricity market into a contract-based framework, where NBET would function as the single buyer of electricity from GENCOs and the sole seller to DISCOs. Under the TEM, the Nigerian electricity market was expected to be wholly governed by contracts (e.g., Gas Supply Agreements, Power Purchase Agreements, and Vesting Contracts) and enabled by a cost-reflective tariff [28-29].

However, the aspirations of the reform process have not been fully realized, and the requirements for a functional TEM remain unmet due to factors such as inadequate policy implementation and sector

[36] After the introduction of the Electric Power Sector Reform Act (EPSRA) in 2005 and the commercialization of PHCN's assets between 2005 and 2007, a roadmap for power sector reform was inaugurated in 2010. The roadmap aimed to implement the reform milestones outlined in the EPSRA through a gradual, phased approach to increasing market competition. It was structured into four stages: the Pre-Transitional Period, which involved the unbundling of PHCN, the establishment of NERC, and the introduction of key frameworks such as the grid code, market rules, and the designation of NBET as the Single Buyer; the Transitional Electricity Market (TEM), characterized by an unbundled service structure with active bulk power trading by NBET and transactions based on contractual agreements; the Medium-Term Electricity Market, which allowed for increased generation competition with bilateral contracts between DISCOs and GENCOs/IPPs, as well as limited retail competition; and finally, the Long-Term Market, envisioned as a fully competitive electricity market, where both retail and generation sectors operate under bilateral contracts between electricity buyers and sellers at all levels, alongside the establishment of a spot electricity market [28-29].

[37] The EPSRA mandated the development of a Grid Code to set the technical rules and standards for governing the planning, operation and maintenance of the national grid, to ensure its stability and reliability [33-35].

[38] According to the EPSRA, market rules are to guide the operation of the national grid and administration of the wholesale electricity market. Market rules establish the framework for the operation of the electricity market, outlining the commercial, legal, and operational relationships between market participants [33-35].

[39] The System Operator, on a real-time basis, is responsible for determining the optimal combination of generating units, generation outputs and generation reserves needed to reliably satisfy load demand, taking into consideration operational constraints and system cost. It is responsible for ensuring the reliability of the transmission grid and maintaining technical stability in the electricity market through enforcing the Grid Code and developing the market rules. In the Nigerian power system, the System Operator is a division within TCN [33-35].

[40] The Market Operator is responsible for implementing the Market Rules, including administering the metering and settlement system among GENCOs, TCN and DISCOs, covering ancillary services, administrative charges, regulatory charges and transmission wheeling charges. TCN is also currently the Market Operator [33, 35].

governance, the absence of an overarching or integrated planning framework, lack of commercial viability, weak operational performance and decades of underinvestment and poor maintenance [24, 28-31]. For instance, despite expectations that privatization would reduce government intervention, the FGN has had to introduce multiple temporary intervention funds through the Central Bank of Nigeria since 2014 [16, 28]. These include the Nigerian Electricity Market Stabilization Facility (NEMSF) set at ₦213 Billion, and the ₦701 Billion Payment Assurance Facility (PAF) [28]. As of 2024, about ₦555 Billion has been disbursed under NEMSF 1-3 and ₦1.3 Trillion under the PAF [32].

Decentralization and The Electricity Act of 2023

On June 8, 2023, Nigerian President Bola Ahmed Tinubu signed The Electricity Act (EA) 2023 into law, repealing the EPSRA and consolidating all laws governing the NESI. Importantly, in line with an earlier Constitutional Amendment[41], the EA recognizes the rights of Nigerian states to make laws concerning electricity generation and transmission within their borders[42]. This grants Nigerian states the power to establish their own electricity markets, build power stations, and set up independent regulatory commissions [24, 36].

As it is uncertain whether state-level grids will be feasible or economically viable in many states, the Nigerian electricity market is expected to remain heavily dominated by NERC in the short to medium term [36]. Furthermore, concerns persist regarding whether NERC and state governments will successfully coordinate efforts to prevent overregulation and market confusion [24]. As of February 2025, ten Nigerian states (Enugu, Ekiti, Ondo, Imo, Oyo, Edo, Kogi, Niger, Ogun and Lagos) have established their own electricity regulatory commissions, gaining the authority to manage and regulate their electricity markets [37-46].

Additionally, the EA introduced several key reforms, including:

- Independent Electricity Transmission Network Licenses (IETNL) which allows licensees to build, own and operate transmission networks outside the national grid and reinforce portions of existing transmission facilities, enabling private sector participation in electricity transmission, alongside TCN.
- Separation of electricity supply from distribution, requiring DISCOs to maintain distribution networks but transfer customer billing and revenue collection to newly created supply companies [36].

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[41] On 17 March 2023, President Muhammadu Buhari assented to the constitutional amendment bill passed by the National Assembly in respect of the amendment to Paragraph 14(b), Part II of the Second Schedule to the 1999 Constitution of the Federal Republic of Nigeria (as amended) to enable states to set up independent electricity markets. The amendment provides that the House of Assembly may make laws for the relevant state with respect to "the generation, transmission and distribution of electricity to areas within that State." Prior to the amendment, the powers of the House of Assembly only extended to areas not covered by the national grid system within that state [49, 50].

[42] Nigeria is a federal republic made up of 36 states and a Federal Capital Territory with political power shared between federal, state and local governments. The Federal Government comprises a legislative body (the bicameral National Assembly made up of the senate and house of representatives), an independent judicial system, and an executive branch led by a strong presidency. Similarly, the state government has an executive branch headed by a Governor, a unicameral legislature known as the State House of Assembly and the State Judiciary. Beneath the State Government, the Local Government is headed by a Local Government Chairman with a Local Government Council (Councillors) acting as the legislative body at the local level. Local Governments do not have independent judicial systems but work closely with customary and magistrate courts [51].

On July 25, 2024, Nigeria's electricity market transitioned to bilateral trading, effectively ending NBET's role as the sole electricity trader [47]. This transition was enacted by NERC pursuant to provisions in the EA [47]. Reports indicate that NBET is now in the process of transitioning into an energy commodity exchange or trading platform [48].

This shift in market structure reflects Nigeria's broader efforts to reform its energy sector and transition toward a more sustainable and resilient electricity system capable of driving national development. While distinct in scope and approach, the Nigeria Energy Transition Plan (ETP) was arguably driven by similar objectives—offering a structured framework for decarbonization while ensuring energy access and economic growth.

Nigeria's Energy Transition Plan: Reducing emissions and powering development

Nigeria's ETP, the first of its kind in Africa, was developed in 2021 and served as the basis for then-President Muhammadu Buhari's commitment to net-zero by 2060 at COP26 in Glasgow that same year [52]. Shortly after this announcement, the plan was unveiled and officially launched by then-Vice President Yemi Osinbajo on August 24, 2022. It was defined as *"a home-grown, data-backed, multipronged strategy developed for the achievement of net-zero emissions in terms of the nation's energy consumption."* [53]. The ETP was approved by the Federal Executive Council, and an Energy Transition Implementation Working Group (ETWG)—chaired by the Vice President—was established to oversee its execution. Core members of the ETWG included the Ministers for Environment, Finance, Power, Works & Housing, Petroleum, and Foreign Affairs, while the Energy Transition Office (ETO), housed within the Office of the Vice President, was designated as the ETWG's dedicated secretariat [54].

Within the scope of the ETP, approximately 65% of Nigeria's emissions are addressed. The plan sets out a timeline and framework for emissions reduction across five key sectors: Power, Cooking, Oil & Gas, Transport, and Industry. However, beyond mitigation, the plan is also centered on low-carbon development, emphasizing that Nigeria's transition must not only cut emissions but also meet the country's growing energy needs [53]. In this sense, the plan articulates the pathways and scale of resources required to achieve SDG 7 by 2030 and net-zero emissions in energy consumption by 2060[43].

In the power sector, the ETP strategy aims for the complete elimination of diesel/petrol generators and the expansion of generation capacity via renewable sources, primarily solar, with an initial ramp-up of gas generation. In the cooking sector, the plan details a shift from traditional fuels—such as firewood, charcoal, and kerosene—to liquefied petroleum gas (LPG) (in the short term), followed by biogas and electric cooking. In industry, the plan proposes that emissions will decrease despite industrial growth through a 100% transition to zero-emission fuels, such as hydrogen and clean electricity for heating, as well as targeted decarbonization efforts in cement and ammonia production. In the transport sector, the uptake of electric vehicles (EVs) in the passenger car segment is expected to drive emissions reductions, even as demand for mobility increases. Meanwhile, in oil & gas,

[43] The Nigeria ETP was initially developed with a 2050 net-zero target but given the significant financial, social and technological requirements, the nation adjusted the timeline to 2060 [53].

emissions are projected to decline primarily due to reduced global demand for fossil fuels. Additional reductions will come from decreased flaring and fugitive emissions, improved electrification, and enhanced energy efficiency in upstream operations, even as local production and refining increases in the short term. [53].

Crucially, the plan is grounded in five key imperatives [53]:

- Lifting 100 million Nigerians out of poverty and driving economic growth
- Providing modern energy services to the full population
- Managing long-term job losses expected in the oil sector as fossil fuel demand declines globally
- Positioning Nigeria as a leader in Africa's energy transition, advocating for an equitable, inclusive transition that incorporates natural gas as a transitionary fuel
- Streamlining and coordinating both existing and new government-led energy transition initiatives

The ETP in Context: An Example

Interestingly, even before the themes that later emerged during its socialization and implementation, both Nigeria's ETP and its development process reflected several insights from my earlier research in Chapters 1 and 2. Among other things, the plan highlighted the following:

The energy sector as the starting point for climate mitigation:
In developing and advancing the ETP, Nigeria explicitly recognized the energy sector as the foundation of its climate mitigation strategy. This was evident in how the nation's landmark net-zero commitment was anchored in energy decarbonization. Similar to global trends, Nigeria estimates that its energy sector is responsible for 60–65% of its total emissions [55-56].

Electrification as the primary strategy:
As discussed in Chapter 1, the mega-trend of electrification is a central pillar of decarbonization. The ETP fully embraces this, envisioning a comprehensive electrification of the economy as its core net-zero strategy. The three phases of electrification outlined in Chapter 1—expanding renewable power generation, enhancing grid flexibility and storage, and sector coupling—are all embedded in the ETP. The plan projects an unprecedented >7x expansion of electricity generation capacity, primarily driven by solar, to meet a 9x increase in electricity demand from the electrification of cooking, transport, and industry alongside hydrogen production (Figures 3-1 and 3-2). Additionally, while Nigeria had no large-scale storage capacity in 2020, the plan projects over 100 GW of storage capacity by 2050.

The duality of electrification:
The ETP was widely framed around two overarching goals—achieving SDG7 by 2030 and net-zero energy emissions by 2060—implicitly acknowledging the duality of electrification. The plan was not solely designed to support decarbonization and carbon neutrality but also to expand energy access and drive industrialization. The language around the ETP consistently emphasized the rapid development of low-carbon, sustainable energy systems as a means to address the dual crises of energy poverty and climate change.

The tensions inherent in pursuing electrification as both energy transition and energy access:

The 'natural gas vs renewables' debate alluded to in earlier chapters was central in the advocacy and strategy of the ETP. Nigeria's immediate past Vice President—Prof. Yemi Osinbajo, the main champion of the ETP—strongly argued that developing nations must leverage available fossil fuels, particularly natural gas, to bridge their massive energy deficits [57-58]. Reflecting this stance, the plan prominently centers natural gas as a transition fuel—to provide baseload energy, stabilize the grid for large-scale renewables integration, and address clean cooking deficits through LPG [59-61]. The ETP projects a 25% increase in gas consumption above 2019 levels by 2030, after which it is expected to decline towards the 2060 net-zero target [60]. This gas reliance was framed as crucial, given Nigeria's abundant gas reserves, energy security considerations, and urgency of scaling energy systems [60]. The plan also incorporates carbon capture and storage (CCS) provisions to mitigate emissions from increased oil production and refining activities [62-63]. However, not all stakeholders in Nigeria support this approach. Several civil society organizations oppose the gas-centered strategy, citing concerns such as shrinking demand for gas in a transitioning world, limited international financing for fossil fuel projects, and the challenges of transitioning twice—first to gas, then to renewables—rather than moving directly to renewables [64]. Citizens, particularly in the Niger Delta, have also urged the Nigerian government to halt new fossil fuel projects and redirect investments toward sustainable, green energy solutions [65].

Climate action exceeding actual responsibility for emissions:
As of 2020, the base year in the ETP, Nigeria was the fourth largest emitter in Africa and the second largest in SSA. However, given Africa's overall low emissions, this ranking carries little significance on a global scale. Estimates of Nigeria's 2020 total fossil fuel emissions range between 120–130 $MtCO_2e$ [66-67]. The nation's own estimates are higher, with the ETP baseline energy emissions at 179 $MtCO_2e$ and the NDC baseline 2018 energy emissions at 209 $MtCO_2e$ [55-56]. Regardless of these variations, Nigeria's energy emissions account for less than 0.6% of global fossil fuel emissions, and historically, the country is responsible for just 0.2% of cumulative global CO_2 emissions [68]. As highlighted in Chapter 2, future emissions from Africa are projected to remain relatively minimal, and Nigeria follows a similar trajectory. The ETP's business-as-usual (BAU) scenario projects that Nigeria's energy emissions will grow to 322 $MtCO_2e$ by 2050, which is less than 3% of China's 2020 emissions [55, 66] (Figure 3-3). This projection aligns most closely with the mid-growth scenario outlined in Chapter 2, rather than the high-growth case, reinforcing the finding that Nigeria's emissions—while expected to increase—are unlikely to significantly impact global mitigation efforts. Taken together, these figures emphasize Nigeria's minimal contribution to past, present, and future global emissions, raising questions about the necessity of the nation's seemingly strong prioritization of climate mitigation—as reflected by the development of the ETP and the net-zero commitment. Nonetheless, discussions within the ETO suggested that both the ETP and net-zero target were largely strategic—designed as signaling tools to mobilize international climate finance and establish Nigeria as a leader in Africa's climate transition discourse.

Technical and Financial Dependency on the West:
The ETP was developed in partnership with Sustainable Energy for All and McKinsey, with support from the UK COP26 Energy Transition Council (ETC) [52]. The ETO itself was also funded by international partners to assist the Nigerian government. This reliance on external consultants and financing is not unique to the ETP but is a defining characteristic of climate action in Nigeria, where most major initiatives depend on foreign expertise and funding [69]. At COP26, where President

Muhammadu Buhari announced Nigeria's net-zero commitment, the governments of France, Germany, the United States, the United Kingdom, and the European Union had pledged $8.5 billion through the Just Energy Transition Partnership (JET-P) for South Africa [70]. Nigeria's ETP was designed to mobilize similar funding. One of the most frequently cited contributions of the plan was its role in quantifying the financial resources required to achieve Nigeria's energy access and transition goals. Indeed, it presented a striking estimate: transitioning to net-zero would cost Nigeria $1.9 trillion over the next four decades, including $410 billion above business-as-usual spending. This additional financing requirement translates to approximately $10 billion per year—a figure that became the foundation of the ETWG's primary objective to secure at least a $10 billion financing commitment by COP27 [54]. For context, Nigeria's entire 2022 federal budget was approximately $40 billion (17 trillion naira, based on the budget's assumed exchange rate of ₦410.15/USD) [71-72]. This meant that the ETP's financing target equaled 25% of the nation's annual budget—a monumental ask. Consequently, the ETP was strategically framed as an investment opportunity, largely targeting international development partners [52]. Unfortunately, Nigeria has not been able to replicate South Africa's success in securing a JET-P, likely due to its lower emissions profile and lack of significant coal capacity—a major global priority in transition efforts. Nigeria's total emissions are only 30% of South Africa's, and whereas coal generates ~90% of South Africa's CO_2 emissions, it accounts for less than 0.1% of Nigeria's emissions [66-67, 73-74].



Figure 3-1: Electricity Generation and Storage Capacity Growth in Nigeria's Energy Transition Plan [75]



Figure 3-2: Electricity Demand Growth in Nigeria's Energy Transition Plan [75]

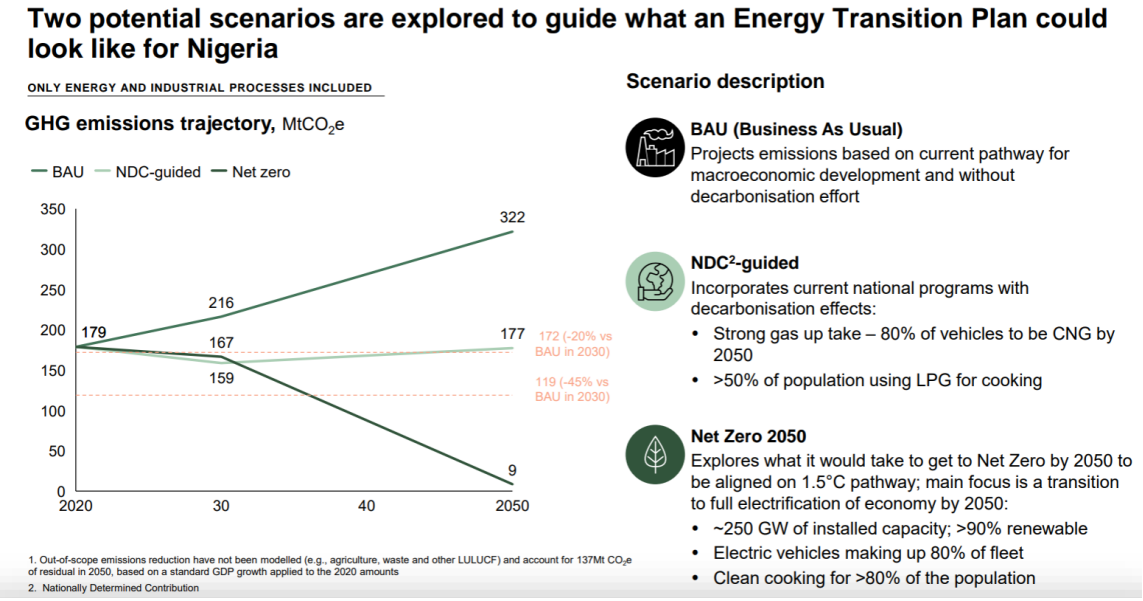


Figure 3-3: Nigeria's projected energy emissions trajectory [55].

The ETP's Uncertain Path

As work began on socializing the ETP across diverse stakeholders—including development partners, local experts, private sector financiers, civil society organizations, and everyday Nigerians—more important themes emerged, highlighting contentious issues in the energy transition agenda. The core criticisms, largely from energy and climate experts as well as international development partners, were that the plan lacked depth and was disconnected from Nigeria's technological, economic, societal, and political realities. This disconnect was attributed, at least in part, to a closed development process that neglected consultations and collaborations with local experts and civil society organizations [76-78]. The widespread knowledge that the plan had been developed by McKinsey & Co., combined with restricted access to documents outlining the plan and the modeling tools underpinning it, only fueled these concerns. As some experts noted:

> "Many have observed that the Nigerian ETP was constructed rapidly, behind closed doors, by multinational consultants using proprietary modelling tools, rather than through a collaborative process incorporating national discourse and national expertise, to which the continuous energy policy debate could recur again and again. It is possible that the Nigerian government's very limited success in mobilising significant money since the elaboration of the ETP may be partly attributed to the apparent lack of national debate and transparency" [78].

Additionally, a persistent argument was that development, not climate change, should be Nigeria's primary focus. Many critics questioned why the country had joined the net-zero *"bandwagon"*, at the insistence of more advanced nations—many of which had failed to meet their own climate commitments [77]. Among everyday Nigerians, this sentiment was frequently expressed alongside complaints about the country's unreliable electricity supply. To illustrate, I highlight below a selection of tweets in response to Vice President Yemi Osinbajo's posts on the launch of Nigeria's Energy Transition Plan (Figure 3-4) [5].

Excluding general insults to the government, spam messages, conspiracy theories, and incoherent comments, approximately 40% of relevant responses focused on Nigeria's unreliable electricity supply and questioned whether energy transition should be a national priority. Interestingly, about 45% of the responses were supportive of the energy transition, with some even advocating for more ambitious action. For instance, one user tweeted, "2050 sir, not 2060; the global range agreement. We also believe half of our emissions by 2030. It is realistic!"[44]

However, the tone of some supportive tweets suggests that a significant share may have come from individuals who were generally supporters of the Vice President. The remaining responses included concerns about Nigeria's limited technical and financial capacity to embark on an energy transition, skepticism about the plan's implementation, fears about the loss of momentum after a change in government, acknowledgment of Western influence in shaping the plan, and critiques of Western hypocrisy—such as Germany reverting to coal-fired power during the energy crisis triggered by Russia's invasion of Ukraine. Some responses also suggested alternative solutions, such as tree planting.

[44] Tweet was accessed on 24th February 2025 from X (formerly Twitter)

On the energy transition not being a priority:

In addition to emphasizing Nigeria's more pressing needs—such as industrialization, education reform, security, and corruption eradication—these tweets often portrayed the ETP as a product of Western pressure or a bid to attract to foreign financiers:

- "100% for reduced CO_2 emissions, but please note, **geopolitics is involved**. Africa contributes less than 3% of Global CO_2 emissions; we need industrialization to develop. What is cheaply and readily available to us? Asia and the West should cut by 75%. **Let Africa develop first**."
- "Without prejudice to the plan, I daresay **carbon neutrality should be at the bottom of priorities** for Nigerian government—not because it is not important, but it doesn't help our growth in anyway and can be directly counterproductive at this time."
- "Africa does not contribute a lot to climate change, but we shoulder parts of its brunt. **Africa needs to industrialize by all means to lift our people out of poverty first and foremost. That should be our priority."**
- **"Try to achieve hunger free, corruption free and well secured society. Masses couldn't understand carbon neutrality."**
- **"If we don't address poverty in Africa**, you can hardly get people to take an interest in global warming. A larger part of our population still depends on firewood for cooking fuel and diesel for transport and powering generators."
- **"Nigeria needs to be developed** like Europe using all the fossil resources we are endowed with. Commitment to carbon capturing technology should be the focus for oil rich countries."
- **"Insensitivity! You leave Nigeria's bad governance, insecurity, dying economy...talking about global climate**...is Nigeria having climatic challenges?"
- "This man, you no get conscience ooo…**your house de burn you de pursue rat!!!** *(You have no conscience…your house is on fire, yet you are chasing a rat!)***. For 8 years now you have consistently pursued things that did not impact Nigeria and Nigerians positively.** Why not use the remaining days to do something, 1 single thing to help Nigeria?"
- **"Person wey neva chop, person wey dey in kidnappers den, u dey tell climate change na his greatest existential threat lol"** *(A person who hasn't eaten, a person held in a kidnapper's den, and you're telling them climate change is their greatest existential threat? Lol)*
- **"Climate change is definitely the least of our problems**. Naija *(Nigerian)* politicians are scam."
- "Dear Vice President, Corruption will kill us first before climate change."
- **"See this people writing threads to win UN funds whitelists**. Maybe you guys should **focus on the more immediate ones facing the country**."

On electricity deficits:

While Nigeria has significant access gaps—at 86 million unelectrified people, the largest in any country—the tweets discussing the nation's electricity supply deficits appeared to focus not necessarily on those without any electricity connection but rather on those experiencing unreliable supply [3]. This reading is supported by specific mentions of electricity utility companies, an emphasis on generating "stable" electricity, the use of the term "fix," and the reasonable assumption that individuals

with access to Twitter/X and an interest in engaging with the VP's tweets likely already had electricity connections.

- "Oga (*Mister/Boss*), you guys should give us electricity and stop all this unfruitful fantasy."
- "You need to have energy first before you talk of transitioning."
- "Sir, **NEPA**[45] don off light[46] since morning *(Sir, NEPA has turned off the light since morning)*, we can't pretend everything is ok o."
- "Go and **fix PHCN**[47] and stop chasing shadows."
- "All those countries you are copying have **stable electricity**. So, what are you guys transitioning from? No energy to no energy. You don't have energy before."
- "Oga, **fix electricity** first jare. Wetin una dey emit." *(Mister, fix electricity first. What exactly are you even emitting?)*
- "We can't even **generate stable electricity** yet."
- "**Electricity workers** are on strike, we don't have light and you're tweeting this rubbish."
- "See them! What is your priority? A country in total darkness is talking of net zero!"
- "Is this a joke? 🤣🤣🤣🤣🤣🤣 does Nigeria have energy, let alone transitioning?"

On both themes:

- "@ProfOsinbajo **the people in Europe that encouraged you to go net zero**, have all gone back to coal. **Meanwhile you don't have electricity, and not yet industrialized**. Seriously our leaders are special kind of human."
- **"You don't have electricity**. Your inability to provide electricity is causing many Nigerians to use generator which adds to smoke. **You have not industrialized**. And **here you are joining white man to talk climate change and energy transition**. Seriously una taya me *(seriously, I'm exhausted by you all)*."
- "And they are seeking $10bn. Can this government be gone already? **While the idea is good, it's not what we need now. We haven't generated electricity every country got**, **it's this one??** I don't trust this government with another loan from anywhere. Earthworms will carry it away."[48]

[45] NEPA (the abbreviation for the National Electric Power Authority, which is now defunct) remains a generic nickname for grid-based electricity [79-81]. To a lesser degree, this also applies to PHCN (Power Holding Company of Nigeria). Smith [82, p.60] suggests that Nigerians still call the national grid 'NEPA' *"as if to note the continuity of failure"*.

[46] Nigerians colloquially refer to electricity as light.

[47] See note 45 above.

[48] All tweets, accessed on 24th February 2025, from X (formerly Twitter).

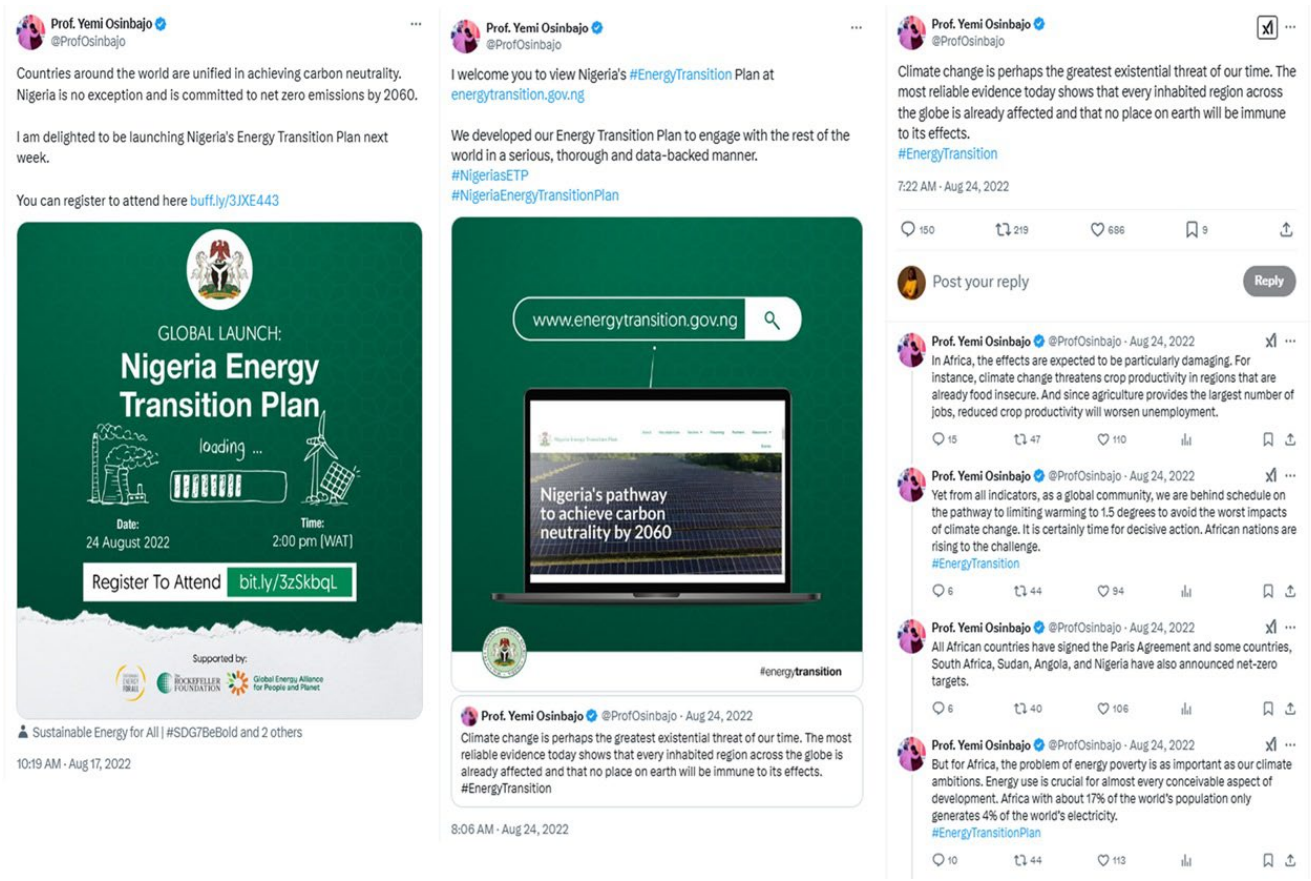


Figure 3-4: Vice-President Yemi Osinbajo's tweets on the launch of Nigeria's Energy Transition Plan [5].

Any of the highlighted themes that emerged before and during the socialization of the ETP—and, interestingly, how they interacted with one another—could serve as the basis for further in-depth analysis and research. For instance, during the initial months of socializing the ETP, the ETO was among the representatives of the Nigerian government that hosted a European Union delegation, including the European Commission Deputy Director General for Energy, in their pursuit of diverse gas supplies in response to the Russia-Ukraine crisis. Yet, over time, the tolerance of foreign actors—particularly the ETO's largely American funders—for natural gas waned, leading us to scale back the emphasis on gas in our messaging and shift our focus more toward renewables. This evolution in positioning could have spurred research into the changing priorities of international partners and their impact on Nigeria's energy transition. It also raises questions about the influence of different international actors—such as European versus American entities—on Nigeria's approach to the transition.

Similarly, criticisms regarding the inaccessibility of the model underpinning the ETP and concerns that its assumptions and scenarios were detached from local realities could have driven efforts toward more context-specific, rigorous, and publicly accessible modeling. Meanwhile, concerns about whether climate mitigation should be a priority for Nigeria have, to some extent, been addressed in the research outlined in Chapter 2. Indeed, in the absence of significant economic development, Nigeria's emissions are projected to remain minimal, potentially negating the need for deep decarbonization

pathways. As such, energy transition efforts should go hand in hand with strategic development efforts—or, in a worst-case scenario, follow after them, but certainly not precede them. Still, deeper analysis into this public concern surrounding the energy transition could have provided further insights.

However, among all these issues, the subject of electricity deficits resonated with me most. As highlighted in both the tweets and my conversations with stakeholders during my time at the ETO, the prevailing concern regarding Nigeria's electricity sector was not just the widespread lack of access across large portions of the country, but perhaps more pressingly, the problem of unreliable supply. This aligns with a growing body of literature recognizing that meaningful electricity access—and consumer satisfaction with electricity services—extends beyond mere connectivity [83-85]. There has, in fact been a shift from binary "on-grid" or "off-grid" categorizations of electricity access to multidimensional measurement frameworks that assess energy supply in terms of usability for desired services [86-91]. For instance, the Multi-Tier Framework (MTF) introduced by the World Bank's Energy Sector Management Assistance Program (ESMAP) delineates electricity access along a continuum of five tiers (Tiers 1 through 5), with a separate category (Tier 0) for individuals in total energy poverty. This framework evaluates improvements in household electricity access across the following attributes: (i) capacity, (ii) duration/availability (including daily supply and evening supply), (iii) reliability, (iv) quality, (v) affordability, (vi) legality, and (vii) health and safety [30, 89, 91-93].

Having grown up in Nigeria, I am intimately familiar with the electricity unreliability that characterizes the nation's grid. Both lived experience and extensive literature discuss the far-reaching impacts of this unreliability across businesses and households, affecting productivity, customer satisfaction, and even the quality of service in critical buildings such as hospitals [4, 18, 81-82, 86, 90, 94-98]. Given this background, it was striking to observe electricity unreliability also rise to the top in the public discourse surrounding the energy transition.

At the time the tweets referenced earlier were posted, no official documentation detailing the ETP's strategies had been made publicly available. Yet, Nigerians instinctively linked the energy transition to electricity—surfacing the tension between electrification as energy transition (EAET) and electrification as energy access (EAEA). The underlying questions being asked were: How can Nigeria embark on EAET when EAEA remains incomplete? How can EAET even be considered when basic electricity access is still unreliable? Many argued outright that EAET was either impossible or, at best, a misplaced priority until the electricity supply improves. This discourse reflected a deeper dilemma: Should Nigeria first move citizens up the energy access ladder before stepping onto the EAET ladder (Figure 3-5), or is it possible to pursue both concurrently (Figure 3-6)? Rather than accepting these arguments at face value, I sought to interrogate them more rigorously using data.

Moreover, the limited knowledge on the suite of interacting technical, social, and cultural factors that define electricity unreliability in power systems—particularly in sub-Saharan Africa—further deepened my curiosity about this topic and underscored its relevance in the literature [85, 92]. Although power outages in Nigeria are widespread, erratic, and both economically and socially disruptive, the precise scope and patterns of these outages are not well understood—neither in the academic literature nor among everyday citizens. In casual conversations, I would often hear people say, *"they have turned the lights off"*—where *"they"* could refer to anyone from government officials to workers in electricity distribution companies. This prevailing uncertainty over the cause of outages—whether they were

planned curtailments, failures in the electric grid network, supply inadequacies, or simply the arbitrary actions of *"they"*—made clear the need for a more thorough investigation of electricity unreliability.

Thus, I centered my research question on understanding the role of electricity unreliability in shaping Nigeria's energy transition—using the country as a case study to explore broader trends across Africa. The research first examines how unreliability interacts with Nigeria's energy transition plans and ambitions, and then turns to the limited understanding of electricity unreliability itself. It seeks to build a clearer picture of reliability by investigating the frequency and duration of outages, how they are classified by distribution companies, what causes them, and how these patterns vary across locations.

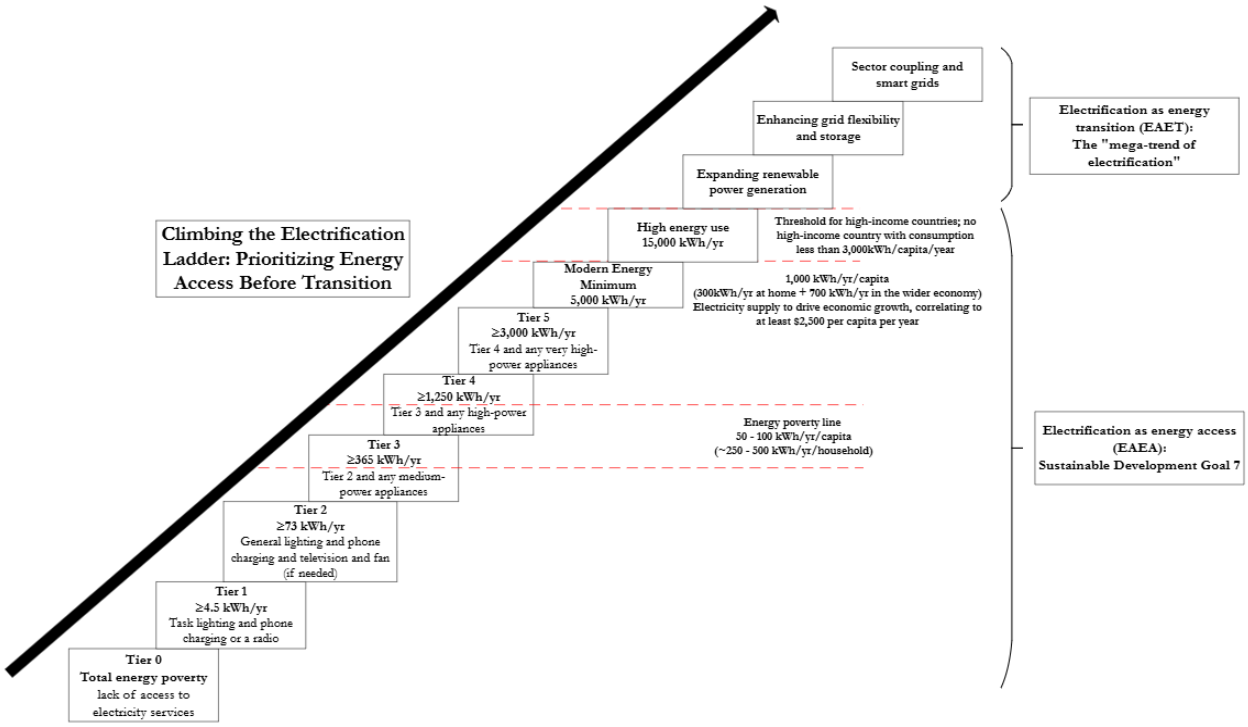


Figure 3-5: ***Climbing the Electrification Ladder: Prioritizing Electricity Access Before Transition.*** *This framework illustrates the argument that countries like Nigeria should first focus on moving citizens up the electricity access ladder—achieving higher tiers of electricity consumption and reliability—before embarking on deep decarbonization and the broader energy transition agenda. The structure is based on ESMAP's Multi-Tier Framework for household electricity access, the Energy for Growth Hub's proposed modern energy minimum, and Aalto's analytical phases of the mega-trend of electrification. *Medium-power appliances include air coolers, refrigerators, freezers, food processors, water pumps and rice cookers; high-power appliances include washing machines, irons, hair dryers, toasters, and microwaves; and very-high power appliances include air conditioners, space heaters, vacuum cleaners, water heaters, electric cookers. To estimate per-capita values, a household size of 5 is assumed [91, 93, 99-101].*

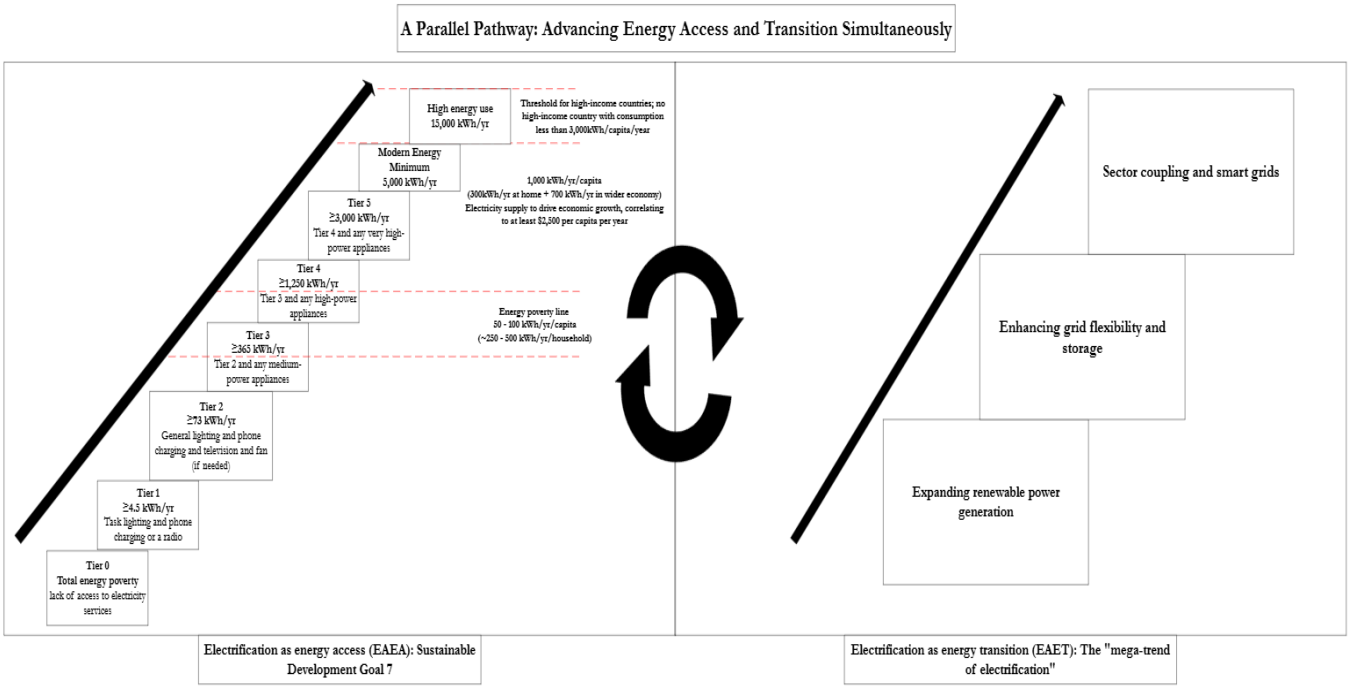


*Figure 3-6: **A Parallel Pathway: Advancing Energy Access and Transition Simultaneously.** This alternative framework presents the possibility of pursuing both Electrification as Energy Access (EAEA) and Electrification as Energy Transition (EAET) concurrently. Rather than a sequential approach, this model suggests that energy policies can simultaneously drive renewable energy deployment and grid decarbonization while also expanding electricity access for underserved populations. The illustration draws from ESMAP's Multi-Tier Framework, the Energy for Growth Hub's modern energy minimum, and Aalto's three-phase model of electrification. *Medium-power appliances include air coolers, refrigerators, freezers, food processors, water pumps and rice cookers; high-power appliances include washing machines, irons, hair dryers, toasters, and microwaves; and very-high power appliances include air conditioners, space heaters, vacuum cleaners, water heaters, electric cookers. To estimate per-capita values, a household size of 5 is assumed [91, 93, 99-101].*

The Shaping Role of Unreliability

Drawing from literature, my experience socializing the ETP, and logical reasoning, I identified three pathways through which unreliability shapes the energy transition via the mega-trend of electrification. While there may be additional pathways, these three serve as a foundation for the research documented in the remainder of this dissertation.

Unreliability contributes to significant, decentralized fossil-fuel power generation:

Unreliability has led to the widespread proliferation of backup fossil-fuel-based generator sets (gensets), which must be phased out in the energy transition. As noted earlier, the core ETP strategy for Nigeria's power sector is the complete elimination of diesel and petrol generators [75]. Nigeria's NDCs also identify the displacement of gensets as a mitigation measure within the energy sector. Several scholars have argued that these gensets are prevalent largely due to Nigeria's unreliable electricity infrastructure [18, 82], with Oseni [97] empirically investigating this relationship. Estimates suggest that the capacity of gensets powering Nigerian households and businesses is nearly eight times the country's centralized electricity capacity [102].

This link between unreliability and genset use is well illustrated in one of the tweets referenced earlier: *"Your inability to provide electricity is causing many Nigerians to use generators…"* What this implies is that unreliability has directly shaped Nigeria's transition trajectory—making it fundamentally different from that of more advanced economies, where the transition largely involves decommissioning coal plants or navigating policy debates over the role of nuclear energy. Since the bulk of Nigeria's ETP envisions an expansion of new power generation capacity rather than the large-scale retirement of existing centralized plants, the challenge is distinct: rather than a state-led phaseout of legacy infrastructure, Nigeria's transition—at least in terms of retiring capacity—will be determined by the private energy choices of thousands of households and businesses. This presents a decisive challenge, as the widespread elimination of diesel and petrol generators will depend not on centralized mandates from the State or large utilities but on the willingness of individual consumers to transition away from gensets. Without meaningful buy-in at this decentralized level, Nigeria will struggle to reduce its electricity-related emissions.

Unreliability contributes to limited end-use electrification:

If electricity is unavailable, it cannot be used to power homes, cook meals, fuel vehicles, or drive industrial production. Greater end-use electrification presupposes a reliable electricity supply, which remains uncertain in the Nigerian context. Beyond this practical limitation, research suggests that unreliability also influences how households interact with electricity, affecting appliance ownership, fuel-switching behavior (particularly in the transition to clean cooking), and broader energy-use patterns [84, 86-87, 96, 103-106].

This issue is further illustrated by public reactions to the Lagos State Governor Babajide Sanwo-Olu's April 2023 announcement of two new electric buses in Lagos—Nigeria's commercial capital (Figure 3-7). Many Twitter/X users questioned the feasibility of such a transition given Nigeria's unreliable electricity supply:

- "Can NEPA[49] support these buses?"
- "The electric buses are a good development. But the maintenance and **stable electricity to power is the most important provision the state government should have put in place**. But time will tell."
- "Commissioned multi-million Naira fire trucks in a state with non-functional fire hydrant systems... **and now commissioning electric buses in a state with epileptic power supply. Do you start building a house from the roof?**"
- "This is a commendable deployment, **but truth be told, Nigeria lacks the capacity currently for anything electricity related, till we fix the underlying power generation infrastructure**. I like this futuristic concept, but we should also focus on the immediate problem. Good luck 🤞🏽 "
- "Bus wey go stop in the middle of ekoncos **no Nepa to recharge**" *(A bus that will stop in the middle of the road because there is no electricity to recharge.)*
- "I laugh in Swahili **how many hours of electricity supply have you given Lagosians? 🤣🤣🤣 Dem neva see light you dey talk electric bus wey go discharge finish inside**

[49] NEPA (the abbreviation for the National Electric Power Authority, which is now defunct) remains a generic nickname for grid-based electricity [79-81]. Smith [82, p.60] suggests that Nigerians still call the national grid 'NEPA' *"as if to note the continuity of failure"*.
[49] Nigerians colloquially refer to electricity as light.

traffic. Who dey advice una se? 🤔🤔🙄🙄 … *(They haven't even seen electricity, yet you're talking about electric buses that will lose charge in traffic. Who is advising you?...)"*

- "**In a state where people ration electricity supply daily, electricity buses and charging stations is not needed. You don't even have electricity why are you electrifying your transportation?** Sanwo-Olu, You and those behind this white elephant project should be arrested 😁😁😃😃😃"
- "Misplaced priorities 🤣🤣🤣🤣. **In a country where the electricity generation is just over a paltry 4 thousand plus MW, why are you electrifying your public transportation?** He said green, when a lot of your population still cooks with firewood 😂😂😂😂😂"
- "Nigeria and misplaced priorities 🤝"
- "**Electric bus for a country wey no get constant electricity** *(Electric buses in a country that doesn't have stable electricity)* 🤡🤡"[50]

These reactions suggest that electricity unreliability is likely to hinder end-use electrification, a key component of the mega-trend of electrification and a central strategy in the ETP. They underscore the perception that Nigeria's power sector challenges are more fundamental than transitioning to cleaner energy sources or electrified end-uses. For many, the priority should be stabilizing and improving existing infrastructure before pursuing large-scale electrification efforts.

[50] All tweets, accessed on 24th February 2025, from X (formerly Twitter).

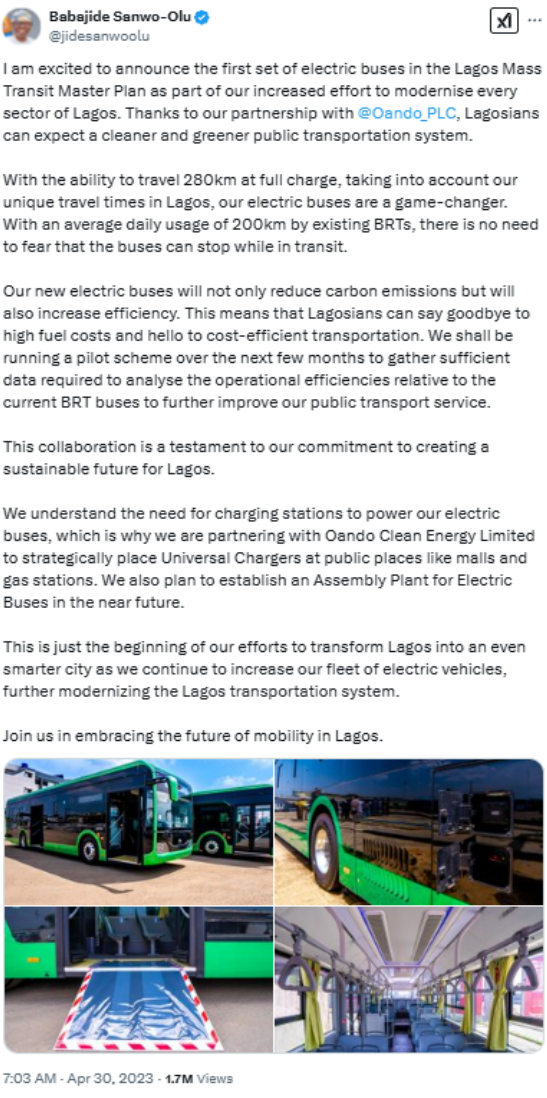


Figure 3-7: Governor Babajide Sanwo-Olu's tweet announcing roll-out of first two electric buses in Lagos State [107].

Unreliability contributes to individualistic citizens:

Nigeria's long history of unreliable infrastructure has reshaped sociopolitical structures in ways that will influence people's preferences and behaviors in the energy transition. From the colonial period into the postcolonial era, the modernist ideology of infrastructure has remained a dominant framework—premised on the belief that *"development would be facilitated by the provision of infrastructure, that this was a key way, perhaps the key way that the state's ambition was to be manifest to its people and their relation to it configured"* [108, p.248]. In other words, colonialists and later nationalist governments—whether civilian or military—used technology as symbols of progress and power, engaging in *"a form of technopolitics where political rule was mediated through the workings of a railway, roads, or power plants"* [108, p.244].

Citizens internalized this expectation, viewing the provision of infrastructure as the hallmark of good governance—one that should be universally accessible, either freely or at minimal cost. As Smith [82, pp.78-79] explains,

> "While the steps taken since 1999 toward establishing a deeper democracy are appreciated by many Nigerians, ordinary citizens tend to judge the performance of the state more in terms of its ability to provide fundamental infrastructure and basic social services than in relation to democratic practices such as elections."

Similarly, in the context of Nigeria's power sector crisis, Olukoju [18, p.67] asserts that *"electricity consumers have yet to reap the dividends of democratic rule,"* drawing a direct link between electricity quality and perceptions of democratic governance.

Thus, as electricity infrastructure—like many other public services—has deteriorated, the relationship between the Nigerian state and its citizens has been reconstituted, reshaping public attitudes toward collective projects such as development and the energy transition. Larkin [108, p.243] captures this shift, noting that:

> "In Nigeria, no building is constructed without the knowledge that state infrastructures fail… The necessity of electrical autonomy is a basic factor in…the form and experience of Nigerian urban life…Now, instead of citizens being linked to the state through the smooth network of the electric grid, the generator dominates Nigerian life. Its presence bears witness to the collapse of the integrated infrastructural idea and the reconfiguration of the state's ambition to provide developmental progress…In the disaggregation from networked electricity to autonomous generators lies the shift in Nigerian society from the developmental state to new forms of individual, competitive, liberalism."

Given this context, it is perhaps unsurprising that Oseni [97] found that only about one-fifth of genset owners would be willing to dispose of their generators even if electricity reliability improved. This suggests both a deep-seated distrust in the centralized system and an entrenched desire for personal control over electricity supply [80, 92].

At the same time, there is evidence that unreliable electricity access exacerbates tax nonpayment and fuels protest actions against the state. In many contexts, including Nigeria, an implicit fiscal pact exists between governments and their citizens: in exchange for tax compliance, the state is expected to provide essential infrastructure and public services. However, persistent infrastructure failures have led many citizens to perceive the government as incapable of upholding its end of the agreement. As a result, nonpayment of taxes is not merely a matter of economic hardship but often an act of resistance—reflecting a broader distrust in state institutions and frustration with governance failures [90, 92]. These dynamics will have important implications for Nigeria's energy transition journey.

Illuminating and investigating these pathways—through both quantitative and qualitative methods—is the central focus of the remaining chapters of this dissertation. By critically examining how electricity unreliability interacts with Nigeria's transition ambitions, this research aims to provide a more nuanced understanding of the challenges and opportunities embedded in the country's evolving energy landscape.

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Chapter 4

Electricity for the Gaps: Household Energy Transitions in an Unreliable System

Preface

This chapter examines the first of the three pathways outlined in Chapter 3 through which electricity unreliability influences Nigeria's energy transition via the mega-trend of electrification. Specifically, it focuses on how unreliability drives decentralized fossil-fuel-based power generation, complicating Phase 1 of the electrification mega-trend—expanding renewable power generation. The widespread reliance on backup generator sets (gensets)—predominantly fueled by petrol or diesel—increases fossil fuel emissions from electricity generation, which must be displaced to enable renewable energy expansion. Accordingly, Nigeria's climate strategies—including the Energy Transition Plan (ETP) and Nationally Determined Contributions (NDCs)—explicitly recognize the need to phase out gensets to achieve decarbonization goals. However, despite extensive anecdotal and qualitative evidence linking genset use to unreliable grid supply, empirical quantification of this relationship remains limited. Even more fundamentally, reliable estimates of the total number of gensets in Nigeria are unavailable, hindering proper target-setting and advocacy. For example, Nigeria's Energy Transition Office (ETO) has struggled to mobilize climate finance for genset displacement because, unlike countries phasing out large coal plants such as South Africa, Indonesia, and Vietnam, there is a lack of data demonstrating the scale of the genset problem in Nigeria.

Beyond the emissions challenge, electricity unreliability fundamentally shapes Nigeria's energy transition trajectory. Unlike in more advanced economies, where the state typically orchestrates the phaseout of centralized fossil-fuel infrastructure (e.g., coal plants), Nigeria's transition is largely decentralized—reliant on individual consumers voluntarily shifting away from gensets, potentially toward renewable alternatives. For instance, the ETP projects an unprecedented solar expansion from 100 MW in 2020 to approximately 213 GW by 2050, with a growing role for decentralized adoption across households, businesses, and industries. Yet, little is known about the factors shaping private energy decisions. This chapter addresses these gaps by empirically linking electricity unreliability to decentralized fossil-fuel generation and exploring the conditions under which genset users might transition to cleaner alternatives. Figure 4-1 below illustrates the key unknowns in this transition—represented by the question marks—which this chapter seeks to explore.

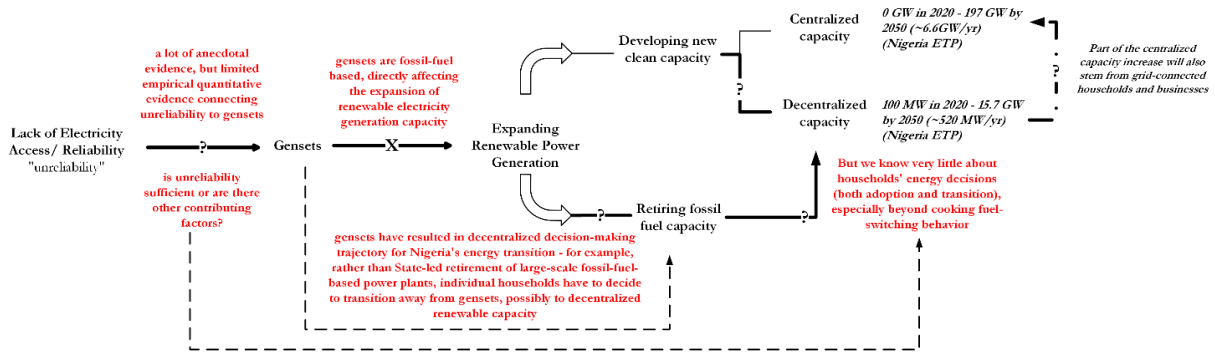


Figure 4-1: Conceptual Framework – How Electricity Unreliability Constrains Renewable Power Generation

The research presented in this chapter builds on a data project initiated at the ETO to estimate the prevalence of backup gensets across Lagos State, spanning the residential, commercial, and industrial sectors. In my analysis, I focus on the residential sector, which not only constitutes the largest portion of the newly collected data but also likely accounts for the largest share of genset ownership in Nigeria. Additionally, while businesses tend to prioritize financial sustainability—transitioning to renewables if cost-effective—households face more diverse and complex decision-making factors, making them a particularly challenging group for energy transition efforts. Given the richness of the dataset, I am able to explore household adoption of both gensets and solar PV systems, resulting in valuable insights into household energy decision-making and broader implications for Nigeria's energy transition.

The findings confirm the widespread reliance on gensets in Nigeria, with nearly 70 percent of surveyed households owning one. The empirical evidence also strongly supports the link between electricity unreliability and genset adoption, as only households with the highest levels of electricity reliability were significantly less likely to own a genset. Similarly, households without grid access were more likely to own gensets than those with, reinforcing the idea that gensets serve as a coping technology for unreliable or absent grid supply. However, the findings further reveal that unreliability alone does not fully explain genset adoption. Household income, size, dwelling type, the education level of the household head, and the presence of a home-based business all significantly influence genset ownership. Social networks and peer effects also play a crucial role, as households whose nearest surveyed neighbor owns a genset are significantly more likely to own one themselves. Additionally, community regulations restricting genset use appear to discourage adoption, suggesting that social norms and policies can shape household energy choices.

Although solar PV adoption is increasing, uptake remains low, with only 1 percent of surveyed households owning a solar system. Nonetheless, most solar adopters (80 percent), like genset owners, cited reliability concerns as their primary motivation for adopting the technology, followed by cost savings (45 percent) and environmental or health considerations (35 percent). Financial constraints remain the dominant barrier, with 90 percent of non-adopters citing affordability as the primary deterrent. Social dynamics also play a key role in solar adoption. I find that households in areas with community restrictions on genset use are more likely to own solar PV, and those whose nearest surveyed neighbor owned a solar system are also more likely to adopt solar. This suggests that early solar adopters may be influencing their communities, potentially creating small clusters of transition from gensets to solar PV. However, despite this emerging trend, solar PV is not yet fully displacing gensets. Over 60 percent of solar adopters also own gensets, and 51 percent reported using their

gensets for the same or longer durations despite having a solar system. This suggests that solar is primarily serving as a supplementary energy source rather than a replacement for gensets.

The findings from this chapter contribute to Nigeria's energy transition discourse in several ways. First, they provide a quantitative foundation for understanding the relationship between electricity unreliability and decentralized fossil-fuel generation, filling a critical gap in both policy and academic discussions. Second, they highlight the multidimensional nature of household energy decisions, demonstrating that economic, infrastructural, and social factors all play a role in genset and solar adoption. Third, they underscore the importance of social networks and peer influences in shaping energy choices, reinforcing the idea that transitions to cleaner energy technologies are often embedded within broader community dynamics. Finally, the prevalence of genset-solar stacking challenges the assumption that increased solar adoption will automatically displace fossil-fuel-based backup power. Instead, the findings suggest that policies targeting solar expansion must also include deliberate measures to phase out gensets.

This chapter lays an empirical foundation for understanding how unreliability drives decentralized fossil-fuel generation, how household-level energy decisions shape transition trajectories, and why solar PV adoption remains limited despite widespread dissatisfaction with gensets. The findings highlight the need for a multidimensional approach to displacing gensets—one that includes targeted financial incentives, community-level interventions, and social norm shifts through education. These insights will be further expanded in subsequent chapters, which explore additional pathways through which unreliability influences Nigeria's broader energy transition.

This research is being prepared for submission to Energy Research & Social Science by June 2025 under the title "Decentralized Dilemmas: Quantifying and Empowering Solar Generation Resources in the 'Grid + Genset' Regime in Nigeria." Supplementary materials can be found in the Chapter 4 Appendix at the end of this dissertation.

> "You don't have electricity. **Your inability to provide electricity is causing many Nigerians to use generator which adds to smoke.** You have not industrialized. And here you are joining white man to talk climate change and energy transition. Seriously una taya me *(seriously, I'm exhausted by you all)*." – Twitter/X user from Nigeria[51]

Abstract

This chapter analyzes the adoption of fossil fuel generator sets ('gensets') and solar systems in Nigeria using a new dataset on alternative, decentralized energy supply covering over 7,000 households. The findings highlight the overwhelming dominance of gensets, with approximately 68% of surveyed households owning one, compared to just 1% with solar systems. Peer-to-peer effects, community regulations, and social dynamics significantly influence adoption, alongside established factors such as electricity unreliability, household income, and demographics. Applying the multilevel perspective on socio-technical transitions, this chapter also examines Nigeria's entrenched 'grid + genset' regime and proposes strategies to accelerate solar PV adoption in support of climate, health, and development goals. While gensets have spread organically in response to grid unreliability, the transition to solar will require more deliberate interventions.

Leveraging policy—with a focus on community-based interventions, targeted financial incentives, and robust awareness and information campaigns—can empower solar systems to displace gensets and transition Nigeria toward a more sustainable energy future, in alignment with its commitment to net-zero emissions by 2060.

Introduction

In framing the energy transition in Sub-Saharan Africa (SSA), Pistelli [2, p.153] argues that *"if the majority of the population does not have access to energy, it does not have anything to transit away from."* While this perspective underscores the importance of energy access, it risks overlooking the fact that deficits in the region's energy systems have led to the widespread adoption of distributed fossil-fuel-based alternatives, which must be addressed in the transition to carbon emission free economies. A prime example is the proliferation of backup generator sets (BUGs/gensets), predominantly diesel and gasoline-powered, often attributed to unreliable grid electricity [3-5]. SSA, notably, has one of the highest rates of BUG usage globally [3].

This dominance of gensets comes with severe economic, environmental, and health consequences. The importation and subsidization of both gensets and the refined petroleum products they require significantly burden local economies, contributing to budget deficits and currency devaluation [3, 6]. Additionally, electricity generated from gensets is significantly more expensive than grid electricity, straining household and business finances [4-5, 7]. In Africa, off-grid private fossil-fuel-based generation is 2-5 times more expensive than grid electricity [6, 8-10]. Beyond economic concerns, gensets emit harmful pollutants linked to health problems such as headache and fatigue, asthma, allergies, irritation of the eyes and nose, changes in lung function, chronic bronchitis, respiratory

[51] A tweet in response to then Vice President Yemi Osinbajo's post on the launch of Nigeria's Energy Transition Plan [1]

diseases, and even lung cancer. They also contribute significantly to climate change, with their emissions sometimes far exceeding those from the grid, especially in renewable-rich countries like the Democratic Republic of Congo [4, 7]. As a result, displacing gensets has become a priority for development and climate goals, as seen in the Nationally Determined Contributions (NDCs) of countries like Nigeria and Senegal [11-13].

While improving grid reliability is central to addressing this challenge, decentralized solar PV systems are gaining traction as viable alternatives to gensets [3, 14-16]. With falling solar and battery prices and excellent solar irradiation, solar energy has become the fastest-growing renewable source in Africa [17]. Solar systems not only offer clean energy but also reduce electricity costs by eliminating the link to fluctuating fuel prices [18-20]. However, despite the potential of solar to replace gensets, few studies have critically examined the drivers behind this transition, particularly in SSA, where the dynamics, such as unreliable electricity, differ from developed economies [21]. Indeed, the literature on transitions in Africa has typically focused on the shift from traditional fuels to cleaner options for cooking [22-25].

This chapter addresses this gap by analyzing the factors influencing the adoption of alternative electricity sources in Nigeria, drawing on new data from Lagos State, the country's commercial hub. Despite Nigeria's vibrant economy, the country faces significant electricity challenges [26-27]. Approximately 86 million people are without electricity access, giving Nigeria the largest energy access gap in the world [25, 28-29]. Furthermore, the 60% of the population connected to the grid is served by only 13 GW of capacity, of which just ~4.5 GW is available on average, leading to frequent outages [3, 5, 28, 30-31]. Consequently, Nigeria is known as the *"world champion"* of BUGs, with per capita generator ownership among the highest in the world [3, p.2 (quote), 27, 32]. For instance, while Nigeria has one of the lowest per capita grid generation capacities globally, it paradoxically boasts one of the highest GDPs per installed watt of grid-scale generation value—surpassing even countries like the United States, China, and India [27]. This stark imbalance underscores the crucial role that gensets play in bridging the country's persistent electricity gap [27].

Although several authors have noted the need to analyze the situation in Nigeria [33-35], few studies have qualitatively or quantitatively examined the factors determining the ownership and use patterns of gensets, especially in households (see [4] for a notable exception). Similarly, most studies on solar PV in Nigeria are scenario-based or techno-economic models, leaving a gap in empirical analyses of post-adoption dynamics [3, 36]. To address this, this chapter provides new insights by analyzing household-level data on both genset and solar ownership in Lagos. Given Lagos's centrality in Nigeria's economy and energy landscape, the state serves as an ideal focal point for understanding alternative electricity adoption and potentially provides a microcosm of the broader energy transition challenges and opportunities facing Nigeria. The focus on the residential section is also crucial given that the sector plays a pivotal role in energy access and the ongoing energy transition [21, 37-38]. Importantly, Nigeria aims for 50% of its urban residential sector to shift from the grid to renewable energy [39].

This chapter also explores household interest in switching to solar, allowing the examination of variables that might not be suitable for explaining actual uptake. For instance, household expenditure on grid electricity and genset use could exhibit reverse causality if included in the study of factors influencing actual solar installations, as solar systems likely impact ongoing electricity bills and genset usage [19].

Furthermore, this study contributes to the limited body of research on both historical and ongoing energy transitions in developing countries, as well as their drivers [40]. Following the econometric analysis, the Multi-Level Perspective on Socio-technical Transitions (MLP) is defined, extended and applied to explore the dynamics of the established genset regime in Nigeria's electricity sector and develop actionable policy insights for empowering the emerging solar PV niche [41]. This framework is consistent with Sovacool's [42, p.14] recommendation that *"the research community needs to aim for more policy relevance, and perhaps less arcane (and at times baroque and inaccessible) theorizing."* Importantly, the MLP helps to center the *"societal adaptation issues"* that characterize energy transitions and *"avoid stunted energy debates that systematically underemphasize the meaning and consequences of energy systems and their changes for human societies"* [16, p.1; 43 cited in 21, p.11].

By integrating new empirical data with a qualitative review of Nigeria's electricity history, this study offers a comprehensive perspective on the evolution of genset and solar adoption, contributing to broader energy transition research and action in developing countries.

Empirical Setting and Data

The analysis in this chapter utilizes a unique dataset from household surveys conducted in Lagos State, Nigeria, between October and November 2023 by a consortium including Sustainable Energy for All (SEforALL), the Nigeria Energy Transition Office (ETO), the Lagos State Ministry of Energy and Mineral Resources (MEMR), and Vista Advisory Partners [44].

With an estimated population of 26 million in 2019—larger than any other economy in the ECOWAS region—Lagos accounts for about 30% of Nigeria's Gross Domestic Product (GDP) and 50% of non-oil GDP [45-47]. Historically, Lagos has been the location for key electricity developments and remains the epicenter for energy policy and infrastructure innovations, which often diffuse to the rest of the country [40, 47].

As Nigeria's economic hub, Lagos plays a central role in its energy landscape, consuming between 20–50% of the national grid's operational capacity [46, 48-49]. Two of the nation's eleven electricity distribution companies serve only Lagos State [47, 49]. However, the state's national grid allocation—approximately 1,000 MW for an average of 12 hours daily—meets only 20% of its energy demand, leaving a 23–33 TWh annual supply gap, largely filled by gensets [47, 50]. Consequently, Lagos has the highest concentration of diesel gensets in Nigeria, particularly in the residential sector, and accounts for about a third of all off-grid gensets nationwide [47, 51]. In response, the Lagos State Government is actively pursuing a distributed solar PV program to reduce reliance on diesel and petrol generators [47, 50].

The Lagos study and its associated surveys were designed to inform and ultimately support this ambition of the State Government. Covering over 7,000 households across the state's 20 Local Government Areas (LGAs) (Figure 4-2), the surveys captured socioeconomic characteristics, grid electricity availability and usage, as well as perceptions and usage patterns of gensets and solar systems. Wards served as the primary sampling units in the study's single-stage stratified cluster strategy. The sampling frame was stratified by LGA, with 200 ward clusters of 30 households each, selected to

ensure representativeness[52,53] [44]. This dataset is the largest dedicated study of alternative electricity supply in Nigeria, significantly expanding upon previous efforts [4, 52-53].

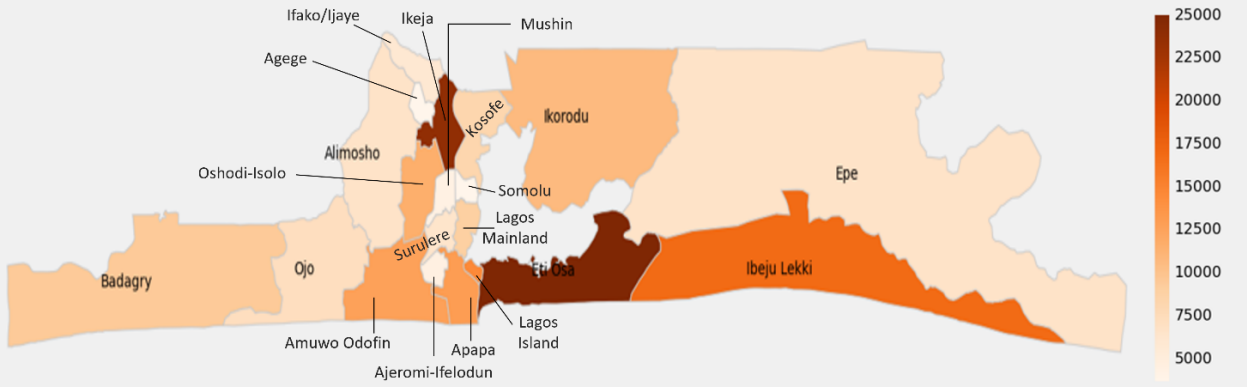


Figure 4-2: Lagos State Local Government Areas (LGA) by estimated Gross Domestic Product (GDP) per capita (PPP, $) in 2020. The lowest value is $3,447 in Somolu, while the highest is $22,939 in Eti Osa. Median values are $7,647 in Kosofe and $8,333 in Lagos Mainland, with an average GDP per capita of approximately $9,451. Data source: WBG [50].

Methods:

Household adoption of gensets and solar PV systems are modeled as binary outcomes, where the probability of adoption is a logistic function of key explanatory variables. Specifically, the following logit model is estimated:

$$P(X) = \frac{1}{1+ e^{-(X\beta+\epsilon)}} \quad (1)$$

Where $P(X)$ represents the probability that a household adopts or expresses interest in an alternative energy source. The dependent variables in the three models in this study are:

1. Genset adoption: $P_{\text{owns genset}} = 1$ if the household owns a genset, 0 otherwise.
2. Solar PV adoption: $P_{\text{owns solar PV}} = 1$ if the household owns a solar PV system, 0 otherwise.
3. Interest in switching to solar: $P_{\text{interested in switching to solar}} = 1$ if the household expresses interest in transitioning to solar, 0 otherwise.

The vector X consists of independent variables that are assumed a priori influence households' ownership of or interest in alternative energy sources. Maximum likelihood estimation (MLE) is used to estimate model parameters.

Although there are *"no systematic frameworks that examine the broad range of human influences on household adoption or rejection of energy technologies,"* the construction of X in this chapter reflects hypotheses and evidence from previous literature [21, p.2 (quote); 22, 55-56]. For instance, Chadwick *et al.* [21] introduced a framework that highlights five psychosocial categories—cognitive, social, affective,

[52] Wards are subdivisions of Local Government Areas (LGAs) [54]. The number of ward clusters per LGA was randomly selected with probability proportional to the LGA household population provided by the Lagos State Bureau of Statistics (LBS)
[53] The number of households per ward cluster was set to 30 in accordance with the household sampling methodology employed by the USAID Demographic and Health Survey [44].

behavioral, and contextual—suggesting that models incorporating multiple influence categories provide a more robust and behaviorally realistic understanding of household energy transitions. Similarly, Selvakkumaran and Ahlgren [56] outlined six superordinate categories of explanatory variables influencing energy technology adoption or non-adoption decisions: economic factors, environmental factors, personal values and preferences, social factors, household characteristics, and market and policy factors. They further developed a two-dimensional conceptual framework to capture interactions between these variables, categorizing them by their origin (internal or external to the household) and their susceptibility to external influence.

Van der Kroon *et al.* [22, p.506] took a broader socioeconomic perspective, positing that household energy decisions are shaped by a *"complex and interactive web of factors"*. They divided these influences into three categories: (i) the external environment of the country, including climate, geography, and historical factors; (ii) the country's internal factors, such as capital markets, government policies, and the structure of consumer markets (including access to credit, and the price, reliability and distribution of fuels); and (iii) the household opportunity set, which encompasses internal household characteristics such as income, education, household size, gender, living conditions, and access to information regarding alternative energy sources. This multi-level perspective underscores the importance of considering both macro-level factors and individual household dynamics when analyzing energy transitions and is similar to the MLP.

Drawing on these frameworks, the existing literature, and the characteristics of the dataset, a set of explanatory variables are selected, tailored to the specific context of genset and solar adoption in Nigeria. Following Selvakkumaran and Ahlgren's [56] superordinate explanatory variable categories (SEVC), established explanatory factors—such as age, gender, income, homeownership, and hours of daily electricity outage[54]—are extracted from the Lagos dataset alongside variables like peer effects and social dynamics, which have not been extensively studied in this region. The variables, as shown in Table 4-1, provide a comprehensive view of the determinants of energy technology adoption. Detailed descriptions of the variables, including the associated survey questions and answer categories where applicable, are included in Table B-1 in the chapter's appendix. Table 4-2 below presents a summary of the data collected in the Lagos State household surveys. Notably, the economic factors SEVC from Selvakkumaran and Ahlgren [56] is not represented in the Lagos dataset, highlighting an important gap for future research.

To contextualize the findings from the analysis within the MLP framework, a literature review is conducted using search terms such as 'history of electricity in Nigeria' and 'history of generator sets in Nigeria', following methods employed in other socio-technical transition studies [58-60]. This search identifies several academic papers, reports, and grey literature, which are prioritized by relevance and credibility. These sources are supplemented using a snowball sampling method, as outlined by Selvakkumaran and Ahlgren [56]. Given that the goal here is not an exhaustive review but a system-level understanding of Nigeria's alternative electricity landscape, this approach is deemed sufficient.

Additionally, to enrich the analysis with industry insights, this chapter draws on semi-structured interviews with 26 experts in Nigeria's electricity sector, including representatives from electricity distribution companies, the national electricity regulatory authority, independent energy firms, and

[54] Outages refer to the total loss of electric power in each location and period [57, p.90].

international development organizations. The study protocol for these interviews was reviewed and approved by the Institutional Review Board of the University of California, Berkeley (Protocol ID: 2024-07-17591).

Table 4-1: Variables included in models. Italicized variables are only in the "interested in switching to solar" model.

Superordinate Explanatory Variable Category (SEVC)	**Sub-category**	**Variables**
Market & policy factors	Electricity Reliability	Typical daily hours of outages
Personal values & preferences + Environmental factors	Electricity Reliability	Willingness to pay for reliability
	Environmental Concerns	Concern about environmental impact of genset use, Rating of air pollution from genset use
Household Characteristics	Demography	Age of household head, education level of household head, gender of household head, size of household
	Housing	Type of building, house ownership, years of residence
	Income and Finance	Monthly household income, primary source of income, bank account
	Business	Household business, size of business in number of employees, income of business
	Energy (Access and Usage Patterns) – grid electricity and gensets	Electricity access, time of major appliance use, *genset ownership, frequency of grid electricity payments, grid electricity expenditure, metering, genset maintenance cost, genset breakdowns, genset fuel purchase frequency, time of major genset use*
	Awareness	Awareness of (i) tariff band, (ii) Nigeria Energy Transition Plan, (iii) solar power systems

	Location	Local Government Area, road accessibility of area, overall security of area
Social factors	Peer effects	Peer effect, *complaints regarding genset noise*
	Regulation	Community/neighborhood/area regulations regarding genset use

Table 4-2: Descriptive statistics for households in Lagos survey

Primary Category	Variables	Description	Observations (count)	Mean/Percentage
Outcome Variables	Genset ownership	Yes (%)	7077	68.22
	Solar system ownership	Yes (%)	5039	2.02
	Interest in switching to solar home system(s)	Yes (%)	4951	74.91
Market and policy factors	Typical daily hours of electricity outage		6906	
		< 4 hours outage (%)		5.15
		4 - 8 hours outage (%)		18.64
		9 - 12 hours outage (%)		25.72
		>12 hours outage (%)		50.49
Personal Value & Preferences + Environmental Factors	Willingness to pay higher for improved reliability/no outages	Yes (%)	6910	74.08
	Concern about environmental impact of generator use	Yes (%)	7186	63.67
	Rating of air pollution from generator set	Highly negative air quality effect (%)	7178	20.48
Household characteristics	Age range of household head	over 50 years old (%)	7180	35.00
	Highest level of education attained - head of household	Higher education (college or above) (%)	7083	36.13
	Gender of household head	Male (%)	7186	61.10
	Size of household	>5 people (%)	7186	32.79
	Type of building	Face to Face (%)	7155	26.57
	House ownership	Homeowner (%)	6737	35.28
	Years of residence	> 5 years (%)	6491	66.88
	Financial Inclusion	Have bank account - Yes(%)	7186	96.70
	Total monthly income	> N100,000 (~$60) (%)	6488	50.23
	Primary source of income		6900	
		Self-employment (%)		68.93
		Employment (full time + contract) (%)		24.43
		Pension and retirement (%)		5.52
		Government, Family or Friend support (%)		0.94
		Other (incl. religious, none) (%)		0.17
	Presence of household business	Have a household business (%)	7186	23.80
	Size of household business (if applicable)	Number of employees who are not household members > 5 employees (%)	1500	10.40
	Income of household business (if applicable)	Monthly sales/revenue - > N100,000 (~$60) (%)	1550	48.77
	Household electricity access	Connected to the grid - Yes (%)	7186	96.10
	Appliance usage pattern	Time when majority of appliances are turned on - Daytime (8am - 4pm) (%)	6687	15.94
	Frequency of grid electricity payments	Weekly or Bi-weekly (%)	6906	12.41
	Expenditure on grid electricity	Monthly Grid Electricity Payment (Naira)	6906	N14,427.21 (~$9)
	Metering status		6894	
		No meter (%)		19.16
		Prepaid Meter (%)		55.92
		Postpaid Meter (%)		24.92
	Frequency of fuel purchase for generator set	Daily or Weekly (%)	4826	76.05
	Generator Fuel Consumption	Monthly amount of fuel purchased (liters)	4828	150.69 liters
	Frequency of routine generator set maintenance	Weekly/Bi-weekly/Monthly (%)	4828	45.07
	Expenditure on routine genset maintenance	Monthly Cost (Naira)	4828	N4,044.81 (~$3)
	Maintenance-related genset breakdowns/challenges	Experienced maintenance-related challenges/breakdowns with generator sets - Yes(%)	4828	41.03
	Generator main time of use	Daytime genset use (8am - 4pm)	4789	8.98
	Genset powers all household appliances	Yes (%)	4828	57.27
	Awareness of Tariff Band	Yes (%)	6910	75.73
	Awareness of Nigeria's Energy Transition Plan	Yes (%)	7186	48.34
	Awareness of solar power systems	Yes (%)	7186	70.12
	Local Government Area	High income LGAs (>$15k GDP PPP per capita - Eti-Osa, Ikeja, Ibeju-Lekki, Lagos Island) (%)	7186	14.29
	Road Accessibility	Above average roads (%)	7179	35.65
	Overall security of area	Above average security (%)	7178	45.22
Social factors	Household with alternative energy supply nearby		7186	
		Nearest household in survey has a genset - Yes (%)		67.53
		Nearest household in survey has solar - Yes (%)		1.24
	Community/neighborhood/area regulations regarding generator use	Yes (%)	7186	14.43
	Received complaints from nearby residents/businesses regarding	Yes (%)	4828	19.49

Results

As presented in Tables 4-3 – 4-5[55], this section outlines the associations between the explanatory variables discussed earlier and the three outcomes: ownership of gensets (column 1), ownership of solar systems (column 2), and interest in switching to solar systems (column 3).

Genset Ownership

Market and Policy Factors:

The only market and policy factor captured in the Lagos dataset is electricity (un)reliability, which can be considered an *"availability of fuel (i.e., electricity)*" factor [56, p.60]. Respondents were asked, *"How many hours of outage from the grid do you typically experience per day?"* and selected from predefined categories reflecting increasing levels of typical daily outage durations (Table 4-2). As a result, all respondents reported experiencing some level of electricity outages, albeit to varying degrees. While some respondents in the <4 hours of outage category could theoretically experience no outages at all, this is highly unlikely in the Nigerian context, where even the most reliable service bands still experience occasional disruptions[56].

Genset ownership rates in the dataset remained relatively consistent across the different levels of electricity unreliability, as illustrated in Figure 4-3a. Compared to respondents experiencing more than 12 hours of outages per day, those in the categories of 9–12 hours and 4–8 hours of outages do not have statistically significant coefficients for genset ownership. Only the < 4 hours of outage category exhibits a statistically significant negative correlation, suggesting that only at the highest levels of reliability are households meaningfully disincentivized from owning gensets. This finding aligns with Oseni's [4] conclusion that households would require substantial improvements in reliability—approximately 9 additional hours—before considering abandoning their generators.

It is worth noting that the categorical nature of the data may have constrained the capturing of more granular relationships between increasing levels of electricity unreliability and genset adoption. However, given Nigeria's service-based tariff structure (SBT), where consumers are classified into bands based on their guaranteed hours of electricity supply [61], the predefined response categories likely approximate real-world service levels.

Personal Values & Preferences + Environmental Factors:

These two SEVCs are combined in this analysis because the environmental factor questions in the Lagos survey capture dimensions of both environmental factors and personal values/preferences as outlined in Selvakkumaran and Ahlgren's [56] framework. Their study distinguishes between externally measurable environmental impacts (e.g., actual pollution levels, GHG emissions) and subjective

[55] In addition to the logit results, I obtain similar results using a probit model. Please refer to Table B-2 in the chapter's appendix.

[56] On November 1, 2020, the Nigerian Electricity Regulatory Commission (NERC) introduced the Service-Based Tariff (SBT) scheme to align electricity tariffs with the actual level of service received by consumers. Under this system, consumers are classified into Bands A to E based on their minimum guaranteed hours of daily electricity supply. Band A customers receive at least 20 hours of electricity per day, Band B a minimum of 16 hours, Band C at least 12 hours, Band D a minimum of 8 hours, and Band E customers are guaranteed just 4 hours. Consequently, a household reporting fewer than four hours of daily outages is likely in Band A, experiencing the most reliable service, while those with 12 or more hours of outages fall into lower bands with significantly poorer supply. Given that respondents were asked, *"How many hours of outage from the grid do you typically experience per day?"*, their responses likely reflect the total duration of daily outages rather than the frequency or pattern of interruptions [61].

attitudes toward environmental issues (e.g., openness to change, willingness to pay, and concern for climate change). Rather than capturing objective environmental conditions, the Lagos dataset focuses on self-reported perceptions, making it more reflective of the latter category. For example, respondents were asked if they were concerned about the environmental impact of genset use, whether they believed genset use contributed significantly to local air quality issues, and, if so, to rank air pollution on a scale of 1 to 5. However, while these responses primarily reflect personal values regarding pollution and climate-related risks, they may also serve as a proxy for local environmental conditions. Given this overlap, these variables are categorized in a way that captures their broader role in shaping household decision-making.

In this category, the willingness to pay for better reliability does not significantly influence genset ownership. However, both environmental factors show a significant correlation. As expected, households that rated air pollution from gensets negatively (4 or 5 on a 1 to 5 scale) are less likely to own gensets. Interestingly, households concerned about the environmental impact of gensets are more likely to own them. This could reflect reverse causality, where households with genset experience become more aware of their environmental effects, reinforcing concerns. Alternatively, this association may stem from omitted variables in the error term that influence both genset ownership and environmental attitudes. For instance, unobserved lifestyle preferences—such as a household's tendency to prioritize convenience over environmental considerations—could simultaneously drive genset ownership and self-reported environmental concern. Future research could explore this potential confounding further.

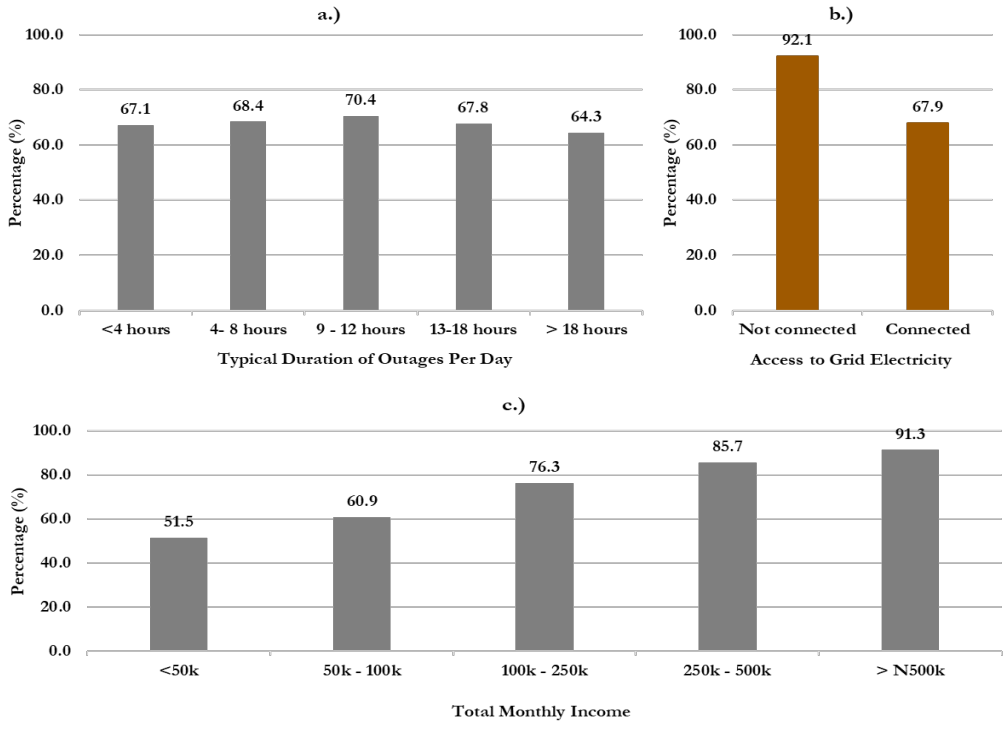


Figure 4-3: a.) Proportion of Households with Gensets by Daily Outage Duration Category in the Lagos Dataset. b.) Proportion of Households with Gensets by Access to Grid Electricity. c.) Proportion of Households with Gensets by Total Monthly Income

Household Characteristics:

As is common in studies of household energy decisions, this category is the most well-represented in the Lagos dataset. Consistent with Oseni [4], wealthier households, male-headed households, and those with home-based businesses are significantly more likely to own gensets. Households with better-educated heads also exhibit a higher likelihood of genset ownership. This is likely because these groups tend to have higher electricity demand and greater capacity to afford alternative power supply [4].

Conversely, households with older heads, more members, or access to grid electricity are less likely to own gensets. As Oseni [4] notes, older individuals may engage in fewer electricity-intensive activities, reducing the need for backup gensets. Additionally, older individuals, who are likely without full-time work, may find it difficult to sustain the operational costs of gensets. Having historically experienced more outages, they may also be more accustomed to electricity disruptions and thus less inclined to invest in backup power. Larger households typically face income constraints and higher basic needs expenditures, limiting their ability to purchase and maintain gensets [4]. The lower likelihood of genset ownership among households with grid access suggests that gensets are predominantly used to compensate for gaps in grid reliability. Nonetheless, both households with and without grid access showed high levels of genset penetration (Figure 4-3b).

Households in Face-to-Face (Face-me-I-face-you) apartments are less likely to own gensets, highlighting the role of dwelling type in genset adoption. Compared to bungalows, flats, storey buildings, and duplexes, Face-to-Face buildings represent high-density, low-income housing. These buildings consist of rows of single rooms facing each other along a corridor or courtyard, with shared facilities like toilets and kitchens [62]. While specific details on shared electrical circuitry in these buildings are limited, it is plausible that communal wiring arrangements or space constraints may restrict individual genset ownership and use. Additionally, the communal living structure and lower-income status of residents may further contribute to the reduced rates of genset ownership [4] (Figure 4-3c). However, since income is accounted for in the model, this suggests that other characteristics of this dwelling type, beyond the financial conditions of residents, limit ownership rates.

Awareness of energy-related information also plays a significant role in genset ownership in Lagos households. Households that know their tariff bands[57] and are aware of solar power systems are more likely to own gensets. Although the latter result may seem counterintuitive, it suggests that households more aware of energy policies and technologies are more proactive in securing alternative energy supply.

Lastly, several location-related variables significantly affect household genset ownership. Households that reported better-than-average road accessibility are more likely to own gensets, suggesting the importance of infrastructure in facilitating access to alternative energy sources. Similarly, households in Local Government Areas (LGAs) with higher GDP per capita, such as Eti Osa and Ikeja, exhibit higher rates of genset ownership [50]. In contrast, households in lower-income LGAs like Ojo and Surulere are less likely to own gensets, reflecting the influence of social dynamics, socioeconomic conditions and infrastructure disparities. However, some LGAs deviate from this pattern. For example, households in Lagos Island, despite being a high-income LGA, are less likely to own gensets, while those in lower-income LGAs like Alimosho and Epe have higher genset ownership rates. This

[57] See Footnote 56

could be attributed to a combination of factors, including the nature of economic activities, the reliability of grid electricity, and proximity to wealthier LGAs. Epe, for instance, is adjacent to higher-income areas such as Ikorodu, Eti Osa, and Ibeju-Lekki, and receives the least amount of grid electricity supply on average, as highlighted in a World Bank analysis [50] (Figure 4-2).

Social Factors:

This analysis also estimates peer effects by assessing whether the nearest survey neighbor of each household owns a genset or solar system and these relationships yield statistically significant coefficients. Households whose nearest neighbor in the survey has a genset are more likely to also own one, while those whose nearest neighbor has a solar system are less likely to own a genset. Additionally, households in neighborhoods with regulations governing genset use are less likely to own gensets. These results suggest that social factors significantly influence genset ownership at the household level.

Solar Access and Ownership

Only 1% of respondents—102 households—reported owning a solar system. Among them, 44 own 'AC Solar Panels + storage batteries + inverters', 26 own 'DC Solar panels + inverters', 20 have 'stand-alone solar appliances', and 3 are connected to a mini-grid. The remaining 9 respondents were unsure of their solar system type. The capacity of solar systems in the survey ranged from 25 watts to 8000 watts[58]. Slightly more than half of the solar-owning households have capacities exceeding 1000 watts, suggesting a notable uptake of larger systems.

The limited number of solar adopters in the dataset poses a challenge for generalizing the findings in this chapter. Additionally, missing values in responses on solar ownership further reduced the sample size available for modeling, and overall, fewer variables were found to significantly influence solar adoption. Nevertheless, despite these constraints, the results offer valuable insights into early adoption trends, suggesting a growing recognition of solar as a viable alternative to gensets. This aligns with national and subnational initiatives aimed at expanding solar deployment.

Nigeria's Energy Transition Plan (ETP) and Nationally Determined Contributions (NDCs) underscore solar energy's role in achieving the country's climate and energy access goals, yet the specific trajectory of decentralized solar adoption—particularly among grid-connected households—is still evolving. The NDCs set a 2030 target of 13 GW in off-grid renewable capacity, including 5.3 GW from minigrids, 2.7 GW from solar home systems and streetlights, and 5 GW from self-generation. While the latter category is not explicitly defined, it likely includes additional off-grid renewable sources beyond solar hybrid minigrids and standalone solar systems [11]. Additionally, the NDCs project 6.5 GW of grid-connected solar PV capacity by 2030, reinforcing Nigeria's ambition to integrate solar into the national electricity mix [11].

Meanwhile, the ETP projects decentralized solar capacity to expand significantly from 100 MW in 2020 to 6.3 GW by 2030 and 15.7 GW by 2050 [63]. Although much of this expansion is targeted at new electrification efforts—including solar home systems for low-density areas (1.8 GW), minigrids for larger communities (2.6 GW), and solar + battery systems for industrial users (1.9 GW) [63]—it

[58] This range serves as the reference for solar PV systems/solar home systems discussed in this paper.

reflects a growing national commitment to decentralized solar solutions. This focus on rural electrification is further reinforced by the Rural Electrification Agency (REA), which has been at the forefront of deploying solar energy solutions in unserved areas [64], mirroring approaches in other African countries like Kenya [65]. Indeed, as the results indicate, those without grid access—largely rural dwellers—are more likely to own gensets, though these are likely smaller in size than those used by urban and more affluent households.

For centralized solar capacity, the ETP envisions a rapid scale-up from 0 GW in 2020 to 8 GW by 2030, 81 GW by 2040, and 197 GW by 2050 [63]. While much of this expansion is expected to come from utility-scale projects, ongoing discussions suggest that part of this growth could also stem from household-level adoption in grid-connected areas. Similarly, Nigeria's Energy Compact targets transitioning 50% of urban residential consumers off the national grid by 2050 through rooftop solar installations and other renewable solutions [39]. Although most existing policies have prioritized expanding access for unserved populations, these targets indicate increasing national interest in solar deployment across diverse consumer segments.

At the subnational level, Lagos State is leading efforts to integrate distributed solar solutions, signaling a potential policy shift toward broader household solar adoption. These developments, coupled with the early trends observed in the dataset, suggest that solar PV could become a more prominent feature of Nigeria's decentralized energy landscape—both as an energy access tool and as a cleaner alternative to backup fossil fuel generators.

Market and Policy Factors:

Compared to households experiencing more than 12 hours of daily outages, only those in the 4–8 hours of daily outages category exhibit statistically significant coefficients for solar system ownership. This suggests that solar systems, typically paired with batteries and inverters, may have higher utility in areas with more reliable grid electricity.

Personal Values & Preferences + Environmental Factors:

None of the variables in this category significantly influence solar system ownership.

Household Characteristics:

Similar to genset ownership, wealthier households, households with better-educated heads, and those with home-based businesses are more likely to own solar systems. In contrast, those living in Face-to-Face apartments and those with access to grid electricity are less likely to own solar systems. Interestingly, home-based businesses that earn higher revenues are less likely to own solar systems. This may be due to the larger electrical loads of higher-income businesses, which are difficult to support with household solar PV systems.

Unlike genset adoption, the source of household income influences solar system ownership. Households whose primary income comes from self-employment, pensions, or retirement are more likely to own solar systems than those with income coming from corporate employment. This may be because self-employed individuals, retirees, and pensioners tend to spend more time at home, requiring stable electricity supply, whereas those who work outside the home can rely on gensets during the night and early morning.

The results show that households with gensets are less likely to own solar systems. The reverse is also true—households with solar systems are less likely to own gensets. This relationship emerges when a solar ownership variable is included in the genset adoption model. However, due to the numerous null responses for solar system ownership, this model is based on fewer observations than the one reported in the preceding section. Nonetheless, most of the variables that are statistically significant in the full model on genset ownership remain significant even with the smaller sample size. For detailed results, please refer to Table B-3 in the chapter's appendix.

Unlike genset ownership, awareness of energy-related information does not significantly impact solar system adoption. Similarly, location-related variables are not significant. Due to the limited number of solar system owners, only high-income LGAs (Eti-Osa, Ibeju Lekki, Ikeja, and Lagos Island) are included in this model and compared to others. Among these, only Eti-Osa, the wealthiest LGA by GDP per capita, shows a significant positive correlation with solar system ownership.

Social Factors:

Each of the social factors included in the model has statistically significant coefficients for solar system ownership. Households whose nearest neighbor in the survey own a genset or a solar system are more likely to own solar systems themselves, suggesting strong peer effects and a potential transition between gensets and solar. In the genset model, households whose nearest neighbor own solar were less likely to own a genset, indicating that transition to solar may be starting in small clusters. However, the reverse effect is not observed; households whose nearest neighbors own gensets are not less likely to own solar—in fact, they are more likely to own solar. This could be due to the prevalence of gensets, with solar households representing early adopters who previously owned gensets or even still have them (see 'Stacking' section below).

Interestingly, households in neighborhoods with regulations governing genset use are more likely to own solar systems, potentially indicating a shift from gensets to solar when genset use is restricted or regulated.

Stacking

As widely discussed in the household fuel switching literature, particularly for SSA, stacking behavior is observed in a number of households. The energy stacking model explains energy transition as a *"complex process in which households do not move linearly toward cleaner fuels but stack different fuels together for carrying out daily tasks",* typically increasing the share of modern fuels as socio-economic status improves [24; 55, p.6450 (quote); 66]. In other words, as income rises, *"new fuels and technologies serve as partial, rather than perfect substitutes for more traditional ones…households choose to consume a portfolio of energy options at different points along the energy ladder."* [22, p.506].

Of the 102 households with solar systems, over 60% also have gensets (65 households). Although this represents only a small fraction of the total genset owners, a multinomial logit analysis is conducted to investigate patterns driving this stacking behavior (see Section 4.1 in the chapter's appendix). The findings indicate that income, homeownership, peer effects and community regulations significantly affect whether a household owns only a genset or both genset and solar. In line with the energy stacking literature, compared to middle- and low-income households, ultra-wealthy households (top 5% earners in the survey) are more likely to own both gensets and solar systems. Additionally, households that own their housing units and those who live in communities with regulations regarding

genset use are more likely to stack a solar system with their genset. Finally, households with a genset whose nearest neighbor in the survey owns a solar system are also more likely to stack a solar system with their genset.

For households that already own solar systems, only peer effects show significant correlation with whether they would also own a genset. In other words, compared to households in the 'Both Genset and Solar' category, households in the 'Solar Only' category are less likely to have a nearest neighbor in the survey with a genset.

In addition to identifying possible drivers of stacking behavior, its potential impacts are explored. Logit models are employed to investigate whether stacking solar systems on gensets influences the likelihood of owning smaller gensets or using them for shorter durations (See Section 4.2 in the chapter's appendix). Unlike factors such as duration of outages; household income, size and location; homeownership; business size; and peer effects, solar ownership did not significantly influence genset size, usage duration, or daily time of use. This could be attributed to the limited number of observations. Additionally, it is possible that, rather than altering genset usage patterns, solar systems provide supplementary reliability for households that stack both energy sources. Notably, 51% of households that stack both technologies reported using their gensets for the same duration or more compared to their solar systems.

The Lagos survey also asked households with solar systems why they decided to adopt them, allowing them to select one or more of the following reasons: 'Cheaper source of electricity', 'Better electricity reliability', and 'Environmental/health impact.' Around 74% of stackers indicated that improved electricity reliability was their primary motivation—similar to non-stackers, 92% of whom cited the same reason. However, fewer stackers (26%) selected environmental/health impact as a reason for adopting solar systems compared to 49% of non-stackers.

Interest in Switching to Solar Home Systems

Market and Policy Factors:

Of the three outcomes considered, the typical duration of daily outages displays the strongest effect in this model—possibly suggesting that while actual uptake of alternative energy sources may be complicated by other factors, interest in these systems is still driven by the unreliability of grid electricity.

Households experiencing 9–12 hours of daily outages are more likely to be interested in switching to solar systems compared to those facing more than 12 hours of daily outages. This supports the earlier proposition that solar systems, typically configured with batteries and inverters, are more useful in areas with relatively better grid electricity reliability. Similarly, households experiencing fewer than 4 hours of daily outages are less likely to be interested in switching to solar systems, reinforcing the idea that those with the most reliable grid electricity have less motivation to seek alternative energy sources.

Personal Values & Preferences + Environmental Factors:

As expected, households willing to pay for better reliability are more likely to be interested in switching to solar systems. Interestingly, households concerned about the environmental impact of gensets are less likely to express interest in switching. It is possible that these households are concerned about the

environmental impacts of energy systems in general, including waste from solar systems, especially given the limited recycling infrastructure in Nigeria.

Household Characteristics:

Similar to actual solar system uptake, households whose primary income comes from self-employment, pensions, or retirement are more likely to express interest in switching to solar systems compared to those in full-time employment. This is likely due to the same reasons described earlier. Although retirees and pensioners tend to be older, households with older heads appear less likely to want to switch to solar systems, as is the case with genset ownership. This may be due to reduced engagement in electricity-intensive activities or concerns about financing solar systems. Older heads may also be more conservative when it comes to adopting newer or less established technologies.

Households with bank accounts are less likely to express interest in switching to solar systems, possibly because they are more aware of the financial implications and their own financial conditions, thus constraining their interest in switching. Households with home-based businesses employing more workers are also less likely to be interested, likely due to higher overhead costs.

Consistent with both genset and solar ownership, households with grid access are less likely to be interested in switching to solar systems. To better understand the role of grid electricity and genset use, several related variables are included and produce statistically significant results. Households making more frequent payments for grid electricity are less likely to be interested in solar systems, suggesting satisfaction with grid supply and/or a preference for recurring operational costs over the upfront capital investment required for solar systems.

Although actual genset ownership reduces the likelihood of solar adoption, it positively influences interest in switching to solar systems, suggesting latent dissatisfaction with genset use. Households that purchase genset fuel more frequently are also more likely to express interest in switching. Boamah & Rothfuß [16, p.7] similarly argue that genset ownership can facilitate readiness to shift to solar home systems (SHS), noting in the Ghanaian case that *"change-over boards used by SHS users who once owned Generator-sets were utilized for the back-and-forth power switch between ECG[59] power supply and SHS."* Conversely, households that reported experiencing genset maintenance challenges or breakdowns, and those that perform routine maintenance more frequently, are less likely to want to switch—possibly due to recent financial commitments to their gensets and perhaps better genset performance.

Similar to genset ownership, households that know their tariff bands are more likely to be interested in switching to solar systems, suggesting that awareness of energy policies and grid electricity costs makes households more proactive in seeking alternatives.

Several location-related factors also significantly affect interest in switching to solar systems. For instance, households with better-than-average security ratings and those in LGAs with higher GDP per capita—such as Eti Osa, Apapa, Ikorodu, Lagos Island, and Oshodi-Isolo—are more likely to express interest in solar. Conversely, households in lower-income LGAs like Epe, Ifako-Ijaye, and Mushin are less likely to be interested in switching. As with genset ownership, there are exceptions to this trend. For instance, households in Badagry—an LGA with slightly above-average GDP per capita—are less likely to express interest in switching to solar, while those in lower-income LGAs like Alimosho and Surulere are more likely to do so. This may be driven by regional economic activities,

[59] ECG: Electricity Company of Ghana

proximity to other LGAs, and geographical factors. For example, the primary economic activities in Badagry, such as fishing and farming, typically require less electricity, which could explain the lower interest in solar adoption.

It is important to note that variables like income and building type, which significantly influence both genset and solar adoption, do not affect interest in switching to solar. This suggests that while the desire for alternative supply sources may be widespread, practical considerations such as financial capacity or housing conditions ultimately determine whether this interest translates into actual adoption.

Social Factors:

Unlike actual genset and solar adoption, peer effects do not significantly impact interest in switching to solar, suggesting that while social networks affect adoption decisions, initial interest in solar energy may be driven by other factors.

Unexpectedly, households in neighborhoods with regulations governing genset use are less likely to be interested in switching to solar. This may indicate the development of alternative community-level energy sources in those areas or household concerns about future regulations on other energy sources.

Table 4-3: Logit Results. Coefficients are presented first. Asterisks indicate statistical significance at the 1% (*), 5% (**), and 10% (***) levels, respectively. Statistically significant coefficients are emboldened. Standard errors are provided in brackets below the coefficients, with average marginal effects italicized below the standard errors.

		Dependent variable	(1) Owns Genset	(2) Owns Solar	(3) Interested in Switching to Solar
		Observations	5308	3635	3559
		P(X) = 1 in Data	70.37%	2.04%	75.05%
		McFadden Pseudo R^2	0.2567	0.1577	0.2991
		Percent correctly predicted	77.28%	97.94%	84.41%
Primary Category	**Sub-Category**	**Variable**			
Market and Policy Factors	**Electricity Reliability**				
	Typical daily hours of electricity outages	9 - 12 hours daily Outage	0.16 (0.10) *0.02*	0.07 (0.32) *0.00*	**0.23***** **(0.13)** ***0.03***
		4 - 8 hours daily outage	-0.05 (0.10) *-0.01*	**0.54***** **(0.33)** ***0.01***	0.04 (0.14) *0.00*
		<4 hours daily outage	**-0.34**** **(0.17)** ***-0.05***	0.33 (0.53) *0.01*	**-0.97*** **(0.23)** ***-0.12***
Personal Values & Preferences + Environmental Factors	**Electricity Reliability**	Willingness to pay for better reliability	0.05 (0.09) *0.01*	-0.11 (0.30) *0.00*	**0.69*** **(0.12)** ***0.08***
	Environmental Factors				
	Genset environmental impact	Concern about genset's environmental impact	**0.32*** **(0.08)** ***0.05***	0.46 (0.32) *0.01*	**-0.41*** **(0.12)** ***-0.05***
	Rating of air pollution from genset	Highly negative rating of air pollution from gensets	**-0.19**** **(0.10)** ***-0.03***	-0.18 (0.32) *0.00*	-0.09 (0.13) *-0.01*
Household Characteristics	**Demography**				
	Age of household head	Older household head (50 and above)	**-0.25*** **(0.09)** ***-0.04***	-0.44 (0.32) *-0.01*	**-0.44*** **(0.12)** ***-0.05***
	Education (highest level attained)	Higher education (college and above)	**0.31*** **(0.08)** ***0.05***	**1.01*** **(0.27)** ***0.02***	0.10 (0.11) *0.01*
	Gender	Male	**0.43*** **(0.08)** ***0.06***	0.02 (0.27) *0.00*	0.01 (0.11) *0.00*
	Size of household	Larger households (>5 members)	**-0.14***** **(0.08)** ***-0.02***	0.15 (0.27) *0.00*	-0.02 (0.12) *0.00*
	Housing				
	Type of building/dwelling	Face to Face (Face-me-I-face-you)	**-0.77*** **(0.09)** ***-0.12***	**-1.15**** **(0.54)** ***-0.02***	-0.18 (0.13) *-0.02*
	House ownership	Owns housing unit	0.12 (0.10) *0.02*	0.49 (0.33) *0.01*	0.22 (0.14) *0.03*
	Years of residence	Longer years of residence (>5 years)	-0.02 (0.08) *0.00*	-0.27 (0.30) *-0.01*	-0.14 (0.12) *-0.02*
	Income and Finance				
	Total monthly income	Higher income (> N100,000 ($60))	**0.73*** **(0.09)** ***0.11***	**1.15*** **(0.33)** ***0.02***	-0.07 (0.12) *-0.01*
	Primary source of income	Government, Family or Friend Support	-0.07 (0.38) *-0.01*	0.80 (1.13) *0.02*	-0.06 (0.50) *-0.01*
		Pension and retirement	-0.09 (0.20) *-0.01*	**1.29**** **(0.53)** ***0.02***	**0.58**** **(0.25)** ***0.07***
		Self-employment	0.08 (0.09) *0.01*	**0.59***** **(0.32)** ***0.01***	**0.83*** **(0.12)** ***0.10***
	Financial inclusion	Has a bank account	0.25 (0.21) *0.04*	0.06 (0.77) *0.00*	**-0.74**** **(0.34)** ***-0.09***
	Business				
	Household business	Has a household business	**0.39*** **(0.12)** ***0.06***	**0.97**** **(0.43)** ***0.02***	-0.09 (0.17) *-0.01*
	Size of household business (employees)	More employees (>5 employees)	-0.42 (0.29) *-0.06*	0.13 (0.76) *0.00*	**-0.95*** **(0.36)** ***-0.12***
	Size of household business (monthly revenue)	More revenue (> N100,000 (~$60))	-0.03 (0.18) *0.00*	**-0.99***** **(0.56)** ***-0.02***	-0.15 (0.23) *-0.02*

Table 4-4: Logit Results (continued). Coefficients are presented first. Asterisks indicate statistical significance at the 1% (*), 5% (**), and 10% (***) levels, respectively. Statistically significant coefficients are emboldened. Standard errors are provided in brackets below the coefficients, with average marginal effects italicized below the standard errors.

		Dependent variable	(1) Owns Genset	(2) Owns Solar	(3) Interested in Switching to Solar
		Observations	5308	3635	3559
		P(X) = 1 in Data	70.37%	2.04%	75.05%
		McFadden Pseudo R^2	0.2567	0.1577	0.2991
		Percent correctly predicted	77.28%	97.94%	84.41%
Primary Category	**Sub-Category**	**Variable**			
Household Characteristics	**Energy**				
	Grid electricity	Have grid electricity access	**-1.54***	**-1.46*****	**-1.62***
			(0.30)	**(0.78)**	**(0.41)**
			-0.23	***-0.03***	***-0.20***
	Usage patterns	Time of major appliance use (daytime (8am - 4pm))	-0.12	-0.18	-0.02
			(0.10)	(0.36)	(0.14)
			-0.02	*0.00*	*0.00*
	Frequency of payment for grid electricity	More frequent payments (weekly/biweekly)			**-0.35****
					(0.15)
					-0.04
	Expenditure on grid electricity	Monthly electricity payment amount (Naira) (standardized)			-0.02
					(0.06)
					0.00
	Metering status	Has a meter			-0.11
					(0.19)
					-0.01
	Type of meter	Has a prepaid meter as opposed to a postpaid meter			-0.21
					(0.15)
					-0.03
	Gensets				
	Ownership of genset	Has a genset		**-1.82***	**0.40****
				(0.31)	**(0.18)**
				-0.03	***0.05***
	Frequency of routine genset maintenance	More frequent routine maintenance (weekly/biweekly/monthly)			**-0.76***
					(0.14)
					-0.09
	Expenditure on routine genset maintenance	Monthly expenditure on genset routine maintenance (Naira) (Standardized)			0.08
					(0.06)
					0.01
	Maintenance-related genset challenges/breakdowns	Has experienced genset maintenance breakdowns/challenges			**-0.51***
					(0.12)
					-0.06
	Frequency of fuel purchase for genset	More frequent fuel purchase (daily/weekly)			**0.82***
					(0.13)
					0.10
	Fuel consumption	Monthly fuel consumption (Liters) (standardized)			0.08
					(0.19)
					0.01
	Genset usage patterns	Time of major genset use (daytime (8am - 4pm))			-0.11
					(0.21)
					-0.01
	Awareness				
		Know electricity tariff band	**0.67***	0.62	**1.35***
			(0.11)	(0.41)	**(0.14)**
			0.10	*0.01*	***0.17***
		Aware of Nigeria energy transition plan (ETP)	0.05	-0.12	0.04
			(0.08)	(0.27)	(0.11)
			0.01	*0.00*	*0.00*
		Aware of solar power systems	**0.21****		0.78
			(0.08)		(0.72)
			0.03		*0.10*
	Location				
	Local Government Area (LGA) *(compared to median/average income LGAs - Kosofe and Lagos Mainland)*	Agege	-0.16		-0.34
			(0.18)		(0.26)
			-0.02		*-0.04*
		Ajeromi-Ifelodun	0.09		-0.28
			(0.18)		(0.25)
			0.01		*-0.03*
		Alimosho	**2.98***		**1.32***
			(0.32)		**(0.24)**
			0.45		***0.16***
		Amuwo Odofin	0.11		-0.40
			(0.24)		(0.33)
			0.02		*-0.05*
		Apapa	0.34		**1.23****
			(0.23)		**(0.57)**
			0.05		***0.15***

Table 4-5: Logit Results (continued). Coefficients are presented first. Asterisks indicate statistical significance at the 1% (*), 5% (**), and 10% (***) levels, respectively. Statistically significant coefficients are emboldened. Standard errors are provided in brackets below the coefficients, with average marginal effects italicized below the standard errors.

		Dependent variable	(1) Owns Genset	(2) Owns Solar	(3) Interested in Switching to Solar
		Observations	5308	3635	3559
		P(X) = 1 in Data	70.37%	2.04%	75.05%
		McFadden Pseudo R^2	0.2567	0.1577	0.2991
		Percent correctly predicted	77.28%	97.94%	84.41%
Primary Category	**Sub-Category**	**Variable**			
Household Characteristics	**Location**	Badagry	0.36		**-1.01****
	Local Government Area (LGA) *(compared to median/average income LGAs - Kosofe and Lagos Mainland)*		(0.28)		**(0.41)**
			0.05		***-0.12***
		Epe	**0.62*****		**-1.86***
			(0.33)		**(0.38)**
			0.09		***-0.23***
		Eti Osa	**3.47***	**1.18***	**0.81***
			(0.72)	**(0.42)**	**(0.31)**
			0.52	***0.02***	***0.1***
		Ibeju Lekki	0.90	-36.4	0.29
			(0.67)	(1.24E+08)	(0.63)
			0.14	*-0.69*	*0.04*
		Ifako-Ijaye	0.17		**-0.46*****
			(0.19)		**(0.25)**
			0.03		***-0.06***
		Ikeja	**0.42****	0.39	-0.27
			(0.21)	(0.58)	(0.25)
			0.06	*0.01*	*-0.03*
		Ikorodu	0.03		**1.84***
			(0.22)		**(0.45)**
			0		***0.23***
		Lagos-Island	**-0.69***	-1.56	**0.67****
			(0.19)	(1.05)	**(0.30)**
			-0.1	*-0.03*	***0.08***
		Mushin	0.05		**-0.47****
			(0.16)		**(0.22)**
			0.01		***-0.06***
		Ojo	**-0.47****		0.22
			(0.21)		(0.31)
			-0.07		*0.03*
		Oshodi-Isolo	0.09		**1.92***
			(0.18)		**(0.34)**
			0.01		***0.24***
		Somolu	**0.63***		-0.07
			(0.19)		(0.22)
			0.09		*-0.01*
		Surulere	**-0.35****		**1.35***
			(0.16)		**(0.27)**
			-0.05		***0.17***
	Road accessibility around household	Above average roads (according to rating by household)	**0.28***	-0.27	-0.10
			(0.08)	(0.29)	(0.11)
			0.04	*-0.01*	*-0.01*
	Security of area around household	Above average security (according to rating by household)	-0.06	-0.16	**0.37***
			(0.08)	(0.28)	**(0.11)**
			-0.01	*0.00*	***0.05***
Social factors	**Peer Effects**	Nearest household in survey has a genset	**0.80***	**0.56*****	0.06
			(0.07)	**(0.33)**	(0.11)
			0.12	***0.01***	*0.01*
		Nearest household in survey has solar	**-0.58*****	**1.38****	0.30
			(0.34)	**(0.54)**	(0.47)
			-0.09	***0.03***	*0.04*
		Has received complaints about genset use			-0.05
					0.15
					-0.01
	Regulation	Is subject to community/area/neighborhood regulations regarding genset use	**-0.69***	**0.81****	**-0.26*****
			(0.12)	**(0.32)**	**(0.15)**
			-0.10	***0.02***	***-0.03***
		const	0.05	**-4.28***	0.77
			(0.39)	**(1.09)**	(0.90)

Discussion

The results reveal interesting dynamics in the adoption of decentralized energy sources. To contextualize these findings at the household level, the multilevel perspective on socio-technical transitions (MLP) offers a useful framework. It also supports an exploration of the broader environment, which is essential for understanding household energy transitions [22].

The Multilevel Perspective on Socio-technical Transitions (MLP)

Technological transitions involve not only shifts in technology but also changes in social elements [41, 60]. These transitions are termed "socio-technical" because technology gains functionality only through interactions with human agency, social structures, and organizations [60, 67]. Technologies and skills are embedded within routines, behaviors, and organizational structures, fulfilling societal functions as part of socio-technical configurations [60, 67]. Thus, transitions, including energy transitions, are multi-dimensional and co-evolutionary [41].

The MLP framework provides a comprehensive understanding of these transitions by focusing on the interplay between **niches (micro-level innovations), regimes (meso-level rules and institutions),** and **landscapes (macro-level contexts),** arguing that successful transitions are achieved through coordinated changes across all three levels [41, 58-60, 68-69].

The stability—sometimes referred to as resistance to change, lock-in or path dependence—of existing socio-technical systems results from the alignment of heterogeneous elements like technologies, policies, markets, infrastructures, cultural meanings and user practices, coordinated by social groups [41, 60]. **Regimes**, consisting of semi-coherent rules and institutions, guide these social groups and create dynamic stability, where innovation is typically incremental [41, 58, 60]. In contrast, **niches** foster radical innovations, often driven by entrepreneurs, start-ups, activists, or other *"relative outsiders"* responding to challenges within established regimes [69, p.189]. These niches, existing on the periphery, provide the *"seeds of change"* necessary for socio-technical transitions [60, p.1261]. However, *"the environment into which these seeds are sown is, of course, the main determinant of whether they will sprout"* [70 cited in 41, p.228]. Due to the alignment of regime elements, innovations often struggle to break through entrenched systems unless *"windows of opportunity"* arise, triggered by regime tensions or shifts in the broader **landscape**, which refers to exogenous factors, including *"both slow-changing developments (e.g., demographics, cultural repertoires, societal concerns, geopolitics, macro-economic trends) and external shocks (e.g., wars, financial crises, accidents, oil price shocks)"* [41, p.1262; 58, p.113; 69, p.190].

This framework is particularly useful for understanding Nigeria's potential transition from backup generator sets (BUGs) to solar PV systems. The MLP helps explain how BUGs have become so deeply embedded in Nigeria's electricity system that it can now be considered a 'grid + genset' regime—one where gensets are not merely backup solutions but have become an institutionalized, co-existing layer of electricity provision alongside the centralized grid. Additionally, it provides insights from Strategic Niche Management (SNM) which can be leveraged to foster the emerging solar PV niche and identify opportunities for reducing reliance on gensets [58, 67].

'Grid + Genset' Regime

As extensively outlined in Chapter 3, Nigeria's electricity sector has experienced multiple transitions since the first plant was established in Lagos Marina in 1896[60] [40]. While extensive literature exists on the development of Nigeria's centralized electricity system, gensets are often treated as peripheral and receive limited scholarly attention[61]. However, far from being secondary, gensets are a critical component of Nigeria's electricity landscape. Trovalla and Trovalla [71, p.45] illustrate this reality, noting that the General Director of Nigeria's Centre of Management Development[62] described gensets as the *"permanent"* solution, with the national grid serving as the *"standby."* Estimates suggest that 22 million small gasoline generators (0–4 kVA) with a total capacity of approximately 42 GW are in use across Nigerian households and small businesses—eight times the capacity of Nigeria's national grid [52]. In Lagos State alone, over 19 GW of genset capacity powers households, businesses and markets, significantly surpassing the 1 GW daily grid allocation for the state [44, 47].

Broadly, the literature suggests that the widespread use of gensets has emerged due to persistent reliability issues on the national grid [5]. Gensets are described as Nigerians' way of coping with "*the country's anaemic electricity infrastructure*"—a way to *"remain within the system's premises while responding to its contingencies"* [32, p.62]. As one interviewed expert put it, *"Yes, we have them [gensets]. They will stay as long as the grid is not available. As long as electricity is not available, generator will stay in Nigeria."*

As early as 1909, power outages occurred in Lagos, leading to public frustration [48]. Edomah and colleagues [40, p.6] explain that the first World War stalled the development of the Lagos power plant, impacting the sourcing of spare parts such that *"it was necessary to cannibalize some power plants to provide spares to keep the others working"* and that *"by 1918, the streetlights had to be turned off due to increased energy demand and insufficient supply."*

However, widespread electrification across Nigeria largely began in the 1950s with the establishment of the Electricity Corporation of Nigeria (ECN), which spearheaded grid expansion across the country [73-74]. In 1962, the Niger Dams Authority (NDA) was created to oversee hydroelectric projects like Kainji Dam [75]. By 1972, the Nigerian government consolidated electricity generation, transmission, and distribution under the newly formed National Electric Power Authority (NEPA), merging ECN and NDA [5, 75]. This centralization was intended to improve efficiency and unify the national grid, linking existing power stations, including the Kainji hydro plant in Niger, the Ijora thermal plant in Lagos, and the Oji River and Afam thermal plants in Eastern Nigeria [5]. By 1974, NEPA supplied 98.7% of Nigeria's electricity, marking the first time the national grid was fully centralized under a single authority [5].

However, as electrification expanded, challenges quickly emerged. Olukoju [5] argues that demand has always outstripped supply in Nigeria's electricity sector, but the gap widened dramatically from the 1970s onward due to rapid population growth and economic expansion driven by the oil boom. The

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[60] Adebayo [48, p.195] explains that *"contrary to popular narrative, the first electrical equipment that was purchased and installed was not technically suitable. The PWD [Public Works Department] carried out further investigations and put in a working system in December 1897 during the tenure of Henry McCallum as governor (1897-9)"*

[61] It is possible that the decentralized nature of genset use which makes related data scarce, fragmented and difficult to collect, hinders in-depth analysis.

[62] *"The Centre for Management Development (CMD) is a resource institution established in 1973 by the Federal Government of Nigeria as the operational arm of the Nigerian Council for Management Development (NCMD), which has overall responsibility for the stimulation, promotion and coordination of management education, training and development in Nigeria."* [72].

post-oil boom period, coupled with military rule in the 1980s, is often linked to the onset of the country's continuously deteriorating electricity service [32, 48]. Therefore, since the 1980s, *"the country then entered an era of unprecedented dependence on stand-by generators. 'There is a sense,' notes one writer, 'in which one can say that from 1980 to 1985 NEPA[63] became the stand-by generators!'"* [5, p.55]. Using MLP terminology, worsening electricity quality issues can be seen as the core tension in the regime that created a 'window of opportunity' for gensets.

Initially, gensets were niche innovations, affordable only to elites and industries [32, 73]. For example, in 1989, only ~8% of industrialists did not have standby power generation facilities [76]. However, by the 2000s, they had diffused into the middle class, driven by several factors in addition to the failure of the centralized electricity system.

Smith [32] identifies three key drivers behind this mass adoption of gensets in Nigeria. First, there was an increasing societal expectation that modern households, businesses, and institutions should have access to electricity and the appliances it powers. This growing demand for electricity, despite the inadequacies of the grid, represented an internal regime tension. Nigerians, within the existing centralized grid system, had come to desire the conveniences powered by electricity, but the grid supply was inadequate, thereby creating a tension that provided an opportunity for gensets to emerge as a solution.

The second driver, according to Smith [32], was the growing income and wealth among different groups in Nigeria. This shift in the market—another regime element—further expanded the window of opportunity for gensets. Not only was there a desire for more reliable electricity, but the market had also become more capable of affording it.

The third, and most significant, factor was the *"arrival of relatively inexpensive, Chinese-made generators that were specifically marketed to middle-class consumers and small businesses"* [32, p.69; 71]. This driver highlights how niche-internal dynamics—particularly the efforts of entrepreneurs and marketers—interacted with landscape-level processes to maximize the windows of opportunity for gensets. At the landscape level, global trade liberalization, outsourcing, offshoring, and China's rapid industrialization played a critical role in making these affordable gensets widely available [77-79]. Duan and colleagues [50, p.1] explain that China ascended as the *"Factory of the World"* due to factors like *"its membership of the World Trade Organization since 2001, its well-educated but relatively low-wage workforce and state-led promotion of foreign direct investment (FDI) in processing export activities."* This confluence of factors at the landscape level improved the price-performance of gensets, allowing Chinese brands such as Elepaq, Sumec Firman, and Tiger—now accounting for over 70% of gensets in the Lagos Survey—to dominate the Nigerian market.

Today, gensets have become institutionalized in Nigeria's electricity regime. They have transcended their functional role and become cultural symbols, with small, portable generators being colloquially known as *"I better pass my neighbor"* gensets reflecting their role in households' competition for status [32, p.69 (quote); 81]. As Shotunde [82] notes, generator ownership has become normalized across all income levels (Figure 4-3c), and many households feel obligated to own one. Additionally, incremental

[63] NEPA (the abbreviation for the National Electric Power Authority, which is now defunct) remains a generic nickname for grid-based electricity [6, 9, 71]. Smith [32, p.60] suggests that Nigerians still call the national grid 'NEPA' *"as if to note the continuity of failure"*.

innovations like power switches that facilitate seamless transition between grid and genset power have reinforced their utility [71].

The embeddedness of gensets is also evident in building practices and regulation. Buildings in Nigeria are now designed with generator spaces [83], and Nigeria's federal electricity regulatory commission (NERC) has established guidelines for genset importation, including small household models [84]. The widespread availability of repair artisans and spare part shops within neighborhoods further supports the maintenance and longevity of gensets, contributing to their persistence in the energy system [82]. Moreover, there have been allegations of a *"generator mafia"*—a powerful group of politicians and businessmen controlling genset imports and sales—deliberately perpetuating grid failures to maintain their hold on the lucrative market [32, p.76]. One interviewed expert shared a similar suspicion:

> "My suspicion is also that the generator industry has a lot of lobbying power in a way that sort of makes it inconsistent for the Nigerian grid to become reliable. I don't have evidence, but I genuinely believe that when policies are being made to increase reliance on the grid, I get the sense that generator companies have a big say—in a way that continues to cement their position as almost the primary provider of generated electricity."

Nearly 70% of households in the Lagos survey own a genset, with most stating that they cope with outages by relying on these backup systems. Of the genset owners surveyed, 84% reported purchasing their gensets due to grid reliability issues, and 96% use their gensets primarily as backup for grid electricity. 23% of the households without gensets cited sufficient grid supply as the main reason for not owning one. These survey findings align with the general narrative that poor grid reliability plays a central role in genset adoption. The results from the genset ownership model further reinforce this point.

Additionally, the significant correlations between genset ownership and wealthier households, better-educated household heads and households with home-based businesses support Smith's [32] claim that higher desire for electricity, coupled with higher income levels, drives increased adoption of gensets. Furthermore, the strong peer effects observed in the adoption model align with the cultural dimension of genset ownership, as evidenced by the *"I better pass my neighbor"* narrative, which frames genset ownership as a marker of social status and acceptance within the community. The fact that nearly 50% of genset owners in the Lagos survey perform routine maintenance on their gensets weekly, bi-weekly, or monthly further underscores the normalization of genset use and the ease of repair and maintenance, as noted by Shotunde [82].

In summary, while gensets began as niche innovations, they are now firmly part of Nigeria's electricity regime, supported by linked elements including cultural meanings, user practices, actor configurations and regulations. As such, any effort to transition away from gensets toward solar PV systems must be understood as a *"multi-dimensional struggle"* [41, p.227].

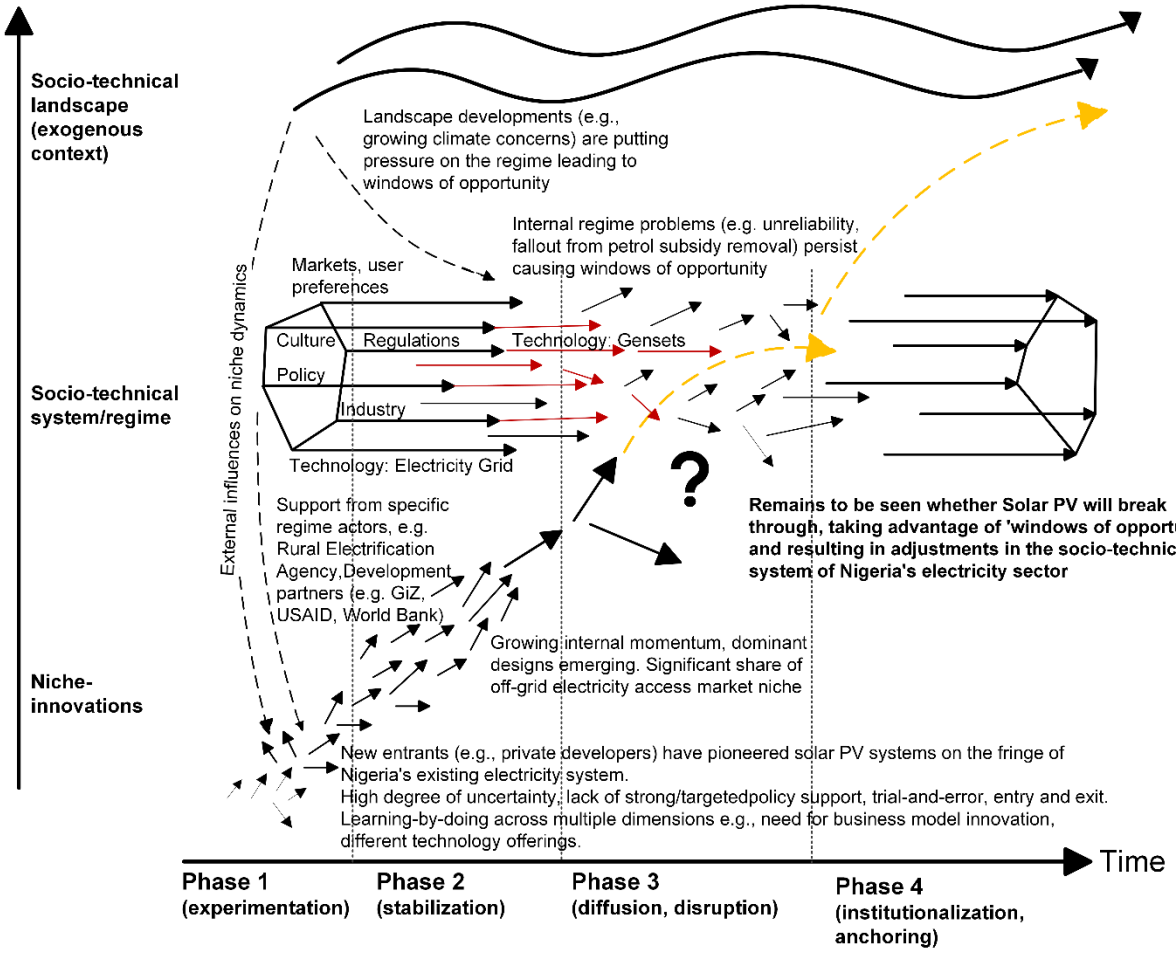


Figure 4-4: Multilevel perspective on the transition from gensets to solar PV in Nigeria. Adapted from [69].

Solar Windows of Opportunity vs. Genset Lock-in Mechanisms

However, while gensets are a central part of Nigeria's electricity regime, they do not appear to have fully closed the core gap of unreliability in the sector. For instance, 83% of genset owners in the Lagos survey reported running their BUGs for shorter durations than the total outage periods they experience. 43% of households with gensets indicated that their gensets do not power all their appliances. Figure 4-4 illustrates this by representing gensets with solid red lines that sometimes connect to the centralized grid's black lines as strong extensions but often fail to do this, leaving gaps.

As noted earlier, 74% of households stacking both gensets and solar systems cited improved electricity reliability as their primary reason for adopting solar, indicating dissatisfaction with gensets. Across all respondents with solar systems, 80% adopted solar for better reliability, 45% for cheaper electricity, and 35% for environmental or health reasons. These last two points highlight additional internal tensions within the 'grid + genset' regime, as gensets have increasingly come under pressure due to economic, environmental, and health concerns [3].

The findings in this chapter show that households with gensets—and those that purchase genset fuel more frequently—are more likely to express interest in switching to solar systems, further indicating latent dissatisfaction. The recent removal of Nigeria's fuel subsidy has exacerbated this dissatisfaction. The fuel subsidy removal, announced by President Bola Tinubu in May 2023, increased petrol prices from ₦238.11 to ₦545.83 per liter within a month [85], with average prices reaching ₦630.63 in October and ₦648.93 in November 2023 when the Lagos survey was conducted [86-87]. Given that over 98% of households in the Lagos survey power their gensets with petrol/gasoline, this increase has had significant effects. In fact, only 5% of genset users reported no impact from the subsidy removal, while 84% reduced their genset usage, 9% stopped using gensets entirely, and 2% switched to renewable energy. Moreover, 28% of households reported considering alternative energy sources, primarily solar power, since the subsidy removal. It is worth noting that the subsidy has, at least been partially reintroduced, to relieve the financial burden on Nigerians [88].

In addition to the reliability and cost tensions, there are also environmental concerns. About 60% of households in the Lagos survey expressed concerns about the environmental impact of genset use. Of those who responded to questions on air quality and noise pollution, over 50% noted that gensets contributed significantly to both issues in their area. Relatedly, the model results indicate that concerns about air pollution from gensets deter their adoption.

There are also conflicts between different actors within the regime. For instance, 14% of respondents reported that their use of gensets was restricted by community or neighborhood regulations—typically limiting operation to specific hours (e.g., before 23:00 or midnight) or banning them entirely. Beyond community-level restrictions, tensions also arise within public institutions, where internal interests can undermine the grid. As one utility executive lamented:

> "They [Gensets] are doing more harm than good, if you ask me. Any country that relies on each customer generating their own electricity—just to run their business or day-to-day activities—is damaging its economy. And this issue of having generators on standby, especially in public agencies, has become a kind of conduit pipe. Even when there's good-quality grid supply, they'll insist on using gensets because of what they're getting from running those generators daily. There was one case where we invested heavily to reroute and upgrade supply for a government agency that claimed poor quality. Even after we improved the line, they still ran generators everyday for their operations, blaming *'voltage issues'*. What does that mean? It's probably because the people supplying the diesel or maintaining the generator don't want their business to go down. So, they'll blackmail the grid supply to ensure the gensets keep running. We had similar issues in another state—this time, an agency on a 33kV line—voltage that can power a water treatment plant—kept saying the grid wasn't good enough just to run lights and an AC. So, you start to wonder: is it really about quality, or is someone protecting a generator business? These are some of the challenges we face."

The Federal Government of Nigeria (FGN) has made several attempts to regulate genset use. In 2015, it banned the bulk importation of small generators to reduce air pollution [89-90]. In 2020, a bill was introduced to ban genset importation and use altogether [91-92]. Meanwhile, growing urgency for climate action at the landscape level, along with policy initiatives by regime actors—such as Nigeria's NDCs and ETP, which specifically target the displacement of gensets—is placing further pressure on the 'grid + genset' regime.

While the regime is under increasing pressure with widening windows of opportunity, it is not guaranteed that solar PV systems will replace gensets (Figure 4-4). For instance, the results from the analysis in this chapter also show that households experiencing genset maintenance challenges or breakdowns are less likely to express interest in switching to solar systems, possibly indicating existing mechanisms that improve genset operation or make it more tolerable. The proposed genset bans have faced significant public resistance and implementation challenges [93-95], further highlighting the need to carefully consider the selection and retention mechanisms that sustain the 'grid + genset' regime.

One of the most resilient lock-in mechanisms is the financial model behind genset use, which is difficult to match with solar home systems (SHS) [3, 16]. Gensets allow users to invest minimal upfront capital and ration their usage based on their financial capacity and preferences [3, 6]. In the Lagos survey, 54% of genset owners reported purchasing their gensets for less than ₦100,000 (~$60)—a sum lower than the monthly income of half the respondents. Comparatively, a 1.5 kVA gasoline generator costs around $150, while a 1.5 kVA solar system costs about $2,500 [52]. Unsurprisingly, high acquisition costs were cited by Lagos households as the primary reason for not considering a switch to solar power. Nearly 90% of households in the survey without solar systems pointed to the high upfront cost as the main barrier[64].

As an independent energy provider explained:

> "The conversation is always around economics. This is a poor country—ability to pay matters a lot more than anything else. That's why the question must be asked: is the transition to renewables organic? Who is funding it, and who is paying for it? Once you incorporate nighttime loads and batteries, can we still sell this? So, if we're really going to transition, we have to make the market—meaning, we need to shrink the original outlay for this technology that makes the price too high. And over time, when it comes down to the level where it can compete with gas—which is the main source on the grid—then solar will become the tool or the resource people are actually interested in using."

Gensets also typically operate far below their maximum capacity [52]. For instance, over 40% of respondents with gensets that cannot fully power all their household appliances reported using them primarily for basic items like light bulbs, fans, and televisions. Technically, small solar systems could replace gensets in such cases—but even for these smaller systems, the price gap often remains significant [52].

SHSs are also less readily available in Nigeria compared to gensets, which are widely sold [3]. Additionally, SHSs often require custom configurations based on load and appliances, making them less straightforward to acquire and use [3, 96]. Only about half of genset owners in the Lagos survey reported performing an internal energy audit or consulting an expert when purchasing their genset, indicating that the process of acquiring a solar PV system is more involved than most genset owners are accustomed to. Furthermore, even standardized solar packages available in the SSA market struggle to match the versatility of BUGs, which can more easily scale up capacity. It is also much cheaper to own multiple backup gensets than to procure additional solar modules and batteries [3]. For example, adding a single large appliance like a refrigerator can increase the cost of a SHS by up to 2.5 times [97]. Given that nearly 70% of solar adopters in the Lagos survey own AC or DC solar systems with

[64] A similar trend was observed in genset adoption. Approximately 60% of households without gensets cited affordability as the main barrier.

batteries and inverters, these cost barriers are particularly relevant. Meanwhile, standalone solar appliances, such as direct current (DC) lighting systems, may offer a lower-cost entry point but are insufficient for most household electricity needs.

Another major advantage of gensets is their ability to run on-demand—a flexibility that solar PV systems struggle to match without adequate battery storage. In the Lagos survey, over 80% of households reported that most of their appliances are used at night, and fewer than 10% used their gensets primarily during the day. As one interviewee explained, *"the issue is that generators tap into some of the Nigerian peculiarities—in that they're generally more reliable than the grid because when you need it, you can call upon it, unless your generator fails."*

Given the strong lock-in mechanisms that support genset usage, such as those discussed above, it is crucial to explore how the emerging solar PV niche can be empowered to challenge this dominance and initiate a shift in Nigeria's electricity supply regime.

Empowering and Expanding the Solar niche

Within a socio-technical niche, innovations are nurtured and protected from mainstream market selection to foster learning and development—such as learning by doing, using and interacting [60, 69]. However, to take advantage of windows of opportunity and break into the regime, these innovations must eventually find acceptance within the mainstream system.

Smith and Raven [98] analyze the role of niches as *"protected spaces"* or *"incubation rooms"* by highlighting three core properties: shielding, nurturing, and empowering [60, p.1261; 69, p.190). **Shielding** refers to both active and passive processes that hold off mainstream selection pressures that would otherwise *"select against"* radical innovation [59, p.346; 98]. By creating a protective space, shielding enables **nurturing**, which relates to efforts undertaken to improve the innovation's performance [59].

In the Nigerian context, solar PV deployment in Northern Nigeria for rural electrification, water pumping, and telecommunications in the 1980s and 1990s can be seen as examples of passively-created niches—areas beyond the reach of the national grid that provided contingent opportunities for solar PV [98, 99]. More recently, the Nigeria Electrification Project (NEP) added an active dimension, by providing subsidies for the electrification of unserved and underserved populations via solar hybrid mini-grids and SHSs [100]. NEP nurtured a strong market for solar solutions with over 50 international and local companies selling more than two million SHSs. Additionally, under NEP, 74 mini-grid developers qualified to participate, and more than 100 operational mini-grids have been developed [101]. These shielding and nurturing efforts have generated internal momentum within the solar niche.

While shielding and nurturing primarily focus on the internal dynamics of the niche, **empowering** relates to the outward-oriented work required for wider deployment of niche innovations [59, p.346]. When aiming for the desired displacement of gensets by solar PV systems, empowerment becomes especially crucial. Two distinct trajectories for empowerment have been identified: *"fit-and-conform"*—which seeks to make niche innovations competitive within the existing selection environment, and *"stretch-and-transform"*—which involves altering mainstream selection environments to favor niche innovations [59, p.346; 98, p.1025].

Although similarities exist between gensets and solar systems in terms of adoption motivations and early adopter characteristics—suggesting that fit-and-conform mechanisms may be effective—many

existing selection mechanisms must likely be transformed for rapid solar adoption. For instance, given gensets' growth over the past two decades and the prominent influence of income in the adoption models considered in this chapter, one could argue that reducing the upfront cost of solar systems to levels similar to gensets would lead to a significant increase in adoption. Heinemann et al. [3] modeled energy-as-a-service (EaaS)/pay-as-you-go (PAYGO)[65] packages for SHSs and found that these can compete with BUGs. However, only 3% and 17% of solar owners in the Lagos survey acquired their systems through EaaS and PAYGO models, respectively, while 77% purchased their solar systems outright—similar to 97% of genset owners who bought their gensets in full. This suggests that significant improvements are needed in both the availability and social acceptability of financing models that make solar systems financially competitive with gensets. Consequently, there is an opportunity for policymakers to explore fit-and-conform empowerment strategies to support solar systems.

On the other hand, conventional economic analyses that find a substantial cost gap between gensets and solar PV systems often fail to account for environmental and health impacts. When factoring in the social cost of carbon, solar systems are more cost-effective than gensets [3]. This suggests that innovative financing mechanisms that internalize the climate or health benefits of genset displacement could significantly improve solar PV systems' cost-effectiveness. Such approaches represent ways to stretch and transform the selection environment for solar adoption. Notably, the Nigerian Government has recently begun exploring the establishment of a national carbon market, which could serve as an enabling factor [102-103].

In addition to providing turnkey solar solutions to facilitate fit-and-conform efforts, advocating for technical consultations prior to adopting alternative energy systems could help transform the selection environment. Making these resources accessible and establishing them as standard practice would foster more informed decision-making among potential adopters, ultimately supporting a smoother transition to solar energy.

Fitting and conforming solar solutions to the dispatchability and flexibility of gensets may be impractical, especially in the short term. Instead, transforming the environment through mechanisms like battery cost subsidies and coordination between private solar systems and the grid—such as through net metering—could significantly boost solar adoption. With most electricity demand occurring at night, enabling households to feed solar power into the grid during the day and draw power as needed would make solar adoption more attractive and potentially improve grid service quality. This is unlike the current setup where personal gensets operate independently of the distribution grid.

Over the past two to three decades, gensets have become prevalent in Nigeria's residential electricity sector, driven largely by cost reductions and social factors. However, unlike the relatively organic adoption of gensets, the transition to solar PV must be more deliberate, especially considering the urgency of climate action and the fundamental differences in the economics and operation of the two technologies [41, 69, 96]. For instance, while the upfront costs of solar systems remain higher than

[65] In the Energy-as-a-Service (EaaS) business model, solar companies provide electricity generated by solar home systems (SHS) without selling the systems themselves. These companies handle the installation, operation, and maintenance costs, while customers make regular payments for the service. In contrast, the pay-as-you-go (PAYGO) or lease-to-own model requires customers to make a small upfront down payment, followed by scheduled payments over time, with the goal of eventually owning the SHS. In both models, solar companies often employ technological innovations, such as remote lockout features, to automatically disable SHSs in the event of a missed payment [3].

those of gensets—despite their continuous decline—waiting for these prices to converge is not the most effective strategy. Instead, innovative business models should be developed and scaled to leverage solar PV's minimal operating and competitive lifecycle costs. In other words, the focus should shift from hoping for further price reductions to taking more proactive measures that address current barriers to adoption. This suggests that while fit-and-conform strategies will be useful in some cases, in several others, new strategies to stretch and transform the environment will be essential for accelerating solar adoption in Nigeria.

Conclusion

The unreliability of Nigeria's electricity grid, supported by factors such as the attainment of higher education, rising incomes, social networks and societal expectations, and the associated desire for electricity and the commodities it powers has given rise to the prevalence of gensets in Nigeria. However, inadequacies, internal tensions and external pressures have created windows of opportunity for a cleaner technology to break through the current 'grid + genset' regime and potentially displace gensets. Accordingly, this analysis of the Lagos case highlights a strong interest in transitioning to solar systems. The results indicate that the factors that influence interest may be insufficient to drive actual uptake. Using the MLP framework, this chapter also demonstrates that the current regime's selection and retention mechanisms present significant challenges to mainstreaming solar PV systems.

While gensets entered the electricity regime in an ad hoc manner—without targeted policy support—the urgency of transitioning to solar PV systems, given climate imperatives and their distinct economic and operational characteristics, demands deliberate policy action [41, 69]. This is further supported by the fact that solar PV systems, despite applications dating back to the 1970s in Northern Nigeria, have yet to reach mainstream adoption [99].

To accelerate this transition, a well-coordinated policy mix is necessary, involving a range of complementary instruments and consistent policy settings [20, 66, 104]. These policies must address not only financial barriers but also social, infrastructural, and regulatory challenges. Consequently, this section outlines six key areas for targeted intervention, drawing on insights from both the quantitative and qualitative analyses. In the short-term, policy efforts should aim to:

1. **Advance Financial Incentives**: Financial barriers remain significant in the adoption of solar PV systems, despite other influencing factors highlighted in the analysis. Addressing these constraints should therefore be integral to any strategy aimed at driving solar PV adoption [38]. Successful policy models in more advanced economies and other African countries illustrate a range of effective approaches—grants, subsidies, rebates, low-interest loans, feed-in tariffs, net metering, carbon pricing, and import duty exemptions for solar equipment—that could be adapted to Nigeria [20, 59, 65-66, 96]. For example, solar adoption in countries like Uganda, Tanzania, and Kenya has been supported by VAT and import duty exemptions, which have helped reduce the cost of solar home systems. Kenya, in particular, introduced such incentives as early as the 1980s [65]. Similarly, the Tunisian government recently introduced investment subsidies and low-interest loans to accelerate solar PV adoption among middle-income households [105-106]. Adopting similar strategies in Nigeria could lower financial barriers and enhance affordability, particularly for households and small businesses. The primary objective of such incentives would be to enhance access to affordable capital and

avoid substantial upfront *("lumpy")* payments, recognizing that the transition from gensets to solar PV involves the structural redirection of costs from ongoing operational expenses to capital expenditures [22, 107]. Given the limited purchasing power of most Nigerian households, financial incentives should focus on making solar systems more affordable rather than increasing genset costs. Additionally, policymakers should consistently evaluate the effectiveness, equity, and sustainability of these incentives to ensure they achieve widespread adoption without unintended market distortions.

2. **Enable Broad Stakeholder Coordination**: The transition from gensets to solar PV systems necessitates a level of stakeholder coordination far beyond what was needed during the genset adoption phase. As Larkin [83, p.243] points out, the adoption of gensets in Nigeria exemplifies *"new forms of individual, competitive, liberalism."* There was no strategic plan that required the involvement of multiple stakeholders in developing the genset regime. Instead, driven by factors like income and building type, each household independently chose to acquire an *"I better pass my neighbor"* genset if they could afford it. This decentralized and competitive approach will not engender a rapid transition to solar systems. A successful mass uptake of solar systems will need collaboration across a broad spectrum of actors—from securing large pools of low-interest capital to facilitating grid tie-ins to balance solar energy's generation patterns. Thus, policy efforts, including their design and implementation, must prioritize coordination across various stakeholder groups, including government entities, private sector actors, financial institutions, donors, development partners, academia, and civil society. For instance, Kenya's experience highlights the crucial role of a dynamic private sector in expanding solar access. Unlike in Tanzania and Uganda, where limited entrepreneurial engagement hindered the growth of solar companies, Kenya's enabling business environment and strong entrepreneurial culture encouraged private-sector-led expansion [65]. While Nigeria's solar PV deployment has been largely government- and donor-driven, these efforts have played a catalytic role in stimulating private-sector participation. Government and donor-led subsidies provided the spark, while Nigeria's strong entrepreneurial culture served as the ready wood for expansion. This should be further encouraged by reducing bureaucratic barriers, creating investment-friendly policies, and providing targeted incentives for private firms—all of which could accelerate decentralized solar adoption. Moreover, similar efforts to incentivize other key stakeholders—such as financial institutions, electricity distribution utilities, and local innovators—will be critical to fostering local innovation and scaling Nigeria's solar market.

3. **Prioritize Community-Level Interventions**: The significant influence of Local Government Area (LGA), peer effects, and community regulation variables in the adoption models suggests that community-level efforts are likely to be more effective than broader state or national initiatives. While national-level genset bans have faced considerable resistance, community-level regulations, as indicated by the analysis in this chapter, seem to have successfully affected genset adoption. Additionally, targeted interventions at the community level could provide solar PV access to households that may otherwise be excluded due to constraints related to income or building type.

4. **Promote Awareness and Information Campaigns**: The significance of awareness in the genset ownership model underscores its crucial role in the mass adoption of alternative energy

technologies. Therefore, policies promoting a transition to solar should be accompanied by robust awareness campaigns that not only increase knowledge of solar systems but, more importantly, emphasize their relative benefits in order to transform the selection environment. This distinction is key because while 70% of households in the Lagos survey were aware of solar systems, fewer than 2% had adopted them. Conversely, those who perceived genset-related air pollution as highly negative were less likely to own gensets, suggesting that targeted media campaigns highlighting these negative impacts could encourage the displacement of gensets. The influence of narratives and discourses in technology adoption is well-established [16, 59, 83]. Boamah & Rothfuß [16], for example, highlighted the impact of the catchphrase *"you have your own Akosombo[66] when you go solar"* in promoting solar adoption in Ghana. Similarly, the widespread use of the phrase 'I better pass my neighbor' to describe gensets in Nigeria reflects the power of intentional framing. Shifting the narrative—positioning gensets as harmful to both self and neighbors while framing solar as 'good for my neighbor, good for me'—could be instrumental in driving solar adoption. Given the established desire among households to use energy technologies as symbols of socioeconomic status, strategic framings could help position solar PV as a desirable alternative to gensets [22]. The model results also suggest that targeting specific groups, such as the self-employed, could be particularly effective, especially in Lagos.

5. **Prevent Stacking**: Stacking—the concurrent use of multiple energy sources—is a common phenomenon in household energy transitions. While large-scale subsidy programs have driven the adoption of cleaner cooking fuels, evidence suggests that they have often led to stacking rather than a full transition away from traditional fuels [66]. Similarly, insights from the Lagos survey indicate that households may stack solar PV systems alongside gensets, potentially diminishing the environmental and health benefits of solar adoption. To avoid this, targeted policy incentives should be designed to promote solar adoption as a complete replacement for gensets. For instance, incentives could include a genset buy-back program where households receive additional financial benefits for surrendering their gensets upon installing solar systems.

6. **Address Potential Justice Issues**: Targeted efforts to displace gensets will lead to their decline and destabilization in the electricity regime, affecting many Nigerians whose livelihoods depend on the genset ecosystem. As Smith [32, p.77] notes, *"besides the vendors who sold generators and the mechanics who repaired them, many others earned a living directly or indirectly off of NEPA's failures."* To ensure a just transition, it is crucial to prioritize stakeholder engagement, reskilling, and capacity-building initiatives, especially for low-income individuals, to help them find new opportunities in the evolving energy landscape. This should be a policy priority.

While the analysis in this chapter is based on data from Lagos State and may not fully represent conditions across Nigeria, it is encouraging that the new Nigeria Distributed Access through Renewable Energy Scale-up (DARES) Project captures some of the above-listed recommendations. Building on the NEP, DARES aims to displace 280,000 gensets by providing financial incentives, coordinating with the private sector, and considering community-level interventions like

[66] This refers to Ghana's first major hydro-power plant developed in 1965. At 1020MW of capacity, it accounts for about 50% of the nation's installed hydropower generation capacity. In the catch phrase, *"Akosombo"* thus connotes power generation [16].

interconnected mini-grids [101]. More of such initiatives should be encouraged and, in the longer term, a strategic approach to local innovation, manufacturing and recycling of solar components should be developed. Experiences from countries such as Kenya, India, and China demonstrate that local manufacturing can accelerate solar adoption by reducing costs and expanding access [65, 108-110].

More broadly, this chapter highlights the value of extensive datasets on energy solutions in developing countries, emphasizing the importance of gathering such data across different regions as a research and policy priority. Additionally, the MLP analysis of genset integration into the regime underscores the importance of historical explorations of energy technology adoption in sub-Saharan Africa to inform strategies for future transitions.

Lastly, although this chapter focuses on the stated goal of transitioning from gensets to solar PV systems, it is essential to acknowledge that both technologies remain viable alternatives due to the unreliability of the grid. Many researchers argue that both gensets and distributed solar systems are inferior to grid electricity in terms of cost and capacity, and that improving grid reliability should remain the ultimate priority [15, 97, 111]. In line with this, some experts caution that both gensets and even off-grid solar solutions—while filling critical gaps—can also inadvertently hinder progress on centralized grid improvements. As one expert reflected:

> "Nigeria is a country that opts for the quickest fix rather than the most permanent one. And we have the tendency to get stuck in whatever that quick fix is. That's my major fear for the off-grid industry.
>
> Going back to an old report I read—it showed that off grid solutions are a quick fix for the electricity market, so to speak. Generators were the quick fix back then. But they exploded. They stuck. They stuck so much that people even joked maybe generators should be in our coat of arms.
>
> Have they helped? Yes. We've all used them. So, we can't say they haven't helped. But the deeper issue is our collective mentality. We keep opting for individualized quick fixes over collective solutions.
>
> So, it's hard for me to say whether they've been positive or negative. Because if I follow that logic, I could even argue that solar and off-grid systems are a negative—if they stop us from thinking holistically about how to properly electrify the country.
>
> So, you decide."

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Chapter 5

Electricity for the End-Uses: Temporal Availability and the Viability of End-Use Electrification in Nigeria

Preface

This chapter examines the second of the three pathways outlined in Chapter 3 through which electricity unreliability may hinder Nigeria's electrification-driven energy transition. Specifically, it focuses on end-use electrification—that is, how unreliable supply constrains households' ability to adopt electricity as the primary energy source for essential activities like cooking and transport. As illustrated in the conceptual framework (Figure 5-1), unreliable electricity introduces a time-of-use constraint where power is often unavailable when it is most needed, limiting the utility and benefits of energy-dependent appliances. Though this is not tested directly here, it may also undermine consumer confidence in electricity as a viable primary fuel, thereby discouraging appliance purchases and fuel switching.

To investigate the time-of-use constraint, this chapter analyzes a previously unexamined dataset of daily outage records across 50 11kV feeder lines in Nigeria spanning 2019 to 2024. The analysis first characterizes the broader patterns of outages, then assesses the temporal alignment between electricity availability and typical demand windows for electric cooking and vehicle charging. This rare empirical assessment makes a valuable contribution given the scarcity of high-frequency, disaggregated reliability data in Sub-Saharan Africa.

The findings reveal a persistent and troubling pattern: electricity is highly unreliable and frequently unavailable during key demand periods. As demonstrated in Chapter 4—where unreliability was shown to drive decentralized fossil-fuel generation—this chapter shows that it also constrains the second pillar of Nigeria's energy transition-by-electrification strategy: shifting end uses onto the grid. Drawing on expert interviews, the analysis further explores intersecting constraints such as affordability concerns, infrastructure limitations, political considerations, and cultural preferences that shape the feasibility of widespread end-use electrification.

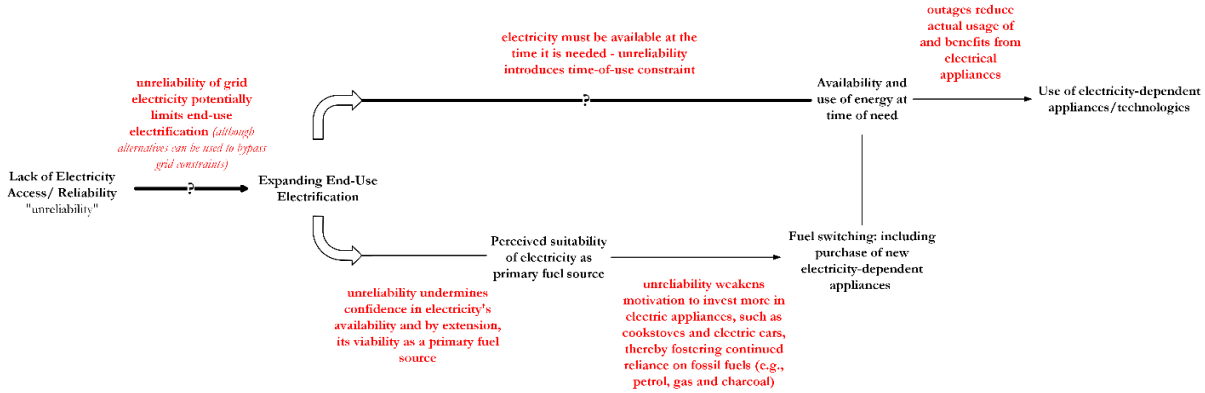


Figure 5-1: Conceptual Framework - How Electricity Unreliability Constrains End-Use Electrification

> "This is a commendable deployment, but truth be told, Nigeria lacks the capacity currently for anything electricity related, till we fix the underlying power generation infrastructure. I like this futuristic concept, but we should also focus on the immediate problem. Good luck [67]"

Abstract

This chapter analyzes how electricity unreliability constrains the electrification of key end-uses—particularly cooking and electric vehicle (EV) charging—in Nigeria. Using high-frequency daily outage records from 50 11kV feeders between 2019 and 2024, it constructs hourly availability profiles to assess whether electricity is present when most needed. Findings reveal that the average cumulative duration of outages amounts to 16–20 full blackout days per month per feeder, with availability often lowest during peak demand windows. Only a small subset of feeders demonstrates availability levels that could support widespread end-use electrification. Expert interviews corroborate these findings and highlight additional barriers such as affordability, limited technical capacity, geopolitical dynamics, and cultural preferences.

Importantly, while both electric cooking and EV adoption face significant constraints, experts generally viewed EVs as more viable in the short term—particularly through targeted rollouts led by public agencies or mini-grid developers. These results underscore that, absent reliability, Nigeria's ambitious energy transition targets are unlikely to translate into widespread adoption of clean, electricity-based services.

Introduction

Recognizing the fundamental role of electricity in economic and human development, the United Nations established Sustainable Development Goal (SDG) 7, which aims to *"ensure access to affordable, reliable, sustainable, and modern energy[68] for all"* by 2030 [1]. Given this importance, progress toward the goal is closely tracked, with urgent warnings that, without accelerated efforts, approximately 660 million people—mostly in Sub-Saharan Africa (SSA)—will remain unserved by 2030 [2].

This strong international policy stance, perhaps motivated by the well-established correlation between electricity access and national indicators such as GDP, income, and human development [3-7], has not always been mirrored in the empirical literature. In fact, causal research—particularly at the household level—has yielded mixed results [4, 6, 8-10]. Some studies report modest, if any, improvements in economic or non-economic outcomes [4, 8, 11], while others suggest more substantial developmental gains [12-14].

This divergence is attributed to a variety of factors—including methodological differences, publication bias, reverse causality, unobserved confounding variables (e.g., local infrastructure or government policies), the scale of electrification interventions, and the broader socioeconomic context at the time

[67] A tweet in response to the Lagos State Governor Babajide Sanwo-Olu's April 2023 announcement of two new electric buses in Lagos [18].
[68] This includes both access to electricity as well as clean cooking technologies.

of access [4, 7-8, 15-16]. Importantly, Meeks *et al.* [17, p.1] argue that *"differences in electricity service quality provide a potential explanation for electrification's heterogeneous impacts across settings."* Since electricity is an enabling technology, it has no inherent value unless users can meaningfully utilize it [4, 7, 19]. Where quality and reliability are poor, utilization is constrained, limiting electricity's developmental impact [10, 17, 20-25].

This has led to a growing emphasis on measuring electricity access through service usability—not just connection—with frameworks like the World Bank's Multi-Tier Framework (MTF) incorporating dimensions such as capacity, supply duration, reliability, voltage quality, affordability, legality, health, and safety [16, 19, 23, 26-28]. However, understanding across these multiple dimensions remains limited. For example, Ferrall *et al.* [29, p.1] argue that reliability is *"comparatively under-investigated"* within the broader SDG7 goal. Furthermore, widely used indicators like the System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) do not adequately reflect the *"nuance of reliability,"* including the reasons, timing, geographical distribution, fairness, and management (e.g., advance notice and coping mechanisms) of outages[69] [21, 27, 29, p.14 (quote), 30].

Indeed, few studies have explored these aspects of reliability due to limited data availability and a lack of definitive standards for what suffices as 'reliable' service [21]. These gaps are especially striking in SSA, where detailed empirical data on outage frequency, duration, causes, and consequences remain scarce—driven in part by poor utility data management and weak institutional incentives [7, 9-10, 16, 19, 21, 24, 29-34]. Even basic year-on-year SAIDI and SAIFI figures—despite their limitations—are rarely available [21]. Yet, electricity unreliability is a persistent challenge in the region. SSA not only has the world's largest electricity access gap, but even in areas where electrification has advanced—sometimes rapidly—the resulting supply is often unreliable and of poor quality [9].

In addition to the scarcity of granular outage data, most research on the impacts of electricity unreliability has focused on firms and industries [7, 10, 16-17, 31, 35]. As Gertler *et al.* [10, p.13] note, *"There is currently very little evidence on the impacts of outages on individual and household outcomes."* Moreover, studies that do examine the effects of unreliability tend to concentrate on coping mechanisms—particularly the use of fossil-fuel backup generators—which impose significant economic, environmental, and health burdens [10, 16, 24, 33, 35-39]. However, the impacts of unreliability manifest through a wider set of pathways—influencing user behavior, undermining trust in public infrastructure and even fueling protest or tax resistance [16]. More broadly, unreliability is increasingly seen as a defining feature that fundamentally shapes the energy transition trajectories of many developing countries [11, 15, 40].

This chapter addresses the identified gaps in two key ways. First, it offers new empirical insight by analyzing previously unexamined outage data from Nigeria—a country often cited as having the highest outage intensity in SSA [16, 29, 33, 35]. While references to unreliability in Nigeria are common, detailed data on outage patterns, causes, and spatial distribution remain limited. For example, the World Bank's Doing Business dataset includes SAIFI values only for Kano State (2014-2017), and the most recent outage data for Nigerian firms in the World Bank's Enterprise Surveys dataset dates back to 2014 [41-42].

[69] Outages—also referred to as blackouts—are defined as the total loss of electric power in a given location and period [16, p.90].

Second, this chapter investigates an understudied consequence of unreliability: its potential to constrain end-use electrification—a core component of energy transition strategies aimed at climate change mitigation [43-44]. To decarbonize the energy sector, the literature widely agrees that the short- to medium-term priorities include the direct and indirect[70] electrification of end-uses such as transport, heating, and cooking—combined with or catalyzed by a low-carbon power generation mix [40, 45-48]. While these transitions are being led by advanced economies, Aalto *et al.* [45, p.9] argue that *"accelerated electrification is both a possible and desirable policy goal."* Relatedly, developing countries are also beginning to adopt this approach. For example, Nigeria's Energy Transition Plan (ETP) targets a shift of 80% of passenger cars to electricity by 2050 [49]. It also envisions industrial heating moving from 60% reliance on natural gas and 40% reliance on biomass in 2020 to 90% electricity and 10% hydrogen by 2050 [50]. The plan further projects that by 2050, 95% of urban homes, 57% of rural homes, and 85% of commercial dwellings will be using electric cookstoves [51]. Beyond climate goals, transitioning household cooking from traditional fuels to cleaner alternatives like liquefied petroleum gas (LPG) and electricity has long been a key health and development objective [22, 30].

However, electric end-uses require consistent power. Where outages are frequent, electricity cannot be reliably used—and households and firms are unlikely to invest in high-load appliances since the benefits are constrained [10, 17, 26-27, 30]. This aligns with a growing body of research examining how unreliability shapes household relationships with electricity. Studies show that service quality affects willingness to pay for electricity [19, 52-53], electrification uptake [19, 28, 54], satisfaction with electricity services [23], appliance ownership and condition [10, 17, 19, 22, 27, 31], consumption [17, 27], and fuel-switching – particularly for cooking [20, 30]. These insights support Taneja's [9, p.16] observation that *"persistent and long-term outages reduce trust in grid electricity, pushing customers to either find other sources of electricity or maintain a lifestyle without modern energy sources."* Yet, despite its relevance, many studies—including detailed techno-economic analyses—still overlook reliability's role in the energy transition [30, 34, 55].

Finally, to enrich and contextualize the quantitative analysis, this chapter draws on interviews with experts in Nigeria's power sector, including officials from electricity distribution companies, the national electricity regulatory commission, off-grid power companies and international development institutions. By combining a novel dataset with stakeholder perspectives, this chapter offers a comprehensive understanding of electricity unreliability and its implications for energy transition efforts in one of Africa's most important national contexts.

Empirical Setting and Data

Empirical Setting

Nigeria's electricity system is broadly organized into generation, transmission, and distribution segments, managed by distinct sector stakeholders and operating at a nominal frequency of 50 hertz. As discussed in Chapter 3, following the privatization and unbundling of the National Electric Power

[70] Typically refers to the use of electricity, by means of electrolysis, to produce energy carriers such as chemicals and fuels in gaseous or liquid form. For example, hydrogen or hydrogen-rich fuels and chemicals like ammonia and methanol [45].

Authority (NEPA)—the former state-run monopoly—only the Transmission Company of Nigeria (TCN) remains fully government-owned.

The country's available electricity generation capacity is estimated to average around 4.5 GW, with approximately 80% classified as thermal and the remaining 20% as hydroelectric. In practice, however, actual generation tends to be closer to 70% thermal and 30% hydro—reflecting seasonal variations in water levels, fluctuations in gas supply, and disparities in plant performance [56]. Thermal power plants, which are primarily gas-fueled, are concentrated in the southern region of the country, while hydro capacity is located further north, notably at Jebba, Kainji, and Shiroro [56-57].

Electricity generated at power plants is first stepped up to 330 kilovolts (kV) for long-distance transmission. It is then transported to transmission substations, where it is stepped down to 132 kV, and subsequently to 33 kV. From this point, 33 kV feeders radiate outward to various load centers. Although these lines fall within the distribution network and are owned by the distribution companies (DisCos), they are operationally managed by TCN[71].

At injection substations, voltage is further stepped down to 11 kV, and finally to 415 V by distribution transformers before reaching homes, businesses, and community infrastructure. Certain customers—primarily industrial users—are supplied directly via 33 kV or 132 kV lines, bypassing the lower-voltage network.

Responsibility for infrastructure below the 33 kV injection point—including the 33/11 kV injection substations, 11/0.415 kV transformers, low-voltage lines, and customer metering systems—rests with the DisCos. This layered technical and institutional architecture underscores the importance of strong coordination between TCN and the DisCos, as well as with generating companies (GenCos), given the interconnected value chain of the electricity sector (Figure 5-2) [57].

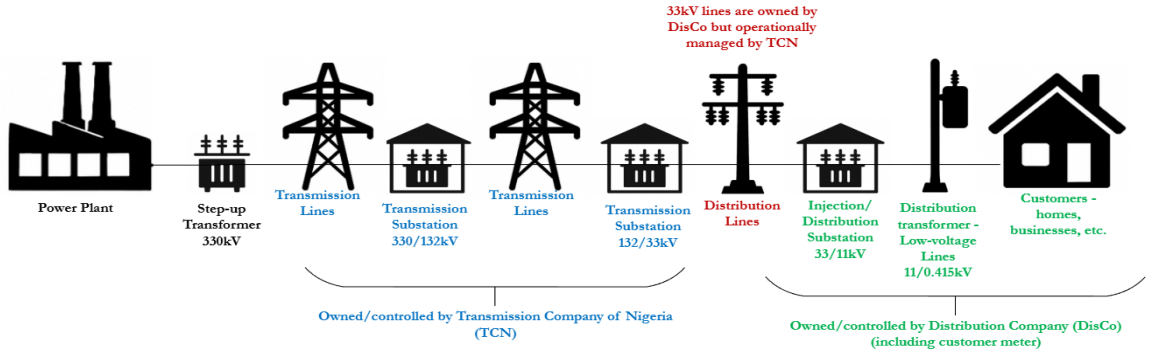


Figure 5-2: Electricity Supply Flow and Infrastructure Management in Nigeria's Power Sector.

Data

This chapter draws on administrative records of interruption incidents from 50 active 11 kV feeders within the service territory of the Ibadan Electricity Distribution Company (IBEDC)—the largest electricity distribution company in Nigeria by geographic coverage and number of registered

[71] Mentioned during interviews with experts.

customers [58]. IBEDC supplies power to approximately 2.5 million customers, accounting for about 19% of all registered electricity users in the country [59]. Its franchise area spans four states—Oyo, Osun, Ogun, and Kwara—and extends into parts of Niger, Ekiti, and Kogi States (Figure 5-3).

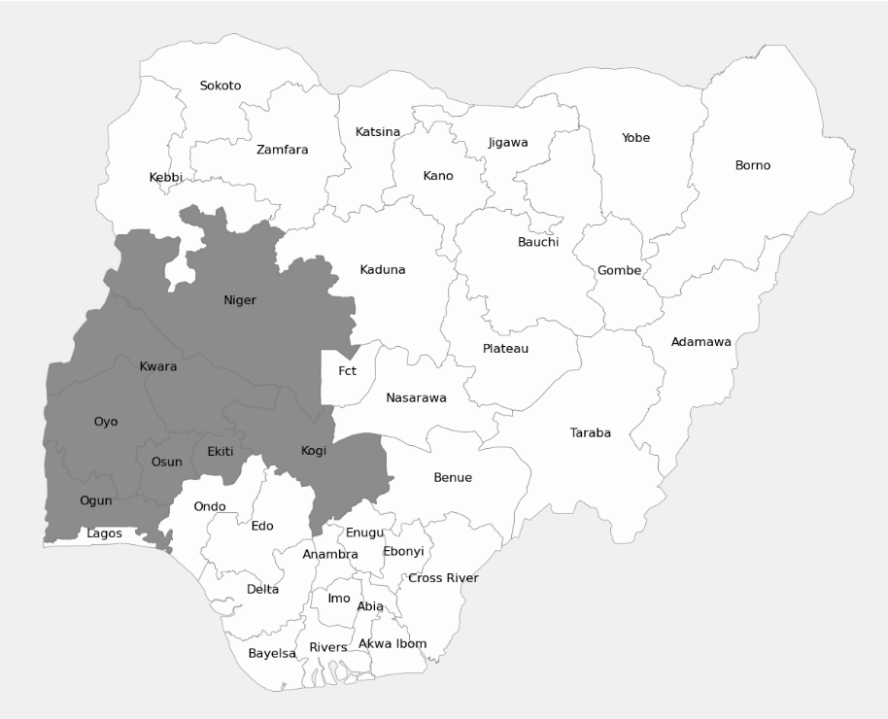


Figure 5-3: Geographic Coverage of the Ibadan Electricity Distribution Company (IBEDC) Network

Operationally, IBEDC organizes its network into five service regions—Ibadan[72], Oyo, Osun, Ogun, and Kwara—which serve as the basis for feeder selection in this study. The utility is structured into four main operational tiers. At the lowest level is the service hub, which serves as the frontline interface with customers, handling local service delivery and complaints. Above this is the business hub, responsible for technical operations at injection substations and staffed by technical engineers, supervisors, and field staff including distribution substation operators and lineworkers. Each business hub reports to a regional office, which coordinates multiple hubs and manages interfaces with TCN, including energy trading points and bulk supply coordination. At the top of the hierarchy is the head office, which oversees corporate governance, regulatory compliance, and strategic direction (Figure 5-4).

[72] Ibadan is the capital of Oyo State but is recognized by the utility as a distinct commercial service region.

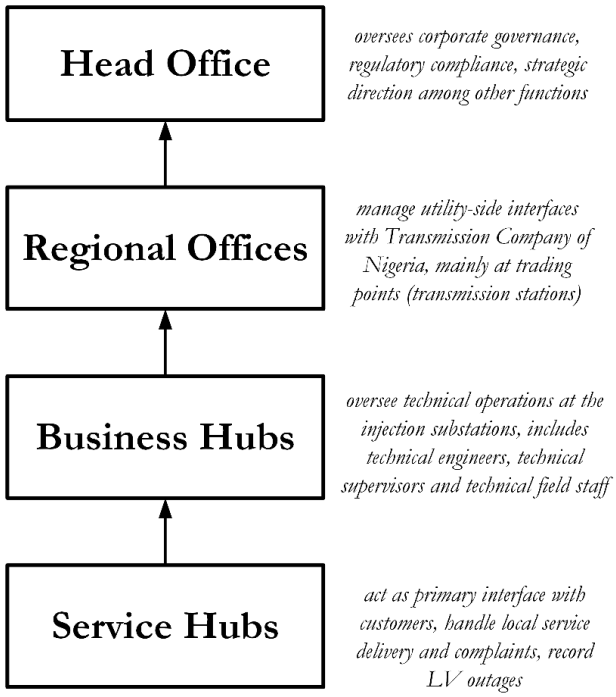


Figure 5-4: Organizational Structure of IBEDC

IBEDC connects to the national transmission grid at 25 interface points with TCN, distributing electricity through 129 33 kV feeders and 263 active 11 kV feeders[73]. For this study, 10 feeders were randomly selected from each of the five service regions. Outage data were compiled for the years 2019, 2020, 2023, and 2024. Records for 2019 and 2020 were obtained during early fieldwork conducted in 2021. However, data for 2021 and 2022 were lost due to a server crash, and are therefore excluded from the analysis. When data collection resumed in 2024, the system had stabilized, allowing for the inclusion of more recent records.

To ensure consistency, only complete monthly records were retained for each feeder. In total, the final dataset includes between 34 and 45 months of validated outage data per feeder, depending on availability. While minor gaps remain—due to administrative disruptions such as staff turnover—the dataset represents the most complete record available across multiple operational cycles.

As in most other DisCos in Nigeria, outage incidents at IBEDC are initially recorded manually in real time by distribution system operators (DSOs) at injection substations (11 kV) or by interface DSOs at transmission stations (33 kV). These operators typically document outages in physical logbooks, noting details such as the feeder name, date and time of interruption, relay-indicated cause or type (e.g., earth fault, overcurrent, forced outage, load shedding), and estimated load interrupted. Once service is restored – including for planned load shedding—the restoration time is recorded, often with additional observations on fault location, cause, and restoration modality. These entries are eventually transferred from handwritten logs or electronic forms into digital spreadsheets, typically in Microsoft Excel or Google Sheets format.

[73] Mentioned during interviews with experts in IBEDC.

Records are compiled and submitted to dispatch officers at the business hub level, where the first round of aggregation takes place. The data is then transmitted to the regional office and ultimately the utility's head office. A sample of the dataset is presented in Figure 5-5 to illustrate the structure and level of detail in the raw records. The data are typically used to generate daily interruption statistics and monthly performance reports—including SAIDI and SAIFI values submitted to the Nigeria Electricity Regulatory Commission (NERC).

Date	BUSINESS HUB	Name of Affected Feeder	Type of Outage	Start Time	Time Restored	Duration (Hours)	LOAD LOSS (MW)	No of Customers restored	Total Customers Served	Customer-Hours Interruption (CHI)
1/1/2024	MONATAN	AKOBO 11KV FEEDER	TCN L/S	0:33	2:30	1.95	120.00	1900	1900	3705.00
1/1/2024	MONATAN	AKOBO 11KV FEEDER	TCN F/O	14:29	14:55	0.43	145.00	1900	1900	823.33
1/1/2024	MONATAN	AKOBO 11KV FEEDER	TCN F/O	15:07	19:23	4.27	140.00	1900	1900	8106.67
1/1/2024	MONATAN	CROWN 11KV FEEDER	TCN F/O	14:29	15:05	0.60	59.00	45	45	27.00
1/1/2024	MONATAN	CROWN 11KV FEEDER	TCN F/O	15:07	15:14	0.12	59.00	45	45	5.25
1/1/2024	MONATAN	ESTATE 11KV FEEDER	TCN L/S	0:00	0:33	0.55	102.00	2057	2057	1131.35
1/1/2024	MONATAN	ESTATE 11KV FEEDER	TCN F/O	14:29	14:55	0.43	110.00	2057	2057	891.37
1/1/2024	MONATAN	ESTATE 11KV FEEDER	TCN F/O	15:07	15:16	0.15	108.00	2057	2057	308.55
1/1/2024	MONATAN	ESTATE 11KV FEEDER	TCN L/S	18:48	19:23	0.58	107.00	2057	2057	1199.92
1/1/2024	MONATAN	IBR 11KV FEEDER	TCN F/O	14:29	14:52	0.38	0.10	1	1	0.38

Figure 5-5: Sample of administrative outage records maintained by IBEDC staff at the 11 kV level. Each row corresponds to a distinct interruption event recorded at the injection substation, including start and end time, outage cause, and customer/load impact.

At the 33 kV level, outage monitoring also involves a joint tracking and attribution process between TCN and the DisCos, increasingly conducted with oversight from NERC. A centralized data dropbox maintained by the National Control Center (NCC) supports this process.

While the technical team monitors feeder-level outages, IBEDC's customer care unit maintains separate logs of 415 V-level interruptions—typically caused by transformer faults, disconnections, or metering issues—reported through service complaints via customer calls and visits to service hubs. These events are not included in the technical dataset and are generally excluded from formal performance reporting. This is particularly noteworthy given findings in the literature that utility-reported metrics often understate the true extent of outages, and that a substantial share of interruptions occur at this lower voltage level [9]. As such, the records analyzed in this chapter likely underestimate the full extent of unreliability experienced by end users, due to the absence of systematic data collection at the low-voltage level.

Additionally, given the largely manual nature of the dataset—generated, validated, and analyzed using paper logs and spreadsheet software—there is potential for human error, classification inconsistencies, and timing inaccuracies. While the data structure is standardized and reviewed at multiple levels, these risks must be acknowledged as a limitation of the analysis.

Nevertheless, efforts are underway across Nigeria's electricity sector to automate feeder monitoring through IoT-enabled metering systems. NERC has piloted installations on Band A feeders[74], and some DisCos are experimenting with remote monitoring across their networks. However, limitations in telecom coverage at TCN premises, cost barriers, and slow adoption by utilities have hindered widespread real-time implementation.

[74] On November 1, 2020, the Nigerian Electricity Regulatory Commission (NERC) introduced the Service-Based Tariff (SBT) scheme to align electricity tariffs with the actual level of service received by consumers. Under this system, consumers are classified into Bands A to E based on their minimum guaranteed hours of daily electricity supply. Band A customers receive at least 20 hours of electricity per day, Band B a minimum of 16 hours, Band C at least 12 hours, Band D a minimum of 8 hours, and Band E customers are guaranteed just 4 hours [60].

Methods

Data Preparation and Descriptive Analysis

The dataset described above, originally provided in Microsoft Excel format, was subjected to extensive cleaning and validation. Cleaning focused on ensuring logical time sequences of outages for each feeder and reconciling inconsistencies in how feeder names were entered over time. Records with missing start or restoration times were excluded unless those values could be reasonably inferred from adjacent entries on the same feeder.

In cases where multiple outages were recorded on the same feeder with overlapping timestamps—for example, a load-shedding event recorded from 2:22–3:45 a.m. and a forced outage from 2:50–3:51 a.m.—temporal adjustments were made to ensure consistency while preserving the total outage duration. In such instances, unplanned outages were prioritized over planned ones, reflecting operational realities: forced outages are inherently unpredictable and typically override relatively more discretionary events like load shedding.

Discussions with utility staff confirmed that overlapping records are not necessarily errors but rather reflect the dynamic and layered nature of outage events, with outage types not always mutually exclusive. For instance, a forced outage may create the opportunity for staff to act on previously noted maintenance needs or may coincide with long-scheduled repairs. As one expert noted, *"everything that happens is recorded,"* even when outages stack or unfold simultaneously. In such cases, staff must still obtain separate permits for safety compliance—resulting in distinct entries for planned and unplanned events during the same period. These operational nuances were incorporated into the data processing steps to preserve the integrity of the event records while ensuring temporal consistency.

In this chapter, the cleaned data is used to generate descriptive statistics on outage duration and frequency across feeders, months, years, regions, and tariff bands. Feeder band classifications—used in the subsequent analysis—are based on the IBEDC's designations as of October 2024 (Table 5-1). Under Nigeria's Service-Based Tariff (SBT) framework introduced by NERC in 2020, consumers are grouped into Bands A to E based on their minimum guaranteed daily supply hours: Band A customers receive at least 20 hours of electricity daily, while Band E customers are entitled to a minimum of 4 hours (Table 5-1) [60].

Although these classifications are reviewed monthly, discussions with utility officials revealed that downgrades are typically avoided, while upgrades are not easily achieved. As a result, the band designations used in this study had remained consistent from January to October 2024—the latest available data at the time of collection in early November 2024. These bands serve as a sector-recognized shorthand for service quality, and while they were not used as criteria for randomized feeder selection, they provide a useful framework for grouping feeders in the analysis and for assessing how reliably each band meets its daily supply threshold. Notably, the distribution of feeders by band in this study does not deviate significantly from general trends in the utility's network (Table 5-1).

Table 5-1: Distribution of IBEDC's 11kV Feeders by Tariff Band

S/N	Band	Minimum Hours of Supply	Count Across 11kV Feeders in IBEDC Network	Share of Total 11kV Feeders in IBEDC Network	Count Across 50 11kV Feeders Studied	Share of Total 11kV Feeders Studied
1	A	20	39	15%	4	8%
2	B	16	32	12%	6	12%
3	C	12	31	12%	5	10%
4	D	8	61	23%	11	22%
5	E	4	100	38%	24	48%

Analyzing Availability for End-Use Electrification

To explore the potential implications of unreliability for end-use electrification, weekly hourly availability statistics are constructed for each feeder. Availability is defined as the proportion of time within each hour-slot across the week during which electricity was available. For example, from Sunday to Saturday, what share of the seven '1–2 p.m.' hours had power? The resulting availability profiles are then compared with typical time-of-use patterns for key end uses—cooking and electric vehicle (EV) charging—to assess whether electricity tends to be available when it is most needed for electrified services.

Going beyond band-based groupings, KMeans clustering is applied to the feeders using normalized 24-hour average availability profiles. KMeans is an unsupervised machine learning technique that minimizes variation within clusters and maximizes separation between them [27]. Using the elbow method, four clusters are identified as optimal (Figure 5-6). As a validation check, these clusters are compared to the predefined tariff bands. As shown in Table 5-2, there is both overlap and divergence—e.g., all Band A feeders fall into Cluster 1, while Bands C and E span two clusters, and Band D spans three. This suggests that tariff bands do not consistently capture underlying reliability patterns, reinforcing the value of data-driven grouping approaches.

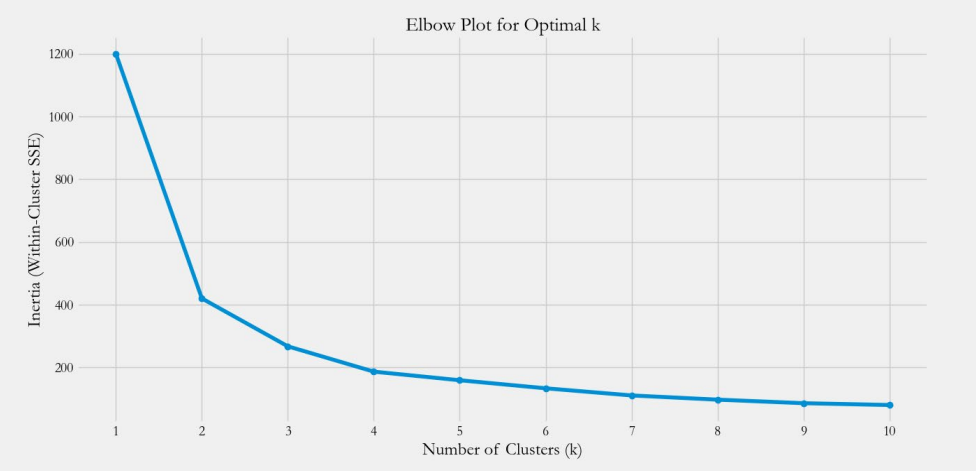


Figure 5-6: Elbow Plot for KMeans Clustering Analysis

Table 5-2: Comparison of KMeans Availability Clusters and Predefined Tariff Bands

Cluster	**0**	**1**	**2**	**3**
Tariff Band				
A	0	4	0	0
B	1	0	0	5
C	0	1	0	4
D	8	1	0	2
E	10	0	14	0

In terms of end-use timing, most Nigerian households cook three times a day: breakfast in the early morning, lunch around midday, and dinner in the evening [61-62]. Urban households often skip or abbreviate the midday meal, while rural households typically eat their largest meal at noon after morning farm work [63]. To reflect these patterns, the analysis uses the following cooking windows:

- Breakfast: 5:00–9:00 a.m.
- Lunch: 11:00 a.m.–2:00 p.m.
- Dinner: 6:00–9:00 p.m.

These windows span weekday and weekend variations and serve as conservative estimates of peak cooking demand.

For residential EV charging, the peak demand window is set at 6:00–10:00 p.m., based on usage patterns observed in other regions, given Nigeria's nascent EV market [64-65]. Globally, over 80% of EV charging occurs at home, primarily during the evening hours after users return from work or daytime activities [66]. Although strategies like delayed charging (e.g., after 11:00 p.m.) or daytime solar charging could reduce pressure on the grid, they are excluded from this analysis due to the current lack of enabling mechanisms such as time-of-use pricing [64].

Following the quantitative analysis, qualitative insights are incorporated from interviews with 26 experts in Nigeria's electricity sector, conducted between November 2024 and February 2025. Interviewees included staff from five electricity distribution companies (DisCos), the Nigerian Electricity Regulatory Commission (NERC), the Transmission Company of Nigeria (TCN), independent power developers, and international development partners. The interview protocol was approved by the Institutional Review Board at the University of California, Berkeley (Protocol ID: 2024-07-17591). All quotes cited in the chapter are lightly edited for clarity and anonymized to protect confidentiality. Identifiers such as feeder names, regions, and institutions are also masked in the dataset to comply with data-sharing protocols and reflect the operational and political sensitivities surrounding reliability issues in Nigeria's power sector.

Results and Discussion

The cleaned dataset contains 94,761 outage records across the 50 feeders. As noted above, due to certain factors—including data loss, personnel turnover, the timing of data collection, and other administrative disruptions—these records do not capture complete yearly records for all feeders under consideration. However, across feeders with complete data, the average total duration of outages—defined as the sum of all outages recorded on each feeder per year—equals approximately 180 days of full blackouts in 2019, 199 days in 2020, and 247 days in 2023, indicating a significant and worsening trend (Figure 5-7).

This is far worse than the Multi-Tier Framework's (MTF) reliability threshold of about 4 days for Tier 5 household electricity supply[75] and the maximum recommended threshold of 12 hours of annual outages proposed by Ayaburi *et al.* [21]. Even more conservative MTF targets, which allow up to 122 days for Tier 4 and 15 days for Tier 5[76], are significantly exceeded in this dataset [26].

[75] Calculated based on the Tier 5 target of *"max 3 disruptions per week with aggregate disruption duration of <2 hours per week"* [26, p.74].
[76] Calculated using the MTF's availability (duration) attributes of minimum 16 hours daily electricity supply and minimum 23 hours supply for Tiers 4 and 5 respectively [26].

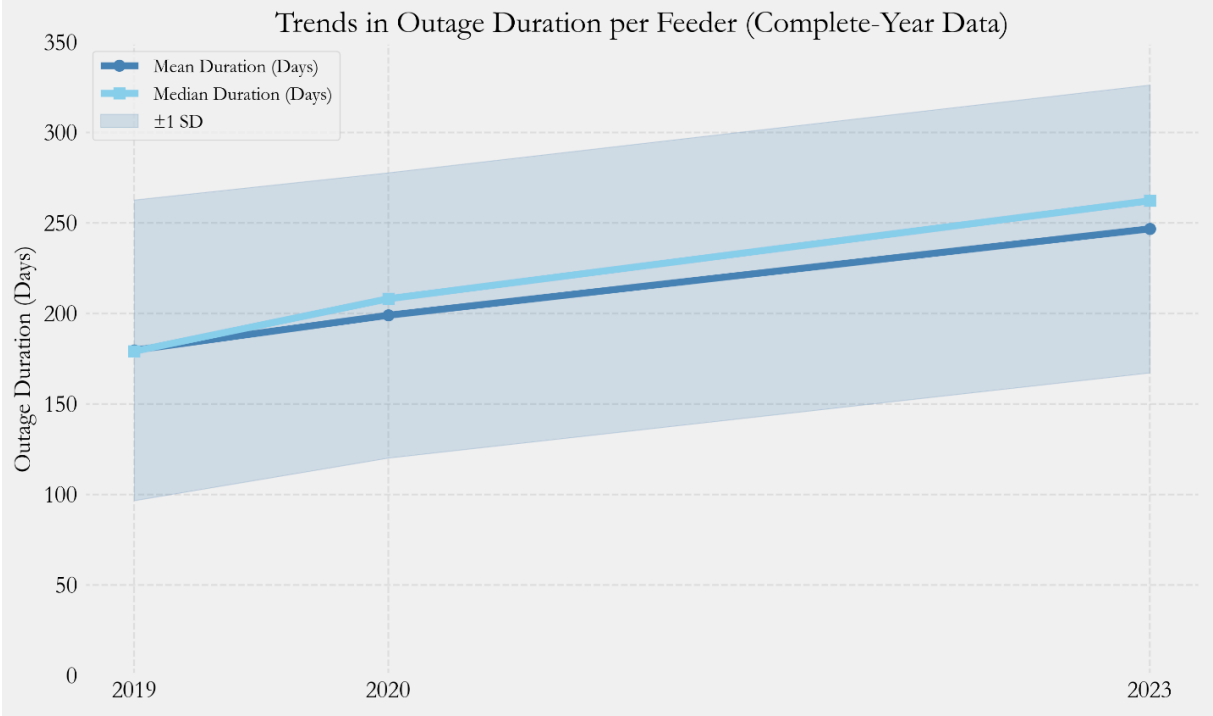


Figure 5-7: Annual Trends in Outage Duration per Feeder (Complete-Year Records, 2019–2023). Mean and median outage durations are shown with one standard deviation shaded.

Annual average outage frequencies per feeder are similarly poor, though they follow a slightly different pattern: 694 in 2019, 618 in 2020, and 544 in 2023—suggesting a decline in the number of interruptions over time (Figure 5-8). However, this improvement is offset by rising outage durations, indicating that outages are becoming fewer but longer. Still, the observed frequencies far exceed Ayaburi *et al.* [21]'s benchmark of 12 outages per year and the MTF's Tier 5 threshold of 156 outages annually. While they fall slightly below the Tier 4 benchmark of approximately 730 outages per year, the MTF nonetheless considers Tier 4 service unreliable, stating that *"a reliable supply should not have interruptions exceeding 120 minutes per week"* [26, p.74].

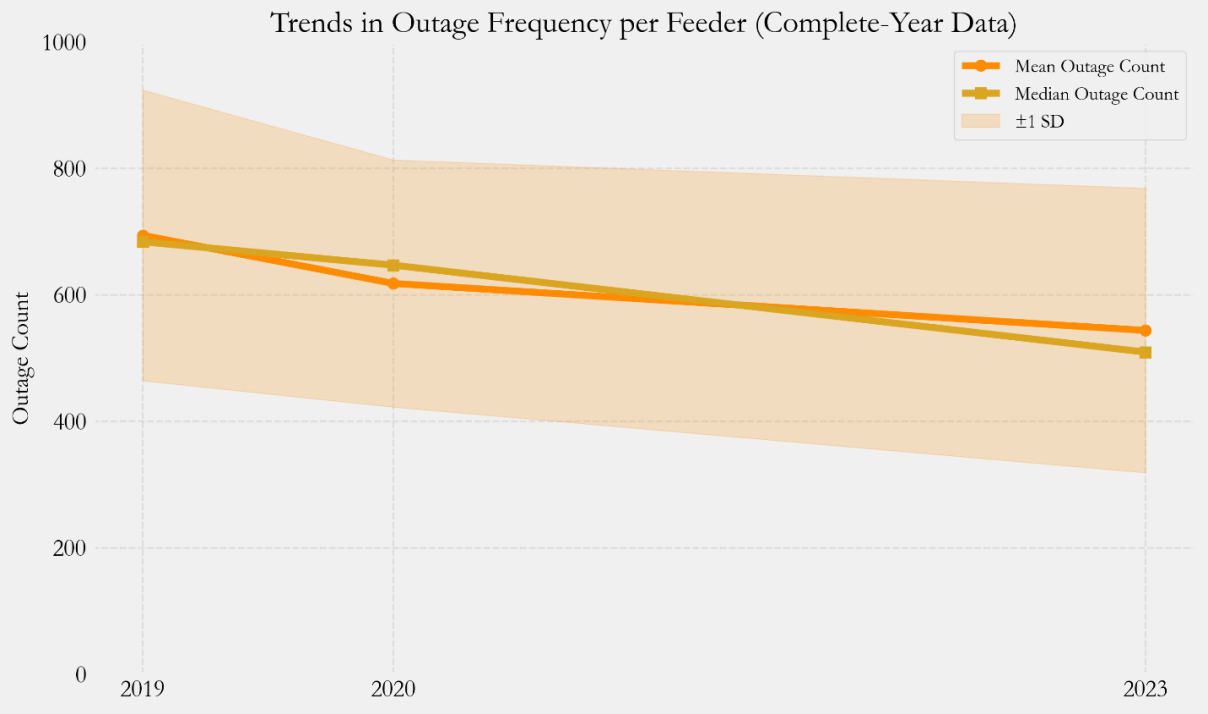


Figure 5-8: Annual Trends in Outage Frequency/Count per Feeder (Complete-Year Records, 2019–2023). Mean and median outage durations are shown with one standard deviation shaded.

To capture the full dataset—including feeders without complete annual records—monthly outage statistics are also analyzed. These show similarly concerning outcomes: average total outage duration per feeder per month is ~18 days in 2019, 16 days in 2020, 19 days in 2023, and 20 days in 2024 (Figure 5-9). Average monthly outage counts are 54 in 2019, 51 in 2020, 50 in 2023, and 51 in 2024 (Figure 5-10). Like the annual figures, these data reveal a rising trend in outage duration, even as the frequency of outages modestly declines. A small dip observed here in 2020 may reflect broader operational shifts—such as COVID-19 disruptions—or reporting inconsistencies smoothed out in the annual totals. However, it is more likely due to the exclusion of partial-year feeders in the annual data and the averaging effect across months, which helps moderate outliers. This is particularly relevant for 2019, when the full-year dataset excludes several lower-tier feeders—especially Band E feeders—which tend to be less reliable. Although only a few feeders are excluded in 2019 and 2020, their composition meaningfully influences the observed trends. In contrast, the complete dataset, which includes partial-year records and averages by month, arguably offers a more representative picture of unreliability over time.

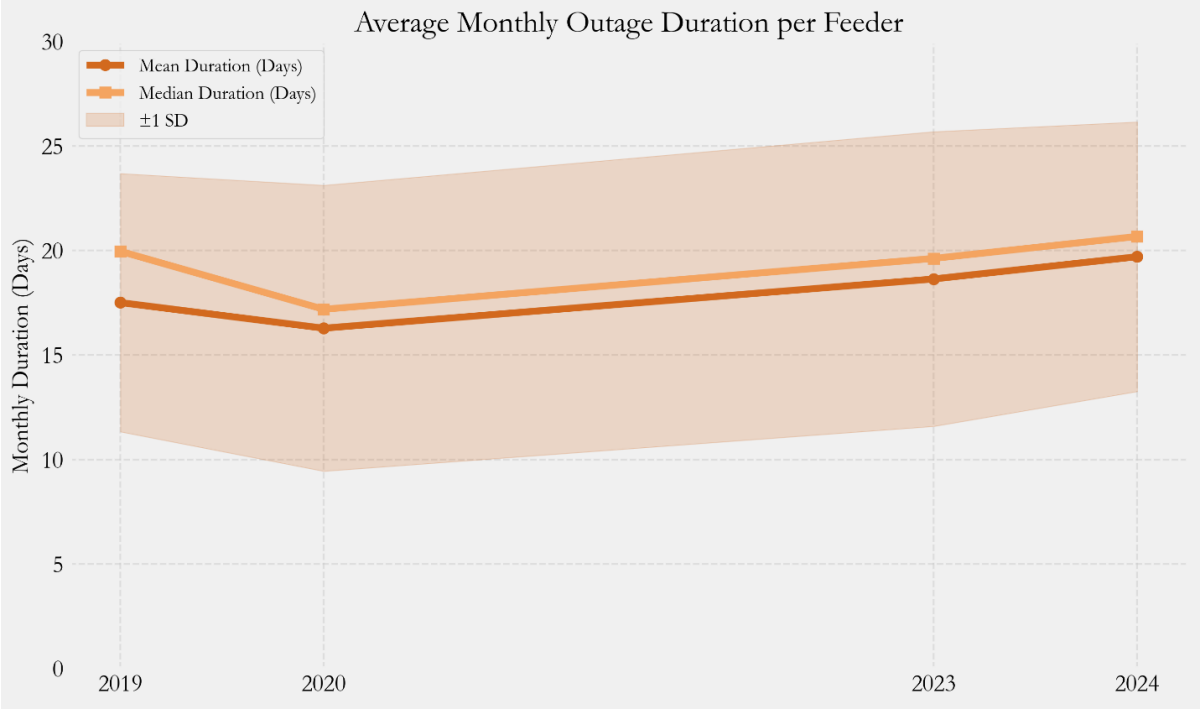


Figure 5-9: Average Monthly Total Outage Duration per Feeder (Across All Feeders, Including Partial-Year Records)

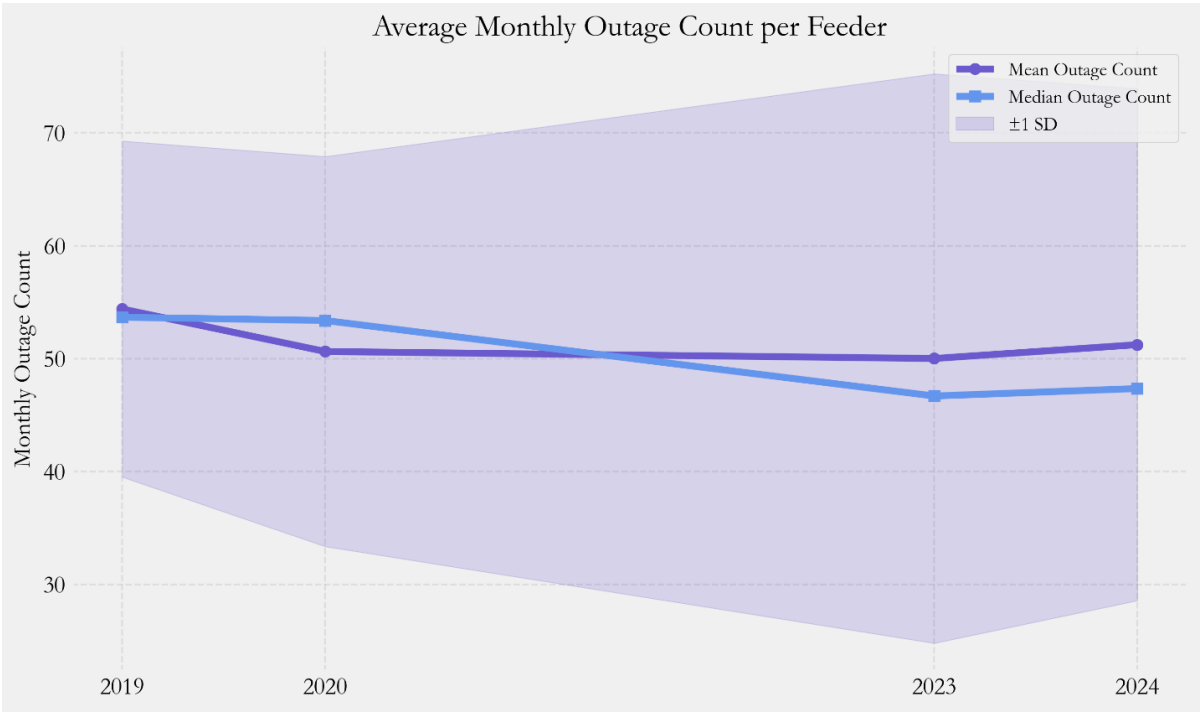


Figure 5-10: Average Monthly Outage Count/Frequency per Feeder (Across All Feeders, Including Partial-Year Records)

Across both the annual and monthly analyses, the median outage duration is generally higher than the mean. This points to a small subset of highly reliable feeders—likely those in Band A—that pull the average downward.

Large standard deviations in both outage duration and frequency further highlight disparities across feeders. These findings point to a key limitation of aggregate metrics like SAIDI and SAIFI: they mask considerable inequality in reliability experiences across feeders—and by extension, across the customers they serve. For instance, in 2023, the total outage duration ranges from 41 days on one feeder to 332 days on another (Figure 5-11). Similarly, at the individual event level, the average duration of an outage is 8.36 hours, while the median is 5.12 hours, and the standard deviation is 14.53 hours—indicating a skewed distribution with a number of prolonged outages disproportionately inflating the mean.

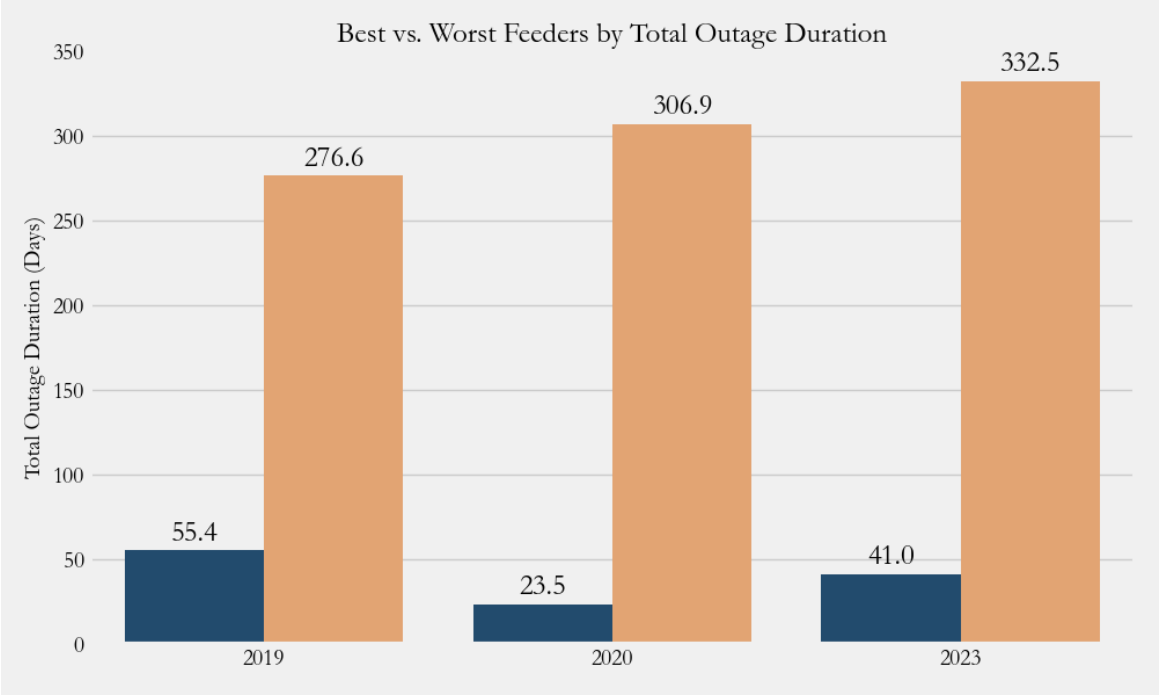


Figure 5-11: Extremes in Outage Duration: Best vs. Worst Performing Feeders (2019–2023)

Overall, these results confirm that electricity outages in Nigeria are both severe and worsening over time. However, they also exhibit significant variation—likely driven by a combination of feeder characteristics, temporal patterns, and outage types. To examine these differences more systematically, the next section analyzes outage variation by SBT bands, a key operational and policy-relevant grouping in Nigeria's power sector.

Outage Patterns by Service-Based Tariff Bands

Grouping feeders by tariff band reduces the observed variability—except for Band E feeders. As shown in Figures 5-12, 5-13 and 5-14, a clear reliability hierarchy emerges in line with Nigeria's SBT structure, especially at the extremes: Band A feeders experience the shortest and most consistent outages, while Band E feeders experience the longest and most erratic. Monthly outage durations

range from 5–7 days for Band A to 22–26 days for Band E (Figure 5-12). In terms of individual event duration, Band A feeders average 3.5 hours, with a tightly concentrated distribution. Bands B–D exhibit progressively longer and more variable outages—though with substantial overlaps—while Band E outages exceed 12 hours on average with a standard deviation of ~20.64, notably higher than the overall dataset's 14.53 hours (Figure 5-13).

Despite the SBT's intention to establish a tiered reliability structure, the overlaps among Bands B, C, and D suggest that this differentiation has not fully materialized. Their overlapping monthly outage sums—9–18 days for Band B, 10–13 days for Band C, and 14–21 days for Band D—point to inconsistent implementation of the SBT, likely due to operational constraints and enforcement gaps, especially for Band B feeders (Figure 5-13). Similar trends are observed in Figure 5-14, which shows daily feeder availability by tariff band (see Figure C-1 in the Chapter 5 Appendix for trends in this metric from 2019 to 2024).

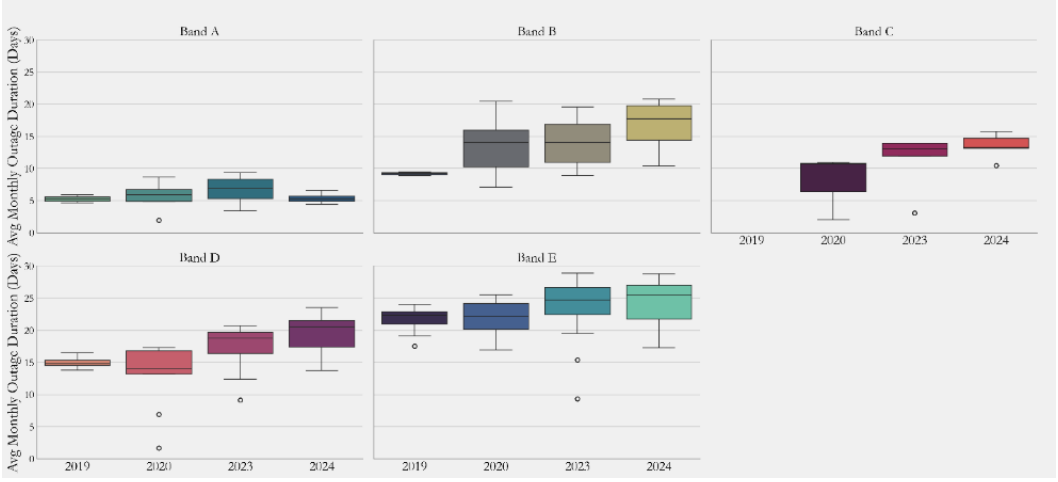


Figure 5-12: Average Monthly Total Outage Duration per Feeder by Tariff Band

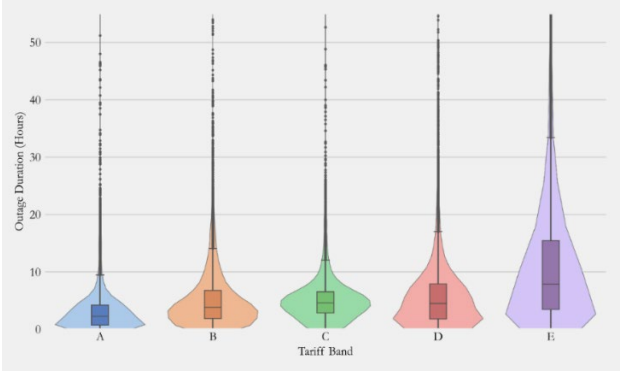


Figure 5-13: Outage Duration per Event by Tariff Band (Violin + Box Plot)

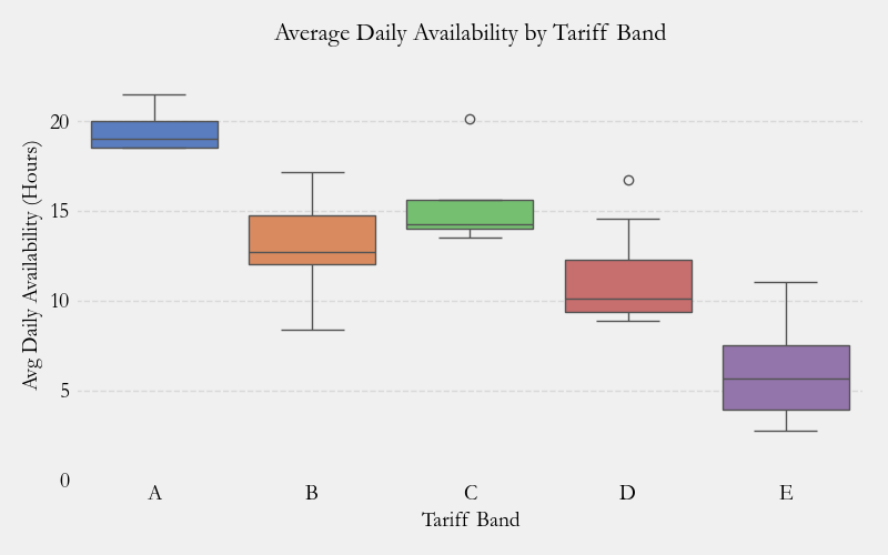


Figure 5-14: Average Daily Availability per Feeder by Tariff Band

Seasonal, Regional, and Outage-Type Disaggregation

While tariff bands capture important variations in outage experience, disaggregating by season, region, and outage type offers additional insights.

Seasonal Disaggregation

Outage durations show limited seasonal variation across all bands, but some noteworthy patterns emerge (Figure 5-15). For Bands A and B, average monthly outage durations per feeder are slightly higher during the dry season (November–March), likely due to hydropower generation constraints typical of that period. In contrast, Bands C and D experience a slight uptick in outage durations during the rainy season, possibly driven by weather-induced faults—further explored in Chapter 6.

Interestingly, Band E displays a trend mirroring the higher service bands, with marginally longer outage durations during the dry season. This dry-season increase—relative to Bands C and D—probably suggests that feeders in this class are more frequently curtailed when supply is insufficient. Given Band E's lowest priority in the SBT dispatch hierarchy, its feeders are likely the first to be dropped in efforts to maintain service levels for higher bands.

Outage frequency adds another layer to this picture (Figure 5-16). With the exception of Band A, all bands experience a higher average monthly count of outages during the rainy season. This pattern suggests that dry-season outages tend to be longer (due to supply constraints), while rainy-season outages occur more regularly (likely due to weather-related disruptions)[77]. Band A's relatively stable frequency may point to better infrastructure or stronger fault management protocols.

While these seasonal patterns are clear, differences across bands are not dramatic, underscoring the persistent nature of grid challenges throughout the year.

[77] See Figure C-2 in the Chapter 5 Appendix for complementary trends in individual event durations.

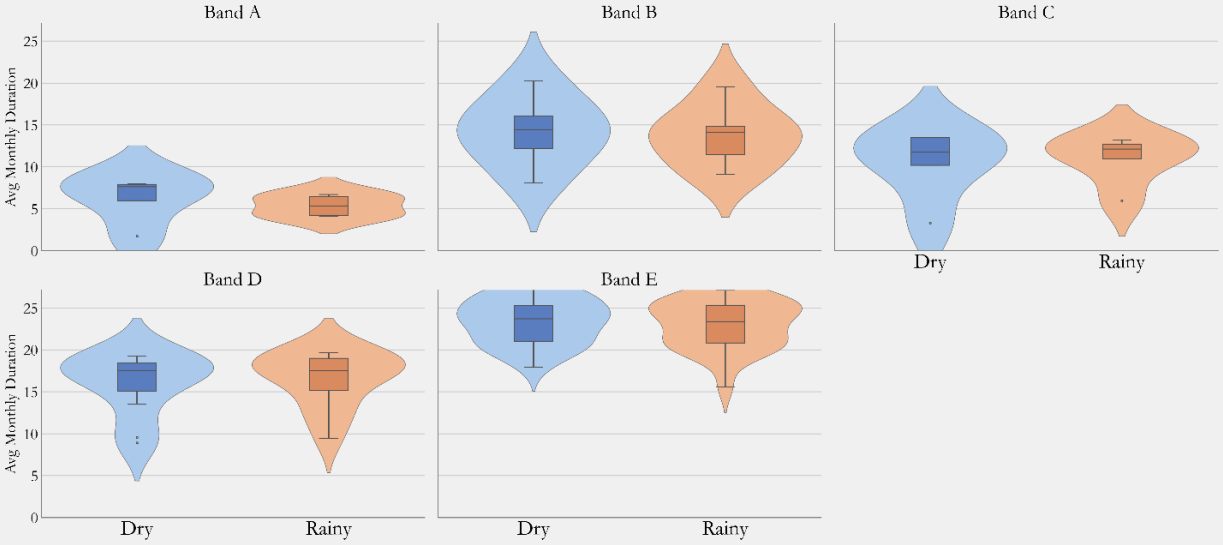


Figure 5-15: Seasonal Patterns in Average Monthly Outage Duration per Feeder by Tariff Band

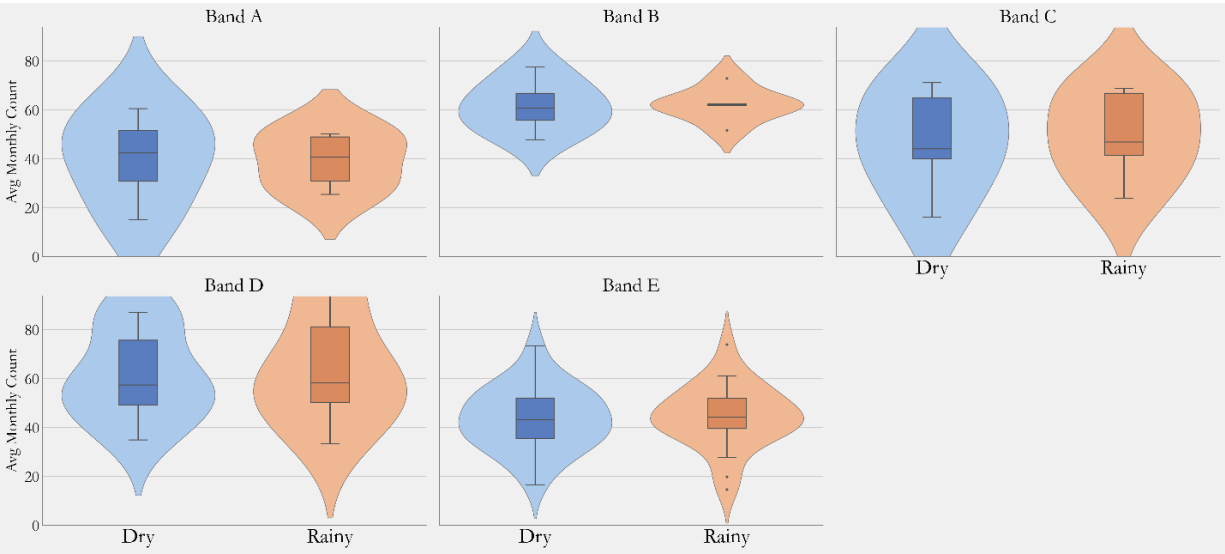


Figure 5-16: Seasonal Patterns in Average Monthly Outage Count per Feeder by Tariff Band

Regional Disaggregation

Due to randomized feeder selection, the distribution of feeders across regions and tariff bands is uneven, limiting the strength of regional comparisons within individual bands. Nevertheless, where data is sufficient, some regional patterns are observed—though they are not always consistent across bands (Figure 5-17). For instance, Region 4 feeders show notably lower average monthly outage durations in Band B, but this pattern is reversed in Bands A and D, where they experience relatively high outage durations. Conversely, Region 3 appears to perform better in Bands D and E, suggesting more favorable reliability outcomes in that zone. In terms of outage counts, Region 1 feeders tend to

experience higher outage frequencies across multiple bands, hinting at frequent but possibly shorter outages (Figure 5-17)[78]

These differences may reflect localized DisCo operational practices or grid constraints. However, given the limited and uneven regional representation within some bands, caution is warranted in drawing broad conclusions from these comparisons.

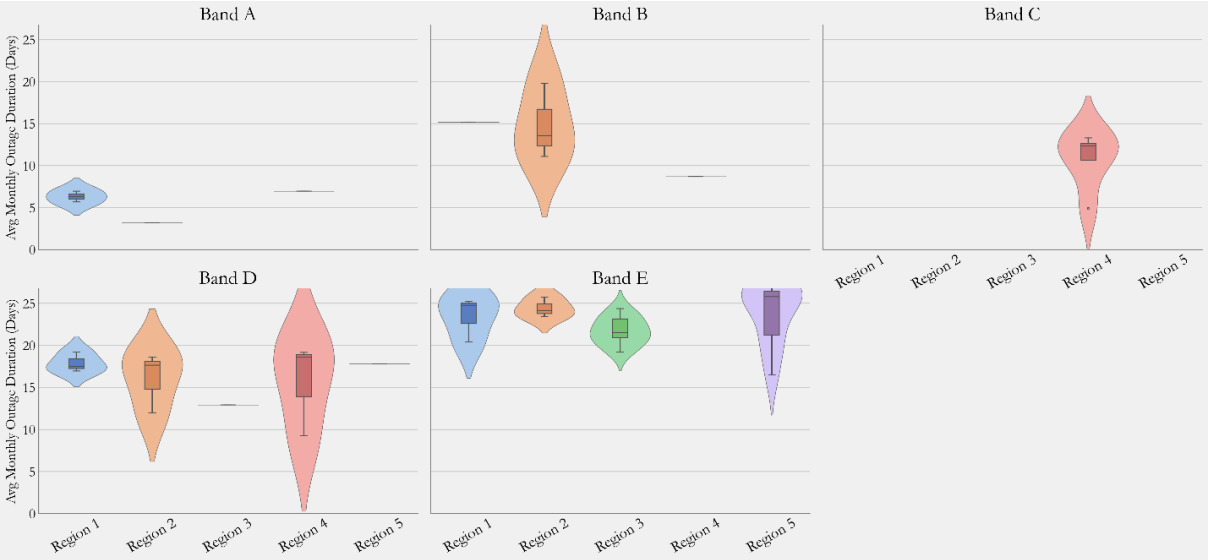


Figure 5-17: Regional Variation in Average Monthly Outage Duration per Feeder by Tariff Band

[78] See Figure C-3 in the Chapter 5 Appendix for trends in individual event durations.

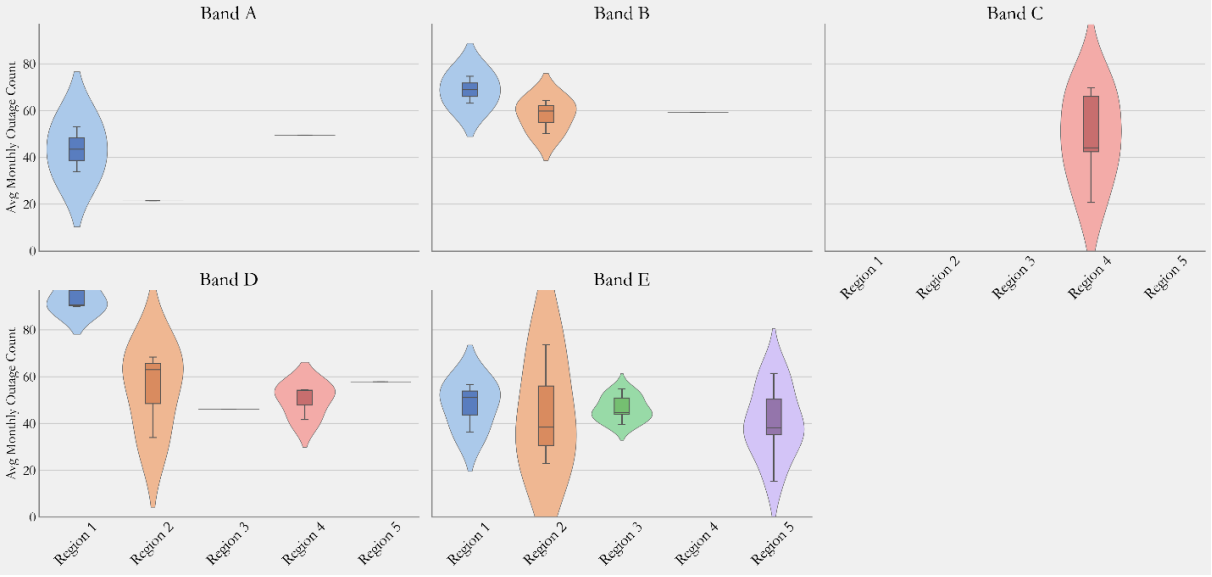


Figure 5-18: Regional Variation in Average Monthly Outage Count per Feeder by Tariff Band

Outage Type Disaggregation

The dataset classifies outages into three main types: load shedding, forced outages, and planned outages. Load shedding refers to the rationing of limited supply—often planned centrally but sometimes unpredictable at the feeder level. Forced outages, by contrast, are sudden and unplanned disruptions that occur within the network, typically due to unexpected faults. Planned outages are usually scheduled in advance for routine testing, preventive maintenance, or follow-up repairs after faults (these dynamics are explored further in Chapter 6).

Since these outage types together constitute the total outage experience for each feeder, directly comparing their average monthly totals would be misleading. Instead, this section examines the share of different outage types across tariff bands and explores how individual outage durations vary by type—both across and within bands.

Figure 5-19 highlights that load shedding is the most prevalent outage type across all bands. However, the difference between the share of load shedding and other outage types is smallest in Band A, consistent with the SBT framework's expectation of high reliability for top-tier feeders.

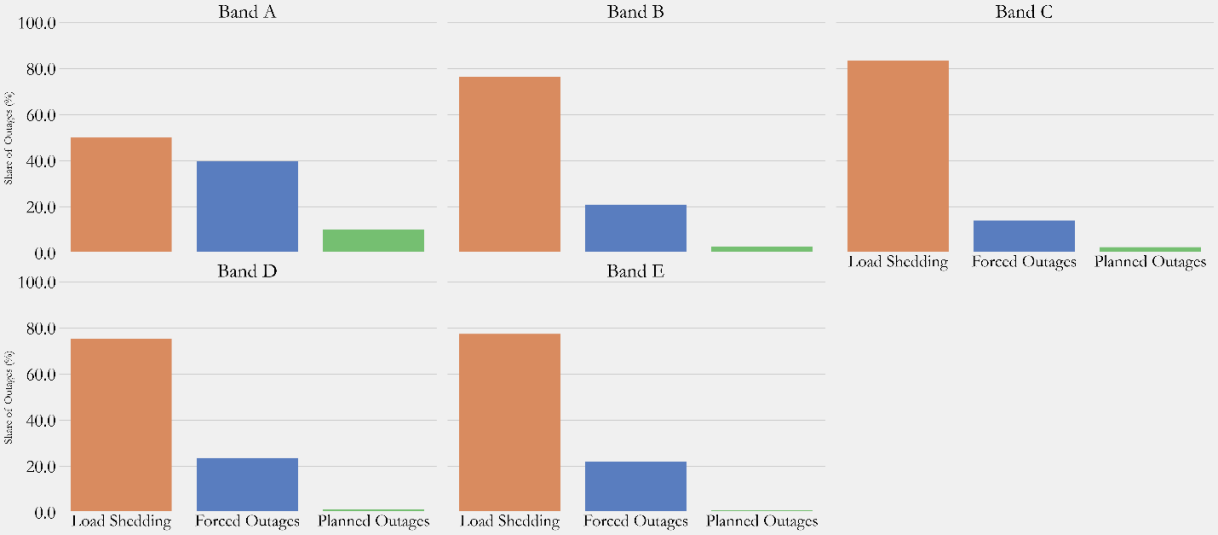


Figure 5-19: Outage Type Distribution by Tariff Band (Share of Events)

As shown in Figure 5-20, outage type meaningfully shapes event duration within each band. Planned outages generally exhibit the shortest and most consistent durations, followed by load shedding, while forced outages are the longest and most variable. This reflects the controlled nature of planned outages versus the uncertainty and complexity often involved in resolving forced outages.

Figure 5-21 compares the duration of each outage type across bands. As expected, load shedding durations increase progressively from Band A to Band E, aligning with the SBT scheme's tiered expectations of reliability. However, the same upward trend is also evident for planned and forced outages—though with some overlap among Bands B, C, and D. This suggests that even outages not directly tied to deliberate load rationing tend to last longer on lower-priority feeders—potentially reflecting deeper structural challenges such as weaker infrastructure, slower fault resolution, or lower operational prioritization. The overlap observed for forced outages reinforces the idea that these events are likely shaped more by technical and operational constraints than policy-driven dispatch logic.

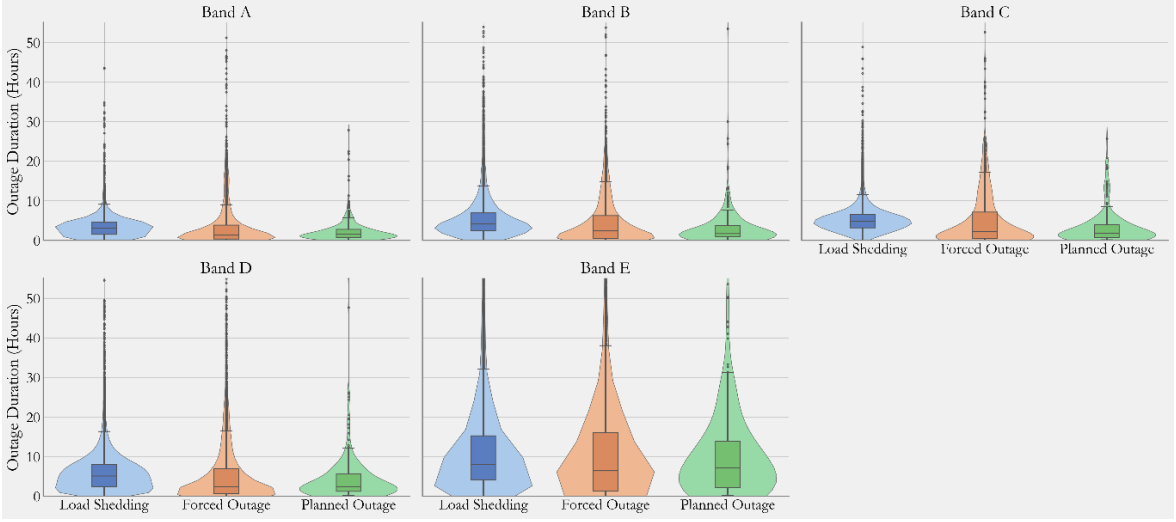


Figure 5-20: Outage Duration by Type Within Each Tariff Band

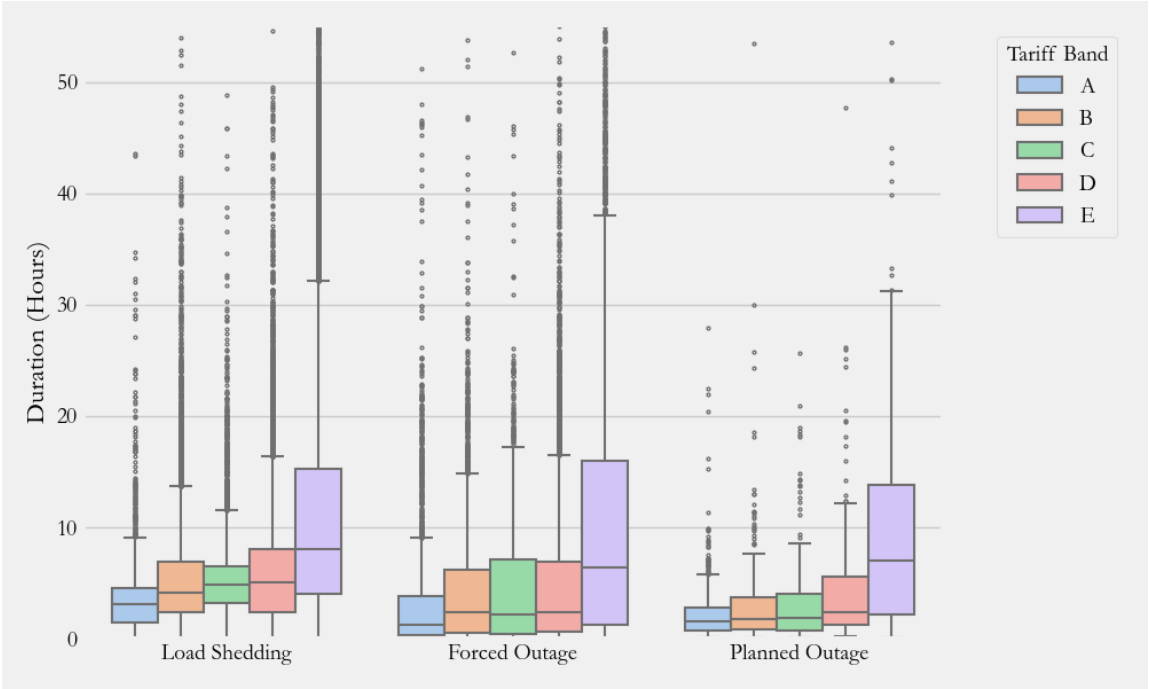


Figure 5-21: Outage Duration by Tariff Band Across Outage Types

Together, these findings deepen the understanding of Nigeria's reliability landscape—revealing how outage frequency and duration vary not only by tariff band, but also by season, region, and outage type. These patterns provide important context for interpreting the temporal reliability trends explored in the next section.

Availability profiles

Figure 5-22 displays the cluster centers for the four availability patterns identified through KMeans clustering of the weekly average hourly availability profiles across the 50 feeders analyzed in this study. These clusters reflect distinct patterns of grid electricity availability and are further illustrated in Figures 5-23–5-26, which show the hourly availability distributions for representative feeders from each cluster. As defined earlier, the hourly availability value represents the share of time within each hour-slot across the week—e.g., all seven '1–2 p.m.' hours from Sunday to Saturday—during which electricity was available.

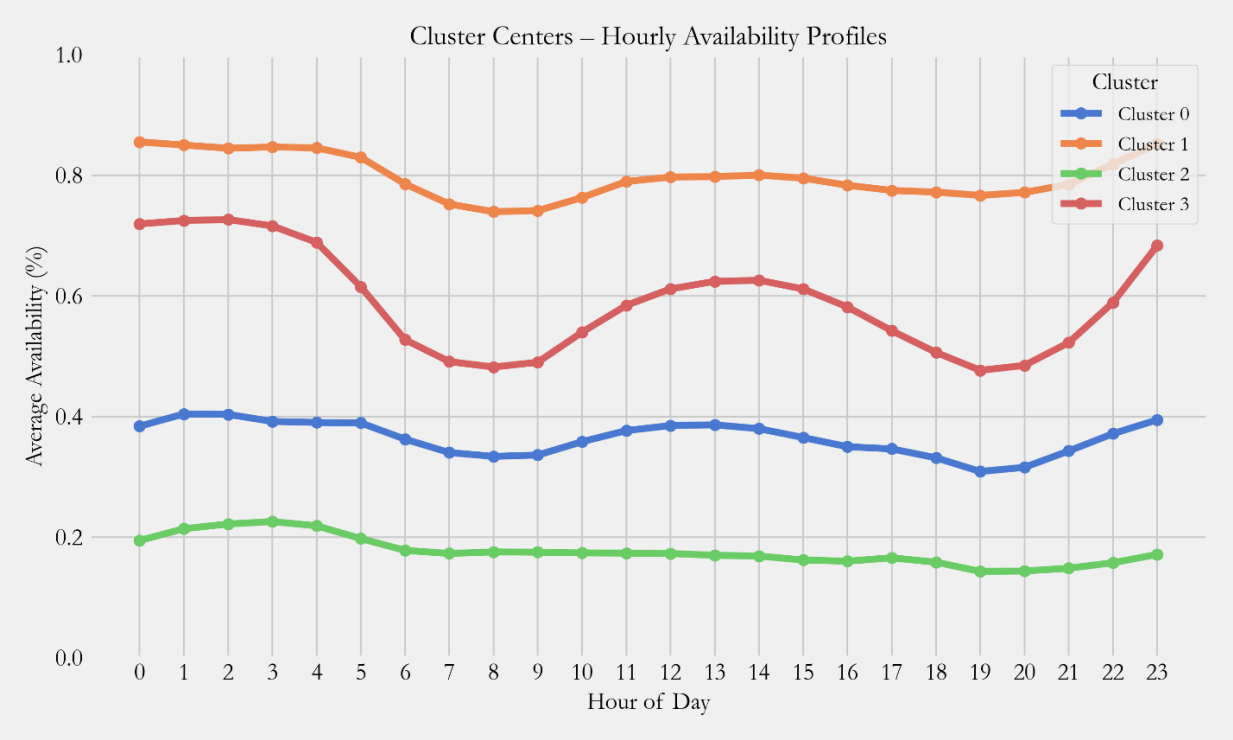


Figure 5-22: Cluster Centers of Hourly Electricity Availability Across Feeders

Cluster 0:

Feeders in this cluster have limited availability throughout the day, with only a modest midday improvement. For example, the representative feeder shown in Figure 5-23 has peak availability ranging from 36-56% between 8 a.m. and 4 p.m. Although this aligns with the typical lunch preparation window, the reliability within those hours—combined with the generally low availability—suggests that electricity can only be used opportunistically. Such patterns are unlikely to inspire confidence in the grid's capacity to support more consistent or high-load end uses. Most feeders in this cluster belong in the Band D or E class, with one Band B feeder included.

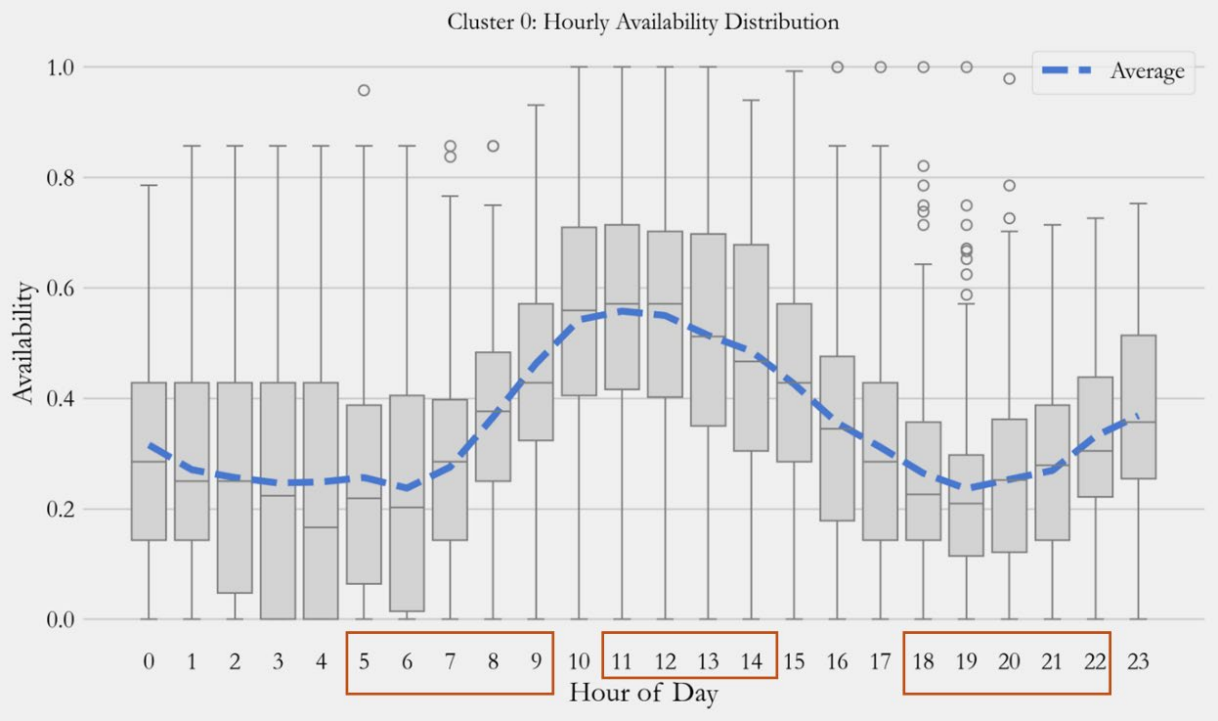


Figure 5-23: Hourly Availability Distribution - Representative Feeder in Cluster 0

Cluster 1:

Feeders in this group exhibit relatively high availability throughout the day, with a slight dip from mid-morning to early evening. As shown in Figure 5-24, the representative feeder reaches peak availability of 77–85% between midnight and 8 a.m., and again from 6 p.m. to 11 p.m., while the lowest availability—ranging from 64–74%—occurs between 9 a.m. and 5 p.m. These peak hours align well with typical demand windows for EV charging and electric cooking during breakfast and dinner. However, the lower availability between 11 a.m. and 2 p.m. may limit the feasibility of midday cooking. While even these availability levels may be insufficient for dependable use of electricity for essential end-uses like cooking or transport, this cluster represents the most reliable feeders in the dataset and is therefore best positioned to support electrified end-uses based on grid supply. Unsurprisingly, all Band A feeders analyzed fall into this cluster. In addition, one feeder each from Bands C and D is also included, though no Band B feeders are represented.

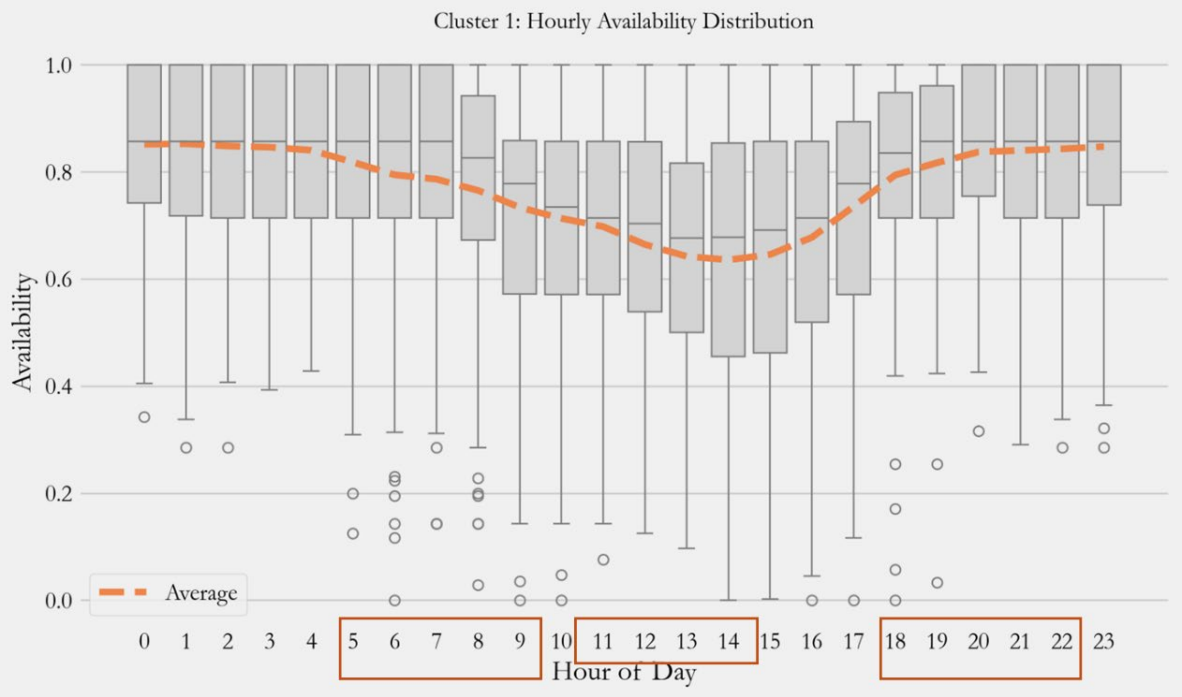


Figure 5-24: Hourly Availability Distribution - Representative Feeder in Cluster 1

Cluster 2:

This is the least reliable cluster, comprising only Band E feeders and characterized by consistently low availability across all hours—generally below 20%. Consequently, feeders in this group are unsuitable for sustained electricity-dependent activity without robust backup systems. In the representative example shown in Figure 5-25, peak availability reaches only 17-25% between midnight and 5 a.m. — a window that falls outside typical periods for cooking or EV charging.

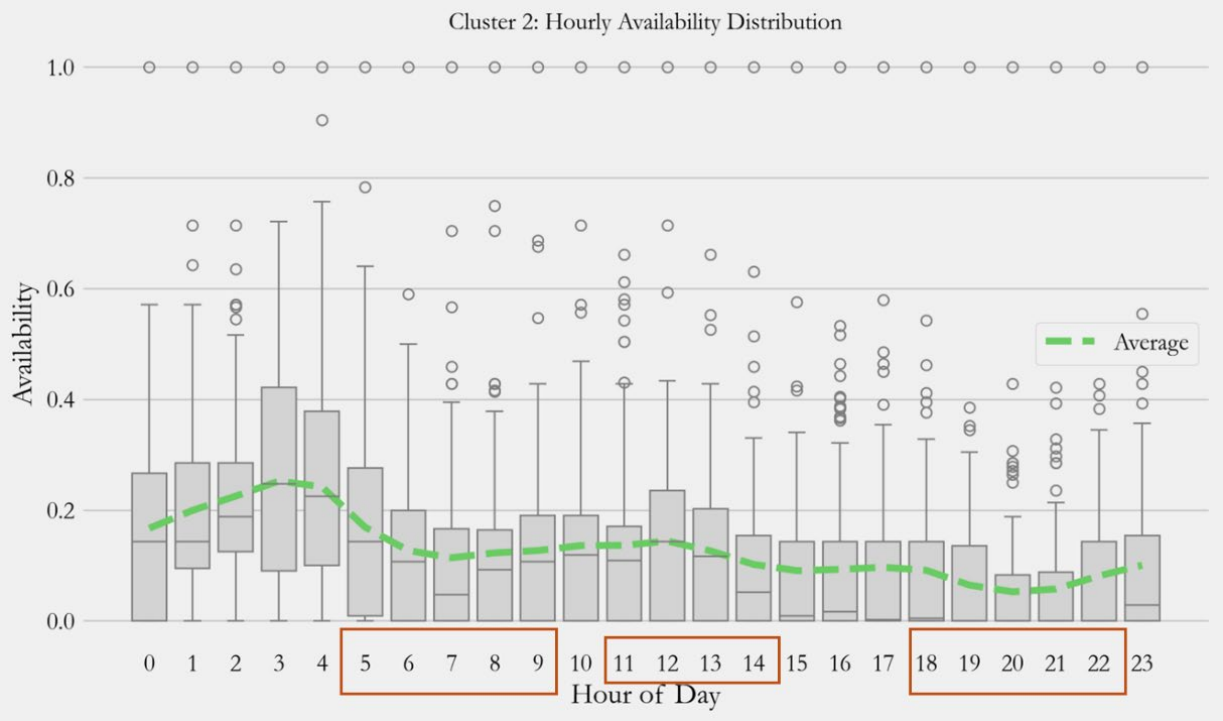


Figure 5-25: Hourly Availability Distribution - Representative Feeder in Cluster 2

Cluster 3:

Comprising feeders from Bands B, C, and D, this cluster reflects moderate reliability with noticeable dips during morning and evening hours. As shown in Figure 5-26, availability is lowest during the very periods when electricity is most needed for cooking and EV charging—for instance, dropping to as low as 35% between 5 a.m. and 9 a.m., compared to peak levels of 66–77% between 11 p.m. and 4 a.m.

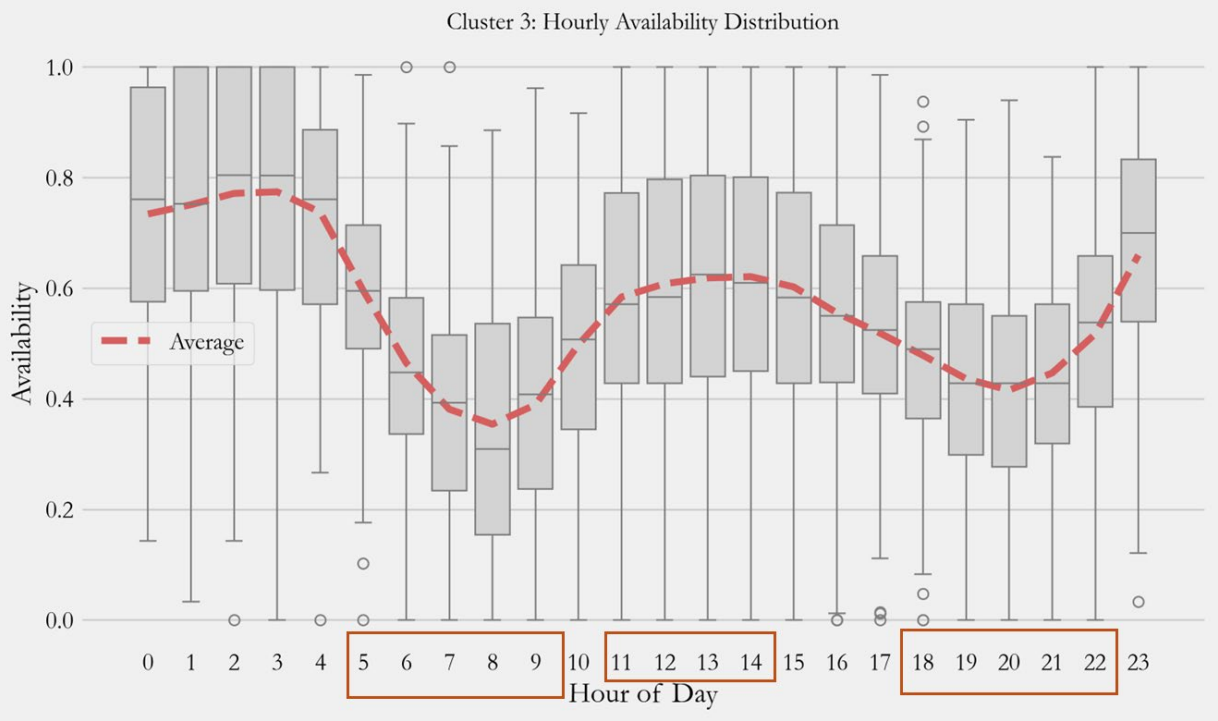


Figure 5-26: Hourly Availability Distribution - Representative Feeder in Cluster 3

Overall, even without accounting for the added load from electrifying new end-uses, these availability profiles suggest that electricity is often not available when it would be most needed for key services like cooking and EV charging. Only Cluster 1, dominated by Band A feeders, could potentially deliver the consistency necessary for end-use electrification. These findings support the argument that widespread unreliability, particularly during peak demand hours, poses a significant barrier to achieving Nigeria's electrification-based transition goals.

Unreliability, Cost and Political Constraints: Expert Perspectives on End-Use Electrification in Nigeria

Perspectives shared during interviews with electricity sector experts further underscore the limiting role of grid unreliability in achieving Nigeria's end-use electrification targets. As one expert said, emphasizing the foundational challenge:

> "To achieve these [electrification] targets, we must all work together to ensure that the grid is actually dependable. Today, we are having suppressed demand and inability to meet up

> with the connected loads. With all this transitioning happening, it means that demand will increase and ability to provide and meet with this demand becomes key."

Another offered a more direct assessment:

> "To be able to achieve such widespread electrification of cooking, transport and industry, you must have enough resources to drive. Assuming it's available, no issue. Currently, our grid can take 7,000 megawatts, but we're only getting 3,000 to 4,000. You know that with this statistic currently, the electrification targets will not make any sense."

In addition to inadequate electricity supply, several experts also raised concerns about affordability, noting that *"the cost of living, the living wage, the financial capability of the people around matters a lot."* Relatedly, one utility executive explained:

> "In my opinion, as it is now in Nigeria, it is not about the issue of electricity or other energy sources. The major issue, because of the economic situation people are in, is availability and affordability. Those two are the ones playing hero."

Speaking specifically to the end-uses considered in this study, one expert highlighted the cost limitations with electric vehicles and another with clean cooking:

> "You have to think of Nigeria as a thrift market. People can only pay in little installments. So people would rather pay in small installments for petrol than buy an EV outright, which is capital intensive."

> "I think the targets are good. I think you always have to be ambitious. But survival will trump all these plans. That's the truth. Unless there is a financially viable method of putting alternatives in place, people will not not eat because it is not clean cooking. Ultimately, citizens would make an economic decision."

Interestingly, a clear dichotomy emerged between experts' perceptions of EV charging and electric cooking. Most considered EV adoption more viable—economically, culturally and technically—than widespread adoption of electric stoves. One mini-grid developer noted:

> "I'm a bit laid back when it comes to electric cooking, especially in isolated mini-grid settings, because there's a lot outside what a typical financial model captures that plays a major role. Cultural factors matter—for example, you often hear people say, '*na food wey dem dey cook with charcoal wey sweet pass' (food cooked with charcoal tastes better).* This perception is common in rural communities.
>
> Technically, electric cooking doesn't really make financial sense, especially in a mini-grid settings where power costs are already high. Heating appliances can triple energy usage compared to other appliances, so we're very cautious—unless new research comes out that significantly changes the dynamics.
>
> But on the EV side, we're running a pilot using electric bikes to transport agro-produce from farms to collection centers and then urban areas for sale. That shows far more

> prospects. It's something that could really redefine a lot of things in the space, and it's a welcomed development.
>
> In-house, we're looking at scaling it in urban centers—where you can easily set up a charging station and have people come charge their bikes for a fee. The EV business model makes much more sense, and it's easier to convince financiers to invest. But on the clean cooking side – especially where it involves electricity—we're still a bit cautious."

Another expert echoed this, arguing that the Nigerian government must take the lead in EV deployment:

> "If the infrastructure were there, would people use electricity over fossil fuels? Yes—very much so. But the real challenge is infrastructure—especially charging. Look at California—probably the U.S. state with the highest EV adoption—and even there, they still struggle: Are there enough charging stations? Are they fast chargers or slow? Will you have to install one at home? What does that mean for your electricity bill?
>
> The point is, transitions happen for a reason, and they don't have to start with consumers. I think the transition to EVs is viable, but it needs to start with government transportation authorities—because they have the money, the capacity to buy vehicles, to build infrastructure, and to manage charging.
>
> Once public vehicles are electric, the business case is proven, and private adoption will follow. In fact, we're already seeing early signs of this—people in Lagos are driving less and turning to trains due to the rising cost of gas. So, for me, the transition starts with public authorities first, then moves into the private sector. But for that proliferation to truly happen, the infrastructure issues—especially around energy distribution—have to be solved.
>
> On the clean cooking side, though, there are still serious challenges. Is it even commercially viable for people who cook at a commercial scale to use electric stoves? I'm not sure. In one pilot project I know of, it costs about ₦1,000 just to cook two pots of rice using battery-powered electric stoves. Which cook would pay that, if they can use firewood or kerosene which are cheaper?
>
> At the consumer level, it is the substitution that matters: what are people switching from and what does it cost? For government-led transitions, infrastructure comes first. So, for me, EVs have a clearer path right now. For electric cooking, I cannot speak to its viability as of today."

Nonetheless, one expert voiced concerns about Nigeria's technical capacity to sustain EV adoption and raised future environmental risks:

> "I think there'll be more campaigns soon about the dangers of mining some of these so-called rare earth minerals used in EVs. I may be wrong about all this—I don't know. And in Nigeria, because we don't necessarily have good technical capability to support EVs, they may not proliferate the way petrol vehicles have."

Finally, in addition to limitations posed by unreliability and affordability, some interviewees also raised geopolitical and macroeconomic dynamics that could constrain widespread electrification. One expert elaborated at length:

> "I don't think fossil fuel technology will go away outrightly. I really don't…If you look at the countries championing EVs, they're often the most at risk of crude oil shortages—like Europe, in particular…But if you look at global markets—just recently, Trump was inaugurated. So, we are back to that whole round and cycle again. I think fossil fuels will still be here for a good run…In countries like Nigeria especially, I don't think we can eliminate fossil fuel technology completely. We have so much to lose if we switch completely without proper infrastructure in place. Imagine, we're a crude oil country, saying by 2050 we'll switch, but we don't even have the manufacturing plants for most of these technologies…I think all energy sources will still exist—just in different degrees."

Conclusions

This chapter has examined the nature of electricity unreliability across 50 11kV feeder lines in Nigeria, drawing on detailed outage data and expert interviews. The analysis finds that outages are frequent, worsening, and unevenly distributed—varying significantly by tariff band, season, region, and type. These outages translate into limited daily electricity availability, especially during key periods for cooking and EV charging. As such, from a supply-side perspective, current levels of unreliability are likely to constrain greater adoption of electrified end-uses, undermining the goals articulated in Nigeria's Energy Transition Plan (ETP).

Although this study focuses primarily on blackouts, the literature highlights that brownouts—low-voltage conditions that degrade electricity quality—are also widespread in Nigeria and other Sub-Saharan African countries [16, 31]. This suggests that even when electricity is technically available, the quality may be too poor to power high-load appliances like electric stoves or vehicle chargers. In such cases, the grid cannot support the sustained, electricity-intensive uses envisioned under end-use electrification.

Moreover, without corresponding investments in generation, transmission, and distribution infrastructure, electrification of cooking and transport—for example, if encouraged through consumer incentives like appliance or vehicle rebates—could exacerbate unreliability. Local system overloads, a common cause of outages in developing countries, may become more frequent as more households attempt to power cooking equipment or charge EVs [19]. Studies from other contexts suggest that significant system expansion would be necessary to accommodate this additional demand [64, 66].

Beyond reliability constraints, interview insights further reveal a broader range of limiting factors—including affordability challenges, geopolitical considerations, cultural preferences, limited technical capacity, and emerging concerns about the environmental impacts of mineral extraction for EV batteries.

While both electric cooking and EV adoption are affected by many of these barriers, experts generally viewed EVs as more promising in the near term. This view is shaped by the potential for targeted EV deployment strategies that align infrastructure development with sustainable business models—

effectively addressing both technical and financial constraints. For example, public sector fleet electrification, particularly through government transportation agencies, was cited as a promising entry point. Similarly, some mini-grid developers are piloting EV charging infrastructure, often incorporating battery-swapping models to reduce upfront costs for consumers [67-71]. These approaches, which tackle infrastructure and affordability challenges simultaneously, offer a scalable pathway for EV adoption. In contrast, experts expressed greater skepticism about the near-term viability of electric cooking, particularly in off-grid or mini-grid contexts, where power costs are high and cultural preferences remain strong.

In summary, these chapter's findings suggest that while electrification of end-uses is an important pillar of Nigeria's energy transition, realizing this goal will require a much more deliberate focus on improving grid reliability, managing new demand, and accounting for economic, cultural, and political constraints. Without these considerations, electrification targets risk becoming aspirational rather than achievable.

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Chapter 6

Electricity for the People: Diagnosing the Multi-Level Causes of Nigeria's Grid Unreliability

Preface

This chapter offers a surgical analysis of the factors driving electricity unreliability in Nigeria. As noted in Chapter 3, electricity deficits—particularly the unreliability of grid power—emerged as a central concern during the socialization of Nigeria's Energy Transition Plan (ETP) and were echoed in both the literature and my lived experience. In Chapters 4 and 5, I examined how this unreliability shapes Nigeria's energy trajectory by driving decentralized fossil-fuel generation and constraining the feasibility of end-use electrification. Given the outsized role of electricity unreliability—empirically established in those chapters—and my commitment to generating knowledge that enables action, this chapter seeks to interrogate its root causes. The aim is to provide evidence that can serve as a foundation for developing critical solutions.

Drawing on detailed classifications of outage data across 50 feeders (introduced in Chapter 5) and complemented by semi-structured interviews with sector experts—particularly those working in electricity distribution companies—this chapter develops a layered analytical framework to unpack the drivers of unreliability. The goal is not only to categorize causes, but to illustrate how different levels interact—and to show why durable solutions must go beyond surface-level disruptions. The resulting insights deepen the understanding of Nigeria's perennial grid dysfunction and highlight grounded, context-specific entry points for reform.

Having grown up under the reality of Nigeria's unreliable power supply, this chapter is both personal and intellectually fulfilling—helping answer questions that have long lingered unanswered. The analysis reveals real and extensive challenges, which I organize into a six-level framework:

- **Level 1** reflects immediate outage types—forced outages, load shedding, and to a lesser extent, planned outages.
- **Levels 2 and 3** unpack midstream operational breakdowns—spanning infrastructure deterioration, systemic design flaws, routine procedural lapses, and grid-level constraints shaped by both technical limitations and commercial considerations.
- **Levels 4 to 6** expose deeper structural barriers including chronic underinvestment, ineffective policies, weak sectoral culture, and embedded behavioral and political dynamics—described by some respondents as the 'Nigerian factor.'

Ultimately, this chapter underscores both the complexity and clarity within the Nigerian Electricity Supply Industry (NESI): the problems are widely understood, yet the alignment, capacity and sustained will to resolve them remain elusive. Still, like many of the experts I spoke with, I am hopeful. While the combination of complexity and clarity fostered inertia in the past, it can also be a catalyst for transformation.

As a scholar-practitioner, I am encouraged by the refined understanding this chapter provides, and I hope that its insights offer clarity, momentum, and strategic direction to all working to solve this urgent development challenge in Nigeria—myself included.

> *"That's Nigeria. Nigeria has happened to Nigeria."* – Interview Respondent[79]

Abstract

Electricity unreliability remains a critical barrier to equitable and sustainable energy transitions—particularly in emerging economies—yet its root causes are often underexamined. This chapter presents a multi-method investigation into the underlying drivers of grid unreliability in Nigeria – an important Sub-Saharan African context and the country with the world's largest electricity access and reliability gap. Drawing on classified daily feeder-level outage data and semi-structured expert interviews across the Nigerian Electricity Supply Industry (NESI), it proposes a six-level causal framework.

The analysis reveals that outages stem not only from immediate technical issues—such as load shedding, system faults, and, to a lesser extent, planned maintenance (Levels 1–3)—but also from deeper structural, financial, and sociopolitical challenges (Levels 4–6), including low revenue recovery, ineffective policies, and entrenched behavioral norms. The chapter argues that solving electricity unreliability requires a layered, coordinated approach, extending beyond infrastructure fixes to address sector liquidity, governance weaknesses, and widely held perceptions of electricity as an entitlement. The findings offer a practical roadmap for scholars, policymakers, and practitioners working to improve reliability as a cornerstone of Nigeria's energy transition.

Introduction

While closing the electricity access gap is a key developmental goal in Africa, it is widely documented that even those with grid connections suffer significant electricity shortages [1-4]. Across the region—particularly in Sub-Saharan Africa (SSA)—the electricity infrastructure is notoriously unreliable, leading to regular blackouts and brownouts [3–11].

This unreliability affects all segments of society. At the household level, it has been linked to lower incomes, poorer health and education outcomes, and limited employment opportunities. Among firms, electricity shortages have been connected to reduced size, productivity, and revenue—driving inefficiencies and, in many cases, leading to business failure, particularly among artisans and small and medium enterprises (SMEs). At the national level, unreliability undermines investor confidence, depresses tax revenue, weakens public services, and contributes to increased crime and unemployment rates [3–5, 10–17].

In South Africa, for example, the economic toll of load-shedding is estimated at US$50–100 million per day [18]. Yet the impacts elsewhere may be even more severe. As Babayomi *et al.* [19] observe, *"if power outages in Sub-Saharan Africa reduced to levels in South Africa, businesses would make up to 116.8% more money if they did not have to operate backup generators."* Murphy *et al.* [20] similarly show that reducing outage days from 100 to 10 per year correlates with almost a tripling of GDP per capita—from US$1,900 to

[79] This quote was shared by one of the sector experts interviewed for this study as part of the qualitative data collection described in Chapters 4, 5 and 6.

US$5,500. They further note that *"no country with an average of less than 1 outage day per year has a GDP per capita of less than $10,000"* [20, p.523].

Despite these wide-ranging impacts, relatively little is known about the specific causes of SSA's outages or their distribution across geography and time, limiting the development of targeted solutions [21]. Several authors have proposed overarching explanations for the region's persistent outages, but these accounts often lack the contextual detail and event-level granularity necessary for informing practical interventions [22].

For instance, Burgess *et al.* [12, p.145] argue that chronic unreliability stems from *"treating electricity as a right, rather than a private good"*—a norm in which electricity is viewed as an entitlement irrespective of payment. This framing is echoed across the literature, where related structural and organizational problems are frequently identified as root causes of unreliability in SSA.

These include severe underinvestment across the power value chain; weak utility creditworthiness; non-cost-reflective tariffs; and low revenue collection rates from both public and private customers [3–4, 10–12, 17, 25–30]. Such systemic constraints are often compounded by—or give rise to—a range of reinforcing challenges: constrained public budgets that limit the state's capacity to offset utility deficits; insufficient or unavailable generation capacity stemming from equipment disrepair, irregular fuel supply, and inadequate maintenance; technical losses along transmission and distribution lines; and chronic overloading, particularly at the distribution level.

Other contributing factors include poor-quality infrastructure at the point of use (e.g., faulty wiring), dependence on imported fuels and equipment, vandalization of assets, and weather-related disruptions such as heavy rainfall and thunderstorms. Beyond these technical and financial issues, corruption, weak governance, limited accountability, and inefficiencies in state-owned utilities are widely cited as persistent structural obstacles [4–5, 7, 9–12, 14, 17, 23–29].

Together, these interlocking issues reflect the deep complexity of the electricity unreliability crisis. Yet, without more fine-grained, empirically grounded evidence on how these drivers manifest in specific outage events, much of the existing literature remains too generalized to inform effective reforms. As Adewuyi and Emmanuel [14] observe, *"what determines electricity outages is very complex and may be of interest to policymakers, profit-oriented enterprises, and households."*

Consequently, following the availability-focused analysis in Chapter 5, this chapter investigates the causes of electricity outages and how they are managed in practice. It contributes to the literature in two primary ways. First, it analyzes daily outage logs from 50 11kV feeders across Nigeria's grid to examine reported outage causes at the individual event level—offering rare insight into the frequency of different outage types. Second, it incorporates semi-structured interviews with electricity sector experts—including developers, operators, engineers, and regulators—to explore the institutional, political, and infrastructural dynamics that shape grid unreliability in Nigeria.

This second contribution is particularly important to highlight, as the few detailed accounts of electricity unreliability in SSA—while providing valuable insights—have primarily focused on end-user experiences [7-8, 17]. These perspectives are important, but the relative absence of data from service providers limits understanding of how unreliability is managed and what realistic solutions may exist. Additionally, scholars have long noted the fraught relationship between utility officials and

consumers, as well as perceived arbitrariness in how outages are distributed. However, there has been limited interrogation of these claims with empirical evidence.

In the Nigerian context, for instance, some believe that utility officials *"made conscious, self-interested choices about when and where to provide power"* and could be bribed to offer uninterrupted supply for specified periods [5, p.56]. Olukoju [17, p.59] similarly recounts:

> "Consumers also take the extreme step of violent resistance such as…assaulting staff if there is an outage before or during a crucial football match involving the national football team, the Super Eagles! Such fans reason that NEPA[80] staff have fiddled with the power supply to their neighborhood to exploit their predictable desperation to watch such matches live."

Yet the extent and mechanisms of such *"fiddling"* remain largely unknown. Relatedly, Adewuyi and Emmanuel [14] report that firms in their study spent an average of 15% of their sales revenue on bribes to electricity officials to avoid outages. As Gertler *et al.* [15] explain:

> "Even within the same city, different groups of users may be rationed different amounts of power. Utilities may provide higher service levels to feeders serving embassies, hospitals, and districts with a high number of commercial and industrial establishments. There may be political, ethical, or commercial reasons for distributing blackouts in this way. There may also be areas that receive better service due to political connections and bribes. Many of these questions remain unanswered due to a lack of data."

This chapter responds directly to such questions. To the best of my knowledge, it represents the first attempt in the literature to distinguish between types of grid-level outages in Nigeria at the level of individual outage events—and perhaps the first such effort across SSA's on-grid systems (see [22] for a rare, comparable study in off-grid contexts).

Methods

This study draws on a unique administrative dataset comprising daily outage records across 50 active 11 kV feeders within the service territory of Nigeria's largest distribution utility, the Ibadan Electricity Distribution Company (IBEDC). As introduced in Chapter 5, the dataset spans 34 to 45 months per feeder, depending on data availability, covering the years 2019, 2020, 2023, and 2024. Records from 2021 and 2022 were lost in a major server crash; however, data from earlier years had been secured during fieldwork in 2021, prior to the crash. All entries were obtained directly from the utility in Microsoft Excel format and were subjected to extensive cleaning and validation.

Each outage record includes a field labeled 'Type of Outage,' which typically specifies both the stakeholder associated with the outage and the nature of the disruption. Outages were often attributed to either the electricity distribution company (EDC) or the Transmission Company of Nigeria (TCN), based on either the stakeholder deemed responsible or the grid level where the issue originated. For

[80] National Electric Power Authority (NEPA). The initial name of the State-Owned, vertically integrated electricity utility established in 1972. NEPA was renamed in 2005 to the Power Holding Company of Nigeria (PHCN) as part of the privatization process. In 2013, PHCN was unbundled into six generation companies, eleven distribution companies, and 1 transmission company. It is worth mentioning that *"as if to note the continuity of failure, Nigerians still call the national grid and its associated bureaucracy 'NEPA'."* [2, 5, p.60 (quote), 14].

example, faults on 11kV lines were often labeled EDC, while events at 33kV and above were attributed to TCN. Specific outage types include planned outages (PO), load shedding (LS), forced or unplanned outages (FO), earth faults (EF), and overcurrent events (OC). For example, 'EDCLS' refers to load shedding induced by the distribution company; 'TCNLS' to load shedding attributed to the transmission company; 'EDCOC' to overcurrent events on the distribution network; and 'EDCEF' to earth faults on the distribution network. System-wide failures of the national grid were recorded as 'GENSC' (general system collapse).

Based on interviews with utility experts, these outage types can be consolidated into three broad categories for analytical purposes: Planned Outages, Load Shedding, and Unplanned/Forced Outages (including earth faults, overcurrent incidents, and system collapses). Interviewees also noted that outage attribution to either the EDC or TCN often varied across operators, reflecting subjective interpretations shaped by the structural ambiguities and operational overlaps within Nigeria's power sector. For instance, several experts explained that while 33kV feeders are owned by the distribution company, they are operationally controlled by the TCN. Moreover, even when EDC personnel initiate the shutdown of feeders at 33kV/11kV injection substations[81], such actions may have been prompted by instructions from the system operator, who falls under the purview of TCN. Given these ambiguities, the quantitative analysis aggregates outages by type, without distinguishing between EDC- and TCN-induced events. However, these operational nuances appear in the qualitative analysis.

To complement the quantitative findings, the qualitative analysis in this chapter is based on expert interviews conducted across multiple service regions, capturing firsthand perspectives from developers, engineers, operators, and regulators on the nature and causes of grid unreliability in Nigeria. The 26 interviewees included staff from five electricity distribution companies (DisCos), the Nigerian Electricity Regulatory Commission (NERC), the Transmission Company of Nigeria (TCN), independent power companies, and international development organizations. Their responses help contextualize the three primary outage categories found in the quantitative data and reveal additional systemic factors that mirror and extend the literature, providing more detailed insight into the Nigerian case.

Based on the integration of both data types, this chapter organizes outage causes across six levels. Level 1 corresponds to the three outage categories captured in the utility records. Levels 2 through 6 are derived from interview insights, offering layered explanations that reflect the underlying technical, institutional, and sociopolitical roots of unreliability.

To generate these insights, interview recordings and transcripts were analyzed thematically using an inductive coding approach. Rather than applying a predefined classification scheme, the analysis was guided by recurring patterns and ideas that emerged organically across interviews. Here, these emergent themes are grouped into deeper categories of explanation, supported by illustrative quotes that reflect how respondents understand and experience grid unreliability in practice. As one expert explained, *"There are a lot of facets to it [unreliability], and then as you grow more into the topic, you would find out that there are levels to it."*

Verbatim quotes are used throughout this chapter to preserve the integrity and richness of participant perspectives. In accordance with ethical research standards and data-sharing agreements, minor

[81] At the distribution level, an injection substation steps down voltage from 33kV to 11kV and serves as the point where power is routed into 11kV distribution feeders.

editorial adjustments were made for clarity and grammar, and potentially identifying references—such as to individuals, locations, or institutions—have been anonymized where necessary. These measures recognize the sensitivity of some remarks, particularly those touching on corporate operations, regulatory relationships, or national equity. The interview protocol was approved by the University of California, Berkeley Institutional Review Board (Protocol ID: 2024-07-17591).

Results and Discussion

Level 1, 2 & 3 Causes

Across the 94,761 outage records available for the 50 feeders analyzed in this chapter, approximately 75% were load shedding events, 23% were forced outages, and 2% were planned outages (Figure 6-1). On average, load shedding events lasted about 9 hours, forced outages about 8 hours, and planned outages about 4 hours. The sub-sections that follow draw on expert interviews to provide context on the underlying drivers and management processes associated with each outage type.

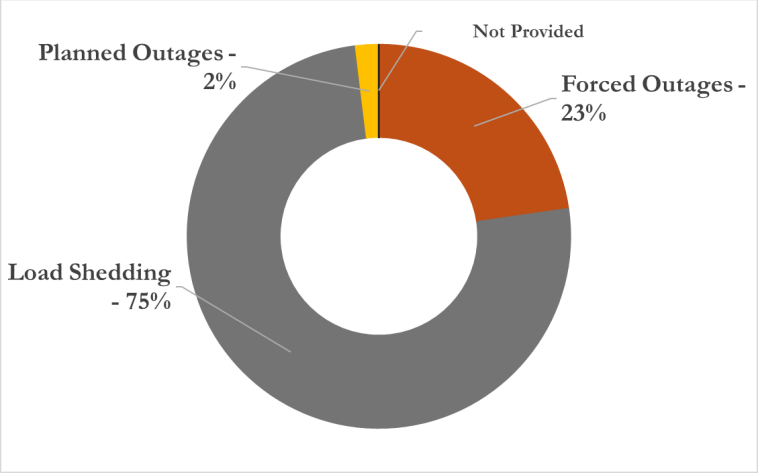


Figure 6-1: Distribution of Outage Types Across the 50 Analyzed Feeders (2019 – 2024)

Load Shedding

Load shedding—used to ration limited power supply—is perhaps the most commonly cited cause of outages in developing regions, and this is supported by the data from Nigeria [12, 15, 25].

Interviewees widely affirmed that load shedding stems from the mismatch between electricity supply and demand. As one energy development expert put it, *"There are too many customers and not enough power on the grid."* For instance, in 2023, Nigeria had available installed grid generation capacity of about 4 GW for a population of over 220 million, compared to Brazil's 240 GW for a population of 211 million [31-32]. A utility official illustrated the scarcity with this evocative analogy:

> "It's like when you have two cups of *garri*[82] and five children. Even the father and the mother might go hungry for the children to manage it. So, the father and the mother are on load shedding while the children are eating."

In Nigeria's electricity system, distribution companies (DisCos) depend on allocations from the national system operator—under the Transmission Company of Nigeria (TCN) and executed from the National Control Centre (NCC) in Osogbo. One utility official explained, *"We in the discos, we don't have the power supply at our disposal, we are only sharing the little the grid operators are allocating to us."* Broadly, allocations refer to the daily amount of electricity each DisCo's service regions can draw from the grid, based on available generation. These allocations are difficult to enforce because electricity is drawn from the grid spontaneously. However, to manage discrepancies, sector stakeholders periodically reconcile accounts and actual usage.

Depending on the frequency of planned maintenance, faults, and other changes on their network, DisCos typically submit load forecasts to the TCN on a weekly or bi-weekly basis. At the same time, within their tariff reviews—referred to as Multi-Year Tariff Orders (MYTO)—the Nigerian Electricity Regulatory Commission (NERC) adopts an average electricity offtake for each DisCo, which, as one respondent put it, represents their *"contracted agreement"*: the daily electricity capacity that should be available to them on average (Table 6-1).

Despite these processes, utilities receive their actual allocations on a daily basis, and these often differ from both their contracted agreements and weekly or biweekly forecasts. As one expert lamented, *"What they have been giving us is lower than what we can take, and we need to manage it so that's why you see frequent load shedding".* Another clarified, *"On a daily basis, we are supposed to have that [contracted agreement] on average. We are not getting it. We are not getting it."* Yet another echoed, *"Maybe as a disco, we need about 600 megawatts (MW). But at times, we get about half of that to distribute."*

Interviewees also described misalignments between daily allocations and customer usage patterns. One official noted,

> "We know that at night, after work, residential use is higher. When people go to offices, residential consumption will go down. The allocation should also follow that pattern. So, we give forecasts, and many times we face allocation results that are arbitrary. They're not following exactly what the DisCos are giving. They give many times flat allocations, which is not correct."

Furthermore, since allocations fluctuate unpredictably—changing multiple times a day—DisCos often cannot plan load shedding schedules in advance. This contrasts countries like Bangladesh, Nepal, and India, where load shedding is typically planned and communicated ahead of time [12, 15, 25, 33]. As an expert explained,

> "Load shedding sometimes comes because of a drop in generation level. That one, the DisCo may not have control over. Yes. The TCN would just call, *'Okay guys, instead of 150 MW you have as your allocation, your allocation has been dropped to 100 MW.'* So, we'll drop here, drop there—it's going to be immediate."

[82] Garri is a popular Nigerian staple made from fermented, sieved, and roasted cassava tubers. The result is a dry, granular flour that can be eaten soaked in water like cereal or stirred into hot water to make *eba*—a dough-like accompaniment for soups. It is widely consumed across Nigeria.

Another respondent echoed this unpredictability, noting that *"the issue of generation... it can drop now, and later they'll say pick load. So, it happens randomly. This is something that you cannot predict."*

Providing a detailed explanation of how allocation works in practice, an energy management expert shared,

> "Allocation is a daily thing...It can change within two minutes depending on what the generator is producing. It doesn't have a fixed time. The first allocation might come 30 minutes to an hour after midnight—that's when the first generator will come up. We can maintain that allocation for a long time—it depends. Maybe before 8 a.m., another generator comes online. Even within an interval of one hour, you can have two different allocations. So, it depends on how the generator is performing. Sometimes, we might only have that one allocation from the early hours of the day, and we'll use it all through.
>
> But if the generators keep coming on, then there will be more allocation to share. That's how it is—it doesn't have a fixed time. Let's say by 8 a.m., you have 400 MW—you share it. From 8 a.m. to 6 p.m., if there's no new allocation, you're still maintaining that 400 MW for every hour. Then maybe at 6 p.m., another generator comes on and generation increases to 500 MW—we share that too. Maybe by 6:45, another one comes up. Allocation has changed again—either it's up or it goes down. That's how it works. It's not static."

Explaining the reason behind such fluctuations, an expert from TCN lamented,

> "The generating companies (GenCos)…sometimes you will wake up to the season of [them saying] we don't have gas. The man said he doesn't have gas, so what do you do? That means that little generation that he has, you have to allocate it in a proportionate manner."

Relatedly, in the absence of spinning reserves and other ancillary services, load shedding has become the default response to system imbalance. As one DisCo official explained, *"When there's instability on the grid, TCN will call our people: 'Please drop some of your feeders.'"* Another added, *"We don't have the power. We rely on what TCN gives us from the grid. Any point in time they say drop, we have no option but to drop. If you don't drop load, they'll open the feeder line themselves to maintain grid stability."* In the words of a third respondent, *"You'll still see where maybe the NCC Osogbo will call the station and say, 'Please drop load. Don't run anything above 3 MW,' so the grid doesn't entirely collapse. Because if there's no grid, there's nothing to give anymore."*

Beyond generation constraints, equipment and infrastructure limitations at the transmission and distribution levels also drive load shedding. As one utility executive noted, *"at TCN, when they have a 60 MVA transformer and the total load on it is 80 MVA, it's too much for it. You have to ration to avoid damaging the equipment."* Another expert elaborated,

> "In my network, I have a 15 MVA transformer, which can evacuate around 12 MW using a 0.8 power factor. But I've got three feeders coming out of it, each needing 6 MW—that's 18 MW total. If I put all of them on at once, I'll overload and damage the transformer. So, I apply load shedding to save the life of the equipment."

A different technical manager added,

> "A 35mm² aluminum conductor can't take beyond a certain current, and it's where we should have a 150mm². So definitely there will be a problem. At 6 p.m., when the load

> peaks, that line must go out on load shedding. That's why some people never see light[83] in the morning at 6 or in the evening at 6—we knock that feeder off to prevent equipment damage. And when the load is lighter, we'll put it on again."

Consequently, while the country's limited installed and available generation capacity poses significant challenges, one expert asserted that the main issue is the *"national grid itself…we all know that generation capacity exceeds transmission capacity, so there's a bottleneck"*

Yet, even in the midst of these pressing constraints, several experts emphasized that, in practice, DisCos' load shedding decisions are often shaped by financial considerations. *"It's just about commercial viability…if you're not getting revenue from customers,"* said one, *"you tend to reduce your service to that place. You do more for those who pay, and less for those who don't."* This dynamic of *"commercially induced blackouts"* has been institutionalized under the Service-Based Tariff (SBT) regime introduced in 2020, which ties higher tariffs to longer supply hours (Figure 6-2). Feeders are classified into Bands A to E, with Band A customers guaranteed at least 20 hours of daily electricity supply, and Band E customers just 4 hours [34]. In return, Band A customers pay significantly more than the estimated cost of electricity supply, while lower-band and lifeline customers are highly subsidized (Figure 6-2) [35].

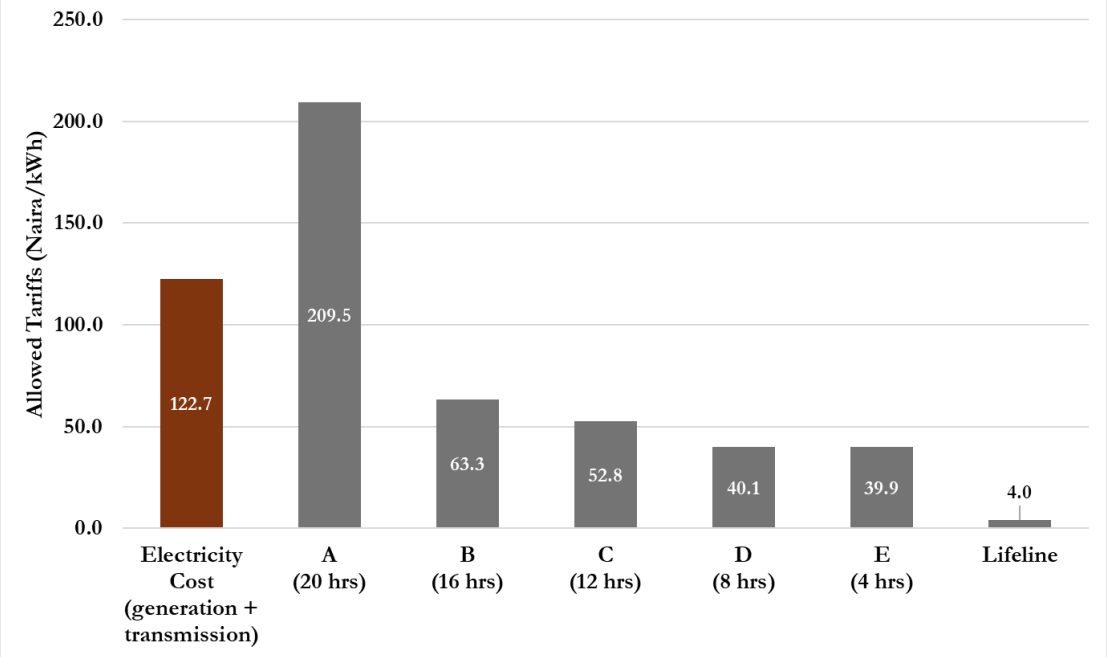


Figure 6-2: Allowed Electricity Tariffs by Band vs. Estimated Cost of Supply (as of 2024) [35].

Consequently, several experts described this logic using the SBT framework. As one utility worker explained,

> "Let's assume that I have 400 MW, and all my customers will be needing like 700 MW. Now I will take scale of preference. The first people that I need to serve—my Band As—I need to serve them, because you can't be charging somebody that huge amount and you

[83] Nigerians colloquially refer to electricity as light.

> shortchange the person. Then the next person, if I have enough, is Band B. And we have Band C, Band D, Band E."

A different utility official described the outcome of this prioritization: *"We have about 60 Band A feeders. These are feeders that don't perform less than twenty hours a day. And if not for faults or maintenance, they meet that. Why? There is an incentive tied to it—it's money."*

Conversely, another respondent explained the financial logic for keeping some feeders in lower bands: "*We have Band E feeders that can stay 24 hours, but we'll never ever upgrade them to Band A because we know we won't get our money."*

Additionally, while significant capacity constraints exist on the Nigerian grid, there are instances—such as during high-generation periods like the rainy season, or when failures in other parts of the network free up supply—when substantial power becomes available. In such cases, financial considerations, rather than technical limitations, become the more important drivers of outages. As one energy dispatch officer explained, *"Though we have our own nomination…sometimes when the generation is much, they will give us more—they may not know where to throw wey (redirect that excess), so they will throw it to us."* In such situations, rather than improving supply across the board, utilities may intentionally limit power to areas with poor payment records. As one respondent described,

> "You now see a situation whereby, even when the power is available, but the place is a high-loss area—these people, they use your power, but they don't pay—you will be constrained. Though the power is available, the energy is available—you may be constrained to ensure that those people don't get much."

The following detailed quote from a utility official further supports this, offering a particularly nuanced view:

> "Load shedding can be in two facets. There's load shedding based on constraints, and there's load shedding based on intent. Constraint-based load shedding will fly in some areas. But in other areas, it won't—because we know there are no real constraints. No installed capacity constraints, no generation constraints, no allocation constraints. We know that in Nigeria, during certain months, generation is high enough that you can pick whatever load you want—mostly due to the rainy season and the high contribution from hydro stations.
>
> So, load shedding can be intentional—and we are intentional about it. For band E feeders, we shouldn't give them more than four hours a day. But at every opportunity—when there's any constraint or whatever—we knock them off. We're not making profit from them.
>
> But for band A feeders, we would never load shed them unless absolutely necessary: generation issues, capacity limits, or line constraints. Maybe the line is already optimized at 100% capacity. Even then, if possible, we can still operate it at a 110%—because we want to make money. So, load shedding: some of it is due to constraints. Some of it, we're intentional about."

Relatedly, as another expert added, *"Sometimes we increase supply to encourage some customers to pay,"* further reflecting how financial considerations shape load shedding outage events.

Despite these complexities, several respondents emphasized efforts to strike a balance. One explained, *"We try to ensure that commercial areas get supply during the day, residential areas at night. It's a win-win…instead of people using their generator set, we try to give them power when they need it most."* However, there are limits to what can be achieved, and load shedding, as another expert stated, is therefore *"counted among the normal operation."*

While the quantitative data established load shedding as a critical Level 1 cause of outages, the interviews revealed that beneath this prevalent issue lie multiple contributing factors—ranging from insufficient or unavailable generation capacity, to equipment and line limitations, to financial considerations and the need for revenue assurance.

Table 6-1: Key Indices in Distribution Companies Multi Year Tariff Order (MYTO) Review for February 2025 [36].

S/N	**Electricity Distribution Utility**	**MYTO Offtake Generation Capacity (MWh/h)**	**Weighted Average Cost Reflective Tariff (₦/kWh)**	**Weighted Average Allowed Tariff (₦/kWh)**	**Aggregate Technical, Commercial and Collection (ATC&C) Loss Target (%)**	**Estimated subsidy benefit (billion)**
1	Ibadan Electricity Distribution Plc (IBEDC)	478	202.1	116.4	20.92	23.63
2	Kano Electricity Distribution Plc (KEDCO)	268	207	115.9	20.88	13.9
3	Kaduna Electricity Distribution Plc (KAEDC)	258	209.3	113	21.32	14.26
4	Jos Electricity Distribution Plc (JED)	225	211.5	115.7	26.09	11.64
5	Ikeja Electric (IE)	603	186.9	114.7	15.93	26.72
6	Eko Electricity Distribution Plc (EKEDP)	513	190.5	118.3	16.88	22.48
7	Enugu Electricity Distribution Plc (EEDC)	310	200.1	115.4	21.26	15.1
8	Port Harcourt Electricity Distribution Plc (PHED)	282	202.5	115	20.42	14.35
9	Yola Electricity Distribution Plc (YEDC)	113	286.3	119.6	44	7.69
10	Abuja Electricity Distribution Plc (AEDC)	611	196	117.3	20.6	27.87
11	Benin Electricity Distribution Plc (BEDC)	325	199.5	117.2	20.76	15.46

Forced Outages

Forced outages account for the second-highest share of recorded outages in the dataset. However, most interviewed utility experts referred to them as the main cause of failures on the network. This reflects a broader perception that views load shedding events separately or regards them as part of routine operations, whereas "outages" are seen as synonymous with faults or unexpected failures. As one expert clarified,

> "Load shedding is not a fault. Somebody says, *'Okay, I did this. Look at the reason why I am doing it. I am putting you on load shedding because I don't have adequate allocation to serve you...You are going on load shedding because of system instability.'* Load shedding is just for balancing. It can be for the grid; it can be to manage the load of the DisCo. The feeder is not faulty."

By contrast, forced outages, as several experts explained, are *"never envisaged," "come suddenly without notification,"* and are *"like an accident."* One official noted simply: *"Outages are unplanned—you can't predict when they will happen."* Another added, *"We do not have control over [them], and they can come from any part of the network."*

Several interviewees traced forced outages to immediate physical failures such as line or conductor cuts, jumper cuts, overhead accessory failures, broken wooden crossarms, shattered insulators, and other failures across both distribution and transmission infrastructure. Beneath these direct causes, some experts pointed to vegetation encroachment and weather conditions—especially during the rainy season—as critical underlying factors. Indeed, Figure 6-3 illustrates the presence of noticeable shifts in the share of forced outages in certain regions—Regions 2 and 4, for example.

One expert explained,

> "Our network covers a wide geographical area…and a very rainy terrain where you have growing trees and all of that. So, our feeders come across a lot of vegetation, trees. We have trees falling on our lines. So, whenever there is breeze or a tree falls on the line, of course, you have what is known as earth fault. And whenever there is earth fault, the protective devices at the injection substation will react to cut off the feeder to prevent it from further damage. And by that interruption, the customers will experience outage."

Another added,

> "Let's say there is wire snap, which is a forced outage. You cannot predict it. When it happens, the light will go off. Same as earth fault. Maybe, let's say, a branch touches the line—it will breach the supply and trip the light. Then you also have weather issues. Maybe when the weather is bad, the line can go down due to lightning."

The outages that were specifically recorded as earth fault events accounted for about 15% of the forced outages across the 50 feeders analyzed. In some utilities, their share was reportedly much higher. One official noted that vegetation-driven faults accounted for 73% of their outages. Speaking bluntly, a utility executive simply said, *"how many of the lines can you say rain is falling, it won't trip? You can't beat your chest."* Relatedly, some estimated that distribution network stability improves by as much as 70–80% when weather effects subside outside the rainy season.

In more extreme cases, weather events can physically destroy infrastructure. For example, one expert described an incident where gully erosion cut off the base of transmission poles. In addition to vegetation and weather effects, some experts pointed to other external factors—such as when *"drivers jam and bring down the line leading to a complete wire twist leading to power interruption."*

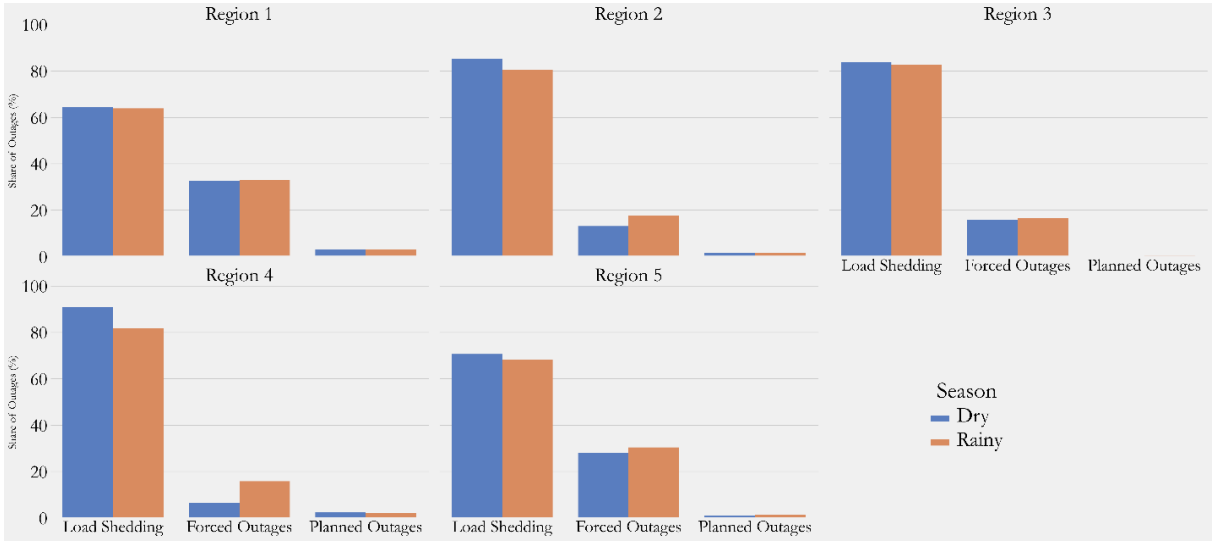


Figure 6-3: Seasonal Variation in the Share of Outage Types Across Regions

Beyond external triggers which often cause equipment failures, several experts directly attributed forced outages to the aged nature of the infrastructure itself—equipment that has long outlived its expected lifespan. As one expert said,

> "For example, circuit breakers—say 10,000 operations. There are breakers with more than twenty, twenty-two thousand operations, and their alerting mechanisms have failed. There are cases where the breaker explodes because you keep using the same breaker again and again, even after the insulation has already failed."

Another added, *"Most of these lines are inherited from NEPA…aluminum conductors have a lifespan, and some of these lines you're looking at are even older than me—over 60 years."*

Several respondents also emphasized that many external-effect-driven faults—such as those caused by vegetation or weather—are ultimately symptoms of a deeper issue: *"aged equipment and the vast network of overhead distribution lines."* As one expert put it, *"Forced outages are the major reason for the failures occasioned by old, dilapidated networks."* Another added, *"Most of our feeders are overhead bare aluminum conductors. So, any slight contact with an external object will ground the feeder, and it will trip."* A third put it plainly: *"Because we use overhead cabling for distribution, weather conditions are always affecting our electricity distribution."*

One utility official gave a vivid example involving feeders with frequent, short-duration outages:

> "Here, if you see such cases, it's either old port insulators—where anytime it rains, that spot has cracked—and that crack allows enough coronal discharge under wet, humid conditions to keep grounding. So, you have a higher percentage of those frequent outages attributed to earth fault. Funny enough, after maybe 30 minutes or one hour, with the linesmen doing nothing, the operators just try the feeder again and it stays on. Some people say, *'Oh, they're playing with the light.'* No. They're not. Even if they patrol from now till tomorrow, they won't see the crack."

These limitations led some experts to argue that even dramatic increases in generation would not solve the problem. *"Even if you start generating 50,000 MW today,"* one expert said, *"this infrastructure cannot cope with it."* Another agreed, emphasizing that even the current supply is not fully utilized:

> "It will surprise you to know that even when Nigeria generates 3,000 MW, and some is exported internationally, the rest—shared among discos—is not completely used. You have some DisCos allocated 500 MW; they end up consuming 300 or 200. Not because there are no customers, but because the network is weak, not able to pick. People are in darkness because the DisCos have weak network."

This weakness is not solely due to age, but also poor design. As one expert summarized, *"Aging and dilapidated infrastructure and poorly designed networks are the major causes of poor electricity supply in Nigeria. Most of the network is outdated. But even worse, it was badly designed."* Specific design flaws that were mentioned include the radial configuration of the grid, the excessive length of distribution lines, and substandard construction, alongside overhead cabling already discussed above. Echoing this, one respondent lamented, *"Our network is radial, not ring. The moment you lose any part of it, the entire network is gone"* Another simply stated: *"A radial system cannot give reliable supply."*

On the unusually long distances covered by some lines, one utility executive shared, *"In Nigeria, our network is too long – very long. You can see feeders as far as 20, 30 kilometers. It's not easy to manage that kind of feeder. You'll have a lot of interference."* Another described a more extreme case:

> "We have serious problems with tripping on 33kV, especially for non-Band A feeders—Bands B, C, D, E because some of them traverse almost 450, 468 kilometers. Ibadan to Lagos is about 130 kilometers. So that distance, and the network—which at one time or the other was substandardly constructed—create problems."

One respondent gave this example of how poor construction standards exacerbate these issues:

> "It starts with the way we design our network. The LT[84] lines back then had specific spacing and depth. You'll see lines constructed in the 1970s—when wind blows or there's a storm, those poles remain. But the ones constructed less than a decade ago—where the required depth is six feet, and you do just three feet—how won't it give way? It will. So, standards need to be really enforced."

In addition to faults caused by aging or poorly designed equipment—often exacerbated by vegetation, weather, and other external effects—several experts highlighted vandalism as a particularly damaging and increasingly common cause of forced outages. The excerpts below illustrate two especially striking examples:

> "We have two lines from Shiroro that feed Kaduna, and from Kaduna, power goes to Kano. When Shiroro feeds Kaduna, Kaduna then feeds Jos, and Jos feeds Gombe. There's another route, but on a good day, it's not even utilized—let's keep that aside.
>
> So, if anything happens and the generators in Shiroro trip, you'll instantly lose supply to Kaduna—and it cascades from there. Once I lose Shiroro, I lose Kaduna—especially if the

[84] LT (low-tension) lines refer to low-voltage distribution lines, typically operating at 230/415V

> backfeed from the eastern axis into Jos, which re-enters Kaduna, is in open position. That means at that moment, Kaduna has no supply.
>
> That's exactly what happened about six weeks or two months ago. In that case, it wasn't a generator trip—vandals brought down the Shiroro–Mando line. Both lines went down. So, we had no choice but to feed the entire Northwest through a very long route: from Ikot Ekpene through Ugwuaji in Enugu, then Makurdi, Lafia, Jos, Kaduna, and finally to Kano. By the time the power gets to Kano, it's *tintini* (very tiny) that the man gets. So, you can see, it's not one particular problem.[85]"

> "There's one state—Bayelsa—that's been in the dark for almost five months running. It started with two towers being vandalized and brought down. Then more materials were taken, and as I speak, 16 transmission towers have been affected. The vandals collapsed them all, and since then, the state has had no power supply.
>
> I'm emphasizing vandalism because we're talking about outages—an entire state is in outage just because of vandalism."

Some experts also pointed to equipment overloading as a common cause of forced outages. As one official explained, *"Whenever there are overloaded distribution lines or overloaded feeders, we have frequent tripping. And whenever there is tripping due to overcurrent, there will be power interruption."* Another put it more plainly: *"If the load actually being evacuated exceeds what the line can accommodate, obviously, there will be a trip."* Yet another utility expert shared, *"Some of our 11 kV feeders are overloaded. Although we set our protection schemes—our relays—to take the load and prevent overloading, sometimes, due to downstream faults, it still reflects as overcurrent or overload."* These comments suggest that even load shedding and protection schemes may be insufficient to prevent trips caused by overloading.

Importantly, this issue is not confined to the distribution level. Overloading—and in some cases, underloading—also occurs at the transmission level, contributing to grid instability and, at times, full or partial system collapses that plunge the entire country or significant portions into blackout. Some experts explained that such collapses can be triggered by the sudden loss of a major generating unit or critical transmission infrastructure, disrupting the delicate balance of the grid. As one expert noted, *"All the generating stations are interlinked through the National Control Center. So, if there's a sudden outage or failure of one of them, it can cause an imbalance in the grid—and it may go off."*

System collapse can also occur when Nigeria's load-shedding-based approach to frequency regulation fails, particularly during sharp mismatches between generation and load. As one expert explained,

> "If there's a frequency issue—whereby, fundamentally, we should be running at 50 hertz in Nigeria—and it fluctuates to the left or to the right[86], there will be a need to either pick load or drop load. Hence, forced outages would have to happen. Or you will now get to the point where you hear what you've heard a lot in the past few months: the grid has collapsed."

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[85] See [37] for the TCN's official map illustrating existing and ongoing 330kV transmission corridors, including the routes highlighted in this quote.

[86] The allowable threshold for frequency is between 49.75 and 50.25 Hertz

Furthermore, most experts emphasized that while individual failures may be significant on their own, they are often exacerbated by fundamental weaknesses in Nigeria's electricity grid architecture—most notably, the absence of adequate protection schemes, equipment redundancy, spinning reserves, and a fully operational supervisory control and data acquisition (SCADA) system. As one respondent explained, *"We don't also have N-1. That's the reliability... Most of the time, even in the distribution network, we have mostly one transformer—either one or two. There is nothing like N-1."*

Another expert underscored the lack of grid-wide visibility:

> "Our grid is not yet fully on SCADA, so there are gaps in control. Sometimes, overload—because of the load being drawn compared to what is available—contributes to interruption. A certain portion of the country may be allocated so-so load, but at the end of the day, they're drawing more than that. And because SCADA is not there—the overview is not there—that brings imbalance. The frequency will go down, and that's how we have interruptions."

Providing greater context, a TCN official reflected on the systemic implications:

> "Electricity, largely, cannot be stored. So, what that means is that whatever you generate at time *t* must be utilized at time *t*. As you are generating, somebody must utilize it. So in trying to maintain that balance between generation and load, there are a lot of problems...it's complicated, it's challenging, and it's breathtaking because '*the man*'—when I say '*the man',* I'm not talking about one man—the man who manages the entire system to ensure balance is doing it manually.
>
> There's a difference between managing the grid manually and doing it in an automated environment. You can't compare the outcome—totally different. So now, do you expect the outcome of an automated system from a manually controlled grid? No—it's not possible.
>
> And now with the number of transmission line trippings we're having—it's highly unacceptable—it makes the job of the system operator extremely difficult. That's why somebody said, *'It's difficult to pass through NCC and not develop high blood pressure.'"*

A different expert summed up the risks of this human-reliant approach more bluntly: *"You know, as human beings monitoring, there can be lapses. They can still make mistakes—or maybe they're unable to handle it well at that very time – and the thing may get out of hand."*

In explaining system collapses and forced outages more broadly, many experts emphasized how difficult it is to disentangle the multiple, overlapping causes involved. They often underscored the idea that outages in Nigeria rarely stem from a single, identifiable problem. As one expert explained, *"The efficiency of the protection has to do with the distance. You know, I told you before that most of our feeders are lengthy. So sometimes, it affects the reliability of our protection systems."* Consequently, while outages are administratively assigned a single Level 1 cause, the actual circumstances typically reflect a web of interrelated technical, infrastructural, and operational weaknesses.

Reflecting this complexity, one technical officer lamented,

> "11:30 this morning, we had this system collapse again...And it's very sad because I was in Abuja two weeks ago for a public hearing by NERC on system disturbance.

> It will amaze you to see that a single electrical item—a CT, current transformer—shattered at the 330 kV transmission station level and grounded the entire country. That should have been very isolated. There should be a circuitry that just takes it out, and your system stays balanced within microseconds. But we are not yet there.
>
> Also, that transformer was 47 years old—well beyond its lifecycle—and it should have been replaced. There are pockets of them waiting to go off at any time."

Likely referring to the same incident, another respondent complained,

> "We are in a season of transmission lines tripping madly. In the last few months, during a series of collapses, we lost a lot of lines.
>
> The tripping just doesn't make sense. Sometimes, if you don't do proper protection coordination, you get what we call cascaded tripping—which is unnecessary, but it happens when something is wrong somewhere.
>
> Sometimes you have explosions. And you ask: why is your equipment exploding? Have you tested it? Maintained it? What kind of maintenance did you do on this critical substation equipment?"

Across the country, such events may be logged as 'GENSC' (general system collapse) or 'TCNFO' (TCN forced outage), but their underlying causes often lie in aged infrastructure, poor protection coordination, substandard equipment, and inadequate maintenance. In some cases, they are further compounded by—or stem from—the convergence of vandalism, financial constraints, or distribution-level faults triggered by weather or other external effects. The following accounts illustrate this interconnection:

> "There is this daily effort to balance generation with consumption. That balance is achieved when the frequency—that's the speed of the machines, measured in hertz—is at 50. If it goes below, that is, if the machine slows down, that means overloading—you're drawing too much from the grid. What we do is load shedding. They'll say, *'please drop like 10 MW'*. We quickly look for feeders that can give us that and drop them to stabilize the system. But ideally, there should be equipment to handle that—introduce more machines instead of knocking off supply. We don't have that.
>
> Then if the machine speeds up too much, we're told to pick load. But if I'm already at full load or 80% of my feeders are out on fault, maybe because of heavy rainfall—how do I pick load? When I fail to pick, I'm blamed for taking the grid out of synchronism."

> "There was vandalism in the Northwest. Since then, generation available for DisCos in other regions has increased, so our allocation shot up. One thing is having excess allocation; another is being able to utilize it. If I'm allocated 600 MW and can only consume 350 or 400, that's a loss of 200+ MW—and we still have to pay. In this commercial era, you can't just force supply on customers who won't pay.
>
> Meanwhile, many feeders are on fault—some in areas our people can't access due to insurgency. So, you can't even pick load if you wanted to.

> If I'm a business manager and get 200 MW allocation when I can only do 120, my billing efficiency drops. That gap has to be covered somehow. It's only when you have maximum demand customers who pay well that you can balance it.
>
> It's not easy—the business is somehow.[87]"

This entanglement of challenges not only contributes to the occurrence of outages but also shapes how they are resolved. A transmission expert illustrated this with a vivid account of how grid restoration unfolds slowly in the absence of full system visibility or redundancy:

> There was a time we lost the grid, and during restoration, they had to blackstart the system—which usually starts from the South. There are contracts with generators like Azura and Transcorp for that, but on this day, Transcorp wasn't available, so it was Azura that came up.
>
> Because there was no supply, the system operator at NCC in Osogbo couldn't see the system frequency—the light was off. So, as usual, they told Azura to start with a small generator, just enough to begin energizing the system. That power was sent to Ihovbor, which is nearby in Benin.
>
> All this while, the operator couldn't see anything. So, he's just using his phone: *'Azura, what's the frequency now?'* Because Azura has supply now, it's Azura that's telling him what the frequency is.
>
> Once the power got to Ihovbor, they had a choice: from Ihovbor, there's a line to either Osogbo or Benin. Of course, they want to go to Osogbo, so the NCC can finally see—it's not about light for comfort at that point, *hmm hmm (no)*, it's *'I want to see what I'm controlling.'*
>
> But on this day, the Ihovbor–Osogbo line wasn't available. You can see the complication—that's the system reliability, or the lack of it, that we're talking about: reliability, flexibility, all of that.
>
> So the operator didn't have a choice—they had to go through Benin, then to Lagos, from Lagos to Ikeja West, Ikeja West to Omotosho, and somehow from there, it was able to get back to Osogbo. Instead of going straight, it had to do *merry-go-round* before getting to the control center.
>
> And throughout, the operator was just using his phone: *'Hello, what's the frequency there? Okay, Ihovbor, increase the generation again for me, abeg (please). Okay, give me 20. You – oya (come on), pick load there."*

Similarly, at the distribution level, the multitude of outage causes—compounded by gaps such as the absence of SCADA systems—means that faults often have to be located manually. This typically requires utility staff to patrol the lines physically in order to identify and resolve the issue. Given the lengthy nature of many feeders, this process is often impractical or highly time-consuming. As one expert shared,

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[87] *"The business is somehow"* is a colloquial Nigerian expression that conveys that the system or situation is problematic, complicated, or not functioning as it should.

> "I have a 33kV feeder line, almost 500 kilometers in route length—or more. Another feeder is almost 600 kilometers. Whenever there's a fault, we start tracing. And with the limited resources we have, we need to segment it. Sometimes, before you restore it fully, it takes time."

Due to this, some operators opt to skip line tracing and simply attempt to bring the line back up. Another interviewee described this process:

> "It can be a forced outage and after like 30 seconds, the operator will just say, *'Let me retry.'* He'll retry and it will stay. Or he'll just say, *'Oh, it was raining at the time. The rain has stopped. Let me try it for them again.'"*

As noted in an earlier quote about cracked insulators and coronal discharge, even when patrols are conducted, the underlying fault may remain undetectable. As the expert said, *"Even if they patrol from now till tomorrow, they won't see it."* Frustrated by this pattern, another expert added, *"Whenever we have outages, it's just firefighting— attend somehow, restore. And sometimes, the restoration takes days."*

In light of these recurring and compounding challenges, one expert captured the overall sentiment shared across many interviews: *"It's a complicated system. It's not a straight-line graph—at least not in Nigeria"*

Planned Outages

Planned outages represent the smallest share of recorded events in the dataset—barely 2% of all outages. Interviews suggest that these outages are typically scheduled for one of three main reasons: routine testing or data collection, preventive maintenance to avoid future breakdowns, or as a follow-up to forced outages.

For instance, a planned outage might be used to support technical checks like insulation profiling. As one expert explained,

> "Let's say, for example, the person requesting the planned outage is a protection man. He's trying to do insulation profiling of a particular power transformer—measuring the insulation monthly to monitor its performance over time. That shouldn't take long. The outage might last twenty minutes at most: put off the feeder, discharge it, climb up, plug your insulation resistance tester, take the IR, DAR, PI[88], record the values, and come down then restore. In that case, the people will say, *'They're playing with the light. Just put it off now, then on it now.*'"

Planned outages are also used to prevent *"impending doom"* by addressing equipment or line conditions before full failure occurs. These efforts may involve replacing wooden crossarms or cracked insulators, reconductoring sections of lines or busbars, servicing circuit breakers (oiling, greasing, inspecting moving parts), recalibrating relays, or fixing sagging lines and corroded connectors. As one expert summarized, they allow utilities to repair *"something that is in service that has not entirely collapsed."*

In other cases, a planned outage is initiated to support the safe resolution of a recent forced outage. As another utility official described,

[88] IR (Insulation Resistance), DAR (Dielectric Absorption Ratio), and PI (Polarization Index) are standard diagnostic metrics used to assess the condition of transformer insulation. They help detect issues like moisture, aging, or contamination, with higher values generally indicating better insulation health [38].

> "For example, maybe wind blew some vegetation onto the line. It trips and the relay shows earth fault. Most times, they don't like restoring earth faults right away. So, they'll say, *'Trace your line.'* It might take a while. They might try the feeder, and it comes back on. Still, they'll say, *'Go and find out what happened.'* That's a planned outage too. Even though it was a forced outage that lasted seconds, they now have to plan, so it doesn't happen again.
>
> Normally, if the procedure is tailored toward safety, every place you see FO [forced outage] must be followed by PO [planned outage]. If you don't see PO after an FO, it might mean the linesman didn't go, or he went without taking PO."

Interestingly, only about 3% of recorded utility-attributed forced outages ('EDCFO') were followed by a planned outage ('EDCPO'), suggesting either a failure to follow standard safety procedures or inconsistencies in how these events are documented.

Safety protocols also explain why some feeders are taken offline when nearby lines undergo maintenance. One expert noted, *"In some areas, the same tower carries two lines—side by side. So, for safe working space, if one line is out, the second line is taken out too."*

Despite these use cases, the relatively small number of planned outages is partly due to how they are scheduled. Since utilities control their timing, they are often slotted into periods of load shedding, thereby avoiding additional customer disruptions. One utility executive made this clear: *"When there's a generation shortfall, you have more time to do maintenance without interrupting supply. You use the load shedding period to carry out the planned maintenance."*

More critically, several experts highlighted that planned outages are often de-prioritized due to commercial pressures, especially revenue collection concerns and compliance with tariff band service levels. As one official explained, *"When TCN requests a planned outage for a 33 kV line that will take four or five hours, the DisCo may refuse. They'll say, 'This will affect our revenue.' So they won't give their consent."* Offering further context, a different expert described how forced outages and compliance obligations could delay maintenance:

> "To meet Band A compliance, for example for 25 days, we need to clock 500 hours—20 hours of supply daily for 25 days. But by the time we're approaching the 25th day, we may already have lost some hours to TCN and to our own forced outages. If we now go ahead with planned maintenance, we risk falling short. Dropping from Band A to Band B is a colossal loss for any DisCo—we can't afford that. So, at times, we just don't get the opportunity to carry out planned maintenance on Band A feeders. Unfortunately, that means it sometimes turns into breakdown maintenance instead."

Nonetheless, some utilities try to schedule planned outages on weekends or during the dry season to avoid peak demand periods and minimize overlap with the rainy season, which tends to increase fault frequency and delay repairs.

Importantly, a few experts suggested that—even at just 2%—the number of planned outages may still be too high, given the level of vulnerability it reflects. As one expert put it, *"The reason why we see planned outages happening every now and then is due to the vulnerability of the network. Under normal circumstances, a network will be firm enough and require far fewer outages."*

Level 4, 5 & 6 Causes

As noted earlier, outages in Nigeria are broadly categorized into three administrative types: load shedding, forced outages, and planned outages. While these Level 1 categories provide a useful starting point, the interviews revealed that they are driven by a host of interacting challenges that go beyond immediate causes.

For example, as discussed in the preceding section, load shedding is often necessitated by limitations in generation, transmission, and distribution capacity, as well as the commercial viability of connected customers. Forced outages stem from unexpected faults and failures—caused by vegetation, weather, animals, or vandalism at Level 2—but are also deeply linked to Level 3 drivers such as aging or substandard infrastructure, the grid's radial configuration, long and exposed lines, and the absence of critical systems like SCADA or protection equipment. Planned outages, though far less common, are often required for routine operations like data collection or maintenance—yet, their frequency still reflects the underlying fragility of the network.

These insights on Levels 1 through 3 align with the work of several scholars, while offering grounded illustrations from the field [4-5, 7, 9-12, 14, 17, 23-29]. However, most experts did not stop at technical or operational causes. Instead, they consistently pointed to systemic failures cutting across financial, policy, political, behavioral, and sociocultural domains—what this chapter refers to as Level 4 and Level 5 causes.

One transmission expert, for instance, began with a technical observation about the use of unplanned load shedding to maintain system stability but quickly shifted to broader concerns about GenCo incentives, sector financing, and collective decision-making:

> "Apart from the planned load shedding, we also have the unplanned. Unplanned in the sense that, for example, if I just observe that my frequency begins to nosedive, we have put in place an operating mechanism that will naturally throw out some load to safeguard the system.
>
> However, that should not be, in a sane environment, the first line of defense. But we're using it that way here because the actual first and second lines of defense are not available. The first line is supposed to be provided by the generators, something called free governor mode. But people say, *'Ah, your frequency is dancing? I won't put my generator on that mode—it'll pafuka (spoil). I don't want wahala (problems).'* Others will say they don't have enough gas. The second line is the spinning reserve. It's not free—ancillary services must be paid for. Even if we procure it now, the market may not sustain it.
>
> So where do we go from here? Someone once said, *'Why are you talking about spinning reserve when you don't even have enough generation?'* I said it's a matter of choice. Do you want quantity or quality? The choice is ours as Nigerians. But then and again, somebody has to pay for it"

Another expert, when explaining forced outages, began with infrastructure failures but moved through social, financial, and political bottlenecks before concluding that the unreliability problem is endemic:

> "The problem with power in Nigeria—and most African countries—is that the infrastructure is nearing end-of-life. We have transformers installed in the 1930s and

> 1940s—some over 80 years old, twice their expected lifecycle. We call them *'German mistake'*—because those early German products had such high-quality assurance, they outlasted expectations. So they're still in use. They're not maintained. Nothing is done to them. Everyone is just waiting for the moment they'll stop working. And it's at that point we'll start looking for a replacement. There's no specific fund set aside for them. No money in the bank. Even when you find a way to grab the money from somewhere else—make contributions, move politicians to get it for you—there's still a lot of bureaucracy that slows everything down. So, when it fails, the delay index—SAIDI—worsens. It wasn't planned for, and now there's no clear path to replacement. Basically, it's an endemic problem."

In yet another example, an expert describing transformer-level load shedding traced the issue from technical overloads to broader social and governance failures:

> "On our network, when we know that a particular substation is already overloaded, we carry out load shedding—maybe for a community, we remove the fuse to reduce the load on the transformer.
>
> You know this area, we're still growing. Maybe we have this setup now, then three months later, an industry springs up and connects to the network.
>
> Don't even talk about industry—let's talk residential. Maybe the government builds housing. People come. One individual takes light today, hooks on to supply. Next time, another person joins. And so, it keeps increasing.
>
> If it were something controlled—centralized—we could say it's easy to monitor. But no. Especially in Nigeria, there are so many illegal connections that aren't even on our records. If it were in another country, before anybody hooks up to the grid, government must give approval. Then you can monitor and prepare for the load."

As these examples demonstrate, diagnosing electricity unreliability in Nigeria extends well beyond technical assessments. Two cross-cutting issues surfaced repeatedly in the interviews: (1) inadequate and misaligned investment, and (2) ineffective policies. The following subsections explore these themes in greater depth and introduce their underlying root causes – referred to here as Level 6 causes – such as economic hardship and a sense of entitlement.

Inadequate and Misaligned Investments

Experts widely agreed that Nigeria's electricity sector suffers from chronic underinvestment—and where investments do occur, they are often misdirected. One expert simply said, *"The investment is the issue."*

As detailed in Chapter 3, Nigeria's electricity system transitioned from centralized control under the National Electric Power Authority (NEPA) to a largely privatized structure with separate GenCos and DisCos[89]. However, interviewees described longstanding investment failures in across public and private actors—driven by neglect, misplaced priorities, and distorted incentives

[89] While the Federal Government of Nigeria retained partial ownership stakes in some thermal power plants, the hydropower plants were placed under long-term concession agreements [39]. Additionally, the FGN retained a 40% ownership stake in all 11 DISCOs, while TCN remained fully state-owned [40].

As one utility official recalled:

> "It's that investment…I remember when this privatization came up. The first policy was to rehabilitate and revive the network before handing it over to private investors. At the time, funds were earmarked. We were asked to submit all the bottlenecks in our distribution subsector—everything. But at the end of the day, it wasn't done well. That's why we're here.
>
> Then we thought investors would invest once they came in, but again, here we are. And you know, it's not just the investors—there were gray areas in how the government privatized the sector.
>
> In the end, not everybody did—or is doing—what they were supposed to do."

Another expert echoed this view, emphasizing the persistent infrastructure gaps:

> "Neglect. There's been massive neglect of the network. Misplaced priorities. The people who bought into the DisCos had the wrong intentions. They bought at a subsidized rate and just wanted to start making profit. But before you do that, you need to invest.
>
> Even now, since the NEPA days, we've been talking about the metering gap—up till now, we're still talking about it. That's a very terrible thing."

Misdirected investments were also a recurring concern. As one expert explained,

> "I think transmission is where the most money has gone, but it's not coordinated. This isn't a problem you solve by just throwing money at it—you have to be strategic. Transmission is a superhighway. Imagine a highway from Abuja to Kano, with Zaria and other cities along the way. The connection to each node is only as strong as the trunk line. Tranmission for the DisCos is that trunk line. Unfortunately, for years, transmission investment has lacked coordination. So we've seen lots of expensive projects that don't actually add capacity. My village can get a 60 MVA transformer—but it's not going to be of any use because there's no load there. TCN has had money to invest but because it's government money, they haven't made the right investments."

Another transmission official shared a personal account of this misalignment:

> "In the past, power sector investments just weren't aligned. I remember attending a function and meeting someone from a government agency. I said, *'Una no try at all (you have not done well at all). The substations you build are substandard.'*
>
> He said, *'Come to [location removed][90], if you see our substation!'*
>
> I asked, *'You built a substation there?'* He said yes.
>
> I asked, *'Built or building?'*
>
> He said it was already built.

[90] Specific location omitted to preserve the anonymity of the interviewee, and the government agency referenced.

> I said, *'Do you know that's a colossal waste? What load do you even have there for a 330kV substation?'*
>
> He admitted, *'You're right. It's been completed for five years and nothing is happening. They can't even connect it.'*
>
> A 330kV substation *no be groundnut o (is not groundnut—meaning it's not a small or cheap thing)* – but they've built it. Until we start coordinating and aligning these projects, we'll keep wasting resources."

Beyond capital investment, several experts underscored the lack of operational expenditure (OPEX)—especially for upgrades, routine maintenance, and reliability improvements. One utility manager remarked,

> "If you don't have CAPEX, you should increase OPEX to replace old equipment and conductors. You don't need a massive project to improve reliability. You can segment the feeder, identify weak spots, reconductor specific areas, and improve tripping performance. That's achievable through operational initiatives. But in our DisCo, OPEX is sometimes just 2%, 3%—less than 5%."

Another DisCo executive added,

> "The problem is poor investment in expansion, maintenance, and operations. Operations matter a lot—faults must be cleared quickly. Engineering has all the performance indices: mean time to restoration, mean time between failure, SAIDI, CAIFI[91]. But no DisCo in Nigeria can say confidently that they're meeting these indices."

This underinvestment also extends to capacity building and digital systems:

> "There's not much going into technology upgrades. Other countries have digitized their systems. But we don't have even basic IT enablement and ERP[92] tools. Fast-moving materials should be tracked—so when there's an outage, you immediately replace parts and restore supply. But that's not happening at TCN or in the DisCos."

Across interviews, the dominant explanation for the sector's investment shortfall was the *"lack of sound market fundamentals"*—specifically, non–cost-reflective tariffs and perennial low revenue collection rates. As discussed earlier in the section on load shedding, these financial constraints shape how DisCos prioritize which feeders receive supply. However, beyond individual feeder decisions, the systemic inability to recover costs has led to chronically low investment rates across the value chain. Describing this, one expert shared, *"It's a value chain. One part pays for the other. But today, consumers can't pay the DisCos, the DisCos can't pay Transmission, and Transmission can't pay Generation."*

Another respondent framed it this way:

> "The people that have money, the only thing they like more than money they have now is money they can make later. So you have to give an incentive for them to invest.

[91] CAIFI – Customer Average Interruption Frequency Index
[92] ERP – Enterprise Resource Planning

> But look at the GenCos – they're owed tons of money so it's difficult for anybody to go and invest.
>
> If I was a strategy officer for any of the GenCos, I won't invest anything because there's nothing in today's market to show you'll get your money back.
>
> That's why the sector is stagnant. The barriers are mostly commercial, not technical. The market fundamentals just aren't there."

Lack of cost reflective tariffs

One expert described the current pricing structure as *"golden handcuffs"* worn by DisCos, then explained the situation:

> "Let's take it from the EPSRA[93] in 2005, when decentralization happened—from NEPA to the 6 GenCos and 11 DisCos. It was almost like franchising the country. That act created NERC, the regulator, which was supposed to oversee an industry where electrons flow one way, and money flows the other.
>
> The idea was that NEPA had failed due to lack of infrastructure investment. Privatization was meant to bring in the private sector to drive progress. But when decentralization happened, the government didn't inject new investment—it took money out. It earned from the sale of DisCos and GenCos, but the plan to reinvest in metering and infrastructure didn't materialize.
>
> Where were the DisCos supposed to get money to invest? Two places: from customers, via the MYTO tariff, and from government covering the shortfall between the actual cost and what customers are allowed to pay. The MYTO tariff isn't cost-reflective. And that government top-up? They're not even paying up to 50% of it. So, the DisCos can't invest. They can't expand their base or earn sustainably.
>
> What does that mean? It means we now have an industry that is frozen."

This lack of cost recovery also constrains DisCos from leveraging available regulatory provisions that allow for embedded generation or contracting additional capacity outside the national grid. These alternatives, if widely adopted, could help address transmission-level outages and reduce the volume of load shedding due to generation shortfalls. However, as another expert put it,

> "You can't just set up embedded generation and be wheeling it to Band D and E customers who can't even cover your costs. The cost of buying electricity from the grid is already higher than what Band B pays. Only Band A offers any real margin. So, if a DisCo doesn't have Band A customers, they're not even in the business."

As Table 6.1 shows, across all eleven DisCos, the weighted average allowed tariffs fall short of cost-reflective levels. The DisCo with the highest level of cost-reflectivity, Eko Electricity Distribution Plc (EKEDP), is allowed to recover just 62% of its weighted average cost-reflective tariff. Figure 6-4 further illustrates this for Jos Electricity Distribution Plc (JED), which has the highest Aggregate

[93] EPSRA – Electric Power Sector Reform Act

Technical, Commercial and Collection (ATC&C) loss target. Only Band A customers are charged more than the ₦122.7/kWh generation plus transmission and administrative cost reported in the February 2025 MYTO review [35].

Table – 2: Approved Allowed Tariffs (₦/kWh) for JED

Tariff Class	Apr 2024	May - Jun 2024	Jul 2024 – Feb 2025
Life-line	4.00	4.00	4.00
A – Non-MD	225.00	206.80	209.50
A – MD1	225.00	206.80	209.50
A – MD2	225.00	206.80	209.50
B – Non-MD	63.26	63.26	63.26
B – MD1	68.02	68.02	68.02
B – MD2	71.97	71.97	71.97
C – Non-MD	52.83	52.83	52.83
C – MD1	58.01	58.01	58.01
C – MD2	59.45	59.45	59.45
D – Non-MD	40.12	40.12	40.12
D – MD1	54.24	54.24	54.24
D - MD2	54.24	54.24	54.24
E – Non-MD	39.90	39.90	39.90
E – MD1	52.95	52.95	52.95
E – MD2	54.24	54.24	54.24

Figure 6-4: Allowed Tariffs (₦/kWh) for JED by Band and Period [35]

Low revenue collection rates

The assertion that "the people don't pay" was the most commonly cited reason for low investment in the sector. As one utility official noted,

> "We have PIPs (Performance Improvement Plans) submitted to NERC. TCN also submitted. But they are not translating—no investors are coming in, no funds are flowing. Investors don't have confidence. Why? Because with CapEx-related issues, it's *'If I invest, will I get my money back?'* And it's not sure. Because people don't pay."

Another expert emphasized the point more bluntly:

> "Money runs business. So, yes, people say there's no light. But if enough money was coming in from customers, we could even find alternative supply. But what do you do when even what you have, you give it out and your ATC&C loss comes back as 50%—even 60% in some areas? Even if they give you power to distribute, you won't give it."

On the OPEX side, a DisCo executive explained that poor revenue collection affects routine maintenance and fault management: *"We need to clean up our lines. Most of our lines are in a big mess but OPEX is tied to performance—to collection. We've been getting 50% when we need 100%."* Another respondent added, *"Ordinarily, all my feeders should be healthy. But because of finance, I can't buy poles, wires, or even get a loan. Where will the money come from? From the customers—who consume but don't pay."*

Across the interviews, this challenge was attributed to several factors: inefficiencies in the collection process—such as limited metering infrastructure and a reliance on estimated billing; widespread

affordability constraints; and what many experts described as an *"entitlement mentality"* that treats electricity as a free public good.

On collection inefficiencies, a non-utility expert suggested,

> "DisCos face significant commercial losses arising from lack of meters. If you don't know where energy is going, you can't bill it. And even those you bill don't always pay…With no customer enumeration or metering, it's impossible to hit the ATC&C targets, generous as they may be"

Indeed, as shown in Figure 6-5 below, across Nigeria's DisCos, the percentage of metered customers ranges from as low as 16% to only 77%.

A DisCo official echoed this concern:

> "I don't know about other discos, but for us, over 60% of our customers are on estimated billing. And that comes with its own challenge—customers just pay whatever they like. Sometimes, it's less than 10% of the amount we bill. It's only with the metered customers that we see some recovery prospects."

Another utility official supported this claim, but introduced additional complexity that challenges a simple reading of collection losses as a metering problem:

> "Electricity is the only fuel Nigerians can access before payment. It's not that it's necessarily cheaper—it's just the only one they can use without paying upfront. And they agree. They'll use it. But when you eventually bring the bill—because we don't have meters to cover everyone—they pay whatever they feel like."

While this highlights how metering deficits affect billing accuracy, it also points to two deeper dynamics: affordability constraints and an underlying tendency to underpay—or avoid paying altogether.

Similarly, a different respondent—while advocating for broader metering—cautioned that even with meters, some Nigerians go to great lengths to avoid paying:

> "Now NERC is saying nobody should be below Band C. We're expected to supply them and recover revenue—how can we do this? By metering them in a way that they can't bypass. But this is Nigeria—you'll find people opening meters, tampering deep inside, resealing, and reinstalling. From the outside, it looks fine. But collection losses just keep growing. You can't stay afloat like that."

Another DisCo manager underscored this inevitability of bypassing: *"When you have an area that is metered, you can get your revenue. Even if it's not 100%, then you can get 80%—because you can't avoid bypass."*

Several experts emphasized that non-payment—and, in some cases, electricity theft—was often driven by affordability constraints. Reflecting on Band A residential customers, one interviewee explained,

> "Basically, they are privileged people. If you bill them ₦50,000 a month—less than $50—they pay without thinking. Many have homes abroad and know what power costs. For them, electricity is just 0.5% of their income, so they have no incentive to steal. With little effort, you get your money. That's why DisCos like Eko, Ikeja, and Abuja perform better—

> they serve high-income areas. Unlike places like Katsina or Kaduna, where it takes four times the effort to recover revenue."

A similar sentiment emerged in one expert's critique of the federal metering rollout:

> "The government got it wrong. When they started their metering program, they began with Band A customers—that was a massive misjudgment. They should have started from Band E and then climbed gradually to Band A.
>
> Energy theft is far more common in the lower bands. Most Band A customers—especially industries—are already properly metered, often at the transformer point, which makes monitoring easier. But on public feeders with high losses, that's where we needed to start."

This perspective—that poverty lies at the root of non-payment and theft—aligns with the broader historical pattern in Nigeria, and in many other SSA countries, of subsidizing electricity and regulating utilities to charge below cost-reflective levels [29].

Some respondents went further, linking economic hardship not only to widespread bill avoidance but also to dangerous behaviors like vandalism. According to one utility executive, *"It's not just about a desire to be a vandal. Sometimes, they get fatal shocks during vandalization—some people lose their lives. I've seen many cases like that. It's because of acute poverty."*

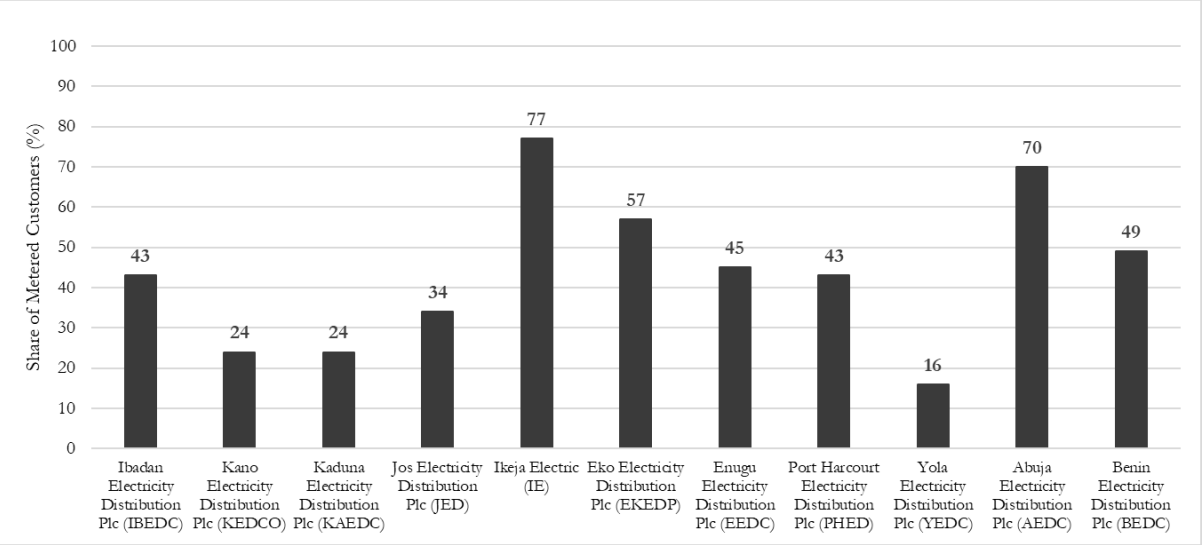


Figure 6-5: Share of Metered Customers Across the Different Electricity Distribution Companies (DisCos) [41].

On the other hand, a number of experts challenged the idea that non-payment is purely rooted in poverty, pointing to cases where lower-income communities pay higher tariffs in off-grid systems. As one development expert explained,

> "If you go with that argument [about poverty], I worry—seriously worry—about the fact that someone in a rural area with maybe a tenth of the earning capacity is paying three times more than someone on Band A in the urban grid. That's very worrying. I know the energy sources are different, but still...our electricity is cheap. Knowing how the market works—even with losses from generation all the way down—our electricity is still cheap."

According to the Multi-Tier Framework for household electricity supply, electricity is considered affordable if it costs less than 5% of household income for a standard consumption bundle—365 kWh/year [42]. At Nigeria's ₦70,000 monthly minimum wage, only Band A tariffs exceed this threshold (9%). For Band B, the cost is below 3%, assuming a household with one minimum-wage earner. Still, as one expert cautioned, *"I think we overly underestimate how poor we are as a country."*

While affordability remains a real constraint, many respondents emphasized the second dynamic that complicates payment behavior—a widespread *"entitlement mentality."* As one utility official remarked,

> "You'll see a community where the facility is there, but they don't pay. Maybe because living standards are really poor...[but] another thing happening is this entitlement mentality. People see light as a fundamental human right—something they shouldn't have to pay for."

Another respondent echoed this, distinguishing between ability and willingness to pay:

> "If you supply a customer who cannot pay, they will still take the supply. Some customers can't pay—but the nature of our customers, some just won't pay. Some of them, it's not that they cannot even pay, they are just not willing to pay"

This sentiment was reinforced by several interviewees who described a deep-seated perception of electricity as a public good, owed by the government. One DisCo manager shared, *"We have communities that say, 'This is our land—we don't have to pay for light. It's our right. Light needs to be given to us free'"* Another added:

> "Customers are cheating us because many of them still believe electricity is something they should get for free. In some areas, you'll see supply, but people aren't paying—without realizing that DisCos actually have to buy that electricity. Light is not free.
>
> Some even see it as their inheritance—something they're entitled to enjoy. In some rural areas, you'll find people disconnecting the supply during the day and restoring it at night, just to avoid being billed. Others simply bypass the system.
>
> These are the kinds of things we're dealing with. The Nigerian mentality is that electricity is free—that's the real problem."

This view—of electricity as a right rather than a service—aligns with arguments made by Burgess *et al.* [12] and echoes the symbolic logic of infrastructure discussed in Chapter 3—where state-provided utilities are perceived less as market-based services and more as entitlements tied to citizenship and belonging.

One respondent explained:

> "Historically, power in Nigeria didn't start as something people were encouraged to pay for. Power was a free resource. So, Nigerians, generally, don't understand the concept of paying for power.
>
> Of course, in more urban or peri-urban areas, it's fairly understood. But still, for most people, power is almost like water—they see it as something that should be free. They wonder, *'Why should I have to pay for this? It's the job of the government to ensure that I get power. And even if I have to pay for it, it should be minimal.'*

> When you start historically from something that was free, then move to something subsidized—trying to make that final shift to cost-reflective tariffs, where people have to pay fully—that's a big challenge."

While DisCos are now largely privatized, several non-utility experts emphasized that this transition may have been lost on much of the Nigerian populace. As one development consultant explained, contrasting off-grid mini-grid developers with the DisCos:

> "Yes, mini-grids face some tampering—but nothing like the DisCos. The DisCos are still seen as government. Government built them. Government was the initial seller of energy, and the privatized DisCos haven't done enough to change that perception.
>
> So customers feel that same entitlement toward the DisCos as they do toward government—but it's less so with private mini-grid developers.
>
> Of course, you'll hear of someone trying to bypass a meter in a rural mini-grid. But the systems are there to flag that kind of thing pretty quickly.
>
> Yes—Nigerians will try their luck. Right? But they understand they have to pay."

However, this lingering public perception continues to strain DisCo operations. As one utility official lamented—emphasizing the shift from government-led to privatized management:

> "It's not like the era of the government of Nigeria running the power sector, where whether people paid or not, workers were paid and the government continued using other resources to augment.
>
> Now, if you don't have money, you can't do projects. You can't pay your staff. You can't buy equipment or vehicles. You can't pay contractors, pensions, HMOs, rent. You can't pay NBET[94] and the market operator too."

In some cases, unwillingness to pay may also serve as a form of protest—a symbolic act of resistance against poor electricity service [3]. Whether rooted in dissatisfaction, entitlement, or economic hardship, the outcome is the same: DisCos are trapped between mounting obligations and limited revenue, making them unattractive to investors.

Finally, several experts pointed to broader macroeconomic instability as a compounding factor. As one explained:

> "It's not just the sector—it's Nigeria as a whole. The naira keeps falling. You bring in capital at ₦800 to a dollar, and now it's ₦1,700, and you're collecting revenue in naira. So, the economy itself has not helped investment at all"

[94] NBET – Nigerian Bulk Electricity Trading Plc.

Ineffective policies

Ineffective policies were another underlying cause of electricity unreliability highlighted by experts, with the lack of cost-reflective tariffs frequently cited as a particularly glaring example. As one utility official vented,

> "There's no common sense in the regulation we're having—even to a layman. How can you expect me to invest billions of naira and then tell me what price I must sell at?
>
> If you're truly a regulator working in the public's best interest, come to the table. Check my books. Look at the investments I've made. I took loans—I have to service them. I have to set aside funds for when equipment reaches end-of-life. It's not a charity.
>
> You don't just sit somewhere and arbitrarily say, *'sell at 80.'* That's why the real business moguls didn't buy DisCos. Dangote[95] didn't touch one—because he saw the landscape. And now they're trying the same thing with him on fuel pricing—saying, *'sell at ₦500.'* He said no, he'd rather buy crude from the U.S. and sell in Ghana than sell at a loss in Nigeria.
>
> We're buying electricity at ₦110 per unit on average and being mandated to sell to some customers at ₦80—because of their economic power. If that's the case, then government should sell us that portion of energy at ₦70 so we can serve those people. Subsidize it, pay for them. Whatever it is, we don't care. It's a private firm. But they are mandating us to give them at 80.
>
> If you know what your population consumes monthly, sell us that quota at a lower rate. We'll add our O&M costs and push it out. That's what a real subsidy should look like. So they know, the regulatory body—NERC—knows what band B,C,D,E would consume, sum it together, sell that quota of energy to us at a lower rate. So we can serve them at a lower rate."

Several experts also raised concerns about Nigeria's Eligible Customer Regulations, first issued in 2017, which allow large power users to bypass DisCos and the Nigerian Bulk Electricity Trading (NBET) company by contracting directly with GenCos and independent power producers (IPPs). Under this policy, electricity consumers must meet a minimum consumption threshold—initially 2MWh/h in 2017 and later adjusted to 6–20MWh/h over a 90-day period in 2024 [44-45].

According to one DisCo official, this regulation has created confusion and competition between DisCos and the TCN:

> "Ordinarily, TCN should wheel power to the DisCos for distribution. But with this eligibility window, it's like TCN is becoming another DisCo. Some customers we could serve on 33kV lines—and they will be stable—tend to go for this eligibility on 132kV and at the end of the day, they are not taking the supply on 132. They would still be on 33kV. The policy is hurting DisCos. It's posing a kind of existential threat to some of us because

[95] Aliko Dangote is Africa's richest person, with an estimated net worth of $28 billion as of early 2025. He is the founder and CEO of the Dangote Group, a Nigerian multinational conglomerate with interests in cement, sugar, salt, and oil refining, among others. In May 2023, Dangote commissioned the Dangote Petroleum Refinery, a $20 billion facility located in Lekki, Lagos State [43].

> these are the customers who keep us alive. I'm glad the Commission has tightened the requirements a bit."

Another expert explained the financial implications more bluntly:

> "The eligible customer policy isn't helping the DisCos. These large customers are the cash cows—the revenue that helps DisCos serve the areas with high losses. Without them, we can't breathe. The policy removes those customers but offers no alternative relief. If you take away our biggest customers, then you are suffocating the DisCos"

More broadly, a number of experts critiqued Nigerian power sector reforms as well-intentioned but poorly designed or implemented. One respondent explained:

> "There are too many policies that are not created to solve the problem or are created to solve the problem but have not been thought through in the way they're going to be executed. There are a lot of acts and policies that have come out of the power sector to try and solve a problem, but didn't solve that problem. And the policymakers had to either adjust them, augment them, or make another set of policies to try and solve a different problem the other policies created."

Echoing this sentiment, another expert added:

> "Sometimes, Nigerians, we don't do a great job of remembering the problem we're trying to solve. We get so caught up looking for solutions that we forget the root problem. That's critical—don't lose sight of what you're trying to fix."

Other respondents highlighted that many sector policies are vague or ambiguous, with gray areas that hinder enforcement and accountability. This was reported to be true not only of early privatization documents but also of more recent initiatives like the SBT scheme and related Service Level Agreements (SLAs).

Some experts went further, arguing that policy ineffectiveness was not just about design or execution, but about deep-rooted instability and political bias. As one put it, *"the policy makers and the policies are not stable, and they are bigotry-ridden."* Expanding on this, a utility executive shared a detailed account:

> "The plans are not stable. There was a plan—but that was under the previous administration. Immediately a new government came in, they abandoned it. Ideally, government should be a continuum. But in African countries, that continuity just isn't there.
>
> During Buhari's sixth or seventh year, they signed an agreement with Siemens—first to build human capacity, then to develop a roadmap. Nigeria's whole system was modeled: 330kV, 132kV, 33kV, 11kV—all the parameters, the technical specs, the simulations. And those at the top knew the problem—or at least, they should have.
>
> But in Nigeria, once the top leadership changes, the middle management changes too. The legislators change. The Senate committee on power changes. Just because the president changes, the minister of power must change—even if the last one was performing well. They'll probably also sack some executive directors and bring in their own people.

> And if those new people aren't interested in continuity, then all those documents, all that software and simulation work—it ends up in some dustbin somewhere. It's back to square one.
>
> There was a plan in progress. But they're not following it. This new government has already spent over a year—and it's been silent. Towards the end of the Buhari administration, we started seeing Siemens equipment arrive—transformers and so on. But now? Nothing.
>
> That plan should have been continued—but it wasn't."

Nigerian Factor

Across the interviews, many respondents eventually arrived—at some point—at what they referred to as the 'Nigerian factor.' Essentially, this was a diagnosis that electricity unreliability in Nigeria is not just a technical or policy failure, but a deeper, more structural issue rooted in human behavior, institutional culture, and broader dysfunctions in the Nigerian state. One expert, when asked about the persistent state of electricity unreliability, simply remarked, "*That's Nigeria. Nigeria has happened to Nigeria."*

Another respondent contrasted the nation's situation with systems abroad:

> "Let me use the U.S. as an example—the way they handle outages, because the system works there. Everything is in place. In our case, since I was born—and now I'm getting old—I've never seen Nigeria work properly. And it's not just power. Railway too. My dad used to tell me how they traveled from Ibadan to Imo by train. Now, those things are gone. Electricity is just harder to ignore because it's a must-have. If it weren't, Nigeria might have abandoned it too. It's a system issue."

This view was echoed across multiple conversations. One expert put it this way, *"The electricity industry is not in isolation. It's in Nigeria—so all of Nigeria's problems affect it. You can't just copy Canada's grid modeling and paste it here. It won't work. We have specific problems that need specific answers."*

Some of these "specific problems" stem from interactions between everyday Nigerians and the grid itself. One respondent described how direct acts of sabotage or error lead to forced outages:

> "A lot of things cause interruption…Vehicles hit our poles. People cut trees and they fall on the line—then they run away. Fulani herders looking for lost cows climb poles and get electrocuted.
> Contractors vandalize lines to steal parts for their own jobs. This is the environment we're working in. You can't compare it to advanced countries where everything is in place. Here, we just manage what we can."

Another technical officer, speaking on interface challenges between grid and customer installations, offered this example:

> "These are rare cases, but sometimes we find that the harmonics or instability in the system isn't from the grid—it's from the customer. But because there's no investment in tracing or protection, they assume it's national. They don't know it's their own equipment causing

> the problem. In other countries, customers are responsible for ensuring that kind of stability. Here, it's different."

Even residential contexts reflect these challenges. One utility worker shared a personal experience:

> "In my area, during Christmas, we didn't have power. I had to call the Technical Supervisor (TS) myself. They checked the feeder and said there was no issue—so I figured it was a transformer problem. The TS went to check and fixed it. But the next day, same problem again. Eventually, they went down the line and discovered a resident had called an electrician to fix their own issue. What he did backfired and disrupted the whole line. That's the kind of thing we're dealing with."

As with previous sections, many respondents linked these behaviors to broader sentiments of entitlement and disillusionment. In some regions, residents believe electricity is theirs by right—either because of historic ties to NEPA infrastructure or the perceived failure of the centralized system to serve them. One utility expert explained:

> "There are some regions where we don't get much revenue. They believe they own NEPA. They can chase our operators out of the control room and put on the feeders themselves—because their fathers worked in the power stations. Some of them grew up following their parents to substations. They know exactly where to switch things on. So sometimes we just instruct our operators to drop the load, because we know they'll power it up anyway. There's no revenue recovery from there."

Beyond issues with everyday customers, several utility officials pointed to internal challenges within the electricity sector itself. A commonly cited issue was the growing knowledge gap, as older staff retire, and younger staff enter the system with limited training. An experienced utility manager offered this detailed account:

> "It's there. We all can see it…the expertise is seriously being depleted with people leaving the system, going on retirement—old hands that were employed at commissioning. They know all the secrets, all the ideas on how to manage these things. It's not just generation—even in distribution. Those employed 35 years ago are retiring. Some got extensions due to privatization, but now they're turning 60. The knowledge gap is being seriously exposed.
>
> I'll give you an example. We recently recorded electrocutions and amputations—accidents—because of that gap. People don't understand how to obtain station guarantees before working on lines. They don't know the basic safety steps, or what to do when an error occurs. When we joined in 1988, we spent two years at Ijora for training, and another two years in graduate internship. All that is gone.
>
> People get hired with barely any training. It's becoming even so frustrating to have any impact in the system now—when you ask for data, you don't get quality. The inexperience across the entire network is affecting stability. Sometimes, it's not even about infrastructure; it's about who installed it. You see a concrete pole and a cross-arm, and someone mounts an insulator too close to the pole. The proximity of the wires is all wrong. In the old days, there was a standard gap you had to maintain. Now, people just say *'current no dey bend'*

> *(current does not bend)*[96]. But at high load, you get flashovers, faults. They'll keep giving it a trial—*'It stayed? Okay, keep going.'* But as soon as load goes up, the air gap ionizes, fault again.
>
> Anyone with experience would ask: *'How many times has this feeder tripped this week? At what time? At what load?'* Then you can narrow it to a time-dependent fault or load-dependent. And then from experience, you say, *'Okay. There is a jumper that is so close to the concrete pole or earth that needs to be addressed.'* On the basis of that, you can now dispatch people to the grid, go and look for that situation and correct it. But how many people know this?
>
> Even engineer registration is an issue. Someone gets a bachelor's degree and is immediately registered by COREN[97], gets a title, and ends up heading a unit with more experienced people. The others just watch—*'Let's see what Oga (the boss) will say.'*
>
> Practical experience should be part of COREN's criteria—not just paper qualifications."

Another frequently cited issue was Nigeria's notoriously weak maintenance culture. As one expert explained,

> "They'll tell you a transformer has a 40-year lifespan—but that's with proper maintenance. In some cases, when it gets to Nigeria, nothing will be done on that transformer till it spoils. Even if it spoils thirty years or twenty years or in just two years or in eighty years, nobody cares about maintaining it. No insulation profiling, no changing of oil, no protective system checks. We only do corrective maintenance. We wait for it to fail.
>
> So in actual sense, we install—and look away. It breaks, then we respond. That's what contributes to so many forced outages."

On the same point, a DisCo executive criticized the national transmission company's servicing approach:

> "TCN told the media they service once a year. Come on. This is 2024. Band A customers need 24/7 power. That keeps the lines under pressure—constant current and voltage. If that's the case, you need to service five or six times a year, not once."

Beyond knowledge gaps and weak maintenance culture, many experts consistently highlighted the troubling theme of corruption. As one interviewee bluntly stated,

> "It's just that all over, we have a corrupt system—and that's a serious problem for us as a country. If not, I think if everybody did the right thing, and the right investments were made, everything should be able to work."

Several utility executives gave specific examples of how corruption manifests in daily operations—starting with discretionary practices at control centers, where operators override protocols to meet personal or community requests. According to one utility executive,

> "You can't run away from that reality—but it can be minimized. We need to go full high-tech—SCADA compliance, CCTV in control rooms—because right now, even if someone's band is officially Band C, they'll plead: *'Oh boy, I need 24 hours, please, please.'* And

[96] Implying that certain sector participants act like electricity does not need space or clearance.
[97] COREN - Council for the Regulation of Engineering in Nigeria

> before you know it, the operators oblige and that energy becomes part of our receivables—but it's not billable.
>
> Most of our distribution transformers (DTs) aren't metered. So, you'll just see the energy reflected on the 11kV level with no way to balance it. And for the DTs that are metered, the discrepancy between their readings and the upstream 11kV supply is often 10–15%. Acceptable standard is ±2%. That's outrageous—so who pays for the gap?"

Relatedly, another executive raised the issue of cash suppression—the diversion of payments by staff:

> "Some of our staff collect cash and don't remit it to the company. Cash suppression by our own people. That's not the public's fault; you can't blame the public for that. In this case, the public pays—it's our own people. That's why we're pushing customers to pay directly through the app and it's really helping. If we do that consistently, we'll know exactly what even Band E customers are paying—because I believe they do pay. Nobody will be that irresponsible to use electricity for months and then you won't pay, and we have people going there everyday to ask. They likely pay. Maybe not 100%, but enough to justify better service."

Technical compromises were another major concern highlighted during the interviews. For example, one DisCo manager explained how forced outages are sometimes exploited:

> "When a forced outage occurs, there should be a follow-up planned outage to trace and fix the issue. But a linesman may go out, see the fault, and return saying there's nothing wrong. Then he collects money privately to fix it. It happens."

Importantly, these practices are not confined to field workers or front-line operators. Experts described systemic compromises extending up to engineering decisions. In one striking account, a utility official criticized his own organization's acceptance of technically flawed and risky decisions:

> "Imagine someone connecting a small 50–100 kVA transformer directly to a 33kV line—with no protection—justifying it by saying, *'The transformer only cost 2 million, why spend 20 million on an auto-recloser?'* That's not how it works.
>
> If you can't afford proper protection, connect it to the 11kV network instead. Otherwise, when that transformer causes a fault, the entire 33kV feeder trips—and with it, all the 11kV feeders downstream. That's what we call penny wise, pound foolish. People focus on *'low-hanging fruit'*—quick revenue—without thinking of the long-term losses.
>
> Grid stability suffers; a 20 MW load drops off suddenly. If we had localized protection, only the faulty section would trip. But we don't.
>
> I'm speaking openly to you, but within the DisCo I'd be seen as anti-commercialization—just because I value grid safety. But we can commercialize smartly. For example, we offered select commercial customers a dedicated feeder—at their cost—and showed them they'd recover the investment in 3 to 9 months. That's the kind of commercialization we need."

A senior engineer at another utility echoed this frustration: *"Most of our engineers—sorry to say—yes, we have design engineers. But many are more like businesspeople. We're not really doing the engineering."*

These shortcuts and compromises, experts warned, have permeated every stage of the system: *"There's compromise in material sourcing. Compromise during inspection and certification. Compromise during commissioning. Even compromise in workmanship standards."*

In addition to electricity consumers and sector workers, many interviewees pointed squarely to Nigeria's political class and governance structures as critical contributors to electricity unreliability. Their critiques ranged from bureaucratic inefficiencies and direct political interference to systemic corruption and a chronic lack of visionary leadership.

On the bureaucratic side, some experts described how basic maintenance tasks—such as vegetation management—are impeded by government restrictions. One utility official explained:

> "We've identified feeders that trip frequently because of overgrown vegetation—which is avoidable. And unfortunately, faults caused by vegetation take longer to fix than equipment faults because you don't always know exactly where the line is affected. You shut down, start searching, get the cutlasses, start trimming. But on some government premises, they won't even allow us access to cut trees. We have a feeder that runs through a zoo, and the zoo authorities refuse to let us clear the trees. So, these kinds of issues are also there, linking with the government."

However, quotes like this were relatively rare compared to the more forceful critiques of political interference. Many experts described how politicians override technical norms for personal or electoral gain. One respondent offered this example that arguably illustrates how the symbolic logic of infrastructure has been internalized by political elites—where electricity becomes a tool of political patronage rather than a technically managed service:

> "Most of the network is old and outdated. That's bad enough. But worse, it was poorly designed from the start. Many of the designs ignored engineering laws—they obeyed only political laws. For example, a 33kV feeder shouldn't be more than 50 kilometers or carry more than 10 MW. I'm just speaking figuratively—if you need specifics, I can provide them. But over the years, politicians have pushed feeders over 200 kilometers just to reach their villages. They never considered voltage drops, line losses, or how hard it would be to restore service after a fault. Now we've inherited these networks, and they are now aged. It takes time to maintain, patrol and restore."

A different expert added, *"And when you get to these [far-flung] areas, their actual demand might be just 500 kilowatts. Not even one megawatt. All that extension for almost no load."*

While such political interventions might be viewed as misguided attempts to serve constituents, other remarks clearly reflected deeper suspicion—portraying government actions not as naïve, but as actively corrosive to the sector's health. Several respondents pointed to political protection of non-compliant communities, sabotage for financial gain, and delayed system upgrades due to poor governance. For instance, one utility manager shared the following:

> "What applies in most business hubs doesn't apply in one particular area of our DisCo. It's what we call an 'ethnic power' zone. They're untouchable. Even if they perform at 8% or 10% collection, nothing happens. In other zones, that would trigger a full disconnection. But if you try it there, they'll sack your MD (Managing Director)"

Others alleged politically motivated vandalism. For example, one development expert said, *"You have vandals disrupting the grid—sometimes deliberately sponsored. I've heard of cases where sabotage was linked to things like dwindling diesel sales in an area. It could be for political reasons. It could be for anything."*

Another respondent lamented how decades-old modernization efforts remain incomplete:

> "SCADA came to Nigeria in 1983. It's still not fully implemented. NCC Osogbo still isn't 100% SCADA-compliant. There's been so much mismanagement. We're just not intentional about getting these things done. That SCADA project should have been completed by 1985 or 1987. We're still trying to close it out."

More broadly, several experts pointed to outright corruption in the Nigerian government—not just political interference or mismanagement—as either the root cause or a central enabler of the persistent dysfunction in the power sector. Offering a detailed illustration, one interviewee described how this corruption operates:

> "The Nigerian sector is hybridized now. Some parts are privatized, others still under government. But on the government side, there's no intentionality. They only react to breakdowns—no proactive maintenance, no planned outages. Even when billions are injected, by the time it passes through ministers, senators, power committees...by the time it reaches the GM or ED[98], the money is already halved. Then the executives also *'drink'* their share. Sometimes it's the people who installed them demanding their cut. Unless the person is exceptionally principled—or was put there by grace rather than politics—the money will never be used properly."

Another put it simply, *"Even if money is allocated, is it really used for power? It's like the allocation of funds for the power sector is not enough—and even what's allocated, we don't know where it ends up. Corruption kills everything. Everything."*

Echoing that view, a utility manager described how corruption actively destroys private-sector investments and long-term infrastructure plans. Reflecting on failed BOOT (Build, Own, Operate, Transfer) arrangements, the manager explained:

> Even if a government signs a BOOT agreement, the next administration will frustrate the investor unless he's willing to *'play ball.'* Now you can't expect someone who did a BOOT operation—most times financed by loans, big banks, multinationals—to finish all the politicking, playing ball, bribing, everything with a particular government, and then after four or eight years, another set of people comes and says, *'Oya (come on), start again.'* The investor will say *'Ahn ahn, I gave shares in my company to the last ones, I gave them billions to sign my papers! And it's a 30-year contract. Why should I start again?'* That's how you frustrate people. And if you do that, the business will die. So, the landscape is not fertile. The problem in Nigeria is endemic.

These frustrations typically culminated in reflections on a deeper problem—how corruption not only exists in place of the visionary leadership needed to transform the sector but actively forecloses its

[98] GM – General Manager. ED- Executive Director

emergence. As one respondent put it, this leadership failure lies at the heart of Nigeria's recurring grid collapses:

> "So, it's basically what has happened, I think, in the last two months to the Nigerian grid, which caused the collapses…of course, the people that built it are the colonial masters, it has been done since their era. They knew that when you do this kind of capital projects, you set aside money every year to replace it at end-of-life. But our leaders don't have that foresight. That's the bane of the whole thing—leadership. The knowledge is there. We have professors—not just academicians but also practically inclined, but they're never called to lead. Instead, you appoint a banker with no sector experience—just because he supported the winning presidential candidate financially. That's how you get backward results.
>
> Since 1999, I've only seen a few round pegs in round holes. Someone like Ngozi Okonjo-Iweala—that's not bigotry, that was vision. A president went out of his way to recruit people with the expertise to execute his vision, gave them political and financial backing. That's what we need. Until leadership works as a unit, the power sector, development, everything will remain stagnant."

Finally, some experts pushed the diagnosis of Nigeria's electricity sector challenges even deeper, attributing many of the previously discussed issues—corruption, poor maintenance culture, resource mismanagement, and a pervasive sense of entitlement—to what they saw as ingrained behavioral patterns. In a few cases, these reflections were framed in more essentialist terms as a "Black man problem."

While this perspective was not widely held and should not be interpreted as a definitive explanation, its recurrence in a subset of interviews reflects an underlying frustration and a search for root causes. Unpacking the origins and implications of this view lies beyond the scope of this analysis, but a few illustrative quotes are included to convey the depth of feeling and worldview behind such claims.

Discussing the failure to retire aging infrastructure, one expert said,

> "This equipment has been in existence for maybe thirty or forty years. And yet we keep using them. As Black people, we don't care. We just keep using things till they break. For instance, a circuit breaker is meant to be discarded after 10,000 operations. But some of those breakers are still in use in our network."

Another expert offered a more sweeping and highly charged reflection:

> "You won't see a sane white man—even if he's sleeping under a bridge—go and destroy public infrastructure. No matter how wretched he is, he'll blame the economy, the government, the hardship, but he won't spoil what benefits him.
>
> They do that here. They break roads so cars will slow down and buy from them. If a Black man can be intentional about growth, then I don't see why you have to destroy the road to stop people.
>
> During protests, they burn transformers, break poles, steal wires—and in the real sense, after all that, the problem still belongs to them. The government wasn't willing to do anything in the first place, and you were intentional about destroying the little you have. You'd suffer with it.

> In the UK or US, no one puts soldiers by transformers. You'd find one in a parking basement, and no one would steal it. No CCTV. But here, you do that, it's gone—cables cut, coils stolen, sold off. They'll say it's their birthright. That government is making them suffer, so they take what they can. But with that mindset, even when a leader wants to help, they get demoralized. They stop. They start stealing too—because of the people, the mindset of the people."

Given this perspective—and consistent with earlier reflections on electricity customers and sector workers—many experts emphasized that corruption and other deep-rooted societal behaviors are not confined to the political class alone. As one expert put it plainly:

> "The truth is the government is made up of the people. The people are a reflection of their leader. The leader came from among them. If the leader is corrupt, it's because he came from a corrupt society. He was once just a member of the masses—his behavior came from the masses"

In other words, as another expert concluded, *"Our government is our problem. Then we, the masses, are also the problem."*

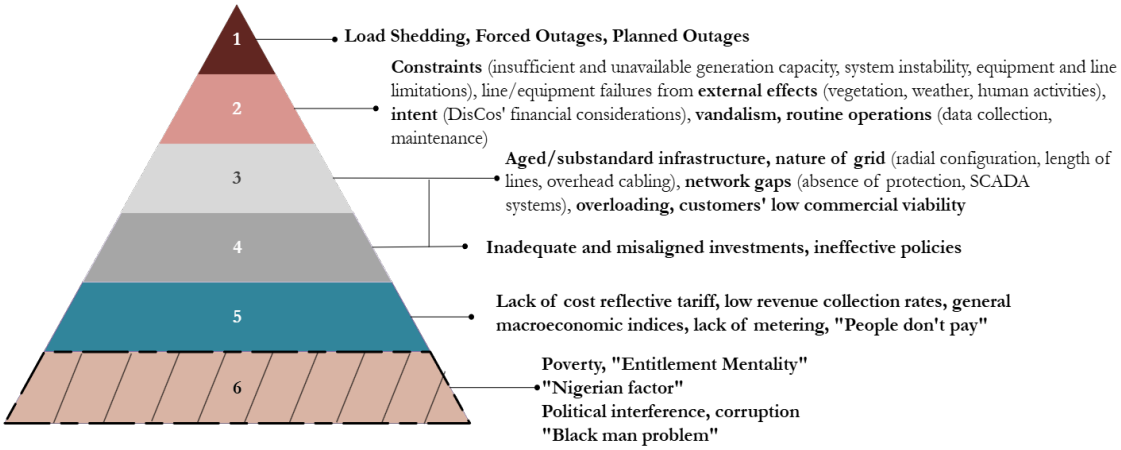


Figure 6-6: A Pyramid of Grid Unreliability: A Six-Level Framework for Diagnosing Outages in Nigeria

Conclusion

The analysis of both the quantitative and qualitative data presented above provides important clarity on the multifaceted, multilayered, and interrelated drivers of electricity unreliability in Nigeria. It also underscores distinctions that are critical for crafting appropriate and sustainable solutions. For instance, at Level 1, the prevalence of outage types—such as regular load shedding and widespread forced outages—highlights the urgent need for expanded generation capacity, grid reinforcement, and greater redundancy. However, these visible disruptions are rooted in deeper structural and systemic issues.

Progressing to Levels 2 and 3, the distinction between planned and unplanned load shedding indicates the need not only for more generation, but also for improved ancillary services to stabilize the grid.

Yet, as earlier quotes revealed, such technical fixes are unlikely to materialize without addressing Level 4–6 causes—particularly those tied to the sector's liquidity challenges. Unless robust payment systems are developed to address both inability and unwillingness to pay, investments in generation and ancillary services will remain out of reach. As one development expert noted, *"The poorer we are as a country, the longer it would take for us to come out of the electricity sector crisis."*

Similarly, while earlier-level causes underscore the need for customer metering, delving into the deeper systemic layers reveals that technical interventions alone—like deploying tamper-proof meters—must be coupled with targeted strategies. These might include phasing meter rollouts by tariff band, accompanying them with tailored customer education campaigns, lobbying for enforcement of anti-theft regulations, and leveraging social norms—such as peer pressure and community leadership—as explored in Chapter 4. Notably, this more integrated and community-responsive approach has already yielded better operating outcomes in Nigeria's rural off-grid sector. As one mini-grid developer explained:

> "Part of the system design covers the technical design, and of course, the financial design. We do a lot of modeling, and once we have the figures, we go back to the community, re-engage them, and explain the tariff—why it's higher than in urban centers, and how it may shift depending on macroeconomic conditions…The sustainability of isolated mini-grids is hell bent on the sustainability of payments from customers. Unlike the DisCos, we don't do estimated billing. Every customer is metered with a smart meter we can monitor remotely. If they default, we can disconnect them. That's the model that works in the mini-grid space in Nigeria. Honestly, we've never had a case where someone says, *'I won't pay.'* The ego, the peer pressure alone—seeing your neighbor with power when you have none—encourages payment. We've also never really had any situation where someone returns the meters because he or she cannot pay."

While the foregoing discussion advances scholarly and public understanding of the drivers of electricity unreliability in Nigeria—a critical Sub-Saharan African context—it also underscores the tremendous clarity that already exists within the Nigerian Electricity Supply Industry (NESI) regarding the sector's challenges. Recognizing this internal clarity is important not only for analytical accuracy, but also for avoiding a long-standing epistemic pitfall in development research—the inadvertent marginalization of local knowledge systems in favor of externally framed "discoveries" [46-47]. To do otherwise risks repeating the missteps of early researchers and explorers like Mungo Park, who famously "discovered" the Niger River while overlooking the centuries of lived knowledge held by the communities along its banks.

To a great extent, experts within Nigeria's power sector already understand both the nature of the problems and the kinds of solutions required. Many offered technically specific and operationally grounded recommendation, such as end-to-end rehabilitation of power lines, full SCADA deployment, increased generation capacity, adoption of mixed-grid systems with distributed generation, battery storage integration, network upgrades using aerial bundled cables, investments in workforce development, and proper metering backed by legal enforcement. However, they all noted that implementation hinges on financing. As one expert put it: *"The electricity industry is capital intensive. Investment is key. There needs to be a lot of funding. Government has a role. Private investors have a role. It's a joint effort."* Another added,

> "The first thing is financing. The industry needs a lot of patient capital—capital that understands the challenges and is willing to wait for the outcomes, given the general situation in Nigeria—how people see power, how people pay for power, and all the infrastructure issues."

In the absence of this financing, it is unsurprising that unreliability has persisted for decades. As one utility official lamented, *"It's not that we don't know what to do. It's that we don't have the resources to do it. So, we just keep managing—managing almost all the time."*

Yet beyond financial constraints, many interviewees pointed to a deeper challenge: inertia—reinforced by the complexity of the system and by seemingly fatalistic perceptions that some dysfunctions are endemic to Nigeria, to its institutions, or, as some controversially argued, to the "black man."

As one interviewee shared, *"All these things form a web. And every day, we just try to balance things—try to stay afloat."*

This inertia appears to have normalized dysfunction. Despite widespread understanding of the sector's failings and the availability of potential solutions, the system has settled into what one interviewee called the *"traditional way of doing the same thing over and over again"*: *"We're not thinking of how to change the pattern…We're not enhancing our processes. We've just adopted something and we're repeating it. And only cosmetic changes won't help."*

In this state, sentiments like this are common: *"I've spent 27 years and some months in this sector. We have been yearning, we have been hoping, praying things will get better."*

Across the interviews, four key factors were consistently identified as necessary to begin breaking this inertia:

- **Strong political will to drive bold policy and regulatory action:** Experts repeatedly emphasized the need for political courage, especially around tariffs and regulatory enforcement. As one expert suggested, *"Brave actions on the policy side…It's not easy for the government to increase tariffs…it requires more political will to make the tough choices."* Another called for *"the true spirit of a regulator—an uncompromising way of enforcement,"* while a third stressed that, *"There has to be the carrot and stick method…people should wake up to their responsibilities."*

- **Reduced political control, increased market accountability:** Some experts argued that dysfunction in the sector is reinforced by the state's outsized role. In their view, the government should *"take a back seat"* and allow market mechanisms to operate without interference. As one regulator explained,

> "Most of the contracts NBET is holding are not effective. It's best endeavor; everybody's doing what they like. That's what explains why today, you can have 5,000 MW. Tomorrow, it's 4,500. Because the GenCos, if their machine doesn't work, they'll say, *'Fine, the machine is not working, what can I do?'* The fact that government is in the middle doesn't give the greatest incentive for proper accounting."

Another interviewee elaborated,

> "The government hasn't really separated itself from the electricity market…It still wants to be front and center, when it shouldn't be controlling it at all. Government's influence is still very heavy. In some other countries you don't necessarily hear government making pronouncements on electricity shortages or things like that. It is the businesses that run them that take responsibility for wherever those shortfalls or shortages come from. The more government takes a back seat, the more the market and its beneficiaries will own it. Right now, electricity players hide behind the government's face and dodge responsibility."

- **Cross-sector collaboration:** Respondents also called for stronger cooperation among key actors in the value chain—starting with the generation, transmission, and distribution companies. As one utility official shared,

> "There's this box passing —TCN blames DisCos, DisCos blame GenCos. But there is need for synergy. Everyone knows the problems in their own domain. We need to agree that the sector is our own. Don't look at yourself as an island because that affects the grid."

Another added, *"That's what people don't like to hear —but it's the reality. Until we work together, we won't see the change we're hoping for."*

- **Targeted government investment:** While many called for the government to step back from daily operations, they also argued for public investment to bridge current gaps—especially while tariffs remain below cost. One utility official explained:

> "To reach 100% reliability, government has to invest more—maybe even for 20 years. India privatized and re-acquired the sector multiple times before getting it right. Nigeria needs to do the same...We need Government's intervention. Government needs to come in as quickly as possible to invest more. The Federal Government has been investing in TCN. However, generation and distribution have been left in the hands of the investors. Government needs to make a U-turn—come and reinvest heavily, make the DisCos more viable and enticing to the investors. The investment is so low. Government has 40% share in the DisCos but has barely invested in them over the years"

Similarly, one development expert emphasized the need for patient, state-backed capital:

> "Look at the US, Europe, Japan, China—they used 50- to 60-year capital to build power systems. In Nigeria, the current five- to ten-year financial models just won't work. Because I don't know who you'll recover five-year debt funding from if you're really trying to fix power issues in the country."

Related to the call for stronger regulatory action, several respondents pointed to recent policy shifts—especially the introduction of the Service-Based Tariff (SBT) scheme—as early signs of progress. As one regulator explained, *"We sort of hoped that the SBT would send a tariff signal. Because for the longest time,*

everybody was just waiting around, paying low rates, and nobody was making progress." Another sector expert described the SBT as *"a very, very good way to go,"* explaining that,

> "It has made the DisCos up their game because before now it was a big mess. Now you prioritize your feeders. You know Band A is the profitable margin where you can actually breakeven. That has really led the DisCos to up their game. And equally the players in the value chain to see the need for them to be up and running. So, there is no room for laxity. It's made everybody to wake up from their slumber and to be more efficient."

Experts also noted that the SBT has helped strengthen regulatory enforcement—prompting more detailed reporting, higher staffing requirements, and digital compliance mechanisms like IoT-enabled meters to verify service levels on Band A feeders.

Some further emphasized that the SBT is just a starting point. As one official explained,

> "When you have a big problem, you don't tackle it all at once. You break it into chunks. That's really what the SBT is—a disaggregated way of solving a sector-wide issue. If I have 200 feeders, and 40 of them are good to go on my day zero, I can start there. With the higher tariffs on those feeders, I begin to generate more revenue. And I don't just pocket the extra profit—I use it to fix the fundamentals in my weaker areas, so that over time, more of the system can be elevated to that higher standard. That's the intention."

However, perspectives differed on the overall effectiveness and potential of the scheme. One development expert shared,

> "I was never really a fan of it. To me, it felt more like a politically palatable solution than a technically competent one. Tariffs needed to increase—but politically, it's difficult to do that, especially if you're not improving service. A better approach would've been to say, *'Everyone's tariffs will rise, but those receiving better service will see a higher increase.'* That would have helped to manage the situation better and deliver a better outcome. Because right now, output hasn't really increased significantly."

Another pointed out the zero-sum risk of reallocating limited energy: *"If you don't increase generation, you're basically allocating more of the energy that you have to a smaller group of people. That has its own complications."* Indeed, as shown in Figure 5.12 (Chapter 5) while Band A customers have maintained relatively high service, other bands have experienced worsening conditions over time.

Furthermore, the SBT is affected by some of the underlying contradictions that reform efforts must contend with—particularly those tied to the 'Nigerian factor' discussed earlier. As one expert noted, *"The good thing is that even at the cost-reflective tariff under SBT, it's still much cheaper than diesel. So, the idea was to show people that it's possible to get good quality supply from the grid—and to encourage them to start moving away from this their diesel behavior."* But, the expert continued, *"still, you know, everybody wants something cheap. So, the complaints persist."*

This tension—between a desire for better service and resistance to paying for it, particularly at the centralized (i.e., grid payments vs. diesel use)—echoes the broader behavioral and institutional dynamics flagged earlier. Additionally, while the SBT has delivered some improvements, it has not been sufficient to trigger the fuller systemic change envisioned in the four-part reform logic outlined

above. For example, multiple utility experts complained of continued failures on the transmission and generation side, and the implicit lack of coordination and accountability.

One utility executive shared, *"As part of Band A compliance, NERC has insisted that DisCos have rapid response teams. But the same requirement wasn't placed on TCN. So, the expected outcomes just aren't coming."*

Another provided a more detailed example:

> "I have some core transmission lines in one State – one line frequently trips. Another was vandalized; they did some patchwork, but it's not completed. In another State, a long line has been down since February 2023 and is still not done. If these lines were fixed, two States would get reliable supply. But it's not happening. I've written mails to TCN, written to the GM. I've explained we're losing revenue; we're losing Band A compliance; our customers are getting restless. We've raised it again and again. Nothing's changed."

In addition to the SBT scheme, the recently enacted Electricity Act was also viewed by several experts as a promising—but contested—reform. Many praised it for paving the way for state-level regulation, which could increase competition and bring enforcement closer to the ground. *"States will be more particular about revenue. They'll legislate and arrest energy thieves,"* said one official. *"Unlike the Federal Government, they won't just manage it."*

Yet, others were more skeptical. As one put it: *"It's just a change of hand from NERC to state regulator – and then continuation of business as usual."* Another added, *"The foundational problems that are around commerce in the sector won't be solved just by changing a regulator from A to B."*

Concerns also included limited technical capacity at the state level, and fears of deeper politicization. One expert worried that most states lack *"the needed or adequate knowledge of the responsibility they are trying to accept from the regulator, NERC and the wherewithal to actually take advantage of the new legal environment."* Another respondent warned, *"Some states might not go into the real thing. They may assume the DisCos are making billions of naira and want to come in so they will have their own share."* A third expert highlighted the risk of even more localized political pressure:

> "I think affordability will become a bigger problem. At the federal level, the structure is more diffuse—you can set tariffs across regions. But with a state regulator, say in Abuja, if you raise tariffs, everyone knows it's you and only you.
>
> Also, the federal structure in Nigeria, for all its flaws, has proven to be more resilient when it comes to managing differing perspectives. The president is powerful, yes—but there's the National Assembly, the judiciary…it's a large system so the president doesn't have his feet in every pair of shoes. But at the state level, governors are far more in control. So, if you're lucky and have a governor who wants the market to work—great. You've got a good chance. But if you get a governor who doesn't care or actively obstructs reform, then you're literally doomed—because there's no counterbalancing force."

As the discussions of the SBT and the Electricity Act illustrate, even well-intentioned reforms are often complicated by deeper, systemic challenges. Consequently, one expert stated, "*Nigeria is complicated, that's the truth… you fight till the end."* Another went further, arguing that only a political revolution could fix the situation. A more tempered perspective emphasized intentionality:

> "I think we need to be intentional about most of these things. What's happening in the nation—socioeconomic factors, attitudes—it's eaten deep into every facet. So, if you're doing any project, like in the DisCos now, you must really want to see it through. Not just looking at what's in it for you. Government has many policies, but how well are we pushing through to make them a reality—something we can be proud of? The required change is in people. Culture, mindset, attitude—those must shift. And for that to happen, people must be empowered, the economy must work. Until that's done, we don't even have the basics. So how does it work? You can't just jump forward. We need to get it right. We need to be very intentional."

Still, several experts cautioned that good intentions alone may not be enough, pointing instead to entrenched forces—what some described as "*the cabal*"—that prevent anything from working, no matter how laudable. As one official argued:

> "Sixty to seventy percent of our national grid generation comes from gas—and we have it in abundance. In fact, in some states, it is just wasting. Now imagine someone who isn't driven by profit. Maybe someone in the twilight of his years who just wants to leave a legacy. He says, *'Let's give this gas to the power sector for free for six months, so they can reset, stabilize, and then resume paying later.'* They won't let it happen. No matter your good intention.
>
> There's this slang you always hear on Nigerian social media: *'the cabal, the cabal.'* But it's real. There's this cabal; a group of people with a shared idea—and that idea has become an ideology. They hold power. And no matter how few they are, their idea wins. If their idea is to make money for themselves, they will. And they'll fight to keep that power—because without it, they're finished."

In light of these structural and political barriers, some experts shifted the frame from system-wide transformation to segmental reliability—highlighting interventions for specific customer groups. In this framing, 100% reliability becomes possible, not everywhere, but for those who can afford it. As one utility manager shared,

> "We have Band A feeders that haven't tripped this year. Some commercial feeders—whether dedicated or public—have only had one or two issues all year. Why? Because Band A customers pay more—₦209 per unit—so they get more attention."

In this scenario, access to reliable electricity increasingly reflects ability to pay. As another expert described,

> "There are Band A feeders that haven't tripped this year. Over time, Band B customers will push to become Band A, Band C will try to move up to Band B. But eventually, only the rich will have reliable power—supply won't be for the poor anymore. If you can't afford it, you can't afford it.
>
> As this plays out, others will step in—solar providers, private developers, embedded generators. Everyone will be in the market, competing to serve those who can pay. If I can't serve you and someone else can, they'll snatch my customer.
>
> 100% reliability is possible. Everyone will reach whatever power level they can afford."

In essence, this approach bypasses the limitations of a centrally owned and underfunded grid, offering customers the level of service they are willing—or able—to pay for. Across Nigeria, this translates into the continued entrenchment of backup generation—though increasingly in more coordinated forms, such as interconnected mini-grids and using cleaner energy sources like natural gas and solar, which have become more viable due to relative cost reductions.

As one expert predicted, *"In Nigeria, I think minimum, the next 20 years, we'll still be suffering under lack of energy"* However customers are not willing to wait. Describing how industrial clients are increasingly leaving the centralized grid, a utility official explained,

> "They've done overly well on complaints—*'You guys are not giving us supply, we're not enjoying it.'* And we keep promising, we'll try, we'll improve. But even when we're making progress, the grid fails—everything gets messed up. Sometimes, frequent tripping from our own old infrastructure makes it worse. We can't maintain everything at once because of the cost, so we do it bit by bit. But the customer isn't willing to wait. Meanwhile, you've got embedded generation—new, running 24/7, uninterrupted. Come on, one doesn't even need to think—they just move, they switch."

Though pragmatic and already unfolding, most experts described this individualized, self-help approach with a sense of regret—viewing it as suboptimal, inequitable and unsustainable. According to many interviewees, the preferred path remains a coordinated one. In this vision, the Nigerian government, leveraging its regulatory authority and financial influence, would undertake targeted, well-directed investments in the power sector: upgrading grid infrastructure, enabling cost-reflective tariffs to ensure utility viability, and instituting safeguards to protect low-income consumers. It would enforce discipline and accountability across the value chain through a calibrated mix of incentives and penalties.

In parallel, sector actors would collaborate more effectively—responding to credible market signals and pursuing returns in a more efficient, competitive environment. Well-designed public education campaigns would help nurture a culture of timely and complete payment for electricity, bolstered by visible government support, improved sector accountability and, consequently, renewed trust in both public institutions and service providers. Over time, the productive use of energy would drive inclusive development, raise incomes, and elevate living standards—further boosting demand for and growth in the electricity sector.

Under this aspirational paradigm, progress would be driven by a combination of stronger regulatory and judicial institutions, transformative education, patient capital, and perhaps the emergence of altruistic, effective leadership. Such a shift would help the sector transcend the complex challenges often attributed to the 'Nigerian Factor' and reorient it toward real and lasting transformation.

Still, given Nigeria's history, most experts doubted whether such a scenario could emerge—at least not in the near term. Yet, many held on to a quiet, persistent hope. As one expert concluded our conversation, *"By the grace of God, there is light at the end of the tunnel."*

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Chapter 7

Electricity for the Future: Confronting the Tensions of the Energy Transition in Nigeria

> "The ETP envisions vibrant industries powered by low-carbon technologies, streets lined with electric vehicles, and livelihoods enabled by sufficient and clean energy."

This dissertation set out to investigate Africa's energy transition—beginning with the foundational question: should Africa even prioritize a transition, given its minimal historical contribution to climate change and its urgent development needs?

As Chapter 2 demonstrates, while rapid economic growth on the continent would lead to rising emissions, Africa's aggregate contribution to global emissions is likely to remain marginal. From this perspective, externally imposed restrictions on African emissions are difficult to justify. Yet, paradoxically, many African countries have taken bold public positions on climate targets—though often struggling with implementation. This proactivity could reflect a genuine recognition of the continent's acute vulnerability to the worsening impacts of climate change. However, it also possibly reflects the influence of external actors and the promise of international financial and technical support, underscoring Africa's enduring strategic dependencies—particularly with the West and increasingly with China.

Considering this, the question may be less about whether Africa should engage in the global energy transition, and more about what form that transition could take. How can it be achieved? What factors constrain or support it? How might the region navigate the tensions between ambitious climate goals and pressing development imperatives? These questions highlight the uniqueness of Africa's position. Unlike most industrialized nations that advanced their development before turning to decarbonization, many African countries are now being called upon—or choosing—to pursue both simultaneously. Mainstream transition discourses—rooted in the experiences of advanced economies—offer limited guidance for navigating this dual challenge, underscoring the need for tailored, context-specific approaches. In this context, Nigeria's public declaration of its intent to pursue an energy transition offered a timely and important case study for deeper analysis.

The energy transition is vast and inherently multifaceted. Therefore, in approaching it, this dissertation focused on what the literature identifies as a near-term priority: *'the megatrend of electrification'*. That is, the shift toward renewable electricity generation and the electrification of as many end-uses as possible—either directly or through energy carriers such as hydrogen. Working within this framing of the energy transition as primarily electrification-based, the dissertation turned to the Nigerian context—drawing on my unique positionality as both a scholar and a practitioner embedded in the country's energy transition ecosystem.

Through deep engagement with the socialization of Nigeria's Energy Transition Plan (ETP)—the official framework outlining the country's transition path—alongside gaps in the literature and

lingering questions from lived experience, I settled on interrogating a central tension: How can a country pursue electrification for energy transition when it has not yet achieved reliable electricity access? In particular, my dissertation research zeroed in on the shaping role of electricity unreliability—defined by frequent outages, in Nigeria's electrification-based transition.

As detailed in Chapters 4 and 5:

- Unreliability significantly influences both the perceived need for, and actual adoption of, decentralized fossil-fuel generation—undermining the ETP's vision of expanding renewable capacity.
- Unreliability constrains the viability of end-use electrification by introducing time-of-use mismatches, where power is often unavailable during key periods for uses like electric cooking or vehicle charging.

In this sense, electricity unreliability does not just hinder development, as widely acknowledged in the literature—it hinders decarbonization. The persistent deficits of electrification-for-access obstruct the feasibility—and even the imagination—of electrification-for-transition. As many Nigerians intuitively understand and often express in sharp tweets and commentary, it is difficult to prioritize *"green"* electricity when "*any"* electricity is still elusive.

One expert vividly illustrated this tension:

> "Globally, it's not just about transitioning to electricity, but to green electricity. But for us in Nigeria—let me go back to what I said during my master's in the UK. Someone mentioned 2030 plans for green energy, and my lecturer asked why I wasn't contributing. I said, '*You're dancing around green electricity here because you have electricity. If you give Nigerians red electricity—any electricity—we can start there. Then we'll talk about green, yellow, or whatever color later.*[99]*"*'

Another expert echoed this perspective, emphasizing what they viewed as global hypocrisy around energy survival:

> "It's very hard to tell anyone, *'You could have electricity from a source, but don't take it—climate change is more important.'* That's not going to work. Look at when gas prices spiked during the Ukraine war—no one needed to tell Germany to fire up coal plants. That's survival. Meanwhile, in Africa, people are told to *'rough it.'* But in the UK, even in spring, they won't accept rolling blackouts. So why should anyone else?"

Indeed, many experts suggested that in the face of persistent shortfalls, Nigeria may need to rely on legacy fuels—like diesel, coal, and especially gas—even though this runs counter to the clean energy transition.

As one utility executive explained,

> "We're even thinking about using some captive diesel sets. Diesel isn't obsolete yet. Right now, power shortages are the real issue. So, if there are big diesel generators—say, above

[99] Minor editorial adjustments have been made to the verbatim quotes included in this chapter for clarity and grammar. These quotes come from the interviews described in Chapters 4, 5 and 6.

> 500kVA—we could synchronize them to the grid. We'd buy from them and resell to customers. That's a bilateral deal. It doesn't have to be solar. Yes, diesel pollutes, but we can use additives and other energy-efficiency measures to mitigate that."

Another private sector actor offered a practical defense of gas:

> "We already have enough gas—it's available. It doesn't have the storage issues that solar has, and while initial costs are high, gas is more cost-effective at scale. Most of the power on the grid today already comes from gas. Policymakers understand it. It's the least-cost fuel for the population and the most familiar. Yes, infrastructure is a bottleneck—we lack pipelines—but, even the government is thinking, if I solve that, I get to my goal faster than I would with solar."

Additionally, one regulator admitted, *"If someone brings a commercially viable coal plant today, I would absolutely license it. At the end of the day, we have to survive first to even see the benefit of minimized climate change."*

Yet, these perspectives should not be mistaken for a rejection of renewable energy. In fact, efforts to integrate more renewables into Nigeria's power sector are ongoing. For instance, the Nigerian Electricity Regulatory Commission (NERC) has mandated that 5% of each Distribution Company (DisCo)'s energy consumption must come from renewable sources [1].

Interestingly, many experts described this growing interest in renewables not just as a climate-driven imperative but as a practical response to the country's entrenched energy deficits—mirroring the logic of the ETP, which seeks to achieve both universal energy access (SDG7) by 2030 and net-zero emissions by 2060. As one utility executive put it:

> "The simple logic is that energy—in whatever form—is necessary. Rapid power for all is the goal. Whether it's from renewables, gas, whatever...the key thing is to provide access to more and more people. We've seen so many areas with no electricity. Children are studying at night with kerosene lamps. So, if we go for mini-grids or micro-grids in those areas, they can later be interconnected. Eventually, we'll have a broad-based grid where surplus energy can be redirected to where it's needed most."

Several utility officials echoed this logic, pointing to the potential of decentralized renewables—particularly solar—to reduce pressure on the national grid while expanding access:

> "What we have now is not enough. We have many underserved communities. But their consumption is small, so with solar, at least they see light. It helps them, and it takes stress off the grid. There's a push to increase the DisCo's renewable requirement to 20%. That would be good. It's a win-win."

> "Solar is good. If more people invest in it, we reduce pressure on the grid. Nigeria's national grid is always collapsing—it's not good for business."

Still, optimism about renewables was tempered by concerns about implementation capacity. On the technical front, one developer cautioned, *"The national grid is not robust enough to accommodate integration of renewables. We know there are issues with interconnection."*

These constraints bring the conversation full circle: electricity deficits continue to limit the realization of energy transition goals. Whether the ambition is to expand renewable power generation, accelerate end-use electrification, or simply build public confidence in the transition, closing Nigeria's infrastructure gaps remains a foundational priority.

Although as one utility executive put it, this need not be a linear process: "*It's a parallel approach. We're not saying the status quo will remain. We must improve the system, even as we move toward renewables and alternatives like biomass. These efforts support each other—they're complementary."*

Nonetheless, if reliability and access must be addressed first—or at least in parallel with the transition—what does that mean for Nigeria's net-zero ambition, and for other emerging economies in similarly constrained positions? Given how elusive grid reliability has been over several decades, is the 2060 target simply aspirational? One expert offered a perspective that may be instructive, describing Nigeria's signing of international energy compacts:

> "They are a signaling opportunity…It's a way of the country saying, 'This is something we want to be a part of.' It's not a commitment to do anything. It's just kind of signed. There's a ceremony, a photo op. That's it."

In unpacking the roots of electricity unreliability to inform potential solutions, Chapter 6 developed a six-level causal framework—from immediate technical issues (forced outages, load shedding, and planned maintenance) to deep-rooted sociopolitical dynamics ("the Nigerian factor"). The analysis revealed that progress has been slow, and timelines remain uncertain on many of the core reforms needed to improve reliability—including sector discipline, cost-reflective tariffs, patient investment, and improved coordination.

Without far-reaching change engendered by such reforms, Nigeria's electrification-based transition is unlikely to succeed. Even under a parallel approach, many of the same measures proposed to improve the grid are prerequisites for progress on the energy transition. For example, in discussing widespread household adoption of renewable energy, one developer said:

> "Things need to really change for Nigeria to make gains. Macroeconomic dynamics need to improve. People need purchasing power—to afford residential solar home systems, for instance. Even those in the off-grid sector need better financial conditions to buy power."

Such a comprehensive transformation would require coordinated, sustained efforts—ideally led by the government. At a minimum, it would need to prioritize addressing cost barriers, which emerged repeatedly across Chapters 4, 5, and 6 as critical obstacles to transitioning to decentralized solar, adopting electrified end-uses, and even paying electricity bills to support sector viability.

However, as highlighted in Chapter 6, many of the experts I interviewed—as well as several colleagues and everyday Nigerians I encountered during my time at the Energy Transition Office (ETO)—expressed either deep skepticism or, at best, fragile hope that a coordinated approach rooted in visionary leadership and sector-wide reform could materialize. As a result, Nigeria's energy transition—and its broader energy future—remains, for many, a distant and uncertain prospect, contingent on leadership that may never come.

One utility manager, leaning toward skepticism, recalled:

> "I remember in the early 2000s, there was a slang then: Vision 2020. *It don pass 2020 (it's long past 2020)*—nothing happened. Until an intentional group grabs power—whether by accident or revolution—nothing will change…You need intentional people to achieve this transition. But they're not there. The ones in power are just making money for themselves. So, this transition? It's just on paper. And the people who originally wanted it may not even be around anymore."

On the more cautiously hopeful side, another expert offered:

> "It will be good if it will come to pass…They said 2050, 2060—we are still in 2024. So many years to go. I pray we have a good government to lead us to that. It will be good… Let's see. Let's pray. It's a thing of prayers."

Still, just as in the discussion of reliability targets, several experts shifted the conversation away from system-wide transformation and toward a more immediate, observable reality: the transition is already happening—but only for the rich. As reliable electricity is increasingly reserved for those who can afford Band A service or private alternatives, the energy transition, too, is becoming something only the wealthy can meaningfully participate in.

This echoes Larkin's [2, p.243] insight on the breakdown of the symbolic logic of infrastructure in Nigeria:

> "The necessity of electrical autonomy is a basic factor in…the form and experience of Nigerian urban life…Instead of citizens being linked to the state through the smooth network of the electric grid, the generator dominates Nigerian life. Its presence bears witness to the collapse of the integrated infrastructural idea and the reconfiguration of the state's ambition to provide developmental progress…In the disaggregation from networked electricity to autonomous generators lies the shift in Nigerian society from the developmental state to new forms of individual, competitive, liberalism."

Experts I interviewed repeatedly gave voice to this same reality—confirming the third pathway introduced in Chapter 3: that alongside other infrastructure failures, unreliable electricity has fostered a deepened individualism among citizens. One respondent explained:

> "I think gensets also attach to our relatively individualistic view of life. Nigerians, we don't have a great sense of community. So, when things are for personal gain, people go over and beyond. But when it's about collective contributions, that's another matter. Gensets tap into this warped sense of individualism. People think: *'Grid power is government something—it should be cheap.'* But when diesel hits ₦1,800 a liter, and it's costing ₦600 per kWh, they still run it—because it's theirs. They control it. They'll bring it on when they want to."

Another expert bluntly said, *"In Nigeria, we have a very selfish attitude. Everybody thinks of themselves only. We don't think of ourselves as a collective."*

This logic has shaped both past and present energy choices—first through the widespread adoption of fossil-fuel backup generators, and now in the contours of Nigeria's energy transition. However, rather than a conscious expression of indifference or malice, this behavior likely reflects a deeper reality: in the absence of reliable public services, individuals continue to construct layered, personalized systems of energy access based on what they can afford. As one development expert observed:

> "Nigeria is a case of organized chaos and I'm seeing the evolution following that same organized chaos…If we're going to transition in a country like this, we're going to keep our generator. We're going to keep our grid power. We're going to have solar. We will install batteries. We will change our water heaters, maybe change one set today, change one AC a week after. It's a process. We are evolving in that chaos as a country at different speeds, in different ways."

Providing a striking example of the pattern described above, another respondent offered a personal reflection:

> "The switch to solar isn't about transition—it's about cost. Diesel at ₦1,000 per liter made solar the cheaper option. I paid ₦4.9 million for a 5kW system. I used to spend ₦1.2 million a month on diesel. Now it's ₦400k. That return is crazy.
>
> In my house, solar runs the day load. At night, it's either diesel or grid. When I'm out, I even tell them to switch off NEPA. My system switches sources automatically. Most people I know do the same. Cooking will follow this same pattern—but again, it's the rich making that switch.
>
> We underestimate how poor this country is. People earn ₦2,000 to ₦3,000 a day. They don't calculate power costs monthly—it's about what they can afford today. If someone offered solar for ₦300 a day, adoption would explode. All day long."

Concluding Reflections

This dissertation demonstrates the extraordinary value of rich, multi-method research in interrogating assumptions, challenging prevailing narratives, and adding empirical depth to often rhetorical debates. It centers Africa's energy transition—using Nigeria as a case study—and explores how the unfinished project of electrification for energy access interacts with the urgent push for electrification for the energy transition. Drawing on previously unexamined quantitative data and qualitative insights from extensive interviews with Nigerian experts, the findings show that Nigeria's energy transition is unlikely to succeed under current conditions—but that outcome is not inevitable.

Across this dissertation's chapters are empirically grounded, context-specific and viable solutions to the intertwined challenges of electricity unreliability and the electrification-based transition. It is therefore evident that the deeper tension lies not in the technical difficulty of pursuing a clean energy transition atop an unreliable grid, nor in the absence of feasible solutions to this challenge. Rather, the constraint appears more rooted in a lack of political will and implementation capacity. Though anecdotal, the following account shared by a development expert offers a compelling example of what political commitment can make possible:

> Let me tell you the origin story as I know it—it's quite remarkable. It actually begins with controversy. About 11 or 12 years ago, there was a donor-sponsored study on the need for off-grid electrification in Nigeria. It was comprehensive—it analyzed solar home systems, mini-grids, and commercial and industrial (C&I) off-grid solutions. The study acknowledged some advantages, especially the speed at which off-grid systems could

> provide electricity to underserved areas. But it emphasized the downsides: high costs, heavy reliance on grants, uncertain sustainability, and long-term maintenance concerns. The cons outweighed the pros, and the conclusion was that the grid should remain the focus, with only limited off-grid interventions.
>
> But then politics stepped in. A major political transition was underway—Nigeria's first presidential change from one party to another. The new administration needed quick wins, and off-grid solutions suddenly became the chosen vehicle. Everything the study had listed as barriers became action points. Grants? Let's find them. Lack of technical assistance? Let's mobilize it. No data? Let's send people out. No local developer base? Let's build one.
>
> And just like that, a full-fledged off-grid program was born. The very framework once dismissed began to scale rapidly. That's how Nigeria's off-grid sector exploded. It's why I said the story began controversially—what was once rejected became the centerpiece of a national strategy, driven by political will and the demand for quick, visible progress. Today, the Rural Electrification Agency, which led much of this effort, has delivered real wins—both for the current and past administrations.

This example suggests that the tension in simultaneously pursuing electrification both as energy access and as energy transition may be less about inherent intractability than often assumed. Instead, the real questions are: Are we willing to be honest about what serious reform would require? Are we prepared to prioritize and pursue it—especially at the highest levels of leadership? Are international partners genuinely committed to providing the kind of support this transformation requires?

While these questions remain open, Nigeria's energy transition is already underway. But it is unfolding in uneven, competitive, and exclusionary ways—largely benefiting those who can afford it. One could interpret this as a familiar story of early adopters leading the way, with widespread access to follow. However, a more grounded reading points to the deepening of energy inequality, reinforcing the need for urgent recalibration toward a just energy transition.

Still, this evolution—messy, fragmented, often frustrating—is widely viewed as distinctly Nigerian. As one expert observed:

> "To say Nigeria is structureless is a lie. To say it's structured is also a lie. We have just enough structure to keep going…It's difficult to explain. But whether you like it or not, there is growth. It's just that we, being trained and disciplined academically, want to see it in a certain kind of way. Nigeria is not going to conform to that kind of way. Accept it."

As I conclude this dissertation and my PhD, I am more convinced than ever that there is still much work to be done—and many realities to be interrogated. I am therefore encouraged. As Hebert [3, p.33] suggests, *"The zeal of scholarly work, when placed within the confines of practice, will sustain the flames of learning, even as one moves through change."* I carry that zeal with me into this next phase.

The energy transition presents an unprecedented opportunity for Nigeria, African nations, and the world to reimagine their energy systems. I recall drafting a speech while working at Nigeria's ETO that read, *"The ETP envisions vibrant industries powered by low-carbon technologies, streets lined with electric vehicles, and livelihoods enabled by sufficient and clean energy."* I still resonate deeply with that vision. It echoes the call of energy democracy scholars, who argue that renewable energy transitions must also be about restructuring systems to advance inclusion, justice, equity, prosperity and sustainability [4-8].

As 1 Corinthians 16:9 puts it in the Good News Translation: *"There is a real opportunity here for great and worthwhile work, even though there are many opponents."* The energy transition is indeed one such opportunity—full of resistance, but also full of possibility. Through this dissertation, I have come to better understand the nature of those opposing forces. That understanding has strengthened my hope that they can, in time, be overcome.

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Chapter 2 Appendix

1. Countries in the Study

In this study, we adopt the African Union's record of Member States and regional groupings [1]. While Africa comprises 55 countries, our analysis focuses on 47 countries due to data availability[100](Table A-1 and Figure A-1).

Figure A-2 displays relevant indicators for the 47 countries in our study, including population, gross domestic product (GDP), GDP per capita, total primary energy consumption, energy consumption per capita, installed electricity generation capacity and electricity consumption per capita. The data on emissions [2], GDP [3-4], and population [5] are sourced from the World Bank Databank, while information on total primary energy consumption, installed electricity generation capacity and electricity consumption is from the U.S Energy Information Administration (EIA) [6-8].

Table A-1: African Countries in the Study Per African Union Classification

S/N	Southern Africa	Northern Africa	Central Africa	Western Africa	Eastern Africa
1.	Angola	Algeria	Burundi	Benin	Comoros
2.	Botswana	Egypt	Cameroon	Burkina Faso	Ethiopia
3.	Eswatini	Mauritania	Central African Republic	Cabo Verde	Kenya
4.	Lesotho	Morocco	Chad	Côte d'Ivoire	Madagascar
5.	Malawi	Tunisia	Congo Republic	Gambia	Mauritius
6.	Mozambique		Democratic Republic of Congo (DR Congo)	Ghana	Rwanda
7.	Namibia		Equatorial Guinea	Guinea	Seychelles
8.	South Africa		Gabon	Guinea-Bissau	Sudan
9.	Zambia			Mali	Tanzania
10.	Zimbabwe			Niger	Uganda
11.				Nigeria	
12.				Senegal	
13.				Sierra Leone	
14.				Togo	

[100] Djibouti, Eritrea, Liberia, Libya, São Tomé and Príncipe, Somalia, South Sudan, and Sahrawi Republic (Western Sahara) did not have complete panel data for the 1990 – 2020 period considered in this study.

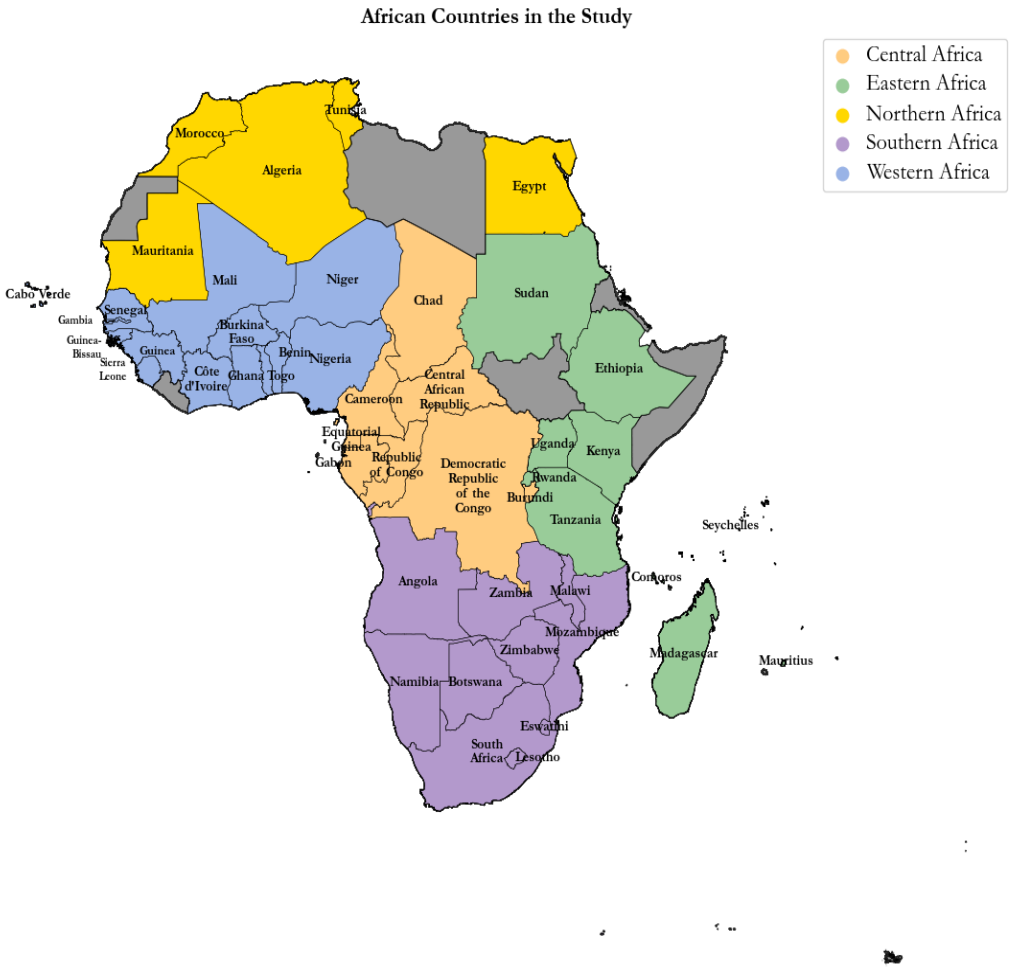


Figure A-1: African Countries in the Study according to African Union Classification. The countries that were not included in the study have been grayed out.

Country	Population (millions of people) - 2022	Gross Domestic Product [GDP] (current international dollars, billions) - 2022	GDP per capita (based on GDP Purchasing Power Parity, $/person) - 2022	Total Primary Energy Consumption (Quadrillion BTU) - 2021	Energy consumption per capita (toe/capita) - 2021	Installed Electricity Generation Capacity (GW) - 2021	Electricity Consumption per capita (kWh/capita) - 2021
Algeria	44.90	195	13,210	2.58	1.47	21.69	1554
Angola	35.59	107	6,974	0.33	0.24	7.34	422
Benin	13.35	17	4,056	0.11	0.21	0.47	40
Botswana	2.63	20	18,323	0.08	0.81	0.77	1295
Burkina Faso	22.67	19	2,546	0.07	0.08	0.39	120
Burundi	12.89	3	836	0.01	0.03	0.10	33
Cabo Verde	0.59	2	9,083	0.01	0.62	0.20	547
Cameroon	27.91	44	4,408	0.15	0.14	1.75	224
Central African Republic	5.58	2	967	0.01	0.02	0.04	26
Chad	17.72	13	1,668	0.02	0.03	0.09	15
Comoros	0.84	1	3,832	0.00	0.14	0.04	124
Congo, Dem. Rep. (DR Congo)	99.01	65	1,337	0.13	0.04	2.92	93
Congo, Rep.	5.97	16	3,791	0.05	0.20	0.64	380
Cote d'Ivoire	28.16	70	6,538	0.22	0.20	2.20	290
Egypt	110.99	477	15,091	3.81	0.88	60.07	1541
Equatorial Guinea	1.67	12	17,396	0.07	1.07	0.35	777
Eswatini	1.20	5	10,782	0.02	0.51	0.30	1254
Ethiopia	123.38	127	2,812	0.36	0.07	4.90	79
Gabon	2.39	21	16,471	0.06	0.69	0.78	1005
Gambia	2.71	2	2,510	0.01	0.08	0.14	90
Ghana	33.48	74	6,498	0.39	0.30	5.35	557
Guinea	13.86	21	3,187	0.06	0.11	0.99	183
Guinea-Bissau	2.11	2	2,190	0.00	0.06	0.03	37
Kenya	54.03	113	5,764	0.35	0.17	3.48	171
Lesotho	2.31	2	2,695	0.02	0.18	0.07	395
Madagascar	29.61	15	1,774	0.05	0.04	0.58	68
Malawi	20.41	13	1,732	0.03	0.04	0.74	48
Mali	22.59	19	2,517	0.09	0.10	0.92	122
Mauritania	4.74	10	6,424	0.06	0.34	0.66	402
Mauritius	1.26	13	26,906	0.09	1.74	0.93	2166
Morocco	37.46	131	9,665	0.95	0.64	14.26	954
Mozambique	32.97	18	1,468	0.25	0.19	2.77	421
Namibia	2.57	13	11,206	0.08	0.75	0.61	1357
Niger	26.21	15	1,505	0.04	0.04	0.32	51
Nigeria	218.54	473	5,860	1.86	0.22	11.70	125
Rwanda	13.78	13	2,792	0.02	0.04	0.27	51
Senegal	17.32	28	4,209	0.14	0.22	1.50	314
Seychelles	0.10	2	35,228	0.02	4.24	0.17	6178
Sierra Leone	8.61	4	1,931	0.01	0.04	0.18	16
South Africa	59.89	405	15,905	5.42	2.30	63.28	3223
Sudan	46.87	52	4,216	0.36	0.20	4.47	290
Tanzania	65.50	76	3,002	0.20	0.08	1.59	113
Togo	8.85	8	2,608	0.03	0.10	0.26	143
Tunisia	12.36	46	12,490	0.40	0.82	5.78	1344
Uganda	47.25	46	2,694	0.12	0.07	1.46	67
Zambia	20.02	29	3,894	0.23	0.29	3.37	735
Zimbabwe	16.32	27	2,531	0.14	0.23	2.48	521

Figure A-2: Relevant indicators for the African Countries in the study. The indicators are depicted using a two-color scale, featuring varying shades of green and white. Deeper shades of green signify higher values.

2. Kaya Identity

The Kaya Identity helps to break down fossil fuel CO_2 emissions into four factors: carbon intensity of energy use(CO_2 emissions per unit energy consumed), energy intensity of Gross Domestic Product (GDP) (total energy consumed per unit of GDP), economic rent (represented as per-capita GDP) and population [9]. The Kaya Identity can be expressed as follows:

$$CO_2\ emissions = \frac{Emissions}{Energy} \times \frac{Energy}{GDP} \times \frac{GDP}{capita} \times Population$$

To build the country-level model, we combine data on emissions [2], GDP [3], and population [5] from the World Bank Databank and total primary energy consumption data from the U.S Energy Information Administration (EIA) [6] for the period 1990–2020[101].

Trends Across Kaya Identity Terms Between 1990 and 2020

The historical data reveals varying growth rates of the Kaya Identity factors across African countries in the three decades under consideration (1990–2000, 2000–2010, 2010–2020). Figures A-3–A-7 below present the annual growth rates of the four terms in the Kaya Identity in each decade considered and over the entire 30-year period for African countries.

While population has consistently recorded positive growth over the past three decades, carbon intensity (emissions/energy), energy intensity (energy/GDP), and economic rent (GDP/capita) exhibit considerable swings from decade to decade. Detailed analysis of these trends is provided below. Additionally, we observe similar growth rates[102] for the different Kaya Identity terms in at least two of three decades across various African countries, supporting our hypothesis that future growth can be estimated based on plausible trajectories from historical patterns. Table A-2 provides a quantitative summary of these trends.

Table A-2: Summary of Key Trends in the Growth of Kaya Identity Terms in African Regions Between 1990 and 2020.

Region	Trend	Carbon Intensity (Emissions/ Energy)	Energy Intensity (Energy/ GDP)	Economic Rent (GDP/ Capita)	Population
SOUTHERN	Percentage of Countries with directional swings in growth (positive to negative or vice versa) between 1990 and 2020	80%	50%	20%	0%
	Percentage of countries with similar growth rates, in at least two of the three decades	50%	80%	70%	100%
NORTHERN	Percentage of Countries with directional swings in growth (positive to negative or vice	80%	60%	20%	0%

[101] The emissions dataset from the World Bank spans the years 1990 - 2020

[102] "Similar growth rates" are the same at 1 significant figure or have a difference of less than or equal to 1 percentage point.

	versa) between 1990 and 2020				
	Percentage of countries with similar growth rates, in at least two of the three decades	100%	40%	60%	100%
CENTRAL	Percentage of Countries with directional swings in growth (positive to negative or vice versa) between 1990 and 2020	88%	63%	75%	0%
	Percentage of countries with similar growth rates, in at least two of the three decades	50%	25%	38%	100%
WESTERN	Percentage of Countries with directional swings in growth (positive to negative or vice versa) between 1990 and 2020	71%	64%	14%	0%
	Percentage of countries with similar growth rates, in at least two of the three decades	29%	50%	86%	100%

EASTERN	Percentage of Countries with directional swings in growth (positive to negative or vice versa) between 1990 and 2020	90%	40%	10%	0%
	Percentage of countries with similar growth rates, in at least two of the three decades	90%	60%	70%	100%

Carbon Intensity (Emissions/Energy) Trends Across African Regions (1990–2020):

Southern Africa: Eight out of the ten countries in the region, including Angola, Botswana, Eswatini, Malawi, Mozambique, Namibia, South Africa, and Zambia, exhibited varying growth rates and directions in carbon intensity between 1990 and 2020. Lesotho and Zimbabwe consistently recorded negative growth but with dissimilar rates over the three decades. Four countries—Malawi, Namibia, South Africa, and Zimbabwe—recorded similar growth rates in two of the three decades. For instance, Malawi maintained a -2% growth rate across both the 1990-2000 and 2000-2010 periods.

Northern Africa: Among the five Northern African countries, Egypt, Mauritania, Morocco, and Tunisia experienced fluctuations in the direction of carbon intensity growth, while Algeria consistently demonstrated positive growth. Countries in the region maintained relatively consistent growth rates, with Algeria, Egypt, Mauritania, and Morocco sustaining similar growth rates in two of the three decades. Morocco, for example, experienced a 1% growth rate during both the 1990–2000 and 2010–2020 periods.

Central Africa: Seven out of the eight countries in the region, including Cameroon, Central African Republic, Chad, DR Congo, Congo Republic, Equatorial Guinea, and Gabon, witnessed shifts in the direction of carbon intensity growth between 1990 and 2020. Only Burundi consistently sustained positive growth. Notably, Burundi, the DR Congo, Congo Republic, and Gabon maintained similar growth rates in two of the three decades. For instance, Congo Republic maintained a 7% growth rate during both the 1990–2000 and 2010–2020 periods.

Western Africa: Ten out of the fourteen Western African countries—Burkina Faso, Côte d'Ivoire, Gambia, Ghana, Guinea-Bissau, Mali, Niger, Nigeria, Senegal and Togo—experienced directional changes in carbon intensity growth. Benin, Guinea, and Sierra Leone demonstrated consistent positive growth, albeit with significant differences in rates over the three decades. Cabo Verde exhibited negative growth in carbon intensity with variations in the magnitude of growth. Nonetheless, Benin, Gambia, Guinea, and Togo sustained similar growth rates in two of the three decades. Togo, for example, maintained a -2% growth rate in both the 1990-2000 and 2000-2010 periods.

Eastern Africa: Among the ten countries in the region—Comoros, Ethiopia, Kenya, Madagascar, Mauritius, Rwanda, Seychelles, Sudan, and Uganda—nine demonstrated swings in carbon intensity growth. Tanzania consistently recorded positive growth with differing magnitudes. Nonetheless, all countries (except Rwanda) sustained similar growth rates in two of the three decades. For instance, Tanzania maintained a growth rate of 4% during both the 1990-2000 and 2010-2020 periods.

Energy Intensity (Energy/GDP) Trends Across African Regions (1990-2020):

Southern Africa: Five out of the ten countries in the region—Angola, Eswatini, Lesotho, Mozambique, and Zambia—experienced fluctuations in the direction of energy intensity growth from 1990 to 2020. The remaining five-South Africa, Botswana, Malawi, Namibia, and Zimbabwe-consistently exhibited negative growth, mostly of differing magnitudes. Nevertheless, eight out of the ten countries maintained similar growth rates in at least two of the three decades: Angola, Botswana, Malawi, Mozambique, Namibia, South Africa, Zambia, and Zimbabwe. For example, Namibia sustained a -3% growth rate in both the 1990–2000 and 2000–2010 periods.

Northern Africa: Three out of the five Northern African countries—Algeria, Mauritania, and Tunisia—exhibited directional changes over the three decades. Egypt and Morocco consistently demonstrated negative growth. Notably, Algeria and Morocco had similar growth rates in two of the three decades. Algeria, for instance, maintained a -3% growth rate across the three decades.

Central Africa: Among the eight countries in the region—Burundi, the Central African Republic, Chad, Congo Republic, and Equatorial Guinea—five demonstrated considerable swings in the direction of energy intensity growth. Cameroon, the DR Congo, and Gabon experienced consistently negative growth rates of generally different magnitudes. Cameroon and Chad recorded similar growth rates in two of the three decades. For example, Chad recorded a -7.2% growth rate in the 1990–2000 period and a -7.8% growth rate in the 2000–2010 period.

Western Africa: Nine out of the fourteen Western African countries witnessed shifts in the direction of energy intensity growth between 1990 and 2020—Benin, Burkina Faso, Cabo Verde, Ghana, Mali, Niger, Nigeria, Senegal and Togo. The other five countries—Gambia, Guinea, Guinea-Bissau, Sierra Leone, and Côte d'Ivoire—exhibited negative growth, largely of varying magnitudes. Nonetheless, eight countries—Burkina Faso, Cabo Verde, Gambia, Guinea, Mali, Senegal, Sierra Leone, and Côte d'Ivoire—sustained similar growth rates in two of three decades. For instance, Guinea maintained a growth rate of -4% in the 1990-2000 and 2010-2020 periods.

Eastern Africa: Among the ten countries in the region, Madagascar, Seychelles, Sudan, and Uganda exhibited varying growth rates and directions in energy intensity over the three decades. Ethiopia, Kenya, Mauritius, Rwanda, and Tanzania demonstrated only negative growth with variations in the magnitude of growth. Only Comoros witnessed consistently positive growth in energy intensity between 1990 and 2020. Six countries in the region—Comoros, Ethiopia, Kenya, Mauritius, Tanzania, and Uganda maintained similar growth rates in at least two of the three decades. For example, Ethiopia maintained a growth rate of -2.5% in the 1990-2000 and 2010–2020 periods, and -2.6% in the 2000-2010 period.

Economic Rent (GDP/Capita) Trends Across African Regions (1990-2020):

Southern Africa: Only Angola and Zimbabwe experienced directional changes in the growth of economic rent, while the remaining countries—Botswana, Eswatini, Lesotho, Malawi, Mozambique,

Namibia, South Africa, and Zambia—consistently recorded positive growth with dissimilar rates over the three decades. Seven countries—Botswana, Eswatini, Lesotho, Malawi, South Africa, Zambia, and Zimbabwe—recorded similar growth rates in two of the three decades. For instance, Zimbabwe maintained a 2% growth rate across both the 1990-2000 and 2010-2020 periods.

Northern Africa: Among the five Northern African countries, Egypt, Mauritania, Morocco, and Tunisia consistently demonstrated positive growth, albeit with significant differences in magnitude between 1990 and 2020. Only Algeria experienced fluctuations in the direction of economic rent growth. Three out of the five countries—Egypt, Mauritania, and Tunisia- maintained similar growth rates in two of the three decades. Tunisia, for example, experienced a 5% growth rate during both the 1990–2000 and 2000-2010 periods.

Central Africa: Six out of the eight countries in the region—Burundi, Central African Republic, Chad, DR Congo, Congo Republic, and Equatorial Guinea—exhibited varying growth rates and directions in economic rent between 1990 and 2020. Only Cameroon and Gabon consistently sustained positive growth. Notably, Burundi, Cameroon, and Gabon maintained similar growth rates in two of the three decades. For instance, Burundi maintained a 2% growth rate during both the 2000-2010 and 2010-2020 periods.

Western Africa: Twelve out of the fourteen Western African countries—Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, Ghana, Guinea, Guinea-Bissau, Mali, Niger, Nigeria, Senegal and Togo—demonstrated consistent positive growth, albeit with significant differences in rates over the three decades. Only Gambia and Sierra Leone experienced swings in the direction of economic rent growth. All countries in the region (except Cabo Verde and Guinea Bissau) sustained similar growth rates in at least two of the three decades. Senegal, for example, maintained a 3% growth rate across the three decades.

Eastern Africa: All countries in the region (except Sudan) consistently recorded positive growth with varying magnitudes. Only Sudan witnessed directional shifts in the growth of economic rent. Seven out of the ten countries—Comoros, Ethiopia, Madagascar, Mauritius, Seychelles, Tanzania, and Uganda—sustained similar growth rates in two of the three decades. For instance, Mauritius maintained a growth rate of 6% during both the 1990-2000 and 2000-2010 periods.

Population Trends Across African Regions (1990-2020):

Southern Africa: All countries in the region consistently exhibited positive growth in population. Additionally, all Southern African countries maintained similar growth rates in at least two of the three decades. For example, both Mozambique and Zambia sustained a 3% growth rate across all three decades.

Northern Africa: The five Northern African countries experienced consistently positive growth rates. Furthermore, they also recorded similar growth rates in at least two of the three decades. Algeria and Egypt, for instance, maintained a 2% growth rate over the three decades.

Central Africa: All countries in the region witnessed only positive growth in population between 1990 and 2020. Additionally, they all recorded similar growth rates in at least two of the three decades. For example, Cameroon, the DR Congo, and Gabon maintained a 3% growth rate across the three decades.

Western Africa: All Western African countries demonstrated only positive growth over the three decades. Furthermore, they all recorded similar growth rates in at least two of the three decades. For instance, Benin, Burkina Faso, Gambia, Nigeria, Senegal, and Togo maintained a 3% growth rate over the three decades.

Eastern Africa: The ten countries in the region consistently recorded positive growth in population between 1990 and 2020. Additionally, all Eastern African countries sustained similar growth rates in at least two of the three decades. For example, Ethiopia, Madagascar, Tanzania, and Uganda recorded a 3% growth rate over the three decades.

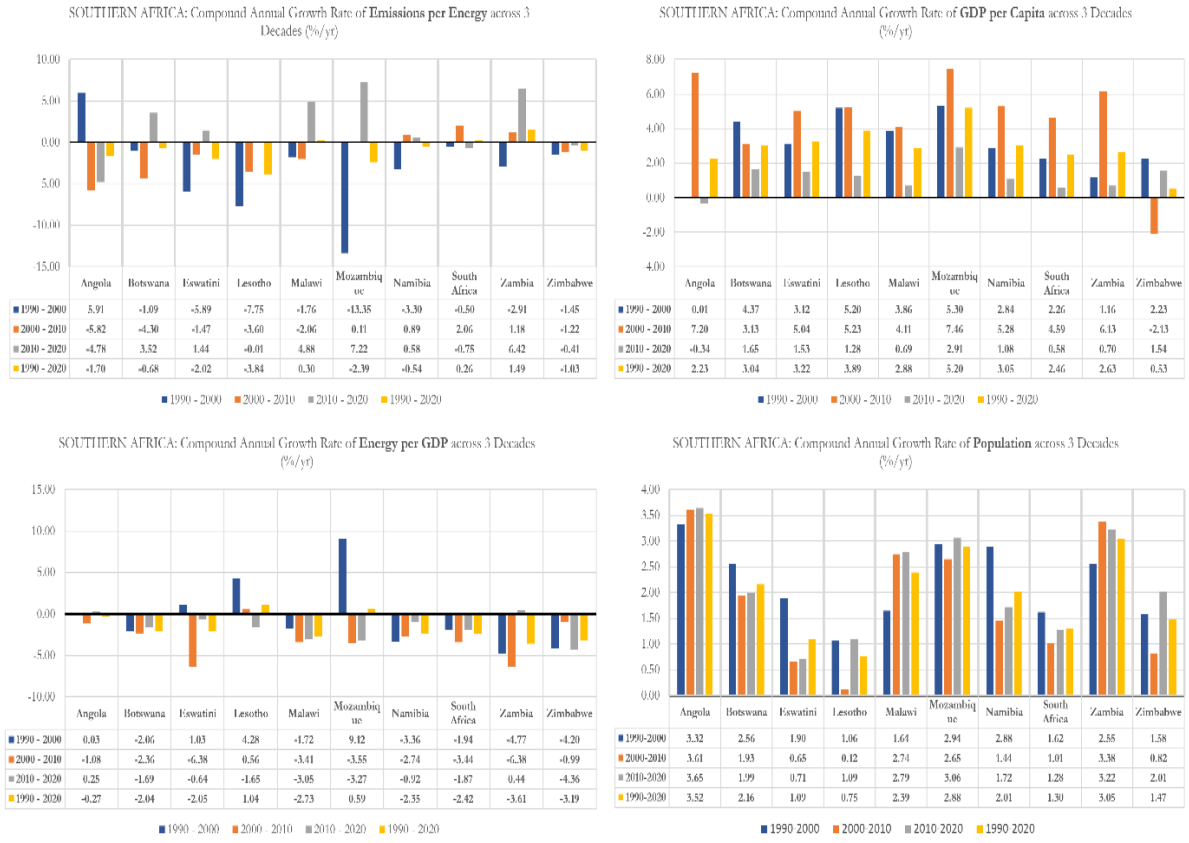


Figure A-3: ***Compound Annual Growth Rate for Kaya Identity Factors in Southern African Countries Between 1990 and 2020.*** *The historical data reveals notable variations in the direction and scale of growth across the three decades under consideration*

for mainly Emissions per Energy, GDP per Capita, and Energy per GDP. Population has consistently recorded positive growth over the past three decades across African countries.



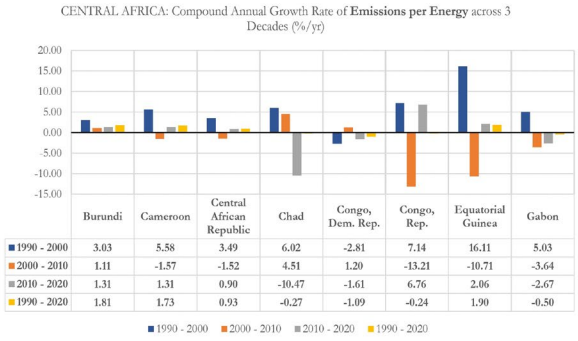
	Algeria	Egypt	Mauritania	Morocco	Tunisia
1990 - 2000	1.97	-0.77	0.47	0.95	-0.54
2000 - 2010	0.22	0.00	0.53	-1.01	3.03
2010 - 2020	0.14	0.19	-0.60	0.98	-2.05
1990 - 2020	0.77	-0.20	0.13	0.30	0.13

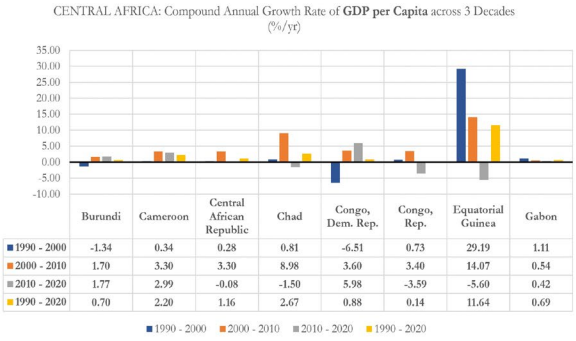
	Algeria	Egypt	Mauritania	Morocco	Tunisia
1990 - 2000	2.01	4.37	1.04	3.59	5.21
2000 - 2010	4.44	4.93	3.50	5.79	5.34
2010 - 2020	-1.37	3.43	2.99	1.55	0.17
1990 - 2020	1.67	4.24	2.50	3.63	3.55

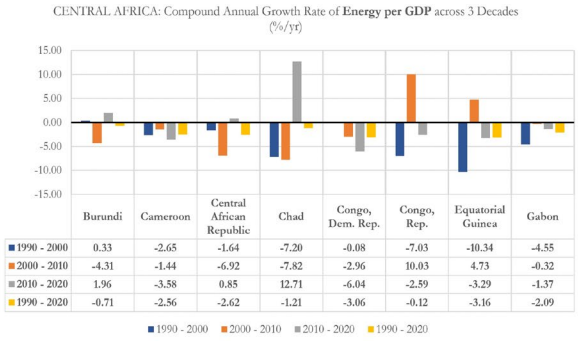
	Algeria	Egypt	Mauritania	Morocco	Tunisia
1990 - 2000	-3.35	-3.00	-1.60	-1.72	-2.48
2000 - 2010	-2.51	-1.23	-0.18	-1.35	-6.01
2010 - 2020	2.83	-5.01	1.10	-1.19	1.15
1990 - 2020	-1.05	-3.09	-0.23	-1.42	-2.49

	Algeria	Egypt	Mauritania	Morocco	Tunisia
1990-2000	1.89	2.24	3.00	1.51	1.60
2000-2010	1.54	2.03	2.41	1.29	0.97
2010-2020	1.94	2.11	2.78	1.23	1.11
1990-2020	1.79	2.12	2.73	1.35	1.23

*Figure A-4: **Compound Annual Growth Rate for Kaya Identity Factors in Northern African Countries Between 1990 and 2020**. The historical data reveals notable variations in the direction and scale of growth across the three decades under consideration for mainly Emissions per Energy, GDP per Capita, and Energy per GDP. Population has consistently recorded positive growth over the past three decades across African countries.*







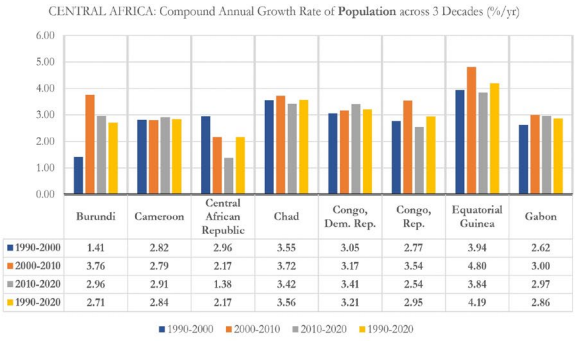


Figure A-5: ***Compound Annual Growth Rate for Kaya Identity Factors in Central African Countries Between 1990 and 2020.*** *The historical data reveals notable variations in the direction and scale of growth across the three decades under consideration for mainly Emissions per Energy, GDP per Capita, and Energy per GDP. Population has consistently recorded positive growth over the past three decades across African countries.*

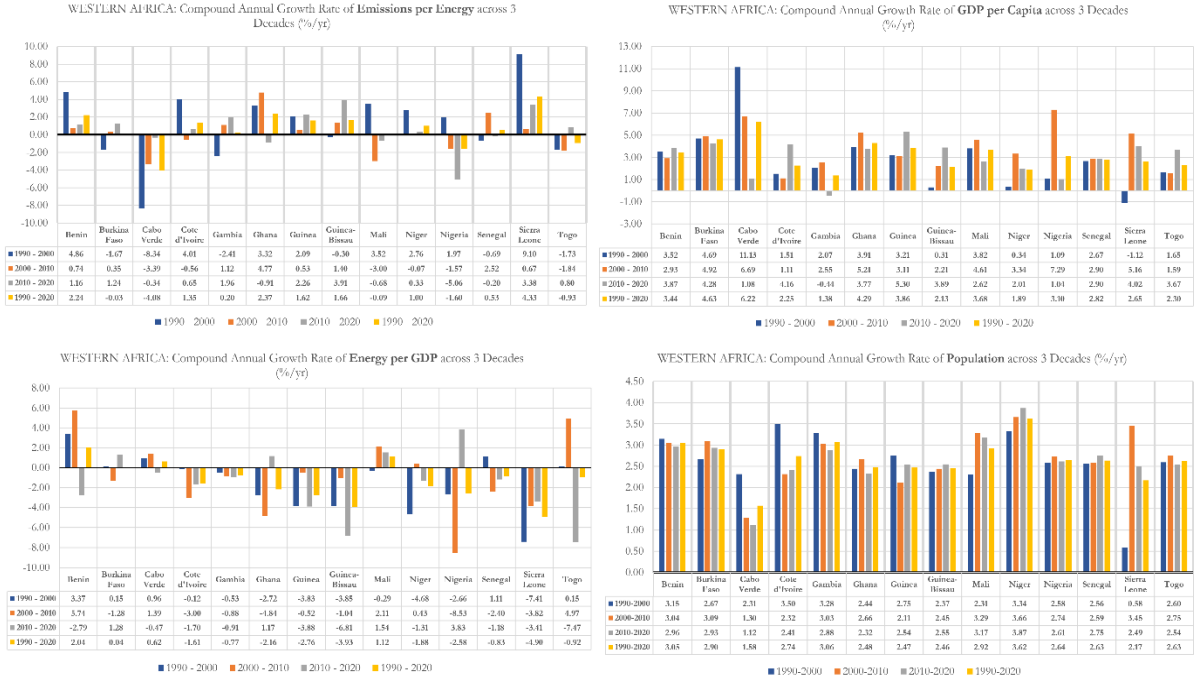


Figure A-6: ***Compound Annual Growth Rate for Kaya Identity Factors in Western African Countries Between 1990 and 2020.*** *The historical data reveals notable variations in the direction and scale of growth across the three decades under consideration for mainly Emissions per Energy, GDP per Capita, and Energy per GDP. Population has consistently recorded positive growth over the past three decades across African countries.*

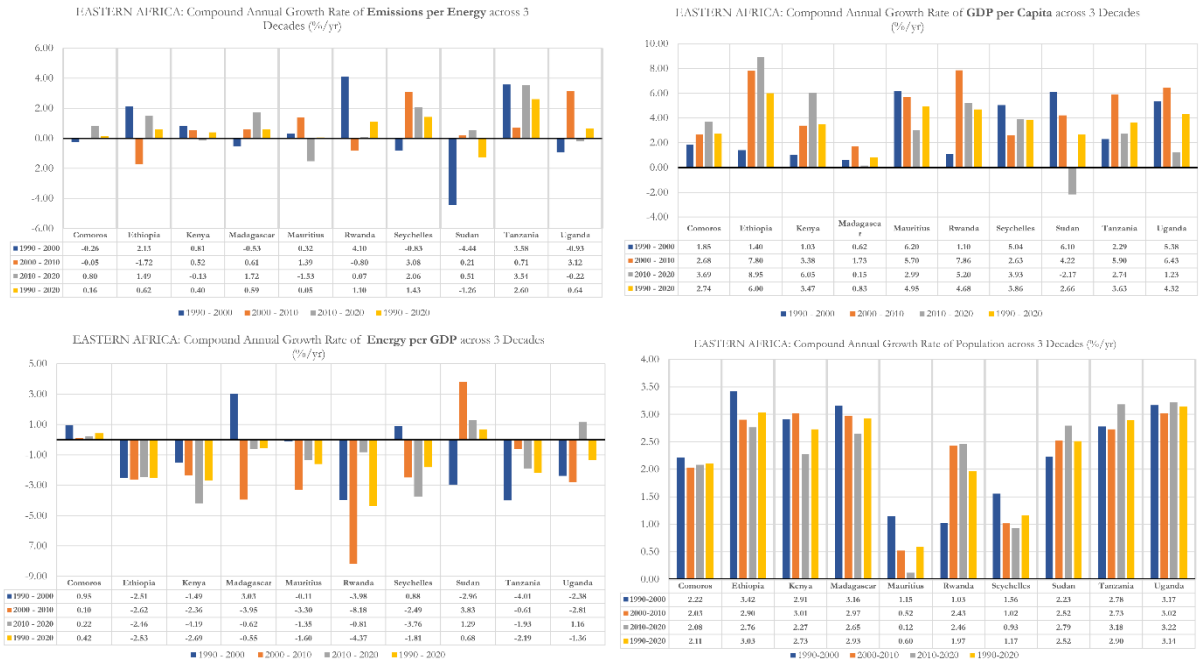


Figure A-7: ***Compound Annual Growth Rate for Kaya Identity Factors in Eastern African Countries Between 1990 and 2020.*** *The historical data reveals notable variations in the direction and scale of growth across the three decades under consideration for mainly Emissions per Energy, GDP per Capita, and Energy per GDP. Population has consistently recorded positive growth over the past three decades across African countries.*

Correlation Analysis Between Carbon Intensity (Emissions/Energy) Values and Share of Renewables in Electricity Generation:

To explore possible drivers of the observed trends, we analyze data from the World Bank [2] and the US EIA [7] to examine whether the emission/energy values for the 47 African countries are correlated with the share of renewables in their electricity generation mixes from 1990 to 2020. Using both the Pearson and Spearman rank correlation coefficients, we quantify the relationship between these variables. The results, presented in Table A-3, reveal a significant and strong negative correlation for 17 countries, indicating, as expected, that as the share of renewables increases, emissions per unit of energy decrease. Conversely, 13 countries exhibit a significant positive correlation, suggesting the presence of confounding factors. In these nations, and in the 17 others with no significant correlation, other sectors, such as transportation, may be more influential drivers of energy emissions.

Table A-3: Results of Correlation Analysis of Carbon Intensity Values and the Share of Renewables in Countries' Electricity Mixes. Statistical Significance is highlighted in green.

Country	Pearson Correlation Coefficient	Pearson P-Value	Pearson Significant (p-value < 0.05)	Spearman Rank Correlation Coefficient	Spearman P-Value	Spearman Significant (p-value < 0.05)
Algeria	-0.436	0.01409	TRUE	-0.295	0.10696	FALSE
Angola	-0.079	0.67400	FALSE	-0.055	0.76952	FALSE
Benin	0.566	0.00090	TRUE	0.375	0.03747	TRUE
Botswana	0.086	0.64471	FALSE	0.215	0.24547	FALSE
Burkina Faso	-0.495	0.00468	TRUE	-0.427	0.01658	TRUE
Burundi	-0.752	0.00000	TRUE	-0.796	0.00000	TRUE
Cabo Verde	-0.458	0.00959	TRUE	-0.501	0.00413	TRUE
Cameroon	0.205	0.26903	FALSE	0.191	0.30303	FALSE
Central African Republic	-0.093	0.62014	FALSE	-0.195	0.29286	FALSE
Chad	-0.714	0.00001	TRUE	-0.685	0.00002	TRUE
Comoros	0.512	0.00327	TRUE	0.351	0.05322	FALSE
Congo, Rep.	0.706	0.00001	TRUE	0.807	0.00000	TRUE
Congo , Dem. Rep. (DR Congo)	-0.231	0.21168	FALSE	-0.313	0.08654	FALSE
Cote D'Ivoire	-0.754	0.00000	TRUE	-0.624	0.00018	TRUE
Egypt	0.095	0.60934	FALSE	-0.007	0.97081	FALSE
Equatorial Guinea	-0.427	0.01656	TRUE	-0.325	0.07457	FALSE
Eswatini	-0.917	0.00000	TRUE	-0.692	0.00002	TRUE
Ethiopia	0.436	0.01415	TRUE	0.151	0.41806	FALSE
Gabon	0.551	0.00131	TRUE	0.502	0.00404	TRUE
Gambia	-0.028	0.88297	FALSE	-0.018	0.92351	FALSE
Ghana	-0.804	0.00000	TRUE	-0.746	0.00000	TRUE
Guinea	0.028	0.88097	FALSE	-0.108	0.56136	FALSE
Guinea-Bissau	0.864	0.00000	TRUE	0.680	0.00003	TRUE
Kenya	-0.114	0.53968	FALSE	-0.153	0.41179	FALSE
Lesotho	0.408	0.05963	FALSE	0.700	0.00029	TRUE
Madagascar	-0.248	0.17902	FALSE	-0.284	0.12172	FALSE
Malawi	-0.354	0.05038	FALSE	-0.246	0.18153	FALSE
Mali	-0.355	0.04987	TRUE	-0.264	0.15173	FALSE
Mauritania	-0.041	0.82758	FALSE	-0.254	0.16750	FALSE

Mauritius	0.350	0.05384	FALSE	0.267	0.14597	FALSE
Morocco	-0.447	0.01169	TRUE	-0.469	0.00779	TRUE
Mozambique	-0.600	0.00036	TRUE	-0.825	0.00000	TRUE
Namibia	-0.149	0.46852	FALSE	-0.277	0.17028	FALSE
Niger	0.369	0.04107	TRUE	0.474	0.00703	TRUE
Nigeria	0.808	0.00000	TRUE	0.749	0.00000	TRUE
Rwanda	-0.845	0.00000	TRUE	-0.532	0.00206	TRUE
Senegal	0.463	0.00871	TRUE	0.444	0.01236	TRUE
Seychelles	0.496	0.00450	TRUE	0.543	0.00158	TRUE
Sierra Leone	0.726	0.00000	TRUE	0.751	0.00000	TRUE
South Africa	0.409	0.02244	TRUE	0.418	0.01937	TRUE
Sudan	-0.191	0.30449	FALSE	-0.341	0.06037	FALSE
Tanzania	-0.750	0.00000	TRUE	-0.816	0.00000	TRUE
Togo	0.241	0.19248	FALSE	0.167	0.37058	FALSE
Tunisia	0.187	0.31283	FALSE	0.318	0.08112	FALSE
Uganda	-0.639	0.00011	TRUE	-0.733	0.00000	TRUE
Zambia	-0.893	0.00000	TRUE	-0.715	0.00001	TRUE
Zimbabwe	-0.896	0.00000	TRUE	-0.920	0.00000	TRUE

Africa's Potential Future Emissions Based on Mean and Median Values

Maintaining the medium variant of the UN population projections as in the four key scenarios considered in this paper (low, high, mid and green), we also estimate future emissions from the continent using the mean and median values of the emissions/energy, energy/GDP, and GDP/capita metrics for each of the 47 countries from 1990 to 2020.

Using the median values, we project that Africa's emissions could rise from ~1225 $MtCO_2e$ in 2020 to ~1600 $MtCO_2e$ in 2030, ~2200 $MtCO_2e$ in 2040, and ~3200 $MtCO_2e$ in 2050. These results are most similar to those obtained in the mid-growth scenario.

Similar to the high-growth scenario, the estimated emissions for Equatorial Guinea and Benin using the mean growth rates had to be capped. For these countries, we found that the estimated emissions using the emissions cap of 38.4 tCO_2e were lower than the estimates using the Kaya Identity based on mean growth rates. Equatorial Guinea's emissions are capped across the three decades, while Benin's are only capped in 2050. Based on the mean growth rates, we find that the continent's energy emissions could rise to ~1800 $MtCO_2e$ in 2030, ~2800 $MtCO_2e$ in 2040 and ~4700 $MtCO_2e$ in 2050. These estimates fall between the results from the mid-growth and high-growth scenario, leaning close to the mid-growth scenario.

3. Defining 'Large Economies'

In this study, we datalog 'large economies' as the top 10 countries with the highest annual fossil fuel CO_2 emissions [2] and highest GDP rankings [10].

Table A-4: 'Large Economies' according to Emissions and GDP ranking

Country/Region	Ranking according to 2020 emissions	Share of Global Fossil Fuel CO_2 Emissions (2020) (%)	Economic ranking according to CEBR 2022 League Table
China	1	32.6	2
USA	2	12.9	1
India	3	6.6	5
Russia	4	4.8	9
Japan	5	3.0	3
Iran	6	1.8	11
Germany	7	1.8	4
South Korea	8	1.7	13
Indonesia	9	1.7	17
Canada	10	1.5	8
United Kingdom	18	0.9	6
Italy	19	0.8	10
France	21	0.8	7

Table A-5: Climate Pledges for 10 Large Economies

		Commitments / Greenhouse Gas (GHG) reduction percentage/target [11-16]			
Region	**2020 Fossil fuel CO2 emissions (MtCO2)** [2]	**2030**[103]	**2050**	**2060**	**2070**
China	10945	Over 65% reduction in emissions intensity of GDP relative to 2005 value.		Net Zero Target (carbon neutrality)	
USA	4321	50 – 52% reduction in GHG emissions relative to 2005 value	Net Zero Target		
European Union	2465	55% reduction in GHG emissions relative to 1990 value	Net Zero Target		

[103] Where a range is given, we use the higher value to estimate emission savings.

India	2201	45% reduction in emissions intensity of GDP relative to 2005 value.			Net Zero Target
Russia	1618	30% reduction in GHG emissions relative to 1990 value (reduction to 70% relative to the 1990 level)	80% reduction in GHG emissions relative to 1990 level	Net Zero Target	
Japan	1014	46% reduction in GHG emissions relative to 2013 levels (760 $MtCO_2eq$)	Net Zero Target		
Indonesia	563	31.89% reduction (unconditional/without support) or 43.20% reduction (conditional/including international support) in GHG emissions relative to baseline emissions level (2869 $MtCO_2eq$)		Net Zero Target (explicit net-zero target has not been communicated. Modeled scenarios, however, target net-zero by 2060)	
South Korea	570	40% reduction relative to the 2018 level (727.6 $MtCO_2eq$)	Net Zero Target (Carbon Neutrality)		
Canada	517	40 – 45% reduction in GHG emissions below 2005 level (438 $MtCO_2eq$)	Net Zero Target		
United Kingdom	309	68% reduction in GHG emissions relative to 1990 value	Net Zero Target		

4. CO_2 Emissions Growth Factor Over Historical 3-Decade Periods for Specific Countries and Continents

Table A-6: CO_2 Emissions Growth Factor Across Specific Countries and Continents Over Historical 30-Year Periods

30-yr period	**CO_2 Emissions Growth Factor** [17]	
	Certain Countries	**Certain Continents**

	USA	UK	China	India	Europe	Asia	North America	South America	Africa
1780 - 1810		2.2			2.5				
1810 - 1840	14.1	2.3			2.9		13.9		
1840 - 1870	16.8	2.8			3.8		17		
1870 - 1900	6.7	1.8			2.8	65	6.9		
1900 - 1930	2.6	1.1		3.6	1.4	5.9	2.7	9.2	14.5
1930 - 1960	1.7	1.3	16.1	2.6	2.3	6	1.7	6.8	4.6
1960 - 1990	1.8	1	3.1	5.2	2	4.3	1.9	3	4.2
1990 - 2020	0.9	0.5	4.4	4.2	0.6	3.1	1	1.6	2.1

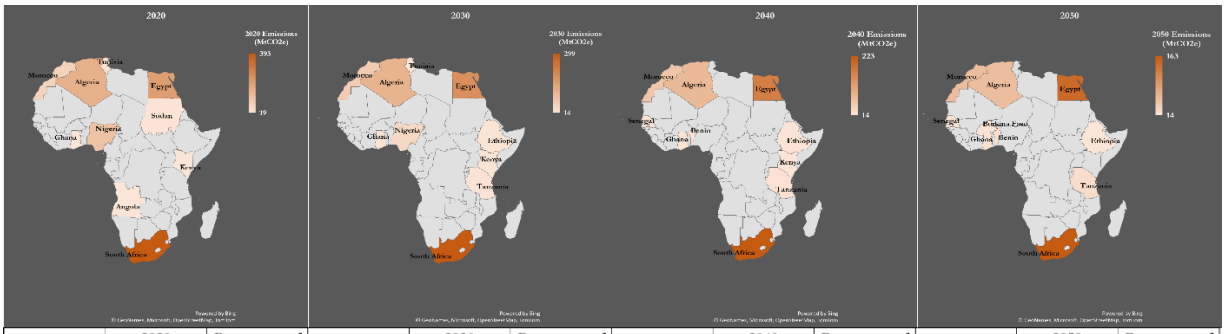
5. Country-Level Trends

As of 2020, the top 5 emitters in Africa (South Africa, Egypt, Algeria, Nigeria, and Morocco) accounted for about 74% of total emissions from the continent [2]. Including the next 5 top emitters (Libya, Tunisia, Angola, Ghana, and Sudan) raises the percentage contribution to 85% [2].

Across the low-growth, mid-growth, green-growth and high-growth scenarios, the top 10 emitters from 2020–2050 account for between 78–87% of the annual emissions from the continent. However, there are noteworthy shifts in what countries feature in this subgroup depending on the decade and scenario. These differences are discussed here and displayed in Figures A-8–A-11 below which show the top 10 emitters on the continent in 2020, 2030, 2040, and 2050 across the different scenarios.

For the subset of 47 countries included in this study, the top 10 emitters in 2020 were South Africa, Egypt, Algeria, Nigeria, Morocco, Tunisia, Sudan, Angola, Kenya and Ghana. For easy reference, we tag these countries as the 'starting group'. It is worth mentioning that there is a wide gap in emissions across these countries. For example, South Africa's 2020 emissions are over 20 times Kenya's in the same year.

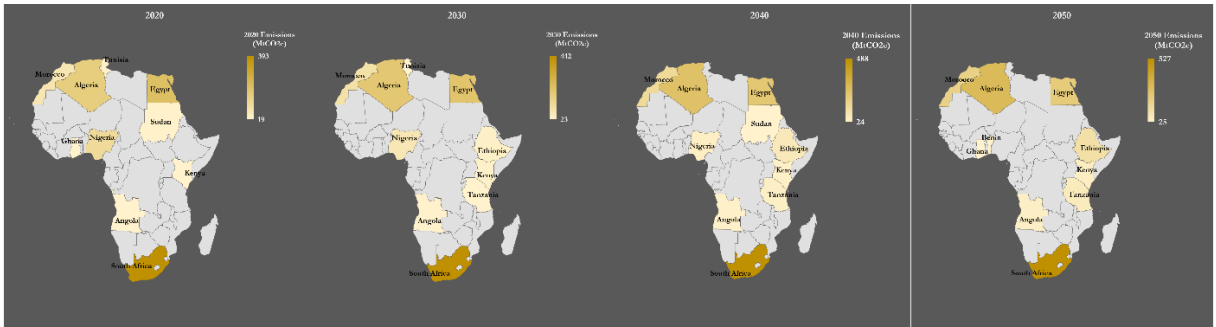
In the low-growth scenario, by 2030, Sudan and Angola will be replaced in the top 10 list by Ethiopia and Tanzania. Moving ahead to 2040, Nigeria and Tunisia also yield their positions to Benin and Senegal, while by 2050, Burkina Faso will take the place of Kenya, leaving just four countries from the 'starting group' on the top 10 list (Figure A-8). This evolving landscape underscores the importance of not only focusing on the historically significant 'starting group' of nations, responsible for approximately 86% of the continent's emissions in 2020, but also acknowledging the growing prominence of five additional countries in the low-growth scenario: Ethiopia, Tanzania, Benin, Senegal, and Burkina Faso. These emerging nations are poised to play an increasingly pivotal role if the nations on the continent experience subdued growth in energy intensity, carbon intensity, and economic rent. We refer to this second group of countries as the 'emerging group' for ease of reference.



	2020 Emissions (MtCO2e)	Percentage of Africa's Emissions (%)		2030 Emissions (MtCO2e)	Percentage of Africa's Emissions (%)		2040 Emissions (MtCO2e)	Percentage of Africa's Emissions (%)		2050 Emissions (MtCO2e)	Percentage of Africa's Emissions (%)
South Africa	393	32	**South Africa**	299	32	**South Africa**	223	30	**South Africa**	163	27
Egypt	211	17	**Egypt**	190	21	**Egypt**	169	23	**Egypt**	147	24
Algeria	162	13	**Algeria**	116	13	**Algeria**	81	11	**Morocco**	57	9
Nigeria	112	9	**Morocco**	65	7	**Morocco**	61	8	**Algeria**	55	9
Morocco	67	5	**Nigeria**	38	4	**Tanzania**	20	3	**Tanzania**	22	4
Tunisia	29	2	**Ghana**	19	2	**Ghana**	18	2	**Benin**	20	3
Sudan	21	2	**Tanzania**	17	2	**Senegal**	16	2	**Senegal**	18	3
Angola	20	2	**Ethiopia**	17	2	**Ethiopia**	15	2	**Ghana**	16	3
Kenya	19	2	**Kenya**	17	2	**Benin**	15	2	**Burkina Faso**	15	2
Ghana	19	2	**Tunisia**	14	2	**Kenya**	14	2	**Ethiopia**	14	2
Total Contribution	1053	**86**	**Total Contribution**	793	**86**	**Total Contribution**	633	**86**	**Total Contribution**	527	**87**

Figure A-8: Top 10 emitters in Africa and their percentage contribution in 2020, 2030, 2040, and 2050 based on the low-growth scenario

Similarly, **in the green-growth scenario**, Sudan and Ghana will be replaced by Ethiopia and Tanzania by 2030. Sudan is projected to rejoin the list in 2040, taking Tunisia's place before being replaced by Ghana in 2050. Nigeria will also drop off the list, making way for Benin in 2050 (Figure A-9). In this scenario, seven countries from the 'starting group' will remain on the top 10 list by 2050, with Ethiopia, Tanzania, and Benin in the 'emerging group'.

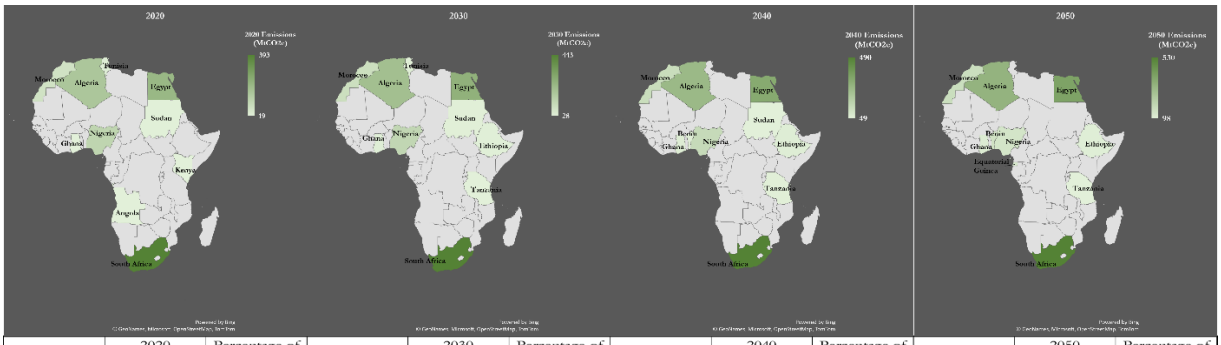


	2020 Emissions (MtCO2e)	Percentage of Africa's Emissions (%)		2030 Emissions (MtCO2e)	Percentage of Africa's Emissions (%)		2040 Emissions (MtCO2e)	Percentage of Africa's Emissions (%)		2050 Emissions (MtCO2e)	Percentage of Africa's Emissions (%)
South Africa	393	32	**South Africa**	442	32	**South Africa**	488	31	**South Africa**	527	29
Egypt	211	17	**Egypt**	220	16	**Algeria**	253	16	**Algeria**	308	17
Algeria	162	13	**Algeria**	206	15	**Egypt**	226	14	**Egypt**	226	12
Nigeria	112	9	**Morocco**	98	7	**Morocco**	139	9	**Morocco**	195	11
Morocco	67	5	**Nigeria**	70	5	**Ethiopia**	65	4	**Ethiopia**	116	6
Tunisia	29	2	**Ethiopia**	35	3	**Nigeria**	42	3	**Tanzania**	62	3
Sudan	21	2	**Kenya**	27	2	**Tanzania**	39	3	**Kenya**	49	3
Angola	20	2	**Angola**	26	2	**Kenya**	37	2	**Angola**	41	2
Kenya	19	2	**Tanzania**	24	2	**Angola**	34	2	**Benin**	27	1
Ghana	19	2	**Tunisia**	23	2	**Sudan**	24	2	**Ghana**	25	1
Total Contribution	1053	**86**	**Total Contribution**	1172	**86**	**Total Contribution**	1347	**86**	**Total Contribution**	1575	**86**

Figure A-9: Top 10 emitters in Africa and their percentage contribution in 2020, 2030, 2040, and 2050 based on the green-growth scenario

In the mid-growth scenario, Ethiopia and Tanzania will take the place of Angola and Kenya in the top 10 list by 2030. Benin will join the list in 2040 and Equatorial Guinea in 2050, replacing Tunisia and Sudan, respectively (Figure A-10). Thus, six countries from the 'starting group' will remain in the

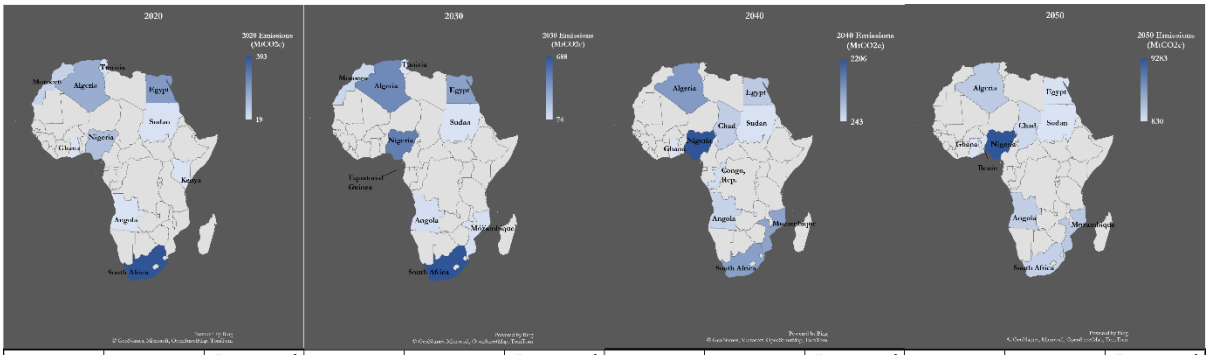
top 10 list by 2050, with Ethiopia, Tanzania, Benin, and Equatorial Guinea constituting the 'emerging group'.



	2020 Emissions (MtCO2e)	Percentage of Africa's Emissions (%)		2030 Emissions (MtCO2e)	Percentage of Africa's Emissions (%)		2040 Emissions (MtCO2e)	Percentage of Africa's Emissions (%)		2050 Emissions (MtCO2e)	Percentage of Africa's Emissions (%)
South Africa	393	32	**South Africa**	443	28	**South Africa**	490	24	**South Africa**	530	19
Egypt	211	17	**Egypt**	266	17	**Egypt**	331	16	**Egypt**	402	14
Algeria	162	13	**Algeria**	212	13	**Algeria**	268	13	**Algeria**	336	12
Nigeria	112	9	**Nigeria**	126	8	**Nigeria**	136	7	**Morocco**	170	6
Morocco	67	5	**Morocco**	93	6	**Morocco**	127	6	**Benin**	157	6
Tunisia	29	2	**Ghana**	36	2	**Ghana**	66	3	**Nigeria**	143	5
Sudan	21	2	**Tunisia**	35	2	**Ethiopia**	61	3	**Equatorial Guinea**	139	5
Angola	20	2	**Ethiopia**	34	2	**Benin**	60	3	**Ghana**	117	4
Kenya	19	2	**Sudan**	33	2	**Tanzania**	54	3	**Ethiopia**	106	4
Ghana	19	2	**Tanzania**	28	2	**Sudan**	49	2	**Tanzania**	98	4
Total Contribution	1053	**86**	**Total Contribution**	1307	**83**	**Total Contribution**	1643	**79**	**Total Contribution**	2197	**78**

Figure A-10: Top 10 emitters in Africa and their percentage contribution in 2020, 2030, 2040, and 2050 based on the mid-growth scenario

In the high-growth scenario, we find that Equatorial Guinea and Mozambique will grow to replace Kenya and Ghana in the top 10 list by 2030. Ghana, the Republic of Congo (Congo Republic) and Chad will join the list in 2040, taking the place of Morocco, Tunisia and Equatorial Guinea. Then, in 2050, the Republic of Congo (Congo Republic) will yield its place to Benin (Figure A-11). In this scenario, seven countries from the 'starting group' will remain in the top 10 list by 2050.



	2020 Emissions (MtCO2e)	Percentage of Africa's Emissions (%)		2030 Emissions (MtCO2e)	Percentage of Africa's Emissions (%)		2040 Emissions (MtCO2e)	Percentage of Africa's Emissions (%)		2050 Emissions (MtCO2e)	Percentage of Africa's Emissions (%)
South Africa	393	32	**South Africa**	688	22	**Nigeria**	2206	22	**Nigeria**	9283	33
Egypt	211	17	**Nigeria**	505	16	**Algeria**	1256	12	**Mozambique**	2421	9
Algeria	162	13	**Algeria**	459	14	**South Africa**	1179	12	**Algeria**	2304	8
Nigeria	112	9	**Egypt**	357	11	**Mozambique**	1124	11	**Angola**	2078	7
Morocco	67	5	**Morocco**	126	4	**Egypt**	597	6	**South Africa**	1977	7
Tunisia	29	2	**Angola**	97	3	**Chad**	542	5	**Chad**	1400	5
Sudan	21	2	**Mozambique**	90	3	**Angola**	458	5	**Egypt**	972	3
Angola	20	2	**Tunisia**	80	3	**Congo, Rep.**	335	3	**Benin**	970	3
Kenya	19	2	**Equatorial Guinea**	77	2	**Sudan**	253	2	**Sudan**	841	3
Ghana	19	2	**Sudan**	74	2	**Ghana**	243	2	**Ghana**	830	3
Total Contribution	1053	**86**	**Total Contribution**	2553	**80**	**Total Contribution**	8192	**81**	**Total Contribution**	23075	**83**

Figure A-11: Top 10 emitters in Africa and their percentage contribution in 2020, 2030, 2040, and 2050 based on the high-growth scenario

Within the 'starting group', we observed that South Africa, Egypt, and Algeria will likely remain in the top 10 list across all scenarios and years considered. For the seven other countries in the 'starting group', their presence in the top 10 list is dependent on the scenario that materializes on the continent. Alongside the pivotal 'starting group' nations, the various scenarios shed light on the significance of nine additional countries in the context of emissions mitigation on the continent: Ethiopia, Tanzania, Benin, Senegal, Burkina Faso, Equatorial Guinea, Mozambique, The Republic of Congo (Congo Republic), and Chad. The role of this 'emerging group' of nations is also dependent on the scenario and decade.

While the evolving list of top 10 emitters highlights the potential variance in emissions growth across African countries under different growth scenarios, the relatively consistent presence of certain nations on the list suggests that the disparity in emissions from the continent will likely persist in the coming decades. Due to factors such as GDP, population, and existing energy systems, certain countries are poised to maintain their dominance in emissions. Simultaneously, the identification of these 19 countries within the 'starting group' and 'emerging group' underscores that at least 28 African countries[104] pose no significant risk to carbon targets. Regardless of the pattern or level of economic rent, energy intensity, and carbon intensity growth on the continent, these countries account for just 1 – 22% of the continent's emissions across all considered scenarios and years.

[104] Botswana, Burundi, Cabo Verde, Cameroon, Central Africa Republic, Comoros, Democratic Republic of Congo, Cote d'Ivoire, Eswatini, Gabon, The Gambia, Guinea, Guinea-Bissau, Lesotho, Madagascar, Malawi, Mali, Mauritania, Mauritius, Namibia, Niger, Rwanda, Seychelles, Sierra Leone, Togo, Uganda, Zambia, Zimbabwe.

6. Proposed Mitigation Strategies in Key African Countries

A review of the Nationally Determined Contributions (NDCs) submitted by the 19 key countries identified above reveals several proposed mitigation strategies for the energy sector, including increasing electricity generation from renewable energy sources; advancing energy efficiency across sectors such as industry, transport, and buildings; deploying clean cooking solutions (e.g., improved cookstoves, liquefied petroleum gas (LPG) and electric cookstoves); developing mass transit systems and transitioning to natural gas, biofuels, and electricity for powering vehicles; and reducing gas flaring (Figure A-12).

PROPOSED MITIGATION MEASURES FOR THE ENERGY SECTOR IN SUBMITTED NDCs

S/N	Group	Country	General economy-wide target/grid-based target	Increase Electricity from Renewable Energy Sources: Switch industry fuel to electricity and/or sustainable biomass – Further details not provided	Increase Electricity from Renewable Energy Sources: Switch industry fuel to electricity and/or sustainable biomass – Specific/additional interventions/sub-activities provided: Promote micro-generation of energy	Increase Electricity from Renewable Energy Sources: Roll out decentralized renewables - Renewables for lighting (particularly in rural households) and powering household appliances; for commercial, residential, and public buildings (health/medical centres); productive use of energy (e.g., agricultural irrigation, livestock watering, fish conservation)	Increase Electricity from Renewable Energy Sources: Advance improved clean power interconnections with neighbouring countries	Increase Electricity from Renewable Energy Sources: No specific sectors or strategies mentioned or economy-wide plan/target	Advance Energy Efficiency (EE): Deploy High-performance, low-energy Lighting (LEDs, efficient lamps) – Further details not provided	Advance Energy Efficiency (EE): Deploy High-performance, low-energy Lighting – Specific/additional interventions/sub-activities provided: Eliminate kerosene lighting (e.g. using clean decentralized power, extending grid connection)	Advance Energy Efficiency (EE): Promote EE particularly in refrigeration and air conditioning	Advance Energy Efficiency (EE): Buildings (residential and commercial) (e.g. through thermal insulation) – Sub-sectors not provided	Advance Energy Efficiency (EE): Buildings – Specific sub-sector mentioned: Agriculture and maritime fishing	Advance Energy Efficiency (EE): Transport (including freight, rail, road, etc)	Advance Energy Efficiency (EE): Industry	Electricity Generation: Convert simple cycle turbines to combined cycle turbines	Electricity Generation: Upgrade transmission and distribution networks (to reduce T&D losses, create "smart grid", extend connections/ electrification)	Electricity Generation: Eliminate diesel, fuel oil and gasoline generators for electricity generation	Reduce Transport Sector Emissions (beyond energy efficiency efforts): Encourage modal shift from private passenger vehicles – Adopt/ improve mass transit options and/or develop associated infrastructure	Reduce Transport Sector Emissions: Encourage modal shift – "Expand inter-city and intra-city transportation modes"	Reduce Transport Sector Emissions: Encourage modal shift – Encourage "Ecomobility", non-motorized transport (walking, using bicycles)	Reduce Transport Sector Emissions: Promote the use of "low-carbon" or "clean/renewable" energy in transportation systems – no specific fuel provided	Reduce Transport Sector Emissions: Promote low-carbon energy – Introduce/ operate hybrid and electric vehicle options (including for mass transit, trains, personal vehicles)	Reduce Transport Sector Emissions: Promote low-carbon energy – Introduce biofuels	Reduce residential biomass and charcoal use/ advance clean cooking solutions, also in productive use (drying ovens for fishing sector) (e.g. using electric stoves, renewable biofuels, improved cookstoves)	Increase use of natural gas to advance decarbonization: No specific sectors highlighted	Increase use of natural gas: Electricity	Increase use of natural gas: Industry	Increase use of natural gas: Households (e.g. for cooking)	Increase use of natural gas: Transport (e.g. natural gas for buses)	Increase use of natural gas: No specific sub-activities highlighted	Decarbonize oil and gas production: Reduce gas flaring and fugitive emissions – No specific sub-activities highlighted	Decarbonize oil and gas production: Reduce gas flaring and fugitive emissions – Recover and utilize associated gases (e.g. to produce LPG, natural gas and condensates)	Decarbonize oil and gas production: Produce green fuels/petrochemicals e.g. oil from plastic waste, algae oil, biofuels
1	Starting Group	South Africa	✓					✓						✓					✓		✓		✓	✓			✓			✓				
2		Egypt	✓	✓		✓			✓			✓			✓	✓	✓		✓		✓		✓	✓					✓	✓	✓	✓	✓	✓
3		Algeria	✓						✓			✓														✓						✓		
4		Nigeria	✓			✓		✓		✓				✓		✓	✓	✓	✓						✓				✓	✓		✓		
5		Morocco	✓								✓	✓	✓	✓	✓				✓				✓				✓							
6		Tunisia	✓	✓								✓			✓		✓		✓				✓											
7		Sudan	✓			✓						✓					✓		✓					✓	✓				✓					
8		Angola	✓	✓		✓			✓																					✓		✓		
9		Kenya	✓					✓						✓								✓			✓									
10		Ghana	✓			✓					✓	✓								✓					✓						✓			
11	Emerging Group	Ethiopia		✓			✓	✓											✓				✓		✓									
12		Tanzania	✓			✓	✓												✓		✓	✓			✓		✓		✓	✓				
13		Benin	✓			✓			✓	✓	✓	✓		✓			✓		✓						✓		✓		✓					
14		Senegal	✓			✓		✓							✓			✓	✓				✓		✓		✓	✓						
15		Burkina Faso	✓			✓			✓		✓								✓															
16		Equatorial Guinea	✓	✓		✓			✓		✓			✓	✓		✓		✓				✓		✓				✓					
17		Mozambique	✓		✓	✓			✓			✓					✓		✓						✓		✓		✓	✓				
18		Republic of Congo	✓			✓			✓		✓	✓					✓						✓		✓			✓				✓		
19		Chad	✓						✓					✓			✓		✓						✓		✓							

Figure A-12: Proposed mitigation measures for the energy sector in submitted NDCs of key African countries.

7. Electricity Generation by Fuel Type

Table A-7: Relevant indicators related to electricity generation by fuel type for the 19 core African emitters identified in the study. The indicators are depicted using a two-color scale featuring varying shades of green and white. Deeper shades of green signify higher values. Data obtained from the World Bank Databank [5] and the U.S. Energy Information Administration [7].

	Electricity Generated (TWh)		Electricity Generation per capita (kWh/capita)		Share of Renewables in Electricity Generation	
	Year - 1990	Year - 2020	Year - 1990	Year - 2020	Year - 1990	Year - 2020
Algeria	15.15	79.21	594	1823	1%	1%
Angola	1.17	16.81	99	503	61%	76%
Benin	0.02	0.99	4	78	0%	1%
Burkina Faso	0.17	0.74	19	34	5%	29%
Chad	0.09	0.35	15	21	0%	6%
Congo, Rep.	0.49	3.83	205	672	99%	24%
Egypt, Arab Rep.	41.41	188.54	724	1754	24%	13%
Equatorial Guinea	0.02	1.41	37	882	12%	35%
Ethiopia	1.20	15.83	25	135	91%	100%
Ghana	5.71	19.73	369	613	99%	37%
Kenya	3.26	11.60	141	223	93%	94%
Morocco	9.09	38.64	370	1053	13%	19%
Mozambique	0.44	19.03	33	610	64%	84%
Nigeria	12.03	35.07	126	168	36%	22%
Senegal	0.90	6.07	120	369	5%	17%
South Africa	156.01	234.61	3912	3990	1%	6%
Sudan	1.47	17.19	70	387	64%	65%
Tanzania	1.69	7.85	65	127	91%	42%
Tunisia	5.21	21.36	617	1756	1%	4%

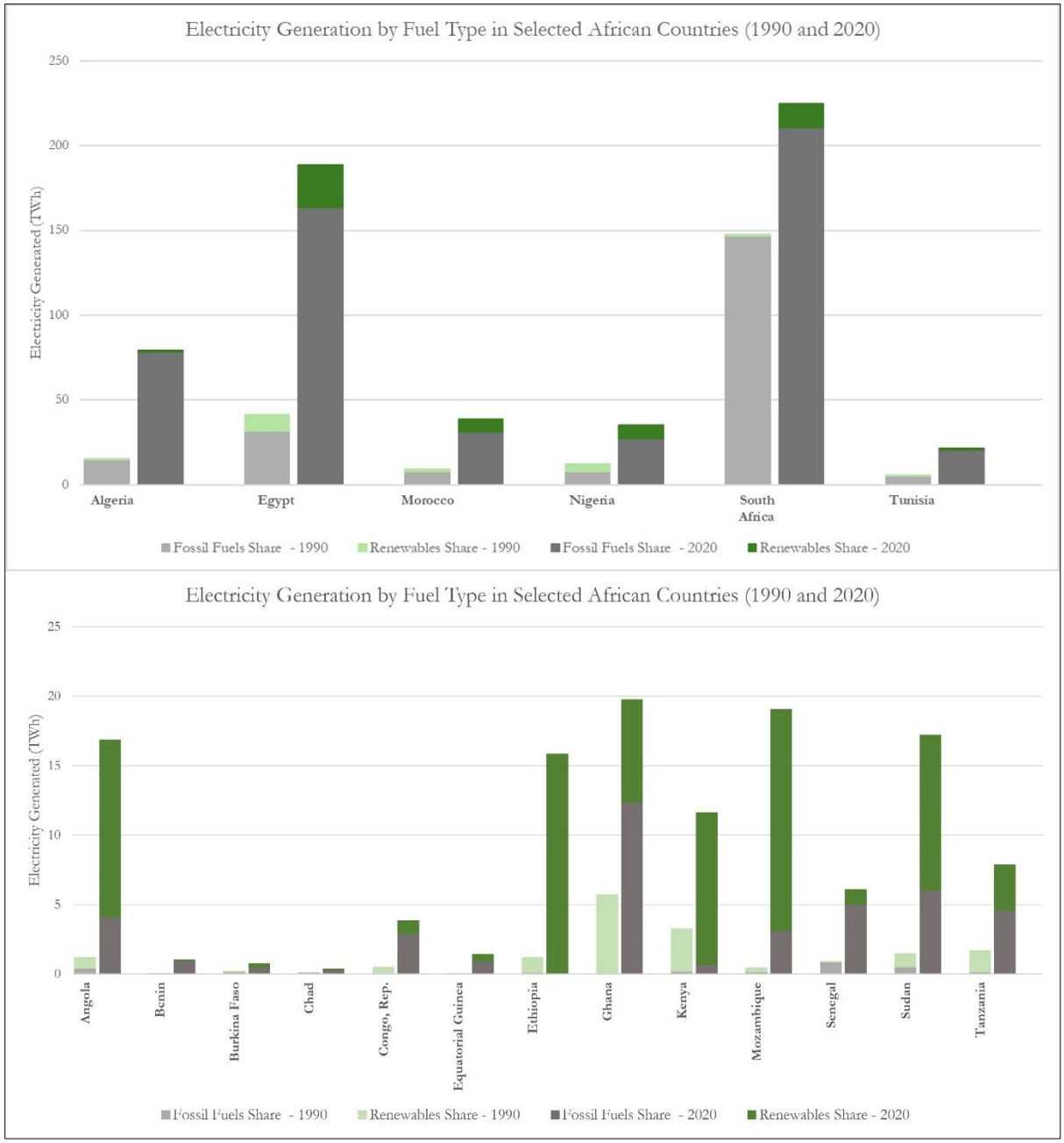


Figure A-13: Electricity Generation by Fuel Type for the 19 core African emitters identified in the study. Data obtained from the U.S. Energy Information Administration [7].

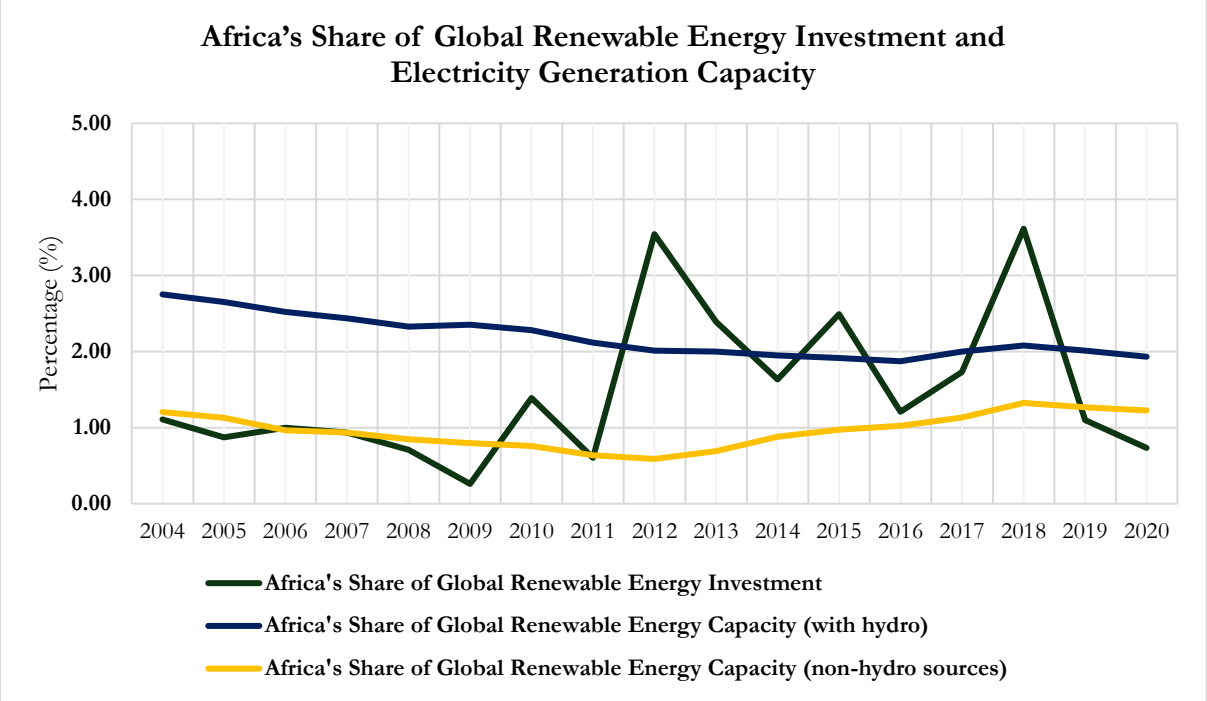


Figure A-14: Africa's share of global renewable energy investment and electricity generation capacity. Investment data were obtained from International Renewable Energy Agency (IRENA) reports [18-19] and Statista [20]. The data exclude investments in large hydropower (greater than 50 megawatts) and begin in 2004, the earliest year for which both African and global data are available from these sources. Electricity generation capacity data were sourced from the U.S Energy Information Administration (EIA)[21].

8. Estimating Carbon Price to Close Financing Gap Between Natural Gas Plants and Renewable Energy Systems: Inputs and Assumptions

While solar systems now offer the *"cheapest electricity in history"* [22], they still cost more to build than the average natural gas plant (Figure 2-9a)[105]. The levelized cost of electricity (LCOE) for a utility-scale solar plant is about $22 - 48/MWh compared to $54/MWh for a combined cycle natural gas plant, with both starting construction in 2024 [23-24]. However, a solar plant would cost $100 more per kilowatt to build in 2024 [24]. For wind and solar plus storage installations, the difference is higher at about $164/kW and ~$1067/kW, respectively, and a margin is expected till 2050 [24] (Figure 2-9a). Given the lack of baseload grid capacity in many African nations, the solar plus storage estimate is perhaps a more accurate depiction of the gap that needs to be filled to facilitate a renewable path for electricity. The LCOE for utility-scale solar plus storage systems is estimated at $73/MWh in 2024 [24].

To determine the carbon price required to bridge the financing gap between natural gas plants and renewable energy systems, we undertake the following steps (see below for detailed assumptions and inputs):

[105] For ease of access and data reliability, we use U.S. estimates for this illustration. However, more rigorous analysis with Africa-specific data is the focus of future work.

a. Calculate the difference in capital costs between the fossil fuel system (natural gas plant) and renewable energy systems (solar, solar plus storage, and wind) in $/ kW for each project construction start year (2021 – 2050) using estimates from National Renewable Energy Laboratory (NREL) [24].

b. Estimate greenhouse gas (GHG) emissions per plant type over a typical 30-year technical life in tCO_2e/kW based on prevalent capacity factors [25], estimated annual production [24], and available lifecycle emission factors [26], and calculate the difference in emissions between the natural gas system and renewable energy systems.

c. Compute the cost premium per metric ton of GHG emissions avoided ($/tCO_2e$) by installing a renewable energy system instead of a natural gas plant. This is obtained by dividing the output of step (a) by the output of step (b)

Consistent with other studies, we find that a fossil gas powerplant emits $3tCO_2e/kW$ more than a solar, solar-plus-storage, or wind plant annually. In a typical 30-year technical life, building a solar or wind plant instead of a natural gas plant would, therefore, save about $90tCO_2e/kW$. Consequently, a moderate price of $\$14/tCO_2e$ is enough to close the financing gap for even solar plus storage solutions starting construction in 2024 (Figure 2-9b). This is driven by both the higher emissions intensity of natural gas plants as well as increased annual production. Even if we assume that generation from future gas plants would be constrained to the level of the intermittent renewables, a carbon price of $\sim\$30/tCO_2e$ would be sufficient to close the capital cost gap between solar plus storage solutions and the gas plants in 2024 (Figure A-15).

Mechanisms that can monetize the expected carbon savings from cleaner solutions upfront (to potentially serve as guarantees or other de-risking instruments) could help facilitate a sustainable development path for the global community, particularly for African nations who have limited financial resources and access to financing. Such a mechanism could also incentivize a stronger commitment to proper operations and maintenance during the lifetime of the related projects. Conversations focused on mitigation activities in Africa must prioritize the provision of the financial premiums required to unlock desired clean investments [27].

Technology: Wind

For this analysis, we obtain data on capital cost ($/kW) and annual energy production (kWh/kW) for typical utility-scale land-based wind plants from the National Renewable Energy Laboratory (NREL)'s Annual Technology Baseline (ATB)[24, 28]. Based on existing literature about average wind speeds on the African continent and data from the Global Wind Atlas [24, 29-30], we use information for Wind Speed Class 9 (wind speed range: 5.9 – 6.5 m/s) and focus on provided estimates for the conservative cost and performance scenario. To estimate emissions from the wind plant, we multiply the annual energy production by the median lifecycle greenhouse gas emissions factor reported by NREL for wind electricity generation ($13\ gCO_2e/kWh$) [26].

Technology: Solar

We also extract capital cost ($/kW) and annual energy production (kWh/kW) data for utility solar photovoltaic (solar PV) systems (with and without battery) from NREL's ATB [24, 31-32]. Based on data from the Global Solar Atlas [33], we utilize information on resource class 3 (Global Horizontal

Irradiance bin: 5.25 – 5.5 kWh/m^2/day) and focus on estimates for the conservative cost and performance scenario. To estimate emissions from the utility-scale solar and solar-plus-battery plants, we multiply the annual energy production for each plant type by the median lifecycle greenhouse gas emissions factor reported by NREL for the different technologies (43 gCO_2e/kWh for solar PV and 33 gCO_2e/kWh for Lithium-ion battery) [26].

Technology: Natural Gas

For Natural Gas, we select capital cost estimates ($/kW) for the conservative cost scenario for the Natural Gas Combined Cycle (F-Frame) technology [24, 34]. The NREL ATB does not provide annual energy production estimates for natural gas plants. Therefore, we rely on the reported capacity factor of 65.5% for combined cycle Natural Gas plants [25] and estimate annual energy production based on the relationship below [35] which yields annual production of ~5,747kWh/ kW. To estimate emissions from the natural gas plant, we adopt the 486 gCO_2e/kWh median lifecycle greenhouse gas emissions factor reported by NREL for natural gas electricity generation [26].

$$Capacity\ Factor = \frac{Actual\ Electrical\ Output\ Produced\ Over\ a\ Period\ of\ Time}{Maximum\ Possible\ Electrical\ Output\ Over\ Same\ Time\ Period}$$

Additional Result Chart

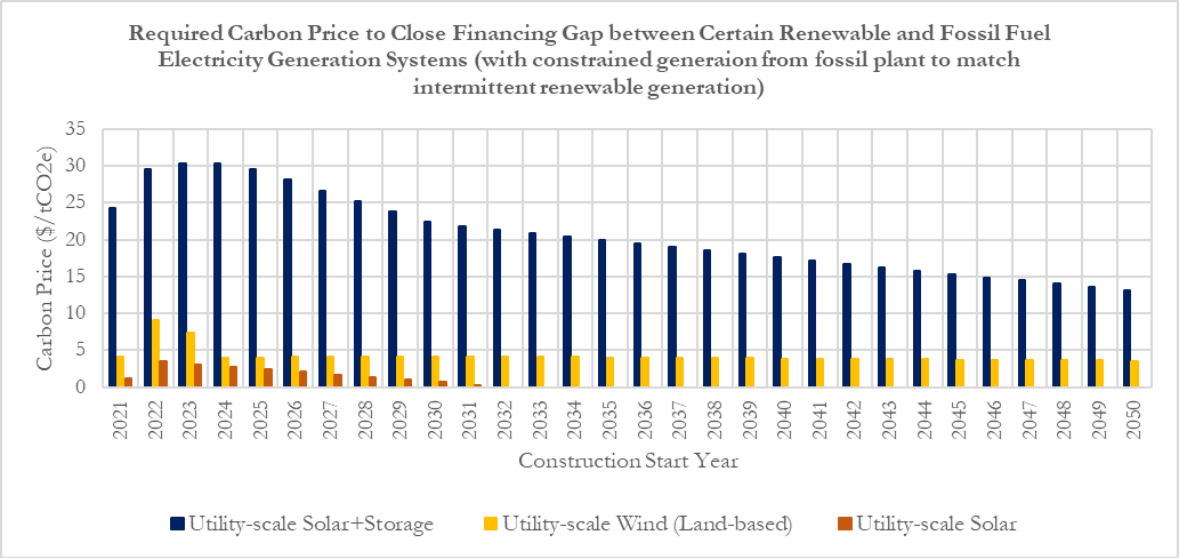


Figure A-15: Required carbon price to close financing gap between utility-scale renewable systems and natural gas plants when output of the fossil plant is constrained to be comparable with renewable generation.

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Chapter 4 Appendix

1. Explanatory Variables included in Study Models

Table B-1: Description of explanatory variables included in models within the study

S/N	Superordinate Explanatory Variable Category (SEVC)	Sub-category	Variables	Associated survey questions/prompts	Data Type	Values
	Outcome Variables	**Own Genset**		Do you own any generator sets?	Boolean	True, False
		Own Solar Systems		Do you use solar power system(s)?	Boolean	True, False
		Interested in Switching to Solar Systems		If not {about solar power system(s)}, would you be interested in switching to solar home system(s)?	Boolean	True, False
		Genset Capacity		What is the capacity (in kilowatts) of the generator set you currently use (rated output)?	Categorical	0.1 - 1.2 kVA, 1.3 - 5 kVA, 6 - 16 kVA, 17 - 33 kVA, 34 - 275 kVA, 276 - 500 kVA, 501 - 780 kVA, 781 - 1000 kVA, 1001 - 2035 kVA, > 2035 kVA
		Genset Duration of Use		On average, how many hours per day do you operate your generator set?	Categorical	< 4 hours, 4 - 8 hours, 9 -12 hours, 13 - 18 hours, >18 hours
		Genset Time of Major Use		What time of the day do you use the generator the most?	Categorical	Early morning (4am - 8am), Morning (> 8am - 12 am), Afternoon (>12 pm - 4pm), Evening (>4pm - 8pm), Night (>8pm - 12pm), Midnight (>12am - 4am)
1	**Market & policy factors**	**Electricity Reliability**	Typical duration of daily outages	How many hours of outage from the grid do you typically experience per day?	Categorical	< 4 hours, 4 - 8 hours, 9 -12 hours, 13 - 18 hours, >18 hours
2	**Personal values & preferences + Environmental factors**	**Electricity Reliability**	Willingness to pay for reliability	If you had electricity 24/7, would you be willing to pay a higher tariff for improved grid power reliability and reduced power outages?	Boolean	True, False
3		**Environmental Concerns**	Concern about environmental impact of genset use	Are you concerned about the environmental impact of generator use?	Boolean	True, False
4			Rating of air pollution from genset use	Would you say that the use of generators contribute significantly to the level of air quality in your area?; If yes, on a scale of 1 to 5, how would you rate the air pollution from the generator? (1 = Not Bad, 5 = Extreme Bad)	Boolean, Categorical	True, False; 1,2,3,4,5
5	**Household Characteristics**	**Demography**	Age of respondent/household head	Age Range	Categorical	<18, 18 - 29, 30 - 49, 50 - 64, 65+
6			Education level of respondent/household head	Highest level of education attained	Categorical	None or incomplete primary, Completed primary, Completed secondary, Higher education (college and above)
7			Gender of respondent/household head	Gender	Categorical	Female, Male
8			Size of household	What is the size of your household (number of individuals permanently living in the household, including yourself)	Categorical	1 - 2, 3 - 4, 5 - 10, 11 - 15, 16 - 20, 21 and above
9		**Housing**	Type of building/dwelling	What type of building is the household residing in?	Categorical	Face to Face, Storey building, Flat, Bungalow, Duplex
10			House ownership	Is the house/housing unit owned or rented?	Categorical	I am a homeowner, I am a renter, I live with family & friends
11			Years of residence	How long have you been residing in this house?	Categorical	0 - 2 years, 3 - 5 years, 6 - 10 years, >10 years

S/N	Superordinate Explanatory Variable Category (SEVC)	Sub-category	Variables	Associated survey questions/prompts	Data Type	Values
12	Household Characteristics	Income and Finance	Total monthly income	What is the total monthly income of the household?	Categorical	<N50,000; N50,001 - N100,000; N100,001 - N250,000; N250,001 - N500,000; N500,001 - N1,000,000; N1,000,001 - N5,000,000; N5,000,001 - N10,000,000; N10,000,001 - N50,000,000; N50,000,001 - N100,000,000; >N100,000,000
13			Primary source of income	Primary source of income of the household?	Categorical	Employment, Employment (contract), Self-employment, Pension and retirement, Government assistant programme, None
14			Bank account	Do you have a bank account?	Boolean	True, False
15		Business	Household business	Do you have a business you run in your household?	Boolean	True, False
16			Size of household business (employees)	If yes, what is the size of the business (number of current employees who are not household members)	Categorical	1 - 5, 6 - 10, 11 - 15, 16 - 20, 21 and above
17			Size of household business (monthly revenue)	If yes, what is the size of the business (estimate monthly sales/revenue)	Categorical	<N50,000; N50,001 - N100,000; N100,001 - N250,000; N250,001 - N500,000; N500,001 - N1,000,000; N1,000,001 - N5,000,000; N5,000,001 - N10,000,000; N10,000,001 - N50,000,000; N50,000,001 - N100,000,000; >N100,000,000
18		Energy	Grid electricity	Do you have access to grid power in your area?; Are you connected to the grid?	Boolean	True, False
19			Time of major appliance use	What time of the day are the majority of your appliances turned on?	Categorical	Early morning (4am - 8am), Morning (> 8am - 12 am), Afternoon (>12 pm - 4pm), Evening (>4pm - 8pm), Night (>8pm - 12pm), Midnight (>12am - 4am)
20			Frequency of payment for grid electricity	How often do you pay for grid power in your area?	Categorical	Never, Hourly, Daily, Weekly, Bi-weekly, Monthly, Quarterly, Yearly, Biennial (2 years)
21			Expenditure on grid electricity	How much do you typically spend on grid power for the period mentioned earlier? (Naira)	Open response	
22			Metering status	Is your grid supply metered?	Boolean	True, False
23			Type of meter	If yes, what type of meter is installed?	Categorical	Prepaid, Postpaid
24			Frequency of routine genset maintenance	How often do you carry out routine maintenance/service of your generator?	Categorical	Never, Hourly, Daily, Weekly, Bi-weekly, Monthly, Quarterly, Yearly, Biennial (2 years)
25			Expenditure on routine genset maintenance	How much do you spend on routine maintenance/servicing of your generator for the period mentioned earlier?	Open response	
26			Maintenance-related genset challenges/break downs	Have you faced any maintenance-related challenges or breakdowns with your generator set?	Boolean	True, False

S/N	Superordinate Explanatory Variable Category (SEVC)	Sub-category	Variables	Associated survey questions/prompts	Data Type	Values
27	Household Characteristics	Energy	Frequency of fuel purchase for genset	How frequently do you purchase fuel?	Categorical	Never, Hourly, Daily, Weekly, Bi-weekly, Monthly, Quarterly, Yearly, Biennial (2 years)
28			Fuel consumption	How much fuel (Liters) do you purchase for the period mentioned above?	Open response	
29			Time of major genset use	What time of the day do you use the generator the most?	Categorical	Early morning (4am - 8am), Morning (> 8am - 12 am), Afternoon (>12 pm - 4pm), Evening (>4pm - 8pm), Night (>8pm - 12pm), Midnight (>12am - 4am)
30			Genset powers all household appliances	Does the generator power all appliances in your household?	Boolean	True, False
31		Awareness	Awareness of tariff band	What current tariff band are you on?	Categorical	Lifeline, A, B, C, D, E, Don't Know
32			Awareness of Nigeria Energy Transition Plan	Are you aware that Nigeria has an Energy Transition Plan?	Boolean	True, False
33			Awareness of solar power systems	Are you aware of any solar power system(s)?	Boolean	True, False
34		Location	Local Government Area (LGA)		Categorical	Agege, Ajeromi-Ifelodun, Alimosho, Amuwo Odofin, Apapa, Badagry, Epe, Eti Osa, Ibeju Lekki, Ifako-Ijaye, Ikeja, Ikorodu, Kosofe, Lagos Mainland, Lagos-Island, Mushin, Ojo, Oshodi-Isolo, Somolu, Surulere
35			Road accessibility around household	How would you rate the overall road accessibility in your area? {Very poor = 1 and Excellent = 5}	Categorical	1,2,3,4,5
36			Security of area around household	How would you rate the overall security in your area? {Very poor = 1 and Excellent = 5}	Categorical	1,2,3,4,6
37			Latitude	GPS Location (Latitude)		Automated from survey app
38			Longitude	GPS Location (Longitude)		Automated from survey app
39	Social Factors	Peer effects	Nearest household in survey has a genset	Calculated by authors based on information in survey		
40			Nearest household in survey has solar	Calculated by authors based on information in survey		
41			Complaints about genset use	Have there been any complaints or concerns from nearby residents or businesses regarding the noise from your generator?	Boolean	True, False
42		Regulation	Community/area /neighborhood regulations regarding genset use	Are there any community/neighborhood/area regulations regarding generator use?	Boolean	True, False

2. Probit Results

We also use the probit model in equation (1) to analyze the uptake of generator sets and solar PV systems, as well as interest in switching to solar systems:

$$P(Y = 1 \mid X) = \Phi(X\beta + \epsilon)$$

*Table B-2: Probit Results. Coefficients are presented first. Asterisks *, **, *** indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Statistically significant coefficients are emboldened. Standard errors are provided in brackets below the coefficients, with average marginal effects italicized beneath the standard errors.*

		Dependent variable	(1) **Owns Genset**	(2) **Owns Solar**	(3) **Interested in Switching to Solar**
		Observations	5308	3635	3559
		P (y = 1) in Data	70.37%	2.04%	75.05 %
		McFadden Pseudo R^2	0.2567	0.1434	0.2949
		Percent correctly predicted	77.15%	97.96%	84.43 %
Primary Category	**Sub-Category**	**Variable**			
Market and Policy Factors	**Electricity Reliability**	Average reliability (9-12 hours typical daily outages)	0.09 (0.06) *0.02*	0.08 (0.14) *0.00*	**0.13***** **(0.07)** ***0.03***
		Better reliability (4 - 8 hours typical daily outages)	-0.02 (0.06) *-0.01*	**0.28***** **(0.14)** ***0.01***	0.01 (0.08) *0.00*
		Much better reliability (<4 hours typical daily outages)	**-0.19***** **(0.10)** ***-0.05***	0.24 (0.23) *0.01*	**-0.56*** **(0.13)** ***-0.13***
Personal Value & Preferences + Environmental Factors	**Electricity Reliability**	Willingness to pay for better reliability	0.03 (0.05) *0.01*	-0.03 (0.13) *0.00*	**0.37*** **(0.07)** ***0.08***
	Environmental Factors				
		Concern about genset's environmental impact	0.17* (0.05)	0.14 (0.13)	**-0.19*** **(0.07)**

	Genset environmental impact		*0.04*	*0.01*	***-0.04***
	Rating of air pollution from genset	Highly negative rating of air pollution from gensets	**-0.11**** **(0.06)** ***-0.03***	-0.03 (0.14) *0.00*	-0.06 (0.07) *-0.01*
Household Characteristics	**Demography**				
	Age of household head	Older household head (50 and above)	**-0.14*** **(0.05)** ***-0.04***	-0.18 (0.14) *-0.01*	**-0.24*** **(0.07)** ***-0.05***
	Education (highest level attained)	Higher education (college and above)	**0.18*** **(0.05)** ***0.05***	**0.47*** **(0.12)** ***0.02***	0.06 (0.06) *0.01*
	Gender	Male	**0.26*** **(0.04)** ***0.07***	0.00 (0.12) *0.00*	0.01 (0.06) *0.00*
	Size of household	Larger households (>5 members)	**-0.08***** **(0.05)** ***-0.02***	0.07 (0.12) *0.00*	-0.02 (0.06) *0.00*
	Housing				
	Type of building/dwelling	Face to Face (Face-me-I-face-you)	**-0.47*** **(0.05)** ***-0.12***	**-0.48**** **(0.22)** ***-0.02***	-0.09 (0.08) *-0.02*
	House ownership	Owns housing unit	0.06 (0.06) *0.02*	**0.23***** **(0.14)** ***0.01***	**0.14***** **(0.08)** ***0.03***
	Years of residence	Longer years of residence (>5 years)	-0.02 (0.05) *0.00*	-0.13 (0.13) *-0.01*	-0.08 (0.06) *-0.02*
	Income and Finance				
	Total monthly income	Higher income (> N100,000 (~$60))	**0.44*** **(0.05)** ***0.11***	**0.44*** **(0.14)** ***0.02***	-0.04 (0.07) *-0.01*
	Primary source of income	Government, Family or Friend Support	-0.11 (0.22) *-0.03*	0.29 (0.55) *0.01*	-0.07 (0.29) *-0.02*

	Pension and retirement	-0.04 (0.12) *-0.01*	**0.61*** **(0.23)** ***0.03***	**0.34**** **(0.14)** ***0.08***
	Self-employment	0.05 (0.05) *0.01*	**0.28**** **(0.14)** ***0.01***	**0.47*** **(0.07)** ***0.10***
Financial inclusion	Has a bank account	0.17 (0.12) *0.04*	-0.10 (0.31) *0.00*	**-0.44**** **(0.19)** ***-0.10***
Business				
Household business	Has a household business	**0.24*** **(0.07)** ***0.06***	**0.45**** **(0.18)** ***0.02***	-0.04 (0.10) *-0.01*
Size of household business (employees)	More employees (>5 employees)	-0.25 (0.17) *-0.06*	0.03 (0.35) *0.00*	**-0.54*** **(0.21)** ***-0.12***
Size of household business (monthly revenue)	More revenue (> N100,000 (~$60))	-0.01 (0.11) *0.00*	**-0.44***** **(0.24)** ***-0.02***	-0.09 (0.13) *-0.02*
Energy				
Grid electricity	Has access to grid electricity	**-0.85*** **(0.16)** ***-0.22***	**-0.65***** **(0.35)** ***-0.03***	**-0.94*** **(0.23)** ***-0.21***
Usage patterns	Time of major appliance use (daytime (8am - 4pm))	-0.08 (0.06) *-0.02*	-0.09 (0.15) *0.00*	-0.02 (0.08) *-0.01*
Frequency of payment for grid electricity	More frequent payments (weekly/biweekly)			**-0.19**** **(0.09)** ***-0.04***
Expenditure on grid electricity	Monthly electricity payment amount (Naira) (standardized)			-0.01 (0.03) *0.00*
Metering status	Has a meter			-0.05 (0.10) *-0.01*
Type of meter				-0.12

	Has a prepaid meter as opposed to a postpaid meter			(0.08) *-0.03*
Gensets Ownership of genset	Has a genset		**-0.70*** **(0.13)** *-0.03*	**0.21**** **(0.10)** *0.05*
Frequency of routine genset maintenance	More frequent routine maintenance (weekly/biweekly/monthly)			**-0.42*** **(0.08)** *-0.09*
Expenditure on routine genset maintenance	Monthly expenditure on genset routine maintenance			0.05 (0.03) *0.01*
Maintenance-related genset challenges/break downs	Has experienced genset maintenance breakdowns/challenges			**-0.28*** **(0.07)** *-0.06*
Frequency of fuel purchase for genset	More frequent fuel purchase (daily/weekly)			**0.46*** **(0.07)** *0.10*
Fuel consumption	Monthly fuel consumption (Liters) (standardized)			0.05 (0.12) *0.01*
Genset usage patterns	Time of major genset use (daytime (8am - 4pm))			-0.05 (0.12) *-0.01*
Awareness				
	Know tariff band	**0.39*** **(0.06)** *0.10*	0.24 (0.17) *0.01*	**0.83*** **(0.08)** *0.18*
	Aware of Nigeria energy transition plan (ETP)	0.03 (0.05) *0.01*	-0.08 (0.12) *0.00*	0.01 (0.06) *0.00*
	Aware of solar power systems	**0.13*** **(0.05)** *0.03*		0.41 (0.43) *0.09*
Location				

	Local Government Area (LGA) *(compared to median/average income LGAs - Kosofe and Lagos Mainland)*	High income LGAs (>$15k GDP PPP per capita - Eti-Osa, Ikeja, Ibeju-Lekki, Lagos Island) - compared to low and middle income LGAs		0.19 (0.14) *0.01*	
		Agege	-0.10 (0.11) *-0.03*		-0.16 (0.15) *-0.04*
		Ajeromi-Ifelodun	0.04 (0.11) *0.01*		-0.11 (0.15) *-0.03*
		Alimosho	**1.47*** **(0.14)** ***0.37***		**0.72*** **(0.13)** ***0.16***
		Amuwo Odofin	0.06 (0.14) *0.01*		-0.19 (0.19) *-0.04*
		Apapa	0.20 (0.14) *0.05*		**0.62**** **(0.28)** ***0.14***
		Badagry	0.19 (0.17) *0.05*		**-0.54**** **(0.23)** ***-0.12***
		Epe	**0.35***** **(0.19)** ***0.09***		**-1.06*** **(0.22)** ***-0.24***
		Eti Osa	**1.67*** **(0.29)** ***0.43***		**0.38**** **(0.16)** ***0.08***
		Ibeju Lekki	0.53		0.25

		(0.37) *0.14*		(0.35) *0.06*
	Ifako-Ijaye	0.10 (0.11) *0.03*		-0.21 (0.15) *-0.05*
	Ikeja	**0.23***** **(0.12)** ***0.06***		-0.14 (0.14) *-0.03*
	Ikorodu	0.02 (0.13) *0.00*		**0.99*** **(0.22)** ***0.22***
	Lagos-Island	**-0.40*** **(0.11)** ***-0.10***		**0.36**** **(0.16)** ***0.08***
	Mushin	0.02 (0.10) *0.01*		**-0.25**** **(0.13)** ***-0.06***
	Ojo	**-0.28**** **(0.12)** ***-0.07***		0.16 (0.18) *0.03*
	Oshodi-Isolo	0.06 (0.10) *0.02*		**1.03*** **(0.17)** ***0.23***
	Somolu	**0.36*** **(0.11)** ***0.09***		-0.03 (0.13) *-0.01*
	Surulere	**-0.21**** **(0.10)** ***-0.05***		**0.73*** **(0.14)** ***0.16***
Road accessibility around household	Above average roads (according to rating by household)	**0.16*** **(0.05)** ***0.04***	-0.15 (0.13) *-0.01*	-0.05 (0.06) *-0.01*

	Security of area around household	Above average security (according to rating by household)	-0.04 (0.05) *-0.01*	0.02 (0.12) *0.00*	**0.22*** **(0.06)** ***0.05***
Social factors	Peer effects	Nearest household in survey has a genset	**0.48*** **(0.04)** ***0.12***	**0.26***** **(0.14)** ***0.01***	0.04 (0.07) *0.01*
		Nearest household in survey has solar	**-0.33***** **(0.20)** ***-0.09***	**0.74*** **(0.27)** ***0.03***	0.18 (0.25) *0.04*
	Complaints	Has received complaints about genset use			-0.03 0.08 *-0.01*
	Regulation	Is subject to community/area/neighborhood regulations regarding genset use	**-0.39*** **(0.07)** ***-0.10***	**0.35**** **(0.14)** ***0.02***	**-0.15***** **(0.09)** ***-0.03***
		const	-0.04 (0.22)	**-2.15*** **(0.47)**	0.41 (0.52)

3. Results from Genset Ownership Model including Solar Ownership Variable

*Table B-3: Logit and Probit Results. Coefficients are presented first. Asterisks *, **, *** indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Statistically significant coefficients are emboldened. Standard errors are provided in brackets below the coefficients, with average marginal effects italicized beneath the standard errors. The solar ownership variable is highlighted in red.*

		Full model + solar ownership variable **Owns Genset**	Full model + solar ownership variable **Owns Genset**
	Dependent variable		
	Model type	**Logit**	**Probit**
	Observations	3635	3635
	P (y = 1) in Data	74.64%	74.64%
	McFadden Pseudo R^2	0.2671	0.2679
	Percent correctly predicted	79.09%	79.04%
Primary Category	**Sub-Category** **Variable**		
	Electricity Reliability	0.14	0.08

Market and Policy Factors		Average reliability (9-12 hours typical daily outages)	(0.12) *0.02*	(0.07) *0.02*
		Better reliability (4 - 8 hours typical daily outages)	-0.14 (0.14) *-0.02*	-0.08 (0.08) *-0.02*
		Much better reliability (<4 hours typical daily outages)	**-0.49**** **(0.21)** *-0.07*	**-0.30**** *(0.12)* *-0.07*
Personal Value & Preferences + Environmental Factors	**Electricity Reliability**	Willingness to pay for better reliability	0.12 (0.11) *0.02*	0.08 (0.07) *0.02*
	Environmental Factors			
	Genset environmental impact	Concern about genset's environmental impact	**0.37*** **(0.11)** *0.05*	**0.21*** **(0.06)** *0.05*
	Rating of air pollution from genset	Highly negative rating of air pollution from gensets	**-0.26**** **(0.13)** *-0.03*	**-0.15**** **(0.07)** *-0.04*
Household Characteristics	**Demography**			
	Age of household head	Older household head (50 and above)	**-0.38*** **(0.11)** *-0.05*	**-0.22*** **(0.07)** *-0.05*
	Education (highest level attained)	Higher education (college and above)	0.05 (0.11) *0.01*	0.03 (0.06) *0.01*
	Gender	Male	**0.52*** **(0.10)** *0.07*	**0.31*** **(0.06)** *0.07*
	Size of household	Larger households (>5 members)	**-0.21**** **(0.10)** *-0.03*	**-0.12***** **(0.06)** *-0.03*
	Housing			
	Type of building/dwelling	Face to Face (Face-me-I-face-you)	**-0.63*** **(0.11)** *-0.09*	**-0.39*** **(0.07)** *-0.09*

House ownership	Owns housing unit	**0.25*** (0.14) *0.03***	**0.13*** (0.08) *0.03***
Years of residence	Longer years of residence (>5 years)	-0.05 (0.11) *-0.01*	-0.03 (0.06) *-0.01*
Income and Finance			
Total monthly income	Higher income (> N100,000 (~$))	**0.96* (0.11) *0.13***	**0.56* (0.06) *0.13***
Primary source of income	Government, Family or Friend Support	-0.33 (0.52) *-0.05*	-0.22 (0.30) *-0.05*
	Pension and retirement	0.02 (0.25) *0.00*	0.01 (0.14) *0.00*
	Self-employment	0.00 (0.12) *0.00*	0.01 (0.07) *0.00*
Financial inclusion	Has a bank account	0.23 (0.27) *0.03*	0.21 (0.16) *0.05*
Business			
Household business	Has a household business	**0.40* (0.15) *0.05***	**0.24* (0.09) *0.06***
Size of household business (employees)	More employees (>5 employees)	**-0.75** (0.34) *-0.10***	**-0.44** (0.20) *-0.10***
Size of household business (monthly revenue)	More revenue (> N100,000 (~$))	0.15 (0.24) *0.02*	0.09 (0.14) *0.02*
Energy			
Grid electricity	Has access to grid electricity	-0.98* (0.36) *-0.13*	-0.54* (0.20) *-0.13*
Usage patterns	Time of major appliance use	0.11 (0.13) *0.01*	0.06 (0.07) *0.01*

		(daytime (8am - 4pm))		
	Ownership of solar systems	**Has a solar system**	**-1.84***	**-1.06***
			(0.31)	**(0.17)**
			-0.25	*-0.25*
	Awareness			
		Know tariff band	**0.95***	**0.55***
			(0.13)	**(0.08)**
			0.13	*0.13*
		Aware of Nigeria energy transition plan (ETP)	0.14	0.08
			(0.10)	(0.06)
			0.02	*0.02*
		Aware of solar power systems	-0.49	-0.39
			(0.49)	(0.29)
	Location			
	Local Government Area (LGA) *(compared to middle income LGAs)*	Agege	-0.04	-0.02
			(0.24)	(0.14)
			-0.01	*0.00*
		Ajeromi-Ifelodun	0.15	0.08
			(0.23)	(0.13)
			0.02	*0.02*
		Alimosho	2.98*	1.46*
			(0.40)	(0.18)
			0.41	*0.34*
		Amuwo Odofin	0.32	0.18
			(0.30)	(0.18)
			0.04	*0.04*
		Apapa	**0.71*** **	**0.39*** **
			(0.41)	**(0.22)**
			0.10	*0.09*
		Badagry	0.58	0.33
			(0.40)	(0.23)
			0.08	*0.08*
		Epe	0.46	0.25
			(0.39)	(0.22)
			0.06	*0.06*
		Eti Osa	**3.57***	**1.67***
			(1.02)	**(0.41)**
			0.49	*0.39*
		Ibeju Lekki	**1.21*** **	**0.71*** **

			(0.67)	**(0.38)**
			0.16	*0.17*
		Ifako-Ijaye	0.17	0.11
			(0.23)	(0.14)
			0.02	*0.03*
		Ikeja	0.41	0.22
			(0.27)	(0.15)
			0.06	*0.05*
		Ikorodu	-0.20	-0.11
			(0.28)	(0.16)
			-0.03	*-0.03*
		Lagos-Island	**-1.07***	**-0.61***
			(0.23)	**(0.14)**
			-0.15	*-0.14*
		Mushin	0.05	0.03
			(0.21)	(0.12)
			0.01	*0.01*
		Ojo	**-0.79***	**-0.44***
			(0.28)	**(0.16)**
			-0.11	*-0.10*
		Oshodi-Isolo	-0.24	-0.12
			(0.22)	(0.13)
			-0.03	*-0.03*
		Somolu	**0.79***	**0.45***
			(0.24)	**(0.14)**
			0.11	*0.11*
		Surulere	**-0.59***	**-0.34***
			(0.20)	**(0.12)**
			-0.08	*-0.08*
	Road accessibility around household	Above average roads (according to rating by household)	0.15	0.09
			(0.10)	(0.06)
			0.02	*0.02*
	Security of area around household	Above average security (according to rating by household)	0.00	0.00
			(0.10)	(0.06)
			0.00	*0.00*
Social factors	Peer effects	Nearest household in survey has a genset	**0.85***	**0.50***
			(0.09)	**(0.06)**
			0.12	*0.12*

		Nearest household in survey has solar	-0.45 (0.42) *-0.06*	-0.27 (0.24) *-0.06*
	Regulation	Is subject to community/area/ neighborhood regulations regarding genset use	**-0.61*** **(0.16)** ***-0.08***	**-0.31*** **(0.09)** ***-0.07***
		const		-0.39 (0.29)

4. Stacking Analysis

4.1 Drivers of Stacking Behavior

We developed a multinomial logit model to estimate the probability of a household falling into either the 'Genset Only' or 'Solar Only' category relative to the 'Both Genset and Solar' category. The log-odds of a household being in the 'Genset Only' category compared to the 'Both Genset and Solar' category is given as:

$$log\left(\frac{P\ (Y =' \ Genset\ Only')}{P(Y = 'Both\ Genset\ and\ Solar')}\right) = X\beta_1$$

Similarly, the log-odds of a household being in the 'Solar Only' category relative to the 'Both Genset and Solar' category is given as:

$$log\left(\frac{P\ (Y =' \ Solar\ Only')}{P(Y = 'Both\ Genset\ and\ Solar')}\right) = X\beta_2$$

For this analysis, we prioritized independent variables X that were found to be significant in our individual analysis of genset and solar adoption, as well as variables with good enough distinction across the three categories. Table 3 below displays the results of our analysis.

*Table B-4: Multinomial Logit Results. Coefficients are presented first. Asterisks *, **, *** indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Statistically significant coefficients are emboldened. Standard errors are provided in brackets below the coefficients.*

		Model type	Multinomial Logit Model	
		Reference Category	Both Genset and Solar (1.2% of observations)	
		Pseudo R2	0.1281	
		Observations	3765	
			Genset Only	**Solar Only**
		Share in Data	98%	0.8%
Primary Category	**Sub-Category**	**Variable**		

Market and Policy Factors	**Electricity Reliability**	Average reliability (9-12 hours typical daily outages)	0.16 (0.42)	0.34 (0.63)
		Better reliability (4 - 8 hours typical daily outages)	-0.59 (0.38)	-0.32 (0.68)
		Much better reliability (<4 hours typical daily outages)	0.17 (0.80)	0.98 (1.08)
Personal Value & Preferences + Environmental Factors	**Electricity Reliability**	Willingness to pay for better reliability	0.09 (0.37)	0.22 (0.61)
Household Characteristics	**Demography** Size of household	Larger households (>5 members)	-0.45 (0.32)	-0.12 (0.51)
	Housing House ownership	Owns housing unit	**-0.63***** **(0.32)**	-0.68 (0.53)
	Income Total monthly income	High income household (> N250,001 - N500,000 (~$))	-0.11 (0.41)	0.81 (0.58)
		Ultra high-income household (top 5%) (> N500,000 (~$))	**-1.13**** **(0.44)**	-1.26 (0.92)
	Business Household business	Has a household business	-0.13 (0.35)	-0.36 (0.62)
	Size of household business (employees)	More employees (>5 employees)	0.55 (1.08)	2.11 (1.40)
	Energy Grid electricity	Has access to grid electricity	0.06 (1.20)	-1.03 (1.57)

	Usage patterns	Time of major appliance use (daytime (8am - 4pm))	-0.08 (0.41)	-0.49 (0.75)
		Genset powers all household appliances (irrelevant to Solar only hence the very large coefficient)	-0.48 (0.34)	-37.96 (2.20E+07)
	Awareness			
		Know tariff band	-0.40 (0.55)	-0.28 (0.77)
		Aware of Nigeria energy transition plan (ETP)	-0.13 (0.33)	-0.10 (0.52)
	Location			
	Local Government Area (LGA) *(compared to middle income LGAs)*	High income LGAs (>$15k GDP PPP per capita - Eti-Osa, Ikeja, Ibeju-Lekki, Lagos Island)	-0.47 (0.39)	-0.97 (0.76)
	Security of area around household	Above average security (according to rating by household)	0.02 (0.33)	-0.10 (0.51)
Social factors	Peer effects	Nearest household in survey has a genset	-0.53 (0.49)	**-1.30**** **(0.65)**
		Nearest household in survey has solar	**-1.98*** **(0.57)**	-0.75 (1.27)
	Regulation	Is subject to community/area/neighborhood regulations regarding genset use	**-0.69***** **(0.37)**	-0.53 (0.64)
		const	**6.51*** **(1.15)**	**3.57**** **(1.44)**

4.2 Impact of Stacking Behavior on Genset Usage

We also employed a logit model to explore the determinants of household genset capacity, duration of use, and primary usage periods, with a particular focus on assessing the impact of stacking solar systems alongside gensets. In the three cases under consideration, the dependent variable *(Y)* in the specified equation below represents the likelihood that a household: (1) owns a genset that belongs in

the smallest size category (P (Genset size is between 0.1 – 1.2 kVA = 1)), (2) uses its genset for the shortest duration reported in the survey (P (Genset daily use is less than 4 hours = 1)), or (3) uses its genset primarily in the daytime (P (Genset mostly used during the daytime (8am – 4pm) = 1)).

$$P(Y = 1|X) = \frac{1}{1 + e^{-(X\beta + \epsilon)}}$$

*Table B-5: Logit and Probit Results. Coefficients are presented first. Asterisks *, **, *** indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Standard errors are provided in brackets below the coefficients, with average marginal effects italicized beneath the standard errors. The solar ownership variable is highlighted in red.*

		Dependent Variable	(1) **Genset in smallest capacity category (0.1 - 1.2 kVA)**	(2)
		Observations	2664	
		P (y = 1) in Data	48.50%	
		Model Type	Logit	Probit
		McFadden Pseudo R^2	0.1937	0.1919
		Percent correctly predicted	71.77%	71.28%
Primary Category	**Sub-Category**	**Variable**		
Market and Policy Factors	**Electricity Reliability**	Average reliability (9-12 hours typical daily outages)	**-0.29***	**-0.17****
			(0.11)	***(0.07)***
			-0.06	***-0.05***
		Better reliability (4 - 8 hours typical daily outages)	-0.09	-0.05
			(0.13)	(0.08)
			-0.02	*-0.02*
		Much better reliability (<4 hours typical daily outages)	-0.14	-0.08
			(0.23)	(0.14)
			-0.03	*-0.03*
Personal Value & Preferences + Environmental Factors	**Electricity Reliability**	Willingness to pay for better reliability	-0.08	-0.07
			(0.12)	(0.07)
			-0.02	*-0.02*
	Environmental Factors			
	Genset environmental impact	Concern about genset's environmental impact	0.07	0.05
			(0.11)	(0.07)
			0.01	*0.01*
	Rating of air pollution from genset	Highly negative rating of air pollution from gensets	0.09	0.05
			(0.12)	(0.07)
			0.02	*0.01*

Household Characteristics	**Demography**			
	Age of household head	Older household head (50 and above)	**-0.54*** **(0.11)** *-0.10*	**-0.31*** **(0.07)** *-0.10*
	Education (highest level attained)	Higher education (college and above)	0.14 (0.10) *0.03*	0.09 (0.06) *0.03*
	Gender	Male	-0.12 (0.10) *-0.02*	-0.08 (0.06) *-0.02*
	Size of household	Larger households (>5 members)	**0.25**** **(0.11)** *0.05*	**0.15**** **(0.06)** *0.05*
	Housing			
	Type of building/dwelling	Face to Face (Face-me-I-face-you)	**0.94*** **(0.15)** *0.18*	**0.55*** **(0.09)** *0.18*
	House ownership	Owns housing unit	**-0.48*** **(0.12)** *-0.09*	**-0.29*** **(0.07)** *-0.09*
	Years of residence	Longer years of residence (>5 years)	0.02 (0.11) *0.00*	0.02 (0.07) *0.01*
	Income and Finance			
	Total monthly income	Higher income (> N100,000 (~$))	**-0.44*** **(0.11)** *-0.08*	**-0.26*** **(0.06)** *-0.08*
	Primary source of income	Government, Family or Friend Support	0.61 (0.54) *0.12*	0.35 (0.33) *0.11*
		Pension and retirement	-0.11 (0.22) *-0.02*	-0.09 (0.13) *-0.03*
		Self-employment	-0.01 (0.12) *0.00*	0.00 (0.07) *0.00*
	Financial inclusion	Has a bank account	**1.52*** **(0.40)**	**0.90*** **(0.22)**

		0.29	*0.29*
Business			
Household business	Has a household business	0.12 (0.16) *0.02*	0.07 (0.09) *0.02*
Size of household business (employees)	More employees (>5 employees)	**1.07*** **(0.41)** *0.20*	**0.62**** **(0.24)** *0.20*
Size of household business (monthly revenue)	More revenue (> N100,000 (~$))	**-0.44**** **(0.21)** *-0.08*	**-0.27**** **(0.12)** *-0.08*
Energy			
Grid electricity	Has access to grid electricity	-0.66 (0.43) *-0.13*	-0.36 (0.24) *-0.11*
Usage patterns	Time of major appliance use (daytime (8am - 4pm))	**0.48*** **(0.13)** *0.09*	**0.27*** **(0.08)** *0.08*
Ownership of solar systems	**Has a solar system**	**-0.25** **(0.38)** *-0.05*	**-0.14** **(0.23)** *-0.04*
Gensets			
Genset usage patterns	Genset powers all household appliances	**-0.56*** **(0.10)** *-0.11*	**-0.35*** **(0.06)** **-0.11**
Awareness			
	Know tariff band	**0.28***** **(0.14)** *0.05*	**0.16***** **(0.09)** *0.05*
	Aware of Nigeria energy transition plan (ETP)	-0.09 (0.10) *-0.02*	-0.04 (0.06) *-0.01*
	Aware of solar power systems	0.44 (0.59)	0.25 (0.34)
Location			
Local Government	Eti Osa	**-3.16*** **(0.36)**	**-1.73*** **(0.17)**

	Area (LGA) *(high income LGAs compared to middle income LGAs)*		*-0.60*	*-0.55*
		Ibeju Lekki	**-2.73***	**-1.60***
			(0.70)	**(0.39)**
			-0.52	*-0.51*
		Ikeja	**-2.80***	**-1.61***
			(0.36)	**(0.19)**
			-0.53	*-0.51*
		Lagos-Island	**-2.51***	**-1.45***
			(0.31)	**(0.17)**
			-0.48	*-0.46*
	Road accessibility around household	Above average roads (according to rating by household)	0.11	0.07
			(0.10)	(0.06)
			0.02	*0.02*
	Security of area around household	Above average security (according to rating by household)	0.14	0.09
			(0.10)	(0.06)
			0.03	*0.03*
Social factors	Peer effects	Nearest household in survey has a genset	**-0.56***	**-0.33***
			(0.12)	**(0.07)**
			-0.11	*-0.10*
		Nearest household in survey has solar	**-0.95****	**-0.59****
			(0.48)	**(0.28)**
			-0.18	*-0.19*
	Regulation	Is subject to community/area/neighborhood regulations regarding genset use	**-0.32****	**-0.20****
			(0.13)	**(0.08)**
			-0.06	*-0.07*

*Table B-6: Logit and Probit Results. Coefficients are presented first. Asterisks *, **, *** indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Standard errors are provided in brackets below the coefficients, with average marginal effects italicized beneath the standard errors. The solar ownership variable is highlighted in red.*

	(1)	(2)
	Genset use in shortest duration category (< 4 hours)	
Observations	2713	
P (y = 1) in Data	33.95%	
Model Type	Logit	Probit

		McFadden Pseudo R^2	0.1119	0.1110
		Percent correctly predicted	71.54%	71.54%
Primary Category	**Sub-Category**	**Variable**		
Market and Policy Factors	**Electricity Reliability**	Average reliability (9-12 hours typical daily outages)	**0.19*** (0.11)** *0.04*	**0.12*** (0.07)** *0.04*
		Better reliability (4 - 8 hours typical daily outages)	**0.65* (0.13)** *0.13*	**0.39* (0.08)** *0.13*
		Much better reliability (<4 hours typical daily outages)	**2.00* (0.24)** *0.39*	**1.21* (0.14)** *0.39*
Personal Value & Preferences + Environmental Factors	**Electricity Reliability**	Willingness to pay for better reliability	-0.06 (0.12) *-0.01*	-0.04 (0.07) *-0.01*
	Environmental Factors			
	Genset environmental impact	Concern about genset's environmental impact	**0.77* (0.11)** *0.15*	**0.44* (0.07)** *0.14*
	Rating of air pollution from genset	Highly negative rating of air pollution from gensets	-0.18 (0.12) *-0.03*	-0.10 (0.07) *-0.03*
Household Characteristics	**Demography**			
	Age of household head	Older household head (50 and above)	0.07 (0.11) *0.01*	0.04 (0.07) *0.01*
	Education (highest level attained)	Higher education (college and above)	-0.05 (0.10) *-0.01*	-0.03 (0.06) *-0.01*
	Gender	Male	0.08 (0.10) *0.02*	0.05 (0.06) *0.02*
	Size of household	Larger households (>5 members)	**0.27** (0.11)** *0.05*	**0.17* (0.06)** *0.05*
	Housing			
	Type of building/dwelling	Face to Face (Face-me-I-face-you)	0.15 (0.14)	0.10 (0.08)

		0.03	*0.03*
House ownership	Owns housing unit	-0.11	-0.07
		(0.13)	(0.08)
		-0.02	*-0.02*
Years of residence	Longer years of residence (>5 years)	0.08	0.04
		(0.11)	(0.07)
		0.02	*0.01*
Income and Finance			
Total monthly income	Higher income (> N100,000 (~$))	**-0.54***	**-0.32***
		(0.11)	**(0.06)**
		-0.10	*-0.10*
Primary source of income	Government, Family or Friend Support	0.09	0.05
		(0.55)	(0.33)
		0.02	*0.02*
	Pension and retirement	**0.64***	**0.40***
		(0.21)	**(0.13)**
		0.12	*0.13*
	Self-employment	**0.33***	**0.20***
		(0.12)	**(0.07)**
		0.06	*0.06*
Financial inclusion	Has a bank account	**-1.38***	**-0.82***
		(0.42)	**(0.24)**
		-0.27	*-0.27*
Business			
Household business	Has a household business	**0.29*****	**0.17*****
		(0.15)	**(0.09)**
		0.06	*0.06*
Size of household business (employees)	More employees (>5 employees)	**-0.75*****	**-0.40*****
		(0.41)	**(0.23)**
		-0.14	*-0.13*
Size of household business (monthly revenue)	More revenue (> N100,000 (~$))	**-0.39*****	**-0.22*****
		(0.20)	**(0.12)**
		-0.07	*-0.07*
Energy			
Grid electricity	Has access to grid electricity	0.36	0.20
		(0.48)	(0.26)

		0.07	*0.06*
Usage patterns	Time of major appliance use (daytime (8am - 4pm))	**0.23*** (0.12)** *0.05*	**0.14*** (0.07)** *0.04*
Ownership of solar systems	**Has a solar system**	**0.29 (0.34)** *0.06*	**0.18 (0.21)** *0.06*
Gensets Genset usage patterns	Genset powers all household appliances	**-0.29* (0.09)** *-0.06*	**-0.17* (0.06)** **-0.05**
Awareness	Know tariff band	**0.92* (0.16)** *0.18*	**0.53* (0.09)** *0.17*
	Aware of Nigeria energy transition plan (ETP)	**-0.18*** (0.10)** *-0.04*	**-0.11*** (0.06)** *-0.04*
	Aware of solar power systems	-0.89 (0.66)	-0.49 (0.38)
Location Local Government Area (LGA) (compared to middle income LGAs)	Agege	**-0.58** (0.30)** *-0.11*	**-0.34** (0.17)** *-0.11*
	Ajeromi-Ifelodun	0.41 (0.26) *0.08*	0.24 (0.16) *0.08*
	Alimosho	**-0.56* (0.19)** *-0.11*	**-0.33* (0.11)** *-0.11*
	Amuwo Odofin	0.47 (0.32) *0.09*	0.26 (0.19) *0.08*
	Apapa	-0.37 (0.34) *-0.07*	-0.24 (0.21) *-0.08*

		Badagry	0.23 (0.46) *0.04*	0.14 (0.27) *0.05*
		Epe	**1.30*** **(0.38)** ***0.25***	**0.80*** **(0.22)** ***0.26***
		Eti Osa	-0.05 (0.23) *-0.01*	-0.03 (0.14) *-0.01*
		Ibeju Lekki	0.20 (0.77) *0.04*	0.13 (0.40) *0.04*
		Ifako-Ijaye	0.14 (0.26) *0.03*	0.08 (0.15) *0.03*
		Ikeja	0.04 (0.26) *0.01*	0.04 (0.16) *0.01*
		Ikorodu	0.35 (0.28) *0.07*	0.21 (0.17) *0.07*
		Lagos-Island	**-1.10*** **(0.32)** ***-0.21***	**-0.65*** **(0.18)** ***-0.21***
		Mushin	0.04 (0.22) *0.01*	0.02 (0.13) *0.00*
		Ojo	-0.68 (0.44) *-0.13*	-0.40 (0.25) *-0.13*
		Oshodi-Isolo	**-0.65***	**-0.38***

			(0.23)	**(0.14)**
			-0.13	*-0.12*
		Somolu	**0.58***	**0.34***
			(0.21)	**(0.13)**
			0.11	*0.11*
		Surulere	-0.04	-0.03
			(0.22)	(0.14)
			-0.01	*-0.01*
	Road accessibility around household	Above average roads (according to rating by household)	-0.03	-0.02
			(0.10)	(0.06)
			-0.01	*-0.01*
	Security of area around household	Above average security (according to rating by household)	**0.21****	**0.12*****
			(0.10)	**(0.06)**
			0.04	*0.04*
Social factors	Peer effects	Nearest household in survey has a genset	-0.19	-0.12
			(0.12)	(0.07)
			-0.04	*-0.04*
		Nearest household in survey has solar	**-1.00****	**-0.58****
			(0.46)	**(0.26)**
			-0.19	*-0.19*
	Regulation	Is subject to community/area/neighborhood regulations regarding genset use	**-0.27*****	**-0.16*****
			(0.14)	**(0.09)**
			-0.05	*-0.05*

*Table B-7: Logit and Probit Results. Coefficients are presented first. Asterisks *, **, *** indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Standard errors are provided in brackets below the coefficients, with average marginal effects italicized beneath the standard errors. The solar ownership variable is highlighted in red.*

			(1)	(2)
		Dependent Variable	**Genset mostly used during the daytime (8am - 4pm)**	
		Observations	2704	
		P (y = 1) in Data	9.06%	
		Model Type	Logit	Probit
		McFadden Pseudo R^2	0.2082	0.2124
		Percent correctly predicted	91.27%	91.05%
Primary Category	**Sub-Category**	**Variable**		

Market and Policy Factors	**Electricity Reliability**	Average reliability (9-12 hours typical daily outages)	-0.06 (0.20) *0.00*	-0.04 (0.10) *0.00*
		Better reliability (4 - 8 hours typical daily outages)	-0.23 (0.23) *-0.02*	-0.11 (0.12) *-0.01*
		Much better reliability (<4 hours typical daily outages)	-0.28 (0.38) *-0.02*	-0.18 (0.21) *-0.02*
Personal Value & Preferences + Environmental Factors	**Electricity Reliability**	Willingness to pay for better reliability	0.14 (0.21) *0.01*	0.09 (0.11) *0.01*
	Environmental Factors			
	Genset environmental impact	Concern about genset's environmental impact	0.08 (0.20) *0.01*	0.04 (0.10) *0.01*
	Rating of air pollution from genset	Highly negative rating of air pollution from gensets	**0.78*** **(0.19)** *0.05*	**0.41*** **(0.10)** *0.05*
Household Characteristics	**Demography**			
	Age of household head	Older household head (50 and above)	0.01 (0.19) *0.00*	0.03 (0.10) *0.00*
	Education (highest level attained)	Higher education (college and above)	**0.34**** **(0.17)** *0.02*	**0.18**** **(0.09)** *0.02*
	Gender	Male	0.19 (0.17) *0.01*	0.11 (0.09) *0.01*
	Size of household	Larger households (>5 members)	-0.20 (0.19) *-0.01*	-0.11 (0.10) *-0.01*
	Housing			
	Type of building/dwelling	Face to Face (Face-me-I-face-you)	0.11 (0.23) *0.01*	0.03 (0.12) *0.00*
	House ownership	Owns housing unit	0.16 (0.21)	0.06 (0.11)

		0.01	*0.01*
Years of residence	Longer years of residence (>5 years)	-0.03 (0.18) *0.00*	-0.03 (0.10) *0.00*
Income and Finance			
Total monthly income	Higher income (> N100,000 (~$))	-0.23 (0.19) *-0.02*	-0.12 (0.10) *-0.02*
Primary source of income	Government, Family or Friend Support	**1.60**** **(0.65)** ***0.11***	**0.79**** **(0.38)** ***0.10***
	Pension and retirement	0.42 (0.37) *0.03*	0.21 (0.19) *0.03*
	Self-employment	0.26 (0.20) *0.02*	0.12 (0.10) *0.01*
Business			
Household business	Has a household business	**0.76*** **(0.25)** ***0.05***	**0.37*** **(0.13)** ***0.05***
Size of household business (employees)	More employees (>5 employees)	-0.83 (0.54) *-0.06*	**-0.52***** **(0.30)** ***-0.07***
Size of household business (monthly revenue)	More revenue (> N100,000 (~$))	**0.60**** **(0.30)** ***0.04***	**0.35**** **(0.17)** ***0.05***
Energy			
Grid electricity	Has access to grid electricity	-0.70 (0.69) *-0.05*	-0.43 (0.35) *-0.06*
Usage patterns	Time of major appliance use (daytime (8am - 4pm))	**1.63*** **(0.17)** ***0.11***	**0.89*** **(0.09)** ***0.12***
Ownership of solar systems	**Has a solar system**	**0.35** **(0.51)**	**0.21** **(0.27)**

		0.02	*0.03*
Gensets			
Genset usage patterns	Genset powers all household appliances	**0.64***	**0.35***
		(0.17)	**(0.09)**
		0.04	**0.05**
Awareness			
	Know tariff band	**0.82***	**0.42***
		(0.28)	**(0.15)**
		0.06	*0.05*
	Aware of Nigeria energy transition plan (ETP)	-0.01	0.01
		(0.18)	(0.09)
		0.00	*0.00*
	Aware of solar power systems		
Location			
Local Government Area (LGA) (compared to middle income LGAs)	Agege	**1.94***	**1.03***
		(0.40)	**(0.22)**
		0.13	*0.13*
	Ajeromi-Ifelodun	-0.19	-0.14
		(0.56)	(0.28)
		-0.01	*-0.02*
	Alimosho	-0.61	-0.27
		(0.39)	(0.19)
		-0.04	*-0.03*
	Amuwo Odofin	-1.46	-0.57
		(0.06)	(0.43)
		-0.10	*-0.07*
	Apapa	0.60	0.29
		(0.53)	(0.29)
		0.04	*0.04*
	Badagry	**1.59****	**0.87****
		(0.69)	**(0.35)**
		0.11	*0.11*
	Epe	-0.11	-0.04

			(0.71)	(0.35)
			-0.01	*-0.01*
		Eti Osa	0.50	0.30
			(0.37)	(0.19)
			0.03	*0.04*
		Ibeju Lekki	1.44	0.66
			(1.02)	(0.53)
			0.10	*0.09*
		Ifako-Ijaye	**1.25***	**0.71***
			(0.39)	**(0.21)**
			0.09	***0.09***
		Ikeja	-0.03	-0.03
			(0.52)	(0.27)
			0.00	*0.00*
		Ikorodu	-0.95	-0.53
			(0.78)	(0.39)
			-0.06	*-0.07*
		Lagos-Island	**0.90****	**0.45*****
			(0.43)	**(0.23)**
			0.06	***0.06***
		Mushin	**1.22***	**0.68***
			(0.35)	**(0.19)**
			0.08	***0.09***
		Ojo	0.41	0.23
			(0.64)	(0.32)
			0.03	*0.03*
		Oshodi-Isolo	**1.04***	**0.60***
			(0.37)	**(0.19)**
			0.07	***0.08***
		Somolu	0.30	0.15
			(0.39)	(0.20)
			0.02	*0.02*

		Surulere	-0.13 (0.43) *-0.01*	-0.06 (0.22) *-0.01*
	Road accessibility around household	Above average roads (according to rating by household)	-0.11 (0.17) *-0.01*	-0.05 (0.09) *-0.01*
	Security of area around household	Above average security (according to rating by household)	**0.42**** **(0.18)** ***0.03***	**0.21**** **(0.09)** ***0.03***
Social factors	Peer effects	Nearest household in survey has a genset	-0.13 (0.19) *-0.01*	-0.07 (0.10) *-0.01*
		Nearest household in survey has solar	**0.89***** **(0.53)** ***0.06***	0.43 (0.30) *0.06*
	Regulation	Is subject to community/area/neighborhood regulations regarding genset use	**0.61**** **(0.24)** ***0.04***	**0.35*** **(0.13)** ***0.04***
		const	**-4.77*** **(0.78)**	**-2.56*** **(0.39)**

Chapter 5 Appendix

Figure C-1: Average Daily Availability per Feeder by Tariff Band and Year

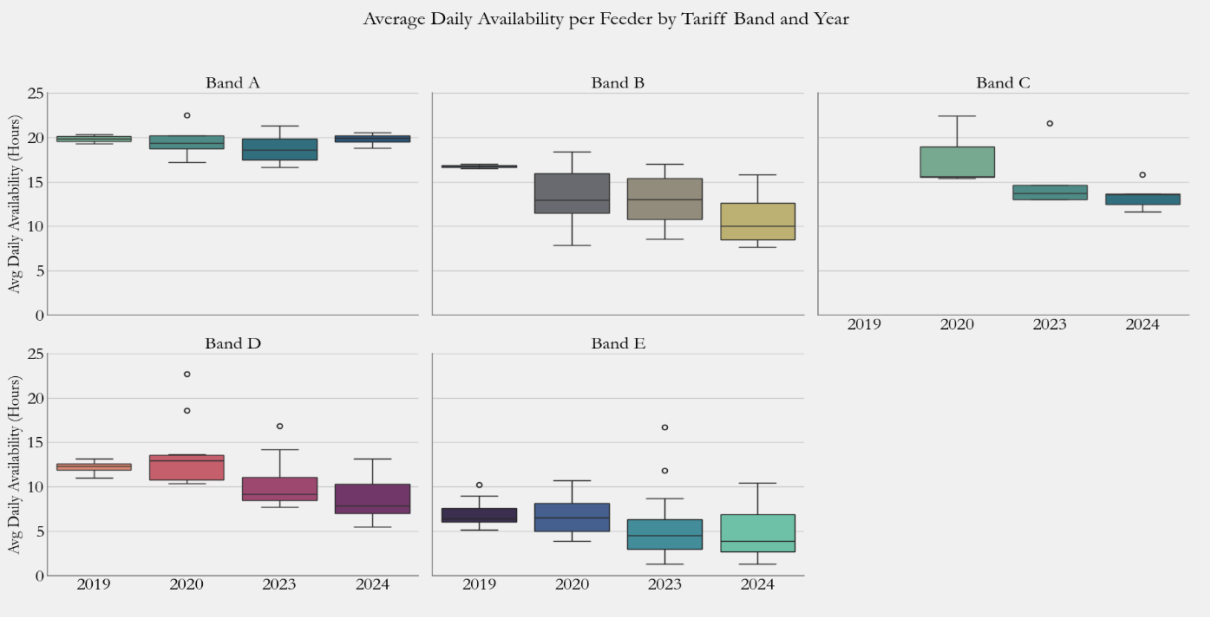


Figure C-2: Seasonal Patterns in Individual Outage Duration by Tariff Band

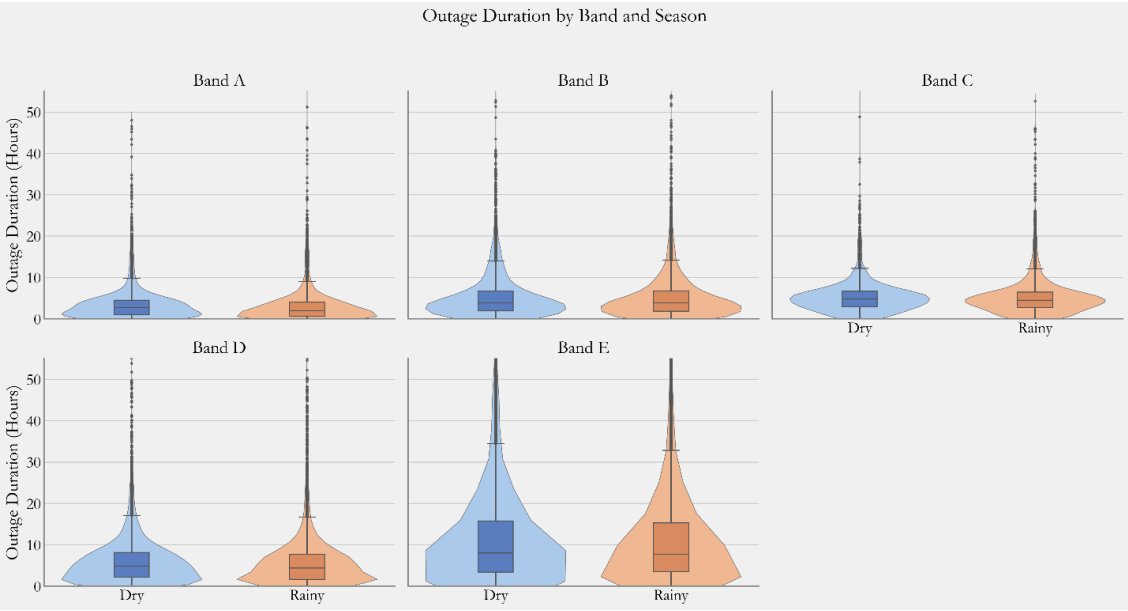


Figure C-3: Regional Patterns in Individual Outage Duration by Tariff Band

