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SECURING ENERGY IN A DIVIDED WORLD: SUPPLY, DEMAND, AND POWER

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PREFACE

The present volume, Securing Energy in a Divided World: Supply, Demand, and Power, emerges from a recognition that energy security is not merely a technical or economic challenge but a profoundly political and societal one, intrinsically linked to questions of equity, sustainability, and global governance. In an era characterized by rapid geopolitical realignments, accelerating energy transitions, and deepening socio-economic divides, it has become imperative to critically examine the ways in which energy systems both shape and are shaped by the dynamics of power, development, and technological innovation.

The chapters gathered herein reflect the intellectual dedication and scholarly depth of all contributing authors, whose rigorous research and innovative perspectives provide analytical clarity and practical insights into some of the most pressing debates of our time. Their collective work interrogates not only the structural challenges of ensuring reliable energy access but also the transformative opportunities offered by renewable technologies, regional cooperation, and forward-looking policy frameworks. The diversity of perspectives and methodologies represented in this book is itself a testament to the interdisciplinary and global nature of the energy question.

We are particularly grateful to the contributors for their unwavering commitment to advancing academic knowledge, for the intellectual care with which they have approached their respective topics, and for their willingness to engage in complex debates with both nuance and vision. Their efforts have enriched the quality, breadth, and relevance of this work, ensuring that it will serve as a valuable resource not only for scholars and students but also for policymakers, practitioners, and all stakeholders concerned with the future of energy and development.

We also extend our sincere appreciation to Liberty Academic Publishers, whose support has been instrumental in realizing this publication. By fostering scholarship and supporting initiatives that bridge theoretical insight with policy relevance, Liberty Academic Publishers has contributed significantly to the advancement of critical dialogue in an area of global importance.

It is our hope that this book will encourage further research, stimulate informed debate, and contribute to the design of inclusive, equitable, and sustainable energy futures in an increasingly interconnected yet divided world.

Editor
Prof. Dr. Maximiliano Martinez Ortiz
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CHAPTER 1
ENERGY SECURITY AND MECHANIZED AGRICULTURE: A POLITICAL-ECONOMIC PERSPECTIVE FROM NIGERIA

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INTRODUCTION

Energy security remains a key factor of modern development, especially in the Global South, where energy deficits directly affect productivity, livelihoods, and economic growth. In countries like Nigeria, Africa's most populous nation and largest oil producer, the paradox of abundant energy resources coexisting with widespread energy poverty has become a defining challenge. While crude oil exports fuel the national economy, domestic electricity access remains critically low. As of 2023, nearly 45% of Nigerians lacked access to grid electricity, and those connected often experience unreliable supply, with daily outages lasting 4–6 hours on average (International Energy Agency [IEA], 2023; Nigerian Bureau of Statistics [NBS], 2022). This energy gap poses severe constraints for agriculture, a sector that employs over 60% of Nigeria's labour force and contributes approximately 23% to GDP (World Bank, 2022).

Agricultural productivity is fundamentally tied to access to modern energy. From land preparation using tractors, to irrigation, post-harvest storage, processing, and transportation, mechanized agriculture is energy intensive. However, Nigeria's tractor-to-hectare ratio remains critically low estimated at 0.27 hp/ha, far below the 1.5 hp/ha minimum threshold required for sustained productivity (Food and Agriculture Organization [FAO], 2021). Smallholder farmers, who account for over 80% of total agricultural output, face high costs of diesel and generator maintenance due to erratic power supply. The removal of long-standing fuel subsidies in 2023 further exacerbated this challenge, causing surges in transportation and input costs, and ultimately contributing to food inflation (Adikwu, Ochimana, & Ikegh, 2023).

This crisis is not isolated. Nigeria's energy and agriculture sectors are deeply interconnected in the global political economy. The volatility of global oil markets, international climate agreements, and growing geopolitical pressure to decarbonize all shape domestic policy decisions. International institutions such as the International Monetary Fund (IMF) and World Bank have long advocated for subsidy removal, citing fiscal inefficiency and market distortion (World Bank, 2022). Yet, for countries like Nigeria, such reforms carry deep socioeconomic implications.

For instance, rural farmers in Benue State reported reduced farm productivity, decreased access to markets, and greater vulnerability to hunger following subsidy reforms (Adikwu et al., 2023; Esheya, 2024).

Amid this, Nigeria has begun to pivot toward renewable energy alternatives to enhance rural electrification and support agricultural productivity. The 2021 Energy Transition Plan and the Renewable Energy Master Plan aim to increase renewable energy's share to 30% by 2030 (Federal Ministry of Power, 2021). Pilot programs using solar mini-grids for irrigation and crop processing in northern Nigeria have shown promising results, increasing productivity by up to 40% and reducing diesel dependency (Carabajal et al., 2024). Nevertheless, these initiatives face barriers: high capital costs, limited access to finance, weak technical support systems, and inadequate coordination between agricultural and energy policies (Essiet, 2024; RMI, 2023).

This chapter situates Nigeria's energy and agriculture within the broader framework of international political economy. It investigates how energy policy especially fuel pricing, electrification, and renewable energy promotion affects agricultural mechanization and food system resilience. It also explores how global energy transitions, geopolitical dependencies, and multilateral policy pressures influence Nigeria's domestic energy-agriculture decisions.

The objectives of this work are to:

1. Examine the current state of energy access and agricultural mechanization in Nigeria
2. Analyse the political and economic implications of energy subsidy reforms and pricing strategies
3. Evaluate the opportunities and constraints associated with renewable energy adoption for agricultural use
4. Propose policy recommendations to foster energy-agriculture integration in a way that enhances national development and aligns with international energy justice goals.

By drawing on policy documents, empirical studies, and international frameworks, the chapter contributes to contemporary debates on energy transitions in the Global South. It argues that sustainable energy interventions in agriculture must be informed by political economy analysis, recognizing power asymmetries, institutional constraints, and the interconnectedness of national and global systems.

1. THEORETICAL FRAMEWORK AND LITERATURE REVIEW

1.1 Theoretical Framework

This chapter focuses on the Political Economy of Energy Transitions and the Energy Justice Framework, two complementary theories that contextualize Nigeria's energy to agriculture connectivity within broader structural forces shaping national development and international policy decisions.

1.1.1 Political Economy of Energy Transitions

The political economy perspective emphasizes the influence of institutional power, economic interests, and governance structures in shaping energy policy. In contrast to purely technical or market-driven approaches, this theory asserts that energy transitions are socio-politically contested processes shaped by the interaction of state actors, multinational corporations, international financial institutions, and civil society (Sovacool et al., 2020; Baker et al., 2014). This perspective is especially useful in analysing Nigeria, where energy reforms such as the removal of fuel subsidies are driven not only by economic necessity but also by geopolitical pressure from global lenders and regional trade agreements. This view is supported by Al and Kaplan (2025, p. 7), who assert that energy functions as a foundational mechanism in the pursuit of power and the orchestration of wealth accumulation, particularly in shaping national policy directions such as those observed in Nigeria.

This framework also allows for interrogation of global energy asymmetries. For instance, while developed economies pursue decarbonisation through renewable energy investments, many developing countries are constrained by technological, financial, and institutional barriers (Newell & Phillips, 2016). In Nigeria, the implementation of international financial reforms often clashes with domestic political realities and local needs, especially in agriculture where energy is a vital production input (Akintande et al., 2023).

1.1.2 Energy Justice Framework

The Energy Justice Framework provides a normative lens to examine how the benefits and burdens of energy policies are distributed across populations. It focuses on three principles: distributive justice (who gets what), recognitional justice (whose voices are heard), and procedural justice (who makes decisions) (Jenkins et al., 2016). This framework is essential in analysing how subsidy removals disproportionately affect rural farmers, how renewable energy solutions are often inaccessible to the poor due to high initial costs, and how agricultural stakeholders are excluded from key energy policy decisions (Carabajal et al., 2024).

Together, these frameworks guide this research's inquiry into how power, policy, and equity intersect in Nigeria's energy and agricultural landscape.

1.2 Literature Review

1.2.1 Energy Policy in Nigeria: From Subsidies to Transition

Nigeria's energy policy has historically centered on the provision of fossil fuel subsidies as a form of social protection. Between 2005 and 2022, the government spent over $30 billion subsidizing petrol and kerosene, yet electricity access remained poor and infrastructural investments lagged (World Bank, 2022). The removal of these subsidies in mid-2023, under advisement from international institutions, was intended to promote economic efficiency and redirect funds toward infrastructure. However, the reform also triggered inflation, disrupted transport, and strained agricultural value chains (Adikwu et al., 2023; Esheya, 2024).

Recent policy documents such as the Nigeria Energy Transition Plan (2021) and the Electricity Act (2023) aim to accelerate the shift to renewable energy through off grid solar, mini grids, and rural electrification (Federal Ministry of Power, 2021). Yet implementation remains sluggish due to financing constraints, regulatory uncertainty, and inadequate capacity at sub-national levels (Adenle, 2023).

1.2.2 Agricultural Mechanization and Energy Access

Mechanization is central to achieving agricultural transformation in sub-Saharan Africa. Studies have shown a positive correlation between energy availability and mechanization rates, especially in irrigation, post-harvest processing, and cold storage (FAO, 2021; Bolarinwa & Oyeyemi, 2023). However, Nigeria's agriculture sector remains predominantly manual. The country's tractor density is less than 10 tractors per 100 km²; this is among the lowest globally (Adeoti & Ajibefun, 2022).

Farmers in off-grid areas rely heavily on diesel generators, whose cost has doubled since the removal of fuel subsidies (Ikejemba & Schreurs, 2023). This has resulted in reduced cultivation areas, labor inefficiencies, and increased post-harvest losses, especially for perishable crops. Despite government interventions such as the Agricultural Equipment Hiring Enterprises (AEHE) scheme, access to mechanized services is still limited and often concentrated among large-scale farmers (NIRSAL, 2023).

1.2.3 Renewable Energy for Agriculture

The intersection of agriculture and renewable energy has received growing academic attention in recent years. Solar-powered irrigation systems, cold storage units, and grain mills have demonstrated notable success in increasing farm productivity and profitability (IRENA, 2022). A pilot study in northern Nigeria found that solar-powered irrigation increased crop yields by 37% and reduced diesel use by 80% (Carabajal et al., 2024).

However, affordability and financing remain major barriers. Studies highlight the need for blended finance models, government guarantees, and decentralized service delivery to enable widespread adoption of renewables in agriculture (Eneh & Asogwa, 2022). Moreover, the absence of an integrated national strategy linking agricultural and energy policies limits the scalability of existing innovations.

1.2.4 International Political Economy Dimensions

Nigeria's energy sector is deeply embedded in global political-economic structures. As a member of OPEC and a participant in global climate negotiations, Nigeria faces conflicting pressures to maximize oil revenues while transitioning to low-carbon pathways (IEA, 2023). The subsidy removal, though domestically controversial, aligns with recommendations from the IMF and World Bank for fiscal consolidation and market liberalization (World Bank, 2022).

At the same time, global decarbonization efforts may lead to reduced demand for Nigerian crude oil, threatening government revenues and foreign exchange reserves. This creates a tension between short-term economic interests and long-term sustainability goals, which is mirrored in agriculture's dependence on fossil fuel driven mechanization (Newell & Phillips, 2016).

Regional trade agreements such as the African Continental Free Trade Area (AfCFTA) also influence Nigeria's energy and agriculture relationship by encouraging investment in infrastructure and renewable energy corridors (UNECA, 2023). However, regional integration efforts must be matched by domestic coherence in policy implementation.

2. ENERGY AND MECHANISATION IN NIGERIA: CURRENT REALITIES

2.1 Introduction

Agricultural mechanisation, the use of machinery and energy driven technologies in farming, is a cornerstone of modern agricultural productivity. In Nigeria, where agriculture employs about 70% of the labour force and contributes approximately 24% to the GDP (National Bureau of Statistics [NBS], 2022), the adoption of mechanised tools remains critically low. The energy systems that support mechanisation diesel, petrol, and increasingly solar energy are under significant strain due to systemic inefficiencies, policy contradictions, and infrastructure gaps. The current landscape of energy and mechanisation in Nigeria reveals both challenges and emerging opportunities, particularly in light of recent policy reforms, including the removal of fuel subsidies and a growing interest in renewable energy technologies.

2.2 Energy Landscape in Nigerian Agriculture

The energy system in Nigeria is characterised by duality: a centralised national grid plagued by instability, and a widespread reliance on decentralised energy sources such as diesel and petrol generators. The latter plays a pivotal role in powering water pumps, tractors, rice mills, and processing machines used in rural agriculture (Ikejemba & Schreurs, 2023). However, fossil fuel dependency creates a volatile production environment. The removal of fuel subsidies in 2023, although fiscally necessary, has resulted in increased input costs across agricultural value chains (Esheya, 2024).

The price of diesel soared by over 200% between 2022 and 2024, directly affecting farm operations and post-harvest processes such as threshing, drying, and milling (Adikwu et al., 2023). These costs are typically passed on to consumers, exacerbating food inflation and reducing the competitiveness of local produce.

Electrification remains limited in rural Nigeria, with only about 55% of rural households having access to electricity, most of which is unreliable (World Bank, 2022). This restricts the adoption of electrically powered agro-processing machinery and cold chain systems that are critical for food security and export viability.

2.3 Mechanisation Trends and Constraints

The state of mechanisation in Nigeria remains rudimentary. According to Adeoti and Ajibefun (2022), Nigeria's mechanisation rate is less than 0.3 hp/hectare, compared to the FAO recommended minimum of 1.5 hp/hectare. The country has less than 30,000 functional tractors, most of which are outdated or poorly maintained (NIRSAL, 2023). Mechanised equipment hiring centres (AEHEs) have been launched across the country, yet their reach and impact remain minimal due to operational inefficiencies, bureaucratic bottlenecks, and inadequate funding.

A significant constraint to mechanisation is the high upfront cost of agricultural equipment and limited access to credit facilities. Financial institutions consider smallholder farmers high-risk borrowers, often demanding collateral and offering loans at prohibitive interest rates (Bolarinwa & Oyeyemi, 2023). Additionally, a mismatch exists between imported machinery and local agro-ecological conditions, leading to poor performance and quick wear-out.

2.4 Regional and Gender Disparities

Mechanisation access is unevenly distributed across Nigeria's geo-political zones. Northern states such as Kaduna and Kano exhibit relatively higher tractor densities due to donor programs and commercial farming enterprises. In contrast, southern regions particularly the Niger Delta struggle with land fragmentation and swampy terrain, which makes mechanisation difficult (Akintande et al., 2023).

Moreover, mechanisation systems tend to exclude women, who constitute over 60% of the agricultural labour force. Gender bias in equipment design, financing access, and cultural norms limits women's participation in mechanised agriculture, exacerbating inequality (FAO, 2021).

2.5 Renewable Energy Solutions and Innovations

In response to fuel cost volatility and climate change, renewable energy solutions are gaining traction. Solar powered irrigation, threshers, and mini-grids for agro-processing are being piloted in several states. A study by IRENA (2022) showed that solar powered irrigation systems increased productivity by up to 30% and reduced water wastage in arid zones of northern Nigeria.

Private-sector-led innovations, such as ColdHubs (solar-powered cold storage) and Arnergy (mini-grid solutions for rural businesses), demonstrate scalable models for integrating renewables into agriculture (Carabajal et al., 2024). However, these remain pilot scale, constrained by inadequate policy support, insufficient data, and lack of coordination between the Ministries of Power and Agriculture.

The Nigeria Electrification Project (NEP), supported by the World Bank, has introduced incentives for renewable energy developers targeting productive use in rural communities. Still, uptake has been slower than projected due to high upfront costs, limited awareness, and challenges in last mile delivery.

2.6 Policy Interventions and Institutional Gaps

The Nigerian government has enacted several policies to promote both mechanisation and energy efficiency in agriculture. Key initiatives include the National Agricultural Technology and Innovation Plan (NATIP) and the National Renewable Energy and Energy Efficiency Policy (NREEEP). However, implementation remains weak due to fragmented responsibilities, poor inter agency coordination, and political interference (Adenle, 2023).

The 2023 Electricity Act, which allows states and private actors to generate and distribute electricity, is a potential game-changer. However, states must develop the technical capacity and regulatory frameworks to actualize its benefits for agricultural stakeholders (Federal Ministry of Power, 2023).

Furthermore, no unified strategy exists to link energy access with agricultural development. This gap results in policy silos where energy projects ignore agricultural needs, and vice versa. There is a critical need for a cross-sectoral approach that aligns investments, research, and capacity-building efforts.

2.7 The Way Forward

Addressing Nigeria's energy and mechanisation challenges requires a multidimensional strategy. First, targeted subsidies and tax incentives for renewable energy solutions in agriculture should be prioritized. Second, mechanisation service delivery must be expanded through public-private partnerships and digital platforms to enhance transparency and scalability.

Capacity building for local artisans and manufacturers can help reduce dependency on imports and improve machinery availability. Additionally, gender-responsive policies must be mainstreamed to ensure inclusive access to equipment and energy services.

Most importantly, integrating energy access planning into agricultural policies will ensure that mechanisation efforts are powered, sustainable, and resilient. Donor agencies, local governments, and civil society must collaborate to create enabling environments for innovation, especially at the last mile.

2.8 Conclusion

The realities of energy and mechanisation in Nigeria reflect a complex interplay of economic, social, and institutional forces. While recent policy reforms and emerging technologies offer hope, systemic constraints continue to undermine the sector's potential. A coherent, inclusive, and forward-looking strategy that prioritizes energy and agriculture synergies is essential to unlock the productivity and food security gains that mechanisation promises in Nigeria.

3. POLITICAL ECONOMY OF ENERGY POLICIES IN NIGERIA

3.1 Introduction

Nigeria's energy sector is emblematic of the broader tensions in the international political economy: a resource-rich country grappling with energy poverty, subsidy controversies, import dependency, and shifting geopolitical allegiances. Nowhere is this more pronounced than in the relationship between energy policy and agricultural development. This section unpacks the political economy underpinning Nigeria's energy policy, tracing its historical evolution, economic implications for the agricultural sector, and the role of international actors in shaping policy directions. It also explores the structural vulnerabilities created by import dependencies and fuel price volatility, situating Nigeria within a global energy and food security framework.

3.2 History and Structure of Energy Subsidy Regimes in Nigeria

Energy subsidies in Nigeria emerged as a populist economic tool in the late 1970s, aimed at cushioning consumers from volatile global oil prices and fostering industrial growth. Over the decades, the fuel subsidy regime grew in scale and complexity. By 2011, Nigeria was spending over ₦2 trillion (approx. $13 billion at the time) annually on petrol subsidies alone, more than its total capital expenditure for health and education combined (BudgIT, 2021).

Despite repeated attempts at reform, subsidy removal efforts have faced significant public resistance due to their regressive impact, particularly on poor households and rural economies. Politically, subsidies have been sustained as a rent-distribution mechanism tied to elite interests, oil marketers, and patronage networks (Ikpe, 2018). Their distortionary effects on the economy encouraging smuggling, corruption, and underinvestment in energy infrastructure have been widely documented (World Bank, 2022).

The formal removal of subsidies in 2023 marked a watershed moment. While the policy aligned with fiscal consolidation goals and international recommendations, its implementation lacked robust social safety nets, leading to inflationary shocks across sectors including agriculture (Adikwu, Ochimana, & Ikegh, 2023).

3.3 Import Dependency in Agricultural Mechanisation

Agricultural mechanisation in Nigeria remains heavily dependent on imported equipment and spare parts, primarily from India, China, and Brazil. This dependency is driven by limited local manufacturing capacity, technological gaps, and policy inconsistencies in the industrial sector (FAO, 2021). Domestic tractor production, for example, is negligible, and even assembly plants such as those in Bauchi and Kaduna operate far below capacity due to lack of investment and spare parts.

This import dependence has significant implications for cost, availability, and adaptability of equipment to Nigerian agro-ecological conditions. During currency devaluations or global supply chain disruptions, the prices of tractors, threshers, and irrigation kits surge making them unaffordable for most smallholder farmers (Adeoti & Ajibefun, 2022).

More critically, the weak backward linkages between the agricultural and manufacturing sectors have prevented the emergence of a sustainable mechanisation ecosystem. The policy space has largely failed to incentivize local innovation, with research institutes underfunded and private sector participation hindered by unstable macroeconomic conditions (NIRSAL, 2023).

3.4 Fuel Price Volatility and Agricultural Input Markets

Fuel prices directly influence the cost structure of agricultural operations in Nigeria, given the widespread reliance on diesel and petrol-powered machinery. Activities such as land clearing, irrigation, transportation, milling, and storage are all energy intensive. The abrupt removal of subsidies in 2023 caused diesel prices to rise by over 200%, triggering cost-push inflation across agricultural value chains (Esheya, 2024).

Transportation of inputs seeds, fertilizers, agrochemicals became more expensive, reducing access in remote areas. Additionally, rising costs discouraged the use of cold storage systems, leading to higher post-harvest losses. Input dealers and small-scale processors have reported a decline in business activity due to the reduced purchasing power of farmers (Bolarinwa & Oyeyemi, 2023).

This price volatility affects not only productivity but also the viability of long-term investments in mechanisation and energy efficient infrastructure. The risk environment created by fluctuating energy prices undermines creditworthiness, disincentivizes innovation, and increases reliance on donor-funded or ad-hoc solutions.

3.5 International Influence on Energy and Agricultural Policy

Nigeria's energy policies have long been shaped by multilateral institutions and donor agencies. The World Bank and International Monetary Fund (IMF) have consistently advocated for subsidy removal, market liberalisation, and private sector led energy reforms under the auspices of Structural Adjustment Programs (SAPs) and Poverty Reduction Strategy Papers (PRSPs) (Newell & Phillips, 2016). These prescriptions, while fiscally rational, often overlook the socio-economic complexities of implementation in agrarian contexts.

The African Development Bank (AfDB) and United Nations Industrial Development Organization (UNIDO) have supported renewable energy and agricultural mechanisation programs, especially through the Technologies for African Agricultural Transformation (TAAT) initiative and Feed Africa Strategy. However, most of these programs operate at pilot scale and lack sufficient domestic ownership to ensure scalability (Adenle, 2023).

Donor-funded initiatives such as the Nigeria Electrification Project (NEP), supported by the World Bank and Rural Electrification Agency (REA), aim to deploy solar mini-grids and standalone systems. While promising, their integration with agricultural clusters remains limited due to poor coordination and insufficient community engagement (IRENA, 2022).

Furthermore, international climate finance mechanisms like the Green Climate Fund (GCF) and the Clean Technology Fund (CTF) have yet to be effectively harnessed to finance energy-mechanisation linkages in rural Nigeria. This is in part due to institutional bottlenecks and a lack of robust project pipelines.

3.6 Geopolitical Implications: Oil Dependence and Food Security

Nigeria's heavy dependence on crude oil exports for foreign exchange earnings and government revenue exposes the country to global price shocks and undermines investment in other sectors, including agriculture. During oil price booms, attention to agriculture typically wanes, reinforcing a cycle of neglect and vulnerability (Baker et al., 2014). Conversely, during price crashes as witnessed in 2016 and 2020 revenue shortfalls lead to budget cuts in critical areas like rural electrification, input subsidies, and extension services.

This oil dependency also shapes Nigeria's geopolitical alliances. As a member of OPEC, Nigeria often aligns with cartel decisions that prioritize export revenue over domestic consumption needs. As Al and Kaplan (2025, p. 22) observe, this alignment illustrates a broader global pattern in which leading energy consumers and producers simultaneously occupy top positions in military investment, underscoring the strategic nature of energy dependency. The contradiction is that while Nigeria exports crude, it imports refined fuel, including petrol and diesel used in agriculture, making food security vulnerable to external refinery disruptions and currency volatility (IEA, 2023).

In a geopolitical landscape marked by climate agreements and energy transition pressures, Nigeria is also under scrutiny to reduce carbon emissions. However, a premature or externally imposed transition risks undermining food security if not carefully aligned with domestic development goals. The challenge is thus to decouple agriculture from fossil fuel reliance without imposing undue hardship on rural populations.

3.7 Conclusion

The political economy of Nigeria's energy policies reveals a deeply entrenched set of historical choices, institutional dynamics, and international pressures. While energy subsidy removal and renewable energy deployment are steps toward reform, they must be implemented within a socially inclusive and sectorally integrated framework. Import dependence, fuel volatility, and donor driven reforms must be addressed with local ownership, industrial capacity building, and strategic investment.

If Nigeria is to meet its food security goals and transition to a low carbon economy, energy policy must shift from being a tool of political patronage to an instrument of structural transformation. This will require a renewed political will, strong institutions, and coherent partnerships that centre the needs of the rural poor and farming communities.

4. EMERGING OPPORTUNITIES – RENEWABLE ENERGY AND POLICY SHIFTS

4.1 Introduction

Nigeria, like many developing countries, finds itself at a crossroads where energy access, climate commitments, and economic development converge. Amidst longstanding energy insecurity and environmental challenges, renewable energy presents a transformative opportunity particularly for the agricultural sector. The transition from fossil fuel dependency to decentralized renewable systems holds promise for enhancing agricultural productivity, improving rural livelihoods, and advancing food security.

This section looks at the emerging landscape of renewable energy in Nigeria's agricultural context, focusing on solar powered irrigation and processing systems, pilot projects under rural electrification programs, the multifaceted challenges limiting widespread adoption, and the potential for South-South cooperation and technology transfer to scale innovations.

4.2 Use of Solar Powered Systems in Irrigation and Agro-Processing

Solar energy has emerged as a leading option for clean, affordable, and decentralized energy in rural Nigeria. The country receives an average solar irradiance of 5.5 kWh/m^2/day, making it highly suitable for solar photovoltaic (PV) technologies (IRENA, 2022). In agriculture, solar-powered solutions are increasingly being deployed for:

Irrigation: Solar water pumps offer a cost effective alternative to diesel-powered systems, especially in off-grid areas. In states such as Kaduna, Katsina, and Borno, small-scale farmers have adopted solar irrigation for dry-season farming, resulting in higher yields and expanded cultivated areas (Carabajal et al., 2024).

Post-Harvest Processing: Solar dryers and milling machines reduce post-harvest losses, improve product quality, and reduce reliance on erratic grid power or expensive fuel generators (FAO, 2021). For perishable crops like tomatoes, mangoes, and fish, solar-powered cold storage such as those provided by ColdHubs has extended shelf life by up to 50% and reduced spoilage.

Lighting and Water Supply**:** Solar mini grids support basic needs that complement agricultural productivity, including lighting, water purification, and refrigeration, thus improving the overall resilience of farming communities.

4.3 Pilot Projects and Rural Electrification Programs

Several government and donor-backed programs have launched pilot renewable energy initiatives aimed at improving energy access in rural areas:

4.3.1 Nigeria Electrification Project (NEP)

Backed by the World Bank and the Rural Electrification Agency (REA), the NEP aims to deliver solar mini grids and standalone systems to unserved and underserved communities. As of 2023, over 300,000 households and small businesses, including agro processors, have benefited from these systems (REA, 2023).

4.3.2 Energizing Agriculture Program (EAP)

This component under the REA aligns renewable energy deployment with productive use, particularly in agricultural clusters. Projects under the EAP provide energy for processing hubs such as cassava mills and rice polishers via solar microgrids, promoting rural industrialization (Adenle, 2023).

4.3.3 UNDP-GEF Solar Irrigation Project

The United Nations Development Programme (UNDP), in collaboration with the Global Environment Facility (GEF), has piloted solar-powered irrigation schemes across seven Nigerian states. Early evaluations show significant improvements in dry-season farming and reduced operational costs (UNDP, 2022).

These pilot projects provide a foundation for policy learning and scale-up. However, their success often depends on local ownership, community engagement, and integration into broader agricultural extension frameworks.

4.4 Challenges to Renewable Energy Deployment in Agriculture

Despite the promise of solar energy in rural Nigeria, several structural and socio economic barriers persist:

4.4.1 High Capital Costs and Financing Gaps

The upfront costs of solar-powered irrigation or processing systems can be prohibitive for smallholder farmers. A basic 2–5 kW solar system costs between ₦1.5 million to ₦4 million ($1,000 – $3,000), far beyond the reach of most rural households without subsidies or concessional financing (Bolarinwa & Oyeyemi, 2023). Additionally, lack of tailored credit products, high interest rates, and limited financial literacy hinder access to finance.

4.4.2 Infrastructure and Supply Chain Limitations

The market for solar equipment in Nigeria suffers from fragmented distribution networks, limited after sales services, and inconsistent quality standards. Many rural areas lack trained technicians to install and maintain systems, leading to high failure rates of initial installations (IRENA, 2022).

4.4.3 Low Awareness and Capacity

Awareness of the economic and environmental benefits of solar technologies remains low in many farming communities. This is compounded by a lack of agricultural extension services that promote energy-smart farming techniques. Many pilot projects fail to scale due to limited capacity building and inadequate local engagement (Akintande et al., 2023).

4.4.4 Policy and Institutional Barriers

Although Nigeria has developed a National Renewable Energy and Energy Efficiency Policy (NREEEP), implementation has been slow. Bureaucratic bottlenecks, lack of policy coherence, and poor inter-ministerial coordination impede progress. Moreover, renewable energy development often occurs in silos, without alignment to agricultural or rural development strategies (Adenle, 2023).

4.5 Potential for South-South Cooperation and Technology Transfer

South-South cooperation offers a promising pathway to overcome technological and financing challenges in Nigeria's energy transition. Countries like India, Bangladesh, and Brazil have pioneered low-cost renewable energy solutions for agriculture that are adaptable to Nigerian conditions.

4.5.1 Learning from India's Solar Irrigation Push

India's Solar Irrigation Pumps (SIP) initiative has supported over 250,000 farmers with grid connected and off grid solar water pumps. Through policy incentives and public-private partnerships, India has drastically reduced pump costs while supporting local manufacturing. Similar models could be replicated in Nigeria via technology licensing and collaborative R&D (IRENA, 2022).

4.5.2 Brazilian Cooperation in Bioenergy and Agro-Tech

Brazil has advanced in renewable powered agro processing, especially bioenergy, through its Embrapa-led research institutions. Technical assistance from Brazil has already influenced Nigeria's cassava processing reforms. Expanding this collaboration to include energy access could enhance productivity in rural processing hubs (FAO, 2021).

4.5.3 Regional Collaboration through ECOWAS and AfCFTA

The Economic Community of West African States (ECOWAS) and the African Continental Free Trade Area (AfCFTA) can foster regional technology transfer by harmonizing standards, pooling demand for solar components, and supporting regional training centers for renewable energy and agricultural mechanisation.

4.6 Conclusion

Nigeria's renewable energy transition in agriculture is gathering momentum through solar-powered irrigation, agro-processing hubs, and rural electrification initiatives. While pilot projects and government programs illustrate the viability of clean energy solutions, scalability remains hindered by high costs, inadequate infrastructure, and limited awareness.

Unlocking the full potential of renewable energy in agriculture requires an ecosystem approach that combines finance, policy alignment, capacity-building, and international cooperation. South-South collaboration and local innovation must be prioritized to accelerate technology transfer and build sustainable rural economies. As Nigeria seeks to meet its climate targets and agricultural productivity goals, renewable energy is not just an option, it is highly imperative.

5. POLICY IMPLICATIONS AND RECOMMENDATIONS

5.1 Introduction

The intersection of energy access and mechanised agriculture in Nigeria presents a vital policy arena that demands urgent attention. While renewable energy solutions and technological innovations are gaining traction, the scale of energy poverty, fossil fuel dependency, and institutional fragmentation continues to limit agricultural productivity and rural development. This section outlines actionable policy recommendations based on the current landscape, addressing energy access for mechanised farming, reform strategies for energy transition, regional trade potentials, and the coordinated role of both international and local stakeholders.

5.2 Strategies to Improve Energy Access for Mechanised Farming

5.2.1 Targeted Energy and Agriculture Integration

One of the most critical gaps in Nigeria's energy policy is the lack of tailored interventions for the agricultural sector. Government policies must formally integrate energy planning into national agricultural strategies. For instance, the National Agricultural Technology and Innovation Plan (NATIP) should be cross linked with the National Renewable Energy and Energy Efficiency Policy (NREEEP) and the Nigeria Energy Transition Plan to create a unified framework for energy powered agricultural growth (Adenle, 2023).

5.2.2 Expand Renewable Energy Infrastructure in Agro-Hubs

Energy access for mechanised farming must prioritize agricultural clusters and processing hubs. Installing solar mini-grids in these areas can support equipment such as grain mills, irrigation systems, and cold storage units. Public-private partnerships (PPPs) should be incentivized to build decentralized renewable infrastructure, with rural electricity cooperatives empowered to manage operations (IRENA, 2022).

5.2.3 Financial Incentives and Smart Subsidies

Access to energy technologies for farmers remains hindered by cost. Policies should establish result-based financing, tax waivers for off-grid solar imports, and concessional loans tailored to rural producers. Special grant schemes should target women and youth-led agribusinesses to ensure inclusivity (Bolarinwa & Oyeyemi, 2023).

5.3 Policy Reforms for Reducing Fossil Fuel Dependence

5.3.1 Transition Away from Diesel-Powered Systems

Diesel use in irrigation, mechanised ploughing, and transportation is economically and environmentally unsustainable. Phasing out diesel reliance should begin with the introduction of solar diesel hybrid systems as transitional tools. Incentives for solar powered pumps and threshers must be institutionalised and scaled nationwide (FAO, 2021).

5.3.2 Reform Energy Subsidy Models

Rather than blanket fossil fuel subsidies, the Nigerian government should redirect subsidies toward clean energy alternatives. Smart subsidy models like those used in India's PM-KUSUM program offer direct support to farmers for adopting solar energy while disincentivizing diesel use (IRENA, 2022).

5.3.3 Localisation and Manufacturing Policy

The importation of fuel dependent machinery and parts has entrenched Nigeria's vulnerability to global oil price shocks. Developing a local manufacturing ecosystem for renewable and compatible agricultural machinery must be a priority. This includes supporting research and development (R&D), providing access to affordable raw materials, and enforcing quality control standards.

5.4 Regional Cooperation and Trade for Machinery and Energy Technology

5.4.1 Harmonising Standards and Tariffs

Through platforms like ECOWAS and AfCFTA, Nigeria should collaborate with neighbouring countries to harmonise equipment standards, reduce import tariffs on renewable energy systems, and facilitate cross border energy trade. Regional agreements can also reduce transaction costs and attract investors into West Africa's agro and energy sector (Newell & Phillips, 2016).

5.4.2 Regional Research and Innovation Hubs

ECOWAS members can pool resources to establish centres of excellence for renewable energy and agricultural engineering. These hubs can lead regional training, innovation, and product development, encouraging South-South knowledge sharing and reducing the reliance on Western technologies.

5.4.3 Solar Manufacturing Clusters

Countries such as Ghana, Morocco, and Kenya have made strides in solar component assembly and battery recycling. Nigeria can tap into these capabilities through regional cooperation by establishing joint ventures and supply chains that lower equipment costs for farmers.

5.5 Role of International Actors and Local Governance

5.5.1 Rebalancing International Partnerships

While international agencies like the World Bank, AfDB, and UNDP have supported Nigeria's energy reforms, their projects often prioritize macroeconomic goals over local realities. Future programs must design projects with Nigerian institutions and farmer associations to improve relevance and sustainability (Esheya, 2024).

5.5.2 Technical Assistance and Climate Finance

International actors can support Nigeria in unlocking climate finance opportunities, such as the Green Climate Fund and Clean Technology Fund. These resources should be channelled towards building infrastructure that supports agricultural productivity, not just emissions reduction.

5.5.3 Strengthening Local Governance and Accountability

Decentralisation of energy governance, enabled by the Electricity Act of 2023, offers states the autonomy to design energy access programs. However, this requires strong local institutions, transparent budgeting, and participatory policy design. States should establish Agro&Energy Task Forces composed of energy providers, cooperatives, civil society, and agricultural unions to align priorities and track progress.

CONCLUSION

This book has examined the intricate interplay between energy policy, agricultural mechanisation, and political economy in Nigeria, offering an in-depth analysis of current realities, emerging opportunities, and pathways for transformative change. Across seven chapters, the study has articulated how Nigeria's agricultural sector remains entangled with structural energy challenges, policy inconsistencies, and global economic dynamics shaping both productivity and rural livelihoods.

Chapter One established the foundation by exploring the theoretical frameworks of political economy and energy justice, highlighting how power relations, resource allocation, and global governance structures influence domestic energy decisions. Chapter Two provided a comprehensive literature review that revealed persistent gaps in rural electrification, agricultural energy integration, and renewable technology adoption.

In Chapter Three, we assessed the lived realities of energy and mechanisation in Nigeria, detailing how diesel dependence, post-subsidy fuel inflation, and unreliable grid access undermine farm productivity and deepen food insecurity. Chapter Four built on this by unpacking the political economy of Nigeria's energy policy, tracing the legacy of fuel subsidies, the impact of import dependency for farm machinery, and the influence of international actors like the World Bank and African Development Bank.

Chapter Five turned toward opportunity, highlighting the potential of solar powered irrigation, rural electrification programs, and pilot projects. While challenges such as high costs and weak infrastructure persist, the emergence of renewable energy presents a viable path for agricultural transformation. Chapter Six then laid out actionable policy recommendations, emphasizing the need for cross-sectoral planning, subsidy reform, regional cooperation, and stronger local governance.

Collectively, these findings reinforce the central thesis: that energy access is not only a technical or environmental issue but also a deeply political and economic one. The future of mechanised agriculture in Nigeria depends on rethinking energy policies through a development oriented lens prioritising equity, sustainability, and rural empowerment.

Looking ahead, further research should turn towards several critical areas like the long-term impacts of energy reforms on smallholder farmer resilience, the design of inclusive financing models for renewable technologies, and the role of local innovation systems in scaling agro-energy solutions. Additionally, policy debates must go beyond subsidy removal and focus on designing energy transitions that leave no one behind.

As Nigeria navigates its energy future, the agricultural sector must remain at the centre of both policy and investment decisions. Only through a cohesive, justice driven approach can energy and agriculture jointly power inclusive growth and sustainable development.

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CHAPTER 2
THE POLITICAL ECONOMY OF RENEWABLE ENERGY TRANSITIONS

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INTRODUCTION

The transition from fossil fuel-based energy systems to renewable energy is one of the most pressing and ambitious undertakings of the 21st century. As the global community confronts the challenges of climate change, energy insecurity, and socio-economic inequality, renewable energy presents both a solution and a battleground. While technological advancements in solar photovoltaics, wind turbines, hydroelectric systems, and bioenergy have significantly reduced costs and improved energy access (IRENA, 2022), the transition is neither linear nor purely technical. Instead, it is deeply embedded in the political economy of individual nations—shaped by power dynamics, institutional arrangements, economic interests, and societal contestation (Geels, 2011; Newell & Paterson, 2010).

1. FRAMING ENERGY TRANSITIONS AS POLITICAL ECONOMY PROCESSES

This chapter moves beyond the mainstream techno-centric narratives of energy transition to interrogate the underlying political and economic structures that condition these shifts. Energy transitions are, at their core, socio-political transformations complex processes negotiated across different scales, involving actors with divergent interests, levels of power, and ideological orientations (Sovacool, 2016). These transitions are neither inevitable nor uniformly beneficial; they are contested by incumbent fossil fuel regimes, shaped by state-market relations, and constrained or accelerated by institutional capacity and governance architectures (Meadowcroft, 2009).

Using a political economy lens allows us to explore not just what drives technological adoption, but who benefits, who loses, and what institutional reforms are required to ensure equity and sustainability. In this regard, transitions are embedded in historical path dependencies and are contingent on broader structures of capitalism, development, and governance (Bridge et al., 2013).

1.1 Understanding the Political Economy Approach to Renewable Energy Transitions

The political economy approach provides a critical lens through which to examine the dynamics of renewable energy transitions by focusing on the interrelations among political institutions, economic structures, and social forces. It moves beyond conventional techno-centric analyses that prioritize engineering solutions and market-based efficiencies, offering instead a framework for understanding how power, interests, and ideology shape the governance and distributional outcomes of energy policies (Bridge, Özkaynak, & Turhan, 2013).

In the realm of renewable energy, the political economy approach asks fundamental questions: Who benefits from energy transitions? Who bears the costs? What role does the state play in enabling or obstructing change? How do international financial flows and global trade regimes influence domestic energy pathways? These inquiries are essential in unpacking the contested nature of decarbonization and the socio-political complexity behind the adoption or rejection of renewable energy technologies.

Baker, Newell, and Phillips (2014) argue that energy transitions are deeply political processes involving the negotiation of competing interests—ranging from entrenched fossil fuel industries and utility monopolies to emerging renewable sectors and civil society actors. These interests often operate within asymmetric power relations, where incumbent actors with established institutional and financial capital can delay, dilute, or co-opt reform efforts. For instance, fossil fuel lobbies have historically leveraged their influence over regulatory agencies and political elites to secure subsidies, favorable tax regimes, and regulatory exemptions (Goldthau & Sovacool, 2016).

The political economy perspective also interrogates the role of the state—not merely as a neutral facilitator of market operations, but as an active agent with the capacity to shape investment priorities, regulate markets, redistribute resources, and create enabling environments for innovation. States vary significantly in their approach: some, like Germany, engage in robust public-private coordination and long-term planning, while others, like Nigeria, exhibit fragmented governance, weak regulatory enforcement, and inconsistent policy implementation due to rent-seeking dynamics and clientelist politics (Aklin & Urpelainen, 2018; Oloruntoba, 2020).

Moreover, this approach is attuned to global dimensions of energy transitions. International financial institutions, development banks, and multinational corporations influence domestic energy agendas through conditional lending, investment flows, and technology transfers. The flow of capital into renewable projects is often mediated by global North-South inequalities, where developing economies may lack the institutional infrastructure to absorb and manage such investments equitably (Newell & Mulvaney, 2013).

Crucially, the political economy approach challenges the techno-deterministic narrative that views decarbonization as a linear, inevitable process driven solely by innovation and market efficiency. Instead, it foregrounds the reality that transitions are uneven, contested, and subject to reversals. Policy fragmentation, bureaucratic inertia, and socio-political resistance—especially from labor unions, rural communities, or regions economically dependent on fossil fuels—can hinder progress (Sovacool, 2016). For example, the "yellow vests" protests in France in 2018 exemplified how energy taxes aimed at climate goals can provoke strong resistance if perceived as socially regressive.

Thus, the political economy perspective underscores that technological readiness, while necessary, is not sufficient. Transitions require political legitimacy, social buy-in, and institutional innovation. They must navigate vested interests, path dependencies, and structural constraints within broader development trajectories and governance arrangements. Recognizing these dynamics is critical for designing policies that are not only technically sound but also politically feasible and socially just.

1.2 The Comparative Case Study Approach

Understanding the political economy of renewable energy transitions requires a method that can account for the complex interplay of political institutions, economic structures, and social dynamics across different national contexts. To this end, this chapter adopts a comparative case study approach that examines three countries—Germany, China, and Nigeria each representing distinct political, economic, and institutional configurations. This methodological choice enables a nuanced exploration of how state capacity, regulatory frameworks, financial incentives, and socio-political coalitions mediate the pace, scope, and character of renewable energy transitions.

Germany: Energiewende and Democratic Governance

Germany's *Energiewende* (energy transition) is widely regarded as a global benchmark for a socially negotiated and legislatively anchored shift toward renewable energy. Since the passage of the Renewable Energy Sources Act (EEG) in 2000, Germany has substantially increased the share of renewables in its electricity mix—from about 6% in 2000 to over 49% by 2022 (BMWK, 2023). The EEG introduced feed-in tariffs, grid priority access for renewables, and long-term investment security, leading to a decentralization of energy generation and widespread citizen participation.

However, Germany's transition also reveals significant structural trade-offs. The rapid expansion of intermittent sources like wind and solar has strained grid stability, necessitating costly grid upgrades and storage solutions. Furthermore, the decision to phase out nuclear power by 2022 and coal by 2038 has triggered concerns over energy affordability and industrial competitiveness, particularly in energy-intensive sectors (Agora Energiewende, 2022). Rising electricity prices, partly due to the EEG surcharge, have fueled public debates over energy equity, even as support for decarbonization remains strong.

China: State-Led Industrial Strategy and Renewable Deployment

China presents a contrasting model of energy transition characterized by centralized planning, state-owned enterprises, and industrial policy as key drivers. The Chinese government has invested heavily in wind and solar energy as part of its national economic development strategy. Between 2010 and 2022, China became the world's largest producer and installer of solar photovoltaic (PV) panels and wind turbines, accounting for over 30% of global renewable energy investment in 2021 alone (IRENA, 2022; REN21, 2023).

This expansion is underpinned by large-scale subsidies, preferential loans from state banks, and massive infrastructure programs such as the Ultra High Voltage (UHV) grid to transmit renewable electricity across regions. Yet, implementation remains uneven. Provinces with less industrial capacity lag in integrating renewables, and curtailment rates i.e., the percentage of generated renewable electricity not used due to grid constraints—have historically been high, though they have declined with recent reforms (Zhang & Gallagher, 2016). Additionally, coal continues to play a pivotal role in the energy mix, with the government approving over 100 GW of new coal capacity in 2022, reflecting energy security concerns and local employment priorities (Global Energy Monitor, 2023).

Nigeria: Resource Dependence and Energy Governance Challenges

Nigeria exemplifies the complex challenges facing resource-dependent countries in the Global South. Despite receiving abundant solar irradiation estimated at 4.0–6.5 kWh/m²/day renewables make up less than 10% of Nigeria's energy mix, primarily from large hydropower (IEA, 2022). The electricity sector is marked by chronic underinvestment, aging infrastructure, and unreliable grid coverage, with over 85 million Nigerians lacking access to electricity as of 2021 (World Bank, 2022).

Institutionally, Nigeria's energy transition is constrained by weak regulatory frameworks, inconsistent policy implementation, and entrenched fossil fuel subsidies. In 2022 alone, the Nigerian government spent over ₦4 trillion (~$9 billion) subsidizing petroleum products, crowding out investments in renewables and public infrastructure (NEITI, 2023). Political resistance to subsidy reform is intense, rooted in the socio-economic role of cheap fuel as a buffer against poverty and inflation.

Although Nigeria has adopted various renewable energy strategies, such as the National Renewable Energy and Energy Efficiency Policy (NREEEP) and the Sustainable Energy for All (SE4All) Action Agenda, implementation remains sporadic due to institutional fragmentation, bureaucratic bottlenecks, and low private sector confidence. Initiatives such as the Solar Power Naija program, which targets 5 million solar connections, represent a promising step, but scale-up is hindered by funding and governance gaps.

1.3 Insights from Comparative Analysis

By juxtaposing these three cases, several critical insights emerge:

- **State capacity and institutional design** matter profoundly. Germany's legalistic and participatory approach, China's bureaucratic authoritarianism, and Nigeria's regulatory fragility all produce divergent energy outcomes.
- **Financial architecture and policy consistency** are key determinants of investment flows. While Germany and China have aligned financial mechanisms with long-term goals, Nigeria's investment climate remains volatile.
- **Political coalitions and interest group dynamics** shape the legitimacy and feasibility of reforms. In each case, incumbent fossil fuel actors, public attitudes, and social movements play different roles in either accelerating or obstructing transitions.

Ultimately, these case studies underscore that there is no one-size-fits-all pathway to renewable energy adoption. Transitions are embedded in specific political and economic contexts, and their outcomes are determined not just by technological readiness but by the capacity of institutions to navigate competing interests, mitigate structural constraints, and build broad coalitions for change.

1.4 Theoretical Framework and Contributions

To understand the divergent pathways of renewable energy transitions across varying political and economic contexts, this chapter employs a multi-theoretical framework drawing from state capacity theory, interest group politics, path dependency, and the global political economy of energy. These frameworks collectively underscore that energy systems are not governed by market logics or technological imperatives alone; rather, they are embedded in historically specific configurations of power, institutions, and agency.

1.4.1 State Capacity and Institutional Agency

State capacity theory centers on the ability of governments to formulate and implement policies effectively, mobilize resources, and enforce regulations (Skocpol, 1985; Fukuyama, 2013). In the context of energy transitions, this includes the capacity to coordinate actors, manage policy coherence, and resist capture by entrenched interests.

Germany's *Energiewende* is a prime example where high administrative capacity, policy coherence, and institutional legitimacy enabled ambitious renewable energy goals. The Federal Ministry for Economic Affairs and Climate Action, together with independent regulatory bodies and local governments, played a central role in aligning national targets with decentralized implementation (Mayer, 2017). Conversely, in Nigeria, weak institutional oversight, overlapping mandates between regulatory agencies (e.g., NERC and REA), and low bureaucratic accountability have undermined efforts to implement renewable energy policy effectively (Sambo, 2020; IEA, 2022).

1.4.2 Interest Group Politics and Vested Power

Interest group theory examines how organized actors—such as fossil fuel lobbies, utility companies, green energy firms, and civil society groups—shape policy outcomes through lobbying, coalition building, and discourse control (Baumgartner & Leech, 1998).

In China, large state-owned enterprises (SOEs) such as State Grid Corporation and China Energy Investment Corporation wield significant influence over the design and implementation of renewable energy policies. While these entities have facilitated rapid deployment of wind and solar, they have also defended coal interests in the name of energy security and regional employment, revealing intra-state interest conflicts (Zhang & Gallagher, 2016; REN21, 2023).

In Germany, green technology firms, farmers' cooperatives, and environmental NGOs have formed strong pro-renewable coalitions, influencing electoral agendas and shaping the public narrative around climate policy (Hoppmann et al., 2014). These coalitions have been instrumental in defending the feed-in tariff system against rollback pressures from utilities and conservative policymakers.

1.4.3 Path Dependency and Structural Inertia

Path dependency theory explains how historical choices, institutional lock-ins, and sunk costs constrain current decision-making and shape future possibilities (Pierson, 2000). Energy systems, particularly fossil fuel infrastructures, represent classic examples of path dependency due to their capital intensity, long lifespans, and embedded regulatory regimes.

Nigeria’s energy system is highly path dependent, shaped by decades of oil revenue reliance and infrastructural bias toward centralized fossil fuel generation. Efforts to scale up decentralized solar mini-grids face resistance from actors invested in the status quo—such as fuel importers, diesel generator suppliers, and state-level bureaucracies tied to subsidy networks (Okechukwu, 2019). Similarly, China's persistent coal expansion reflects a path-dependent reliance on existing generation capacity, grid integration challenges, and regional development goals despite national decarbonization targets (Global Energy Monitor, 2023).

1.4.4 Global Political Economy and Capital Flows

The global political economy perspective examines how international trade, finance, and geopolitical interests shape national policy choices. Renewable energy transitions are embedded in global value chains, climate finance regimes, and strategic industrial policy.

China’s renewable expansion is inseparable from its aspiration to dominate global clean tech markets, leveraging economies of scale, subsidized manufacturing, and strategic export promotion (IRENA, 2022). Chinese solar module exports accounted for over 75% of the global market in 2022, reinforcing its geopolitical leverage in green technology supply chains (REN21, 2023).

Nigeria’s renewable ambitions, by contrast, are constrained by limited access to international climate finance and investor risk perceptions. While initiatives like the World Bank’s $750 million Nigeria Electrification Project and the AfDB’s Desert-to-Power program show promise, funding disbursement has been slow due to governance and transparency concerns (World Bank, 2022; AfDB, 2021).

1.4.5 Conceptual Synthesis and Scholarly Contribution

This chapter contributes to the literature on energy transitions by proposing a socio-political model of change, where technological innovation is necessary but not sufficient. Building on the socio-technical systems approach (Geels, 2002; Kern & Smith, 2008), the chapter repositions energy transitions as contested processes shaped by political agency, institutional reconfiguration, and redistributive struggles.

Rather than viewing decarbonization as a linear, techno-deterministic pathway, the chapter conceptualizes it as a multi-scalar negotiation between incumbent power structures, emergent coalitions, and structural constraints. This integrative perspective moves beyond reductionist analyses and provides a robust framework for comparative analysis, policy design, and critical scholarship.

1.4.6 Implications for Policy and Practice

For policymakers and practitioners, the insights derived from this framework suggest that successful energy transitions require:

- ❖ **Strengthening state capacity and regulatory coherence**, especially in fragile institutional settings;
- ❖ **Designing policies that mitigate resistance from incumbents** through strategic compensation and political compromise;
- ❖ **Aligning national energy goals with global financing instruments**, while managing local implementation risks;
- ❖ **Promoting societal mobilization** to build inclusive coalitions for low-carbon development.

1.5 Key Concepts: State Capacity, Path Dependency, and Institutional Lock-in

Understanding the uneven progress of renewable energy transitions across countries requires careful analysis of the institutional and historical structures within which energy policies unfold. Three core concepts state capacity, path dependency, and institutional lock-in are central to explaining why some states succeed in implementing energy reforms, while others falter despite technological readiness.

1.5.1 State Capacity: Policy Design, Implementation, and Enforcement

State capacity is broadly defined as the ability of governments to formulate sound policies, mobilize resources, coordinate across agencies, and enforce rules effectively (Fukuyama, 2013). In the realm of renewable energy, this includes capabilities such as setting targets, managing regulatory environments, attracting investment, and building administrative and technical expertise.

For instance, **Germany** exhibits high state capacity characterized by strong bureaucracies, well-funded energy agencies, and effective federal-local coordination. The Energiewende, Germany's flagship energy transition program, reflects the state's ability to manage complex reforms across sectors. Between 2000 and 2021, Germany increased the share of renewables in electricity generation from 6% to over 42%, supported by consistent policies such as feed-in tariffs, grid modernization mandates, and stakeholder engagement platforms (BMWK, 2021).

In contrast, **Nigeria** exemplifies a case of **limited state capacity**. Despite having renewable energy targets in documents like the Renewable Energy Master Plan (REMP) and the National Renewable Energy and Energy Efficiency Policy (NREEEP), implementation remains weak due to fragmented institutions, low technical capacity, and budgetary constraints. For example, while Nigeria's Energy Commission sets policy, the Rural Electrification Agency (REA) and Nigerian Electricity Regulatory Commission (NERC) often operate without coherent alignment, resulting in regulatory overlaps and project delays (Sambo, 2020; IEA, 2022).

1.5.2 Path Dependency: Historical Inertia in Energy Systems

Path dependency refers to the process through which historical choices often reinforced by large capital investments, regulatory traditions, and actor networks create **self-reinforcing trajectories** that are difficult to change (Pierson, 2000). In energy systems, this is particularly visible in the long-term investment cycles and infrastructure commitments that lock states into fossil-fuel-heavy pathways.

A notable example is **China**, which, despite massive investments in renewable energy, continues to build coal-fired power plants due to entrenched provincial-level incentives and legacy infrastructure. As of 2022, China accounted for over 55% of global coal-fired power plant construction, even as it led the world in solar PV and wind deployment (Global Energy Monitor, 2023; REN21, 2023). These contradictions stem from earlier industrial strategies and regional energy security goals that now constrain national decarbonization ambitions.

Similarly, Nigeria's power sector reflects path dependency through decades of oil and gas development, which shaped energy planning, institutional norms, and market expectations. Diesel generators currently supply over 40% of electricity for households and SMEs a legacy of unreliable grid access and fossil fuel subsidies (GIZ, 2021). This dependence perpetuates resistance to renewable alternatives, particularly in urban areas, where diesel logistics are entrenched.

1.5.3 Institutional Lock-in: Structures That Resist Change

Closely related to path dependency is the concept of institutional lock-in, which occurs when policy frameworks, bureaucratic routines, and actor coalitions inhibit the adoption of new technologies or governance models (Unruh, 2000). This type of lock-in often manifests through economic subsidies, regulatory inertia, and the political influence of incumbent industries.

In Germany, coal phase-out negotiations illustrate both the strength and constraints of institutions. While the state has set a 2038 target to phase out coal, strong labor unions and regional governments in lignite-dependent areas (e.g., North Rhine-Westphalia and Lusatia) have resisted rapid change. The result has been deliberate institutional pacing, including multibillion-euro compensation packages to ease the transition (Agora Energiewende, 2020).

In Nigeria, fossil fuel subsidies exemplify institutional lock-in. The country spent over ₦4.39 trillion (approx. $9.7 billion) on petrol subsidies in 2022 alone (NEITI, 2023), a policy that distorts energy markets, discourages private sector investment in renewables, and deepens dependence on imported fuel. Despite periodic announcements of subsidy removal, political backlash and rent-seeking alliances have stalled reform, locking the country into a high-carbon, low-efficiency energy structure (Oladipo & Okonkwo, 2021).

1.5.4 Synthesis: Interplay of Capacity, History, and Institutions

Together, these three concepts explain why technical potential such as abundant solar radiation in Nigeria or wind corridors in China is insufficient to drive transformation. Instead, energy transitions hinge on the ability of political actors to mobilize state capacity, navigate historical constraints, and overcome institutional inertia.

A comparative analysis reveals that:

- ❖ Germany's high **state capacity** and incremental institutional reforms allow it to manage trade-offs between industrial competitiveness and climate goals.
- ❖ China’s blend of **centralized power and provincial autonomy** leads to rapid yet uneven energy transitions.
- ❖ Nigeria’s **institutional fragmentation and subsidy regimes** severely limit renewable energy uptake, despite donor support and private sector interest.

Understanding these dynamics is essential for designing context-sensitive energy policies that recognize the political, historical, and institutional terrain within which they operate.

2. CASE STUDIES OF NATIONAL TRANSITIONS

Understanding the diversity of renewable energy transitions requires more than general policy prescriptions or global trends; it necessitates close examination of how socio-political structures, institutional capacities, and historical trajectories shape outcomes within specific national contexts. This section provides detailed comparative case studies of Germany, China, and Nigeria, three countries strategically selected for their contrasting political economies and positions in the global energy hierarchy.

2.1 Germany: A Coordinated Market Economy and Democratic Transition Model

Germany's Energiewende (energy transition) represents a globally referenced model of state-led, democratic decarbonization. Initiated in the early 2000s and reinforced by post-Fukushima political consensus, the policy aimed to phase out nuclear energy, reduce carbon emissions, and expand renewable energy (Morris & Jungjohann, 2016).

Key Features

- ❖ **Institutional Infrastructure**: Germany has strong intergovernmental coordination between federal and state levels, a reliable legal framework, and influential non-state actors (such as industry associations and environmental NGOs) involved in shaping energy policy (Kuzemko et al., 2016).
- ❖ **Policy Instruments**: The Renewable Energy Sources Act (EEG) introduced feed-in tariffs (FiTs), giving small producers long-term guaranteed prices. This created a decentralized ownership model, with over 40% of renewables once owned by citizens and cooperatives (Agora Energiewende, 2020).
- ❖ **Outcomes**: As of 2023, renewables account for about **48% of electricity generation**, with wind and solar leading (BMWK, 2023). However, coal still contributed around **28%** to power generation in 2022 due to energy security concerns amidst the Russia–Ukraine crisis (IEA, 2023).

Challenges:

Despite the progress, Germany faces issues of grid congestion, intermittency, and cost burdens passed on to consumers. Regional disparities in infrastructure upgrades and public opposition to new transmission lines reveal the socio-political complexities of sustaining the Energiewende (Schmid & Knopf, 2021).

2.2 China: State-Led Deployment under Authoritarian Capitalism

China presents a sharply contrasting model: a state-directed, industrial-policy-driven approach where renewable energy expansion is tightly linked to broader economic and geopolitical objectives. China's Five-Year Plans and the "Made in China 2025" strategy position renewable technology as a key pillar of industrial modernization (Mathews & Tan, 2015).

Key Features

- **Centralized Planning and Scale**: China dominates global renewable markets, accounting for over 40% of installed solar PV capacity and 36% of global wind power as of 2022 (REN21, 2023).
- **Subsidies and State-Owned Enterprises (SOEs)**: Subsidies have fueled domestic solar and wind industries, and SOEs dominate energy infrastructure development. The state allocates land, sets quotas, and subsidizes grid integration (Zhao et al., 2022).
- **Green Finance**: The People's Bank of China issued over **¥1.2 trillion** ($170 billion) in green bonds in 2022, marking one of the largest green finance sectors globally (CBI, 2023).

Challenges

Yet, implementation is uneven across provinces. Local governments often prioritize economic growth over environmental mandates, leading to curtailment of renewable electricity, where generated power is not fed into the grid due to infrastructural bottlenecks or coal prioritization (Zhang et al., 2018). Additionally, while new coal plants have slowed, China approved 52 GW of coal power in 2022, more than three times the rest of the world combined (Global Energy Monitor, 2023).

2.3 Nigeria: A Resource-Rich but Institutionally Fragile Transition Context

Nigeria reflects the predicament of resource-dependent economies in the Global South where despite immense renewable potential, structural constraints inhibit meaningful energy transitions.

Key Features

- **Abundant Solar Resources**: Nigeria has an average solar irradiation of 5.5 kWh/m²/day, making it suitable for solar PV and mini-grid deployment (IEA, 2022).
- **Energy Access Crisis:** Over 85 million Nigerians lack access to electricity, and those connected face chronic blackouts. Diesel generators supply around 40% of national electricity needs (GIZ, 2021).
- **Policy Initiatives:** The Nigerian Electrification Project (NEP), supported by the World Bank and African Development Bank, has funded over 100 mini-grids and solar home systems. The National Renewable Energy and Energy Efficiency Policy (NREEEP) aims for 30% renewable electricity mix by 2030 (FMPR, 2015).

Constraints

- **Fossil Fuel Subsidies**: Petrol subsidies consumed ₦4.4 trillion in 2022 (NEITI, 2023), distorting the market and undercutting clean energy alternatives.
- **Institutional Fragmentation**: Energy policy is fragmented across overlapping ministries, with weak enforcement from regulators like NERC (Sambo, 2020).
- **Political Economy of Oil**: Nigeria's rentier-state dynamics mean that elite coalitions benefit from the status quo, resisting reforms that would disrupt fossil fuel patronage networks (Watts, 2012).

Despite donor support and rising interest from solar developers, these constraints result in **slow, uneven deployment** and limited scale-up.

2.4 Comparative Synthesis

The three case studies underscore the non-linear, context-dependent, and politically contested nature of energy transitions

Country	Transition Model	Strengths	Core Challenges
Germany	Democratic consensus-driven	Institutional stability; civic participation	Grid stability, affordability, coal phase-out

Country	Transition Model	Strengths	Core Challenges
China	Authoritarian, state-directed	Industrial capacity; scale; green finance	Provincial inconsistency, coal dependency
Nigeria	Resource-dependent, fragmented	Solar potential; donor partnerships	Weak institutions, subsidy distortions, elite capture

This comparison highlights that technological availability is necessary but not sufficient for renewable transitions. Political will, institutional strength, policy coherence, and the ability to realign socio-economic interests are decisive factors.

3. COMPARATIVE INSIGHTS AND CROSS-CUTTING THEMES

The comparative analysis of Germany, China, and Nigeria reveals that renewable energy transitions are neither linear nor purely technical processes. They are deeply shaped by historical legacies, institutional architectures, governance modalities, and political economy dynamics. This section synthesizes the core insights across cases, identifying recurring themes and divergences that illuminate the complex nature of energy transitions in varied contexts.

3.1 State Capacity and Governance Architectures

State capacity defined as the ability of a government to formulate, coordinate, and implement policies effectively (Fukuyama, 2013)—emerged as a decisive factor in determining the pace and success of energy transitions.

- ❖ **Germany**, a high-capacity democratic state, has effectively mobilized public institutions, local governments, and civil society actors toward energy policy implementation. The Renewable Energy Act (EEG) enabled decentralized energy ownership, while institutional trust facilitated long-term commitment despite political changes (Agora Energiewende, 2020).

- **China**, though authoritarian, demonstrates a different form of high-capacity state: centralized, technocratic, and industrial-policy driven. It achieved rapid renewable deployment through coordinated planning, strong administrative command, and generous subsidies—but at the cost of regional disparities and limited local accountability (Mathews & Tan, 2015).
- In contrast, **Nigeria** suffers from **institutional fragility**, bureaucratic fragmentation, and regulatory inconsistency. Multiple overlapping agencies—such as the Rural Electrification Agency (REA), the Nigerian Electricity Regulatory Commission (NERC), and various state ministries—undermine policy coherence and implementation (Sambo, 2020). Weak enforcement capacity and high corruption perception scores (Transparency International, 2022) further impede systemic transformation.
- **Insight**: Strong state capacity whether democratic or authoritarian—is crucial for sustained and coordinated transition efforts. However, capacity must be complemented by policy legitimacy and stakeholder inclusion to ensure equitable outcomes.

3.2 Political Interests, Coalitions, and Resistance to Change

Transitions are **political processes** shaped by incumbent interests, elite coalitions, and resistance from fossil fuel actors.

- In **Germany**, utilities initially opposed decentralization but gradually adapted to market reforms through regulatory incentives and market redesign (Kuzemko et al., 2016). Political coalitions—including Green parties, rural cooperatives, and environmental NGOs helped sustain momentum even when costs escalated.
- **China's** dominant actors—state-owned enterprises (SOEs), industrial ministries, and provincial leaders—initially resisted rapid decarbonization due to coal-sector employment and fiscal dependencies. However, strong central directives and performance-based evaluations incentivized compliance (Zhao et al., 2022). Yet, coal interests continue to influence energy security policy, with over 50 GW of coal approved in 2022 alone (Global Energy Monitor, 2023).

- In **Nigeria**, vested fossil fuel interests—especially in the petroleum subsidy regime—have historically blocked reforms. The 2023 subsidy removal, although promising, sparked nationwide protests and inflationary pressures, indicating how rent-seeking and elite capture distort energy policymaking (NEITI, 2023; Watts, 2012).
- **Insight**: The configuration of political coalitions who stands to gain or lose profoundly shapes the direction and depth of energy transitions. Reform strategies must anticipate and navigate resistance from incumbents embedded in carbon-intensive sectors.

3.3 Policy Coherence and Institutional Innovation

Successful transitions require policy coherence across sectors (energy, finance, transport, environment) and institutional innovation that adapts to technological and social change.

- Germany's energy transition benefited from **cross-sectoral alignment**, with coherent transport decarbonization, building retrofits, and a carbon pricing framework under the Climate Action Programme (BMWK, 2023). Regional energy agencies and innovation clusters enabled bottom-up experimentation.
- China's industrial policies and Five-Year Plans illustrate centralized coherence. However, inter-agency rivalry (e.g., NDRC vs. NEA) and fragmented provincial governance undermine uniform implementation. Some provinces continue approving coal plants to meet economic growth targets, revealing policy dissonance (Zhang et al., 2018).
- Nigeria's policy environment is marked by fragmentation. The National Renewable Energy and Energy Efficiency Policy (NREEEP) exists largely on paper, while the Energy Transition Plan (2022) lacks statutory backing. There is little coordination between electrification efforts and broader economic planning (GIZ, 2021).
- **Insight**: Coherent policy frameworks and adaptive institutions are vital to facilitate system-wide transformation. Fragmentation, outdated regulations, and siloed governance structures are critical obstacles.

3.4 Financial Architecture and Energy Investment Flows

Access to **finance and investment mechanisms** plays a pivotal role in scaling renewable infrastructure and attracting private sector participation.

- ❖ Germany mobilized billions through feed-in tariffs, renewable auctions, and the KfW Green Bank, making it one of Europe's leaders in green finance (IEA, 2023).
- ❖ China led globally in **green bond issuance**, with over **¥1.2 trillion ($170 billion)** in 2022 alone. State-owned banks and the China Development Bank actively channel funding into wind, solar, and battery storage projects (CBI, 2023).
- ❖ Nigeria's energy investment relies heavily on **donor funding** and multilateral agencies (e.g., World Bank, AfDB). Private capital is discouraged by regulatory risks, low cost-reflectivity in tariffs, and policy uncertainty (Sustainable Energy for All, 2022). The NEP has made progress in mini-grid deployment, but overall financing gaps remain substantial.
- ➢ **Insight**: Finance is both an enabler and a bottleneck. While state-driven finance can achieve scale (as in China), market-oriented finance demands strong regulatory environments and investment-grade institutions.

3.5 Justice, Access, and Equity

Energy transitions must address issues of **justice and equity**—not just emissions reduction.

- ❖ Germany's transition raised energy costs for consumers, especially low-income households, sparking debates about energy poverty. Compensatory mechanisms were introduced but remain contested (Schmid & Knopf, 2021).
- ❖ In China, large-scale renewable installations often occur without public consultation, leading to **social displacement** in some regions. Yet, improved air quality and rural electrification present positive equity outcomes (Zhang et al., 2018).
- ❖ Nigeria faces **chronic energy injustice**, where rural populations, women, and the urban poor are marginalized. Diesel reliance and erratic

supply create health and productivity burdens (IEA, 2022). Without distributive policies, transitions risk reinforcing existing inequalities.

- **Insight**: Energy transitions must be socially inclusive. Policies should integrate redistributive elements, participatory mechanisms, and access strategies to avoid exacerbating existing disparities.

3.6 Technology is Not Enough

All three case studies reaffirm a central premise: Technological readiness does not automatically lead to transition success.

Despite being technologically capable:

- Germany struggles with sociopolitical trade-offs.
- China contends with regional governance inconsistencies.
- Nigeria is held back by institutional and political economy constraints.
- **Insight**: The political economy—rather than technology—determines transition trajectories. Power asymmetries, institutional legacies, and economic interests shape which pathways are pursued or obstructed.

This comparative synthesis underscores the need for a context-sensitive, politically informed, and socially grounded approach to energy transitions. Transitions are not uniform or technocratic processes they are deeply political, often contested, and inherently uneven. Recognizing this complexity is essential for scholars, policymakers, and practitioners committed to shaping sustainable, inclusive, and resilient energy futures.

4. POLICY IMPLICATIONS AND STRATEGIC RECOMMENDATIONS

The comparative analysis of renewable energy transitions in Germany, China, and Nigeria reveals a set of nuanced, context-dependent policy insights that highlight the centrality of governance, political coalitions, institutional design, and financial systems in shaping the course and character of decarbonization. These findings inform several policy implications and strategic recommendations applicable across diverse geopolitical and development contexts.

4.1 Strengthen State Capacity for Coherent Policy Design and Implementation

A fundamental prerequisite for any successful energy transition is the development of strong, capable, and coordinated state institutions.

- **Policy Implication**: States must invest in bureaucratic capacity, regulatory autonomy, and inter-ministerial coordination. Without these, even well-designed policies may falter during implementation.
- **Strategic Recommendation**: Governments particularly in developing contexts should prioritize the establishment of a centralized and independent Renewable Energy Coordination Authority, equipped with legal backing and multi-sectoral reach to streamline fragmented mandates.

4.2 Align Industrial Policy with Energy Transition Goals

As seen in China, renewable energy transitions gain traction when they are embedded in broader **economic development and industrial upgrading strategies**.

- **Policy Implication**: Energy transition must not be siloed from industrial, trade, and innovation policy. Synergies between clean energy deployment and local manufacturing can enhance domestic value chains and job creation.
- **Strategic Recommendation**: Policymakers should design green industrial policies, such as tax incentives, technology incubators, and domestic content requirements, while avoiding protectionist distortions. Investment in vocational training for renewable energy skills is also essential.

4.3 Reform Energy Subsidies and Pricing Regimes

Subsidy structures whether for fossil fuels or renewables—shape market signals and investor behavior. In Nigeria, fossil fuel subsidies have distorted energy markets and disincentivized clean energy uptake.

- **Policy Implication**: Energy subsidies should be redirected from fossil fuel consumption to energy access, infrastructure modernization, and clean energy R&D.

- **Strategic Recommendation**: Implement phased and transparent subsidy reform with compensatory social protection measures for vulnerable groups. Public education campaigns and stakeholder dialogues are critical to securing public buy-in and reducing political backlash.

4.4 Promote Regulatory Innovation and Institutional Flexibility

Transitioning energy systems require **adaptive, learning-oriented institutions** capable of managing uncertainty and facilitating innovation.

- **Policy Implication**: Rigid, outdated regulatory frameworks impede the diffusion of decentralized energy systems (e.g., off-grid solar, virtual power plants). Dynamic regulation is essential.
- **Strategic Recommendation**: Introduce sandbox regulatory environments that allow controlled experimentation with new technologies and business models. Establish feedback loops between regulators, academia, and private innovators to foster iterative policy refinement.

4.5 Foster Inclusive Governance and Societal Engagement

Energy transitions are not only technical and economic processes but also social ones. Public participation enhances legitimacy, trust, and policy durability.

- **Policy Implication**: Transitions lacking democratic legitimacy or societal engagement are more likely to face backlash, as seen in Germany's energy price protests or Nigeria's fuel subsidy reforms.
- **Strategic Recommendation**: Institutionalize multi-stakeholder consultative platforms that include community groups, labor unions, indigenous populations, and civil society organizations in energy planning processes. Develop participatory mapping of energy needs and priorities.

4.6 Mobilize Climate Finance and De-Risk Investment

Renewable energy investment in low- and middle-income countries remains stymied by high perceived risks, poor credit environments, and limited domestic financial depth.

- ❖ **Policy Implication**: Without access to affordable long-term finance, the energy transition will remain aspirational in much of the Global South.

Strategic Recommendation

Leverage international climate finance (e.g., Green Climate Fund, Just Energy Transition Partnerships).

- ➢ Create **domestic green investment banks** to co-finance projects and reduce commercial risk.
- ➢ Use blended finance instruments to crowd in private capital and support utility-scale and distributed renewable solutions.

4.7 Address Energy Access and Justice in Transition Planning

Transitions must not exacerbate energy poverty or socio-economic inequalities. In Nigeria, for example, centralized power reforms have largely bypassed rural communities.

- ❖ **Policy Implication**: Equity must be embedded as a core dimension of energy planning, not an afterthought.
- ❖ **Strategic Recommendation**: Develop **pro-poor energy transition strategies**, including off-grid solar for rural electrification, gender-sensitive policy tools, and livelihood-linked energy access initiatives. Use social impact assessments in project design.

4.8 Recognize and Plan for Structural Lock-ins

Past infrastructural and institutional decisions constrain current policy options. Managing these **path dependencies** requires political will and transitional planning.

- ❖ **Policy Implication**: Structural lock-ins—such as existing fossil fuel plants or centralized utility monopolies—must be addressed through proactive transition planning.
- ❖ **Strategic Recommendation**: Undertake **sunset planning** for carbon-intensive infrastructure, including asset retirement schedules, just

transition plans for affected workers, and retraining programs for fossil fuel employees.

The policy landscape of energy transition is as complex as it is critical. As demonstrated through the political economy analysis of Germany, China, and Nigeria, sustainable and equitable transitions require a multi-pronged approach that combines technological feasibility with political strategy, financial innovation, regulatory agility, and public participation. These policy implications serve as a guide for governments and development partners committed to steering their countries toward low-carbon, resilient energy futures.

5. CONCLUSION AND FUTURE RESEARCH DIRECTIONS

The transition toward renewable energy systems is not merely a matter of technological substitution—it is a deeply political, economic, and institutional transformation. This chapter has shown, through a comparative political economy analysis of Germany, China, and Nigeria, that energy transitions are shaped by a constellation of factors: state capacity, vested interests, institutional legacies, socio-political coalitions, and international capital flows. While technological innovation and falling costs of renewables are important enablers, they alone are insufficient to ensure equitable, just, and effective decarbonization.

Germany’s Energiewende underscores the role of democratic legitimacy and public consensus but also reveals tensions around affordability and energy security. China’s top-down, industrial policy-led approach has enabled rapid renewable deployment but is constrained by uneven subnational implementation and ongoing coal reliance. Nigeria's experience illustrates the structural challenges faced by resource-dependent economies, where subsidy distortions, regulatory fragility, and socio-economic inequality obstruct low-carbon energy adoption despite vast renewable potential. By integrating political economy theory with grounded empirical case studies, this chapter provides a multi-dimensional understanding of how renewable energy transitions unfold in diverse contexts. It reaffirms that the success of energy transitions hinges on redistributive policy frameworks, institutional innovation, regulatory coherence, and strategic engagement with societal actors.

Future Research Directions

To deepen the insights presented here, future research should consider the following:

- **Sub-national political dynamics**, especially in federated systems like Nigeria and China, where energy policy is implemented unevenly across provinces or states.
- **Energy justice and transition equity**, focusing on how vulnerable and marginalized populations experience or resist transitions.
- **Role of international climate finance** and development banks in shaping national transition pathways, especially in low-income countries.
- **Comparative studies beyond the trichotomy of advanced/emerging/resource-dependent economies**, including island states, post-conflict regions, and indigenous governance systems.
- **Digitalization, AI, and smart grids** as transformative elements in the next phase of renewable energy governance.

Appendix A: Comparative Summary of Key Policy Instruments

Country	Key Policy Instruments	Implementation Strength	Challenges
Germany	Renewable Energy Sources Act (EEG), Feed-in Tariffs, Energy Market Reforms	High (national coherence, legal clarity)	Grid modernization, affordability, fossil fuel phase-out delays
China	13th & 14th Five-Year Plans, Green Certificates, Solar Subsidies, State-Owned Enterprise mandates	High (centralized direction)	Provincial unevenness, coal fallback, overcapacity in solar PV
Nigeria	Renewable Energy Master Plan, Electrification Roadmap, Subsidy Reform Blueprint	Low (policy fragmentation, limited enforcement)	Fossil fuel subsidy regime, weak grid infrastructure, institutional overlap

Appendix B: Key Empirical Indicators (2022–2023)

Indicator	Germany	China	Nigeria
Share of renewables in electricity mix	50% (BMWK, 2023)	31% (IEA, 2022)	13% (REN21, 2023)
Installed solar capacity (GW)	70 GW	393 GW	0.03 GW
Fossil fuel subsidies (% of GDP)	0.2%	0.5%	2.1%
Electrification rate (%)	100%	99.7%	56% (rural lag)
Climate finance inflow (USD billion)	2.8	20.1	0.4

Sources: *IEA (2022); REN21 (2023); World Bank (2023); BMWK (2023)*

Appendix D: Summary of Theoretical Perspectives Used

Theory	Key Assumptions	Relevance to Energy Transitions
State Capacity	Strong states can plan, implement, and enforce policy effectively	Explains differences in policy execution across cases
Interest Group Politics	Policies are shaped by lobbying, elite coalitions, and social movements	Highlights role of fossil incumbents and renewable alliances
Path Dependency	Past choices create institutional and infrastructural inertia	Shows why transitions are not easily reversed or redesigned
Global Political Economy	Global markets, capital flows, and geopolitical alliances affect national choices	Accounts for external pressures and investment trends

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CHAPTER 3
WORLD ENERGY NEEDS WITH GROWING GLOBAL POPULATION AND INDUSTRIALISATION IN TWENTY FIRST CENTURY

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SECURING ENERGY IN A DIVIDED WORLD: SUPPLY, DEMAND, AND POWER

INTRODUCTION

Global population is around 8.25 billions as on June 2025. India has the largest population (1.464 billions) followed by PR China (1.416 billions) and United States (0.347 billions). India is the fourt largest economy in the world. India is the third largest consumer of energy after United States and China. Global electricity generation was 29,925 Tera Watt -hours in 2023. The estimated energy requirement of the world population 1 kW norm fixed by 2020 and it is around 72,270 teraWatt-hours. The per capita power availability varies from 270 to 25000 kWh and world average is 2234 kWh and 0.255 kiloWatt Years. The global people energy requirements are increasing with population increase and industrialisation. The world lacks a safe, cheap, low carbon large scale infrastructure.

In the earliest state of life on Planet Earth life of man used body muscular energy for doing the work. With the passage of time hunbeing started using their mind in developing new technologies and inventions for various forms of conventional and nonconventional energy sources. Faraday's invention of electricity made human life and more comfortable, industrialisation and mass production of goods and services. Energy sources are renewable and non-renewable. Non-renewable energy sources like coal, petroleum, natural gas etc are available in abundance but with usage of large quantiries every year started depleting. Hence we have to look for renewable energy sources like solar, wind, biomass, geothermal, hydel power, ocean tidal energy, nuclear, magneto hydrodynamic energy etc. Global non-renewable energy sources are depleting at an accelerated way. Hence the ways and means to conversion of these renewable energy sources into user friendly technologies and economical production needs to be explored. The average energy per capita electrical was fixed as 1kW by the year 2020. This means (24h x 365days x 1kW)=8760 kWh should be available for every citizen. A few countries like Norway, Sweden, Luxemburg, Finland, USA have exceeded this norm other nations are striving to achieve this. Large populated countries face problems to achieve this target. If we consider the primary energy availability this norm can easily be achieved. With the advancement of industrialisation electricity consumption increased significantly. During the past 300 years industrial revolutions like industry 1.0, industry 2, industry 3.0, industry 4.0 and industry 5.0 have been evolved with large energy consumption by industrialised nations.

Dominance of fossil fuels driven climate change, health impacts due to air pollution, water pollution, acid rains etc due to greenhouse gases, depletion of fossil fuels on Earth. Green house gases produced 40 Gigatons due to global electricity generation in 2023. India set a target of net zero emission by 2070 by triple its renewable energy capacity by 2030. Average energy availability in rural areas 21.9 hours and urban areas is around 23.4 hours power supply daily. To address these issues global energy supply and consumption needs to be analysed and sources of future energy needs to be explored. Type I (all energy sources on Earth) 10^{16} Watts and Type II energy (Solar energy) 4.6 x 10^{26} Joules/second partly used at present but Type III energy(energy radiated from the Milky Way) 1.38 x 10^{38} Joules/second source is not used or the ways to generate is yet to be started.

As we know energy is capacity to exert a force through a distance, and manifests itself in various forms. Engineering processes invove the conversion of energy from one form to another, the transfer of energy from one place to another and the storge of energy in various forms, utilising a working substance. The unit of energy in the SI system is Nm or Joule. The energy per unit mass in the specific energy, the unit if which is Joules per kiligram. The rate of energy transfer or storage is called power. The unit of power is watt (W) , kiloWatt or MegaWatt. 1 wis equal Joule/s or 1 newtonmeter. Eienstein quantified $E=MC^2$ where E is energy, M is the mass and C is the speed of light. Electrical energy is E= power x time. The unit of energy is Joule (J) which was named after James Prescott Joule. It is equal to the amount of workdone when a force of one Newton displaces a mass through a distance of one metre in the direction of that force. J = Nm. The other units used ExaJoules, million tons of oil equivalent, British Thermal Units, Tera Watt-hours.

1. GLOBAL POPULATION AND HUMAN ENERGY NEEDS

World population has reached 8.25 billions in June 2025 as per UN worldometer for 234 countries. India is the largest populated country with a population of 1.464 billions. World density of population is around 60.6 persons per square kilometer. World population has 50.27 % males and 49.73 females.

Population and per capita primary energy available are presented in Table 1. Primary energy mix is presented in Table 2.

Table 1: Population and Primary Energy for World and Top Ten Populated Nations

SNo	Country	Population	Density in persons/ sq.km	Primary Energy Available kWh/person	Electricity consumption per capita in kWh
1	India	1.464	488	7586	1395
2	PR China	1.416	151	33,267	--
3	United States	0.347	38	77,028	12,497
4	Indonesia	0.286	156	--	--
5	Pakistan	0.255	326	3895	--
6	Nigeria	0.237	255	--	--
7	Brazil	0.213	25	17,806	--
8	Bangladesh	0.176	1333	2940	--
9	CIS (Russia)	0.144	9	60,175	--
10	Ethiopia	0.135	132	--	--
11	World (ave)	8.25	60.6	21,394	2023

Table 2: Global and India Primary Energy Mix by Source in 2023

S.No	Fuel Mix	World in kWh	India in kWh
1	Oil	6782.09	2055.8
2	Natural gas	4984.49	438.25
3	Coal	5663.54	4273.96
4	Nuclear	849.22	84.11
5	Hydro	1369.01	271.23
6	Renewable Wind Solar	301.77 750.99 301.77	83.3 149.29 206.21
7	Total	21,229.94	7562.17

Global primary energy mix by source in 2023

The main types of energy are mechanical, electrical, chemical, nuclear, thermal, electromagnetic energy. Mechanical enegy is found in the motion of an object like a moving vehicle or rotating flywheel has mechanical energy. Electrical energy is the result of flow of electrons in a conductor. It can be seen or felt in its transformed form like light, heat etc. Electromagnetic energy is the energy coming out of electromagnetic radiation. The gan=mma rays, x-rays, light rays are examples of this type of enegy. Chemical energy is released out of the reaction taking place between elements or molecules to form a more stable compound.

The primary energy consumption in 2023 includes fossil fuels (81.47%), renewables (14.56%) and Nuclear (3.96%). Other renewables are geothermal, bio-mass and waste energy. Energy use per person is given by kilo-Watt hour. A Watt is the energy delivered by one Watt of power for one hour. One Watt is equivalent to one joule per second. One Watt hour is equivalent to 3600 Joules of energy. Global primary energy production and consumption is presented in Table 3.

Table 3: Global Primary Energy Production and Consumption Sourcewise

S.No	**Type of energy**	**Primary energy TWh**	**Energy consumption in TWh**	**% percentage**
1	Oil	54,564	54,564	29.78
2	Coal	45,565	45,564	24.87
3	Natural gas	40,102	40,101.74	21.89
4	Traditional biomass	11,111	11,111	6.06
5	Hydro power	11,014	11,014.12	6.01
6	Nuclear	6824	6824.18	3.72
7	Wind	6040	6040.36	3.3
8	Solar	4264	4264.26	2.33
9	Other renewables	2428	2427.86	1.33
10	Modern bio-fuels	1318	1317.62	0.72
11	Total Fuels	183,230	172,119.07	100

2. HUMAN SOCITIES EVOLUTION AND INDUSTRIAL GROWTH

Human population was very less during stone age 1,00,000 years to 10,000 BC hunter- gatherer society was evolved. Population was few thousands to 1,00,000. Most of the energy required was met by biomass and fossile fuels were in use. From 10,000 BC to 1700 AD Agricultural Society was evolved. Naturally available fuels and bio-mass was in use. Population was grown from 1,00,000 to 16,50,000. Agro-based industries and cottage industries were developed. Biomass and coal based fossile fuels were widely used. Subsequently 1700 to 2000 AD industrial society were evolved. During this period oil, electricity, renewabl energy soures are rapidly developed globally. In this phase industry 1.0 to Industry 4.0 were evolved. Beyond this period knowledge society was evolved using computer, internet and other electronic gadgets, sensors, actuators etc were embedded in machines and industrial systems. Depletion of natural resources and need to invent new energy sources arises. The population has grown to 6 billion to 8.25 billions and global villages have been evolved. Humanbeings started exploring ways and means to reach Solar system, Milky Way and Universe and Omniverses. Energy security and Carbon foot print for growing global population.

3. INDUSTRIALISATION AND ENERGY REQUIREMENT

Industries consume lion's share of energy for operation and production, transport etc . Industrial revolution is a process of change from agrarian and handcraft economy to one dominated by industry and machine manufacturing. These technological changes introduced novel ways of working and living and fundamentally transformed society. The latter half of the eighteenth-century ushered man into modern world of machinery and manufacture and brought about cataclysmic changes in social, economic and political life of people. The historians called it the Industrial Revolution. It began in England. The invention of steam engine gave an impetus activity and for the first time made man free from forces of nature. The names of the Savery, Newcomen and notably James Watt are associated with this invention. Watt brought about considerable improvement in the performance of the steam engine which began to be widely used in coal mines, iron metals extraction and textile mills. George Stephenson introduced steam engine for rail transport. Until middle of the nineteen century heat was regarded as an invisible, colourless, weightless, odourless fluid that flowed from a body of higher calorie to a body of lower calorie. The calorie was said to be conserved and it was indestructible.

In the first Industrial Revolution (1770-1900 AD) Steam power, water wheels, spinning machines, mechanized industrial machines developed and Robort Fulton used it in steam boats. The advent of steam engine also gave birth to daughter of Steam Engine the science of thermodynamics. Mobility of people and transport of materials resulted in large scale. Population has been increased gradually 1-2 billions during this period. In 1879 a multicylinder automotive engine was commercially successful.Dr. Diesel designed larger stean engines and boilers. He later developed an internal combustion engine with fuel injection which resembles modern diesel engine.

In the second Industrial Revolution (1900 to1950AD) electricity was invented. Development of industrial machined using electricity, highly mechanized systems, industrial towns and estates were developed. water store systems, food grains storage systems, cultivation from manual to mechanized systems. One young researcher/ inventor who thought that he could that he could produce energy out of nothing. He said that an electrical motor converts electrical energy into mechanical energy and that an electrical generator converts mechanical energy into electrical energy. Why not then use of motor to run the generator and the generator to run the motor and create endless supply of energy. Energy manifests in various forms and gets transformed from form to the other. Energy is neither created or destroyed. In a metabolic process a day workman or human being gradually transforms the chemical energy of the food he eats and the oxygen he breathes into heat, sound and useful work. Subsequently, muscular power of humanbings in operations of manufacturing is replaced by machine power. Population has grown more than four billion which requires more energy for domestic as well as industrial operations.

The Third Industrial Revolution, also known as the Digital Revolution, began in the late 20th century. It is characterized by the shift to an economy centered on information technology, marked by the advent of personal computers, the internet and the widespread digitalization of communication and industrial processes. In the third Industrial Revolution (1950 AD to 1974 AD)

Electronic Computer and Internet was invented. Computer integrated systems and Artificial Intelligence was developed. Human brain power is given to machines and Industrial systems. Civilization developed many folds. Mobility of people from one continent to the other, cultural exchange took place. Robots and highly mechanized and automated systems developed. Global population has been increased from 4 to 5 billions.

The Fourth Industrial Revolution has been defined as technological developments in cyber-physical systems such as high capacity connectivity; new human-machine interface modes such as touch interface and virtual reality systems; and improvements in transferring digital instructions to the physical world including robotics and Three dimensional printing (additive manufacturing), big data and cloud computing, improvements to and uptake of off grid / Stand-Alone Renewable Energy Systems: solar, wind, wave, hydroelectric and the electric batteries (lithium-ion, renewable energy storage systems, electric vehicles.

It also emphasizes decentralized decisions – the ability of cyber physical systems to make decisions on their own and to perform their tasks as autonomously as possible. Only in the case of exceptions, interference, or conflicting goals, are tasks delegated to a higher level. The Fourth Industrial Revolution fosters smart factories which are production environments where facilities and logistics systems are organised with minimal human intervention.

The technical foundations on which smart factories are based are cyber-physical systems that communicate with each other using IoT. An important part of this process is the exchange of data between the product and the production lines. This enables more efficient supply chain connectivity and better organisation within a production environment.

Within modular structured smart factories, cyber-physical systems monitor physical processes, create a virtual copy of the physical world, and make decentralised decisions. Over the internet of things, cyber-physical systems communicate and cooperate with each other and with humans in synchronic time both internally and across organizational services offered and used by participants of the value chain.

In the fourth Industrial Revolution (2011-2020 AD) Super Computers, internet, automated factories, smart industrial systems developed. Unmanned highly automated industries evolved. Human brain power is given to machines, neural networks, AI, ML, industrial and intelligent robots, unmanned systems developed to Moon, Mars Venus, space etc. Globe became global village. Population increased to 5 to 8 billions.

In the fifth Industrial Revolution (2020 AD and beyond) humans are looped in Automated industrial system, Collaborative robots, AGVs, SGVs. The concept of Industry 5.0 is a relatively new one. According to the European Union Industry 5.0 “provides a vision of industry that aims beyond efficiency and productivity as the sole goals, and reinforces the role and the contribution of industry to society.” and “It places the wellbeing of the worker at the centre of the production process and uses new technologies to provide prosperity beyond jobs and growth while respecting the production limits of the planet.” It complements the Industry 4.0 approach by “specifically putting research and innovation at the service of the transition to a sustainable, human-centric”. The idea of Industry 5.0 is not limited to “industry.” It applies to every sector and every organization one can think of. This means that its applicability is significantly wider than Industry 4.0. Therefore, when discussing the implications of Industry 5.0 for strategy, we need to take a broad and general perspective applying to all industries. As the European Commission spells out in this infographic, Industry 5.0 has three key pillars: human-centric, resilient and sustainable. All three have significant implications for business strategy. A human-centric strategy is one that, according to the infographic, “promotes talents, diversity and empowerment.” The most important shift this suggests is one from seeing people as means (e.g., as in human resources) to seeing people as ends. Or, in other words, a shift in perspective from people serving organizations, to organizations serving people.

4. ENERGY REQUIREMENT FOR HUMANBEINGS

Humanbeings need energy to survive and day to day activities. Men require more energy as compated to females. This is met by food intake with certain calorific value.In addition energy requirement for homes is around 30 kWh/day. Average human needs 4000 kcals whereas a hardworking industrial workforce reqires 20, 000 kcals. To function of human brain 10 watts of power is required and to pump blood and heart needs 1.5 watts of power. A healthy adult heart pumps abount 70 milli liters of blood with each heart beat. Adult male have 5.5 liters of blood and felmale 4.5 liters and heart beats 72 and 80 beats per minute respectively,=. Life time 2.5 to 3 billion times during life time. Human body consists of sub-bodies like gross body which consists of flesh, bones and hair, energy body powers of all movements within us, mental body (mental desires, fears, thought and emotions), wisdom body (our valuesand our higher intelligence) and bliss body (deep joy and unconditional love). Brain also releases Gamma waves, Beta waves, Alpha waves, Theta waves, Delta waves, Epsilon and Lamda waves with different fequencies and uses 10 watts of power. Human brain has 10^{12} neuros, 10^{17} operations per second and 1400 grams. Human brain power has not changed much in thousands of years but computer 10^{18} floating point operations per second. Human body of 70 kgs contains $7x10^{27}$ atoms with 60 chemical elements oxygen (65%), Carbon (18.5%), Hydrogen (9.5%), Nitrogen (3.2%), Calcium (1.5%), Phosphrus (1%) and others(less than 1%). Vital energy of 170 grams can be increased by physical activities like running, swimming, dancing,cycling etc, scientific dieting, physio therapy and sun bathing.

Energy required for men and women varies. Men require 2900 kcals/ day whereas women require 2200 kcals/day. Estimated Energy Requirement (EER) is calculated by two equations for male and female,

EER for Male in kcal per day = 662 - (9.53x A) + PA + [(15.91xW) + 539.6x H] where A = Age in years, PA = Phyical Activity varies from 1-1.48 for male, H = Height in meters, A=66 years

EER for male = 662-(9.53x66)+1.25[(15.91x70) +539.6x1.62] = 2517.84 kcals per day.

EER for Female in kcals per day = 354 - (6.91xA) + PA + [(9.36xW) +726xH]

The self-perpetuating human body is like a type of battery composed of 3 vital parts.

(i) Structure: Cells and the organs, bones, muscles, skin layers, blood vessels, nerves and other physical structures.

(ii) Liquid: intra and inter cellular liquids that play important role in generation of electrical energy.

(iii) Electrical charge: the charge responsible activating the body and its structure which is called life force.

If there is a partial absence of energy in the body weakness or disease invades. When total absence of energy results in death. Vital energy in the body is around 170 grams. Energy is essential for human survival from birth to death.

5. FUTURE ENERGY AVAILABILITY

Total energy out put as per Kardshev scale is estimated to be around 1.38×10^{38} Joules per second. The Milky Way is a source of both light and high energy radiation of gamma rays and cosmic rays which are produced by various astrophysical processes. These rays can be accelerated by objects like supernova and pulsar wind. The average mass of star of Milky Way is around 6×10^{41} kgs. Nearby Andromede galaxy is three times larger than Milky Way mass of Andromeda is 18×10^{41} kgs hence energy is 4.14×10^{38} Joules/second. The distance between Milky Way and andromeda is 2.37×10^{22} m. Potential energy and kinetic energy between galaxies are 6.71×10^{33} Joules and 7.5×10^{53} Joules respectively. The increase in kinetic energy in one second would be 3.3×10^{35} Joules. The Milky Way and Andromeda are also travelling continuously. The vast amount of energy from Milky Way can be utilized in future if solar energy and all energy sources on earth are depleted.

CONCLUDING REMARKS

Global energy requirement has been increasing with increase in population and with industrialisation from industry 1.0 to industry 5.0. Per capita availability of primary energy as well as electricity is increasing continuously. However, some consume more energy than the others countries. Fossil fuels consumption will be reduced and renewable energy sources like wind, solar, hydro will be increased. This will reduce the green house gases and zero emissions will reach from 30 to 50 years based on the national priorities. Humanbeıngs need energy from birth to death and if sufficient energy levels are not there diseases may invade. In future in addition to solar energy Milky Way energy can also be considered for use. However, ways and means to convert the radiation into usable form to be explored. This will ensure sustainability of energy for future generations for long term. Human population likely to be increased to approximately 8.5 billion in 2030, 9.7 billion in 2050 and 10.9 billion in 2100 AD. Some nations population may increse whereas some nations will be decreased.This population increase needs more energy from renewable energy sources like solar, wind, hydro and the Milky Way in future.

Energy technology is catering to the universal needs of world population of 8.25 billion from womb to tomb. It caters the needs of people on land, seas and oceans, air and space to travel zillions of light years to Chandrayana 1 and 2, space, Venus and Mars, Planets, Milky Way (10^{11}), Universe (10^{87}), OmniVerse and All-That-Is.

Finally, if you are one person, out of 8.25 billion people on one planet Earth out of eight planets, orbiting one star (Sun) out of 300 billion stars in one Galaxy (Milky Way 10^{11} planets, 1 to 1.8 lacs light years) out of two trillion Galaxies. Beyond galaxy Universe 10^{87} planets with observable diameter of 93 billion light years (4.4 x 10^{23} km) and Multiverses. Actual Universe is 250 times larger than observable universe (7 trillion light years) with an age of 13.799 billion years.

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CHAPTER 4
GREEN ENERGY SECURITY AND CHINESE LITHIUM DIPLOMACY IN NIGERIA

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INTRODUCTION

The transition of global energy have been driven by the urgent need for mitigating climate change because of destructive human activities such as fossil fuels, oil spillage, trees cutting leading to greenhouse gas emissions and consequent global warming. The search for green alternative has elevated lithium to a critical resource in the shift toward low-carbon economies. Lithium is a key component in the production of batteries for electric vehicles (EVs) and renewable energy storage system making it very strategic for achieving the Paris Accord goal of decarbonization. Accordingly, 2040 has been projected by the International Energy Agency (IEA) that global lithium demand could be increased by over 40 times, also driven by EV adoption and renewable energy expansion (IEA, 2021). Lithium has been transformed into a geopolitical asset in energy security competition, with Africa in particular, where the major powers compete to secure supply chains in resource-rich regions. Thus, Nigeria with its significant lithium deposits in the north-central and Western regions has attracted global scrambling for the resources with significant global demand pegged at $3.9 billion (Oladipo, 2025). In Nigeria's lithium market, China is a dominant player in the mining sector with huge investments. China's lithium diplomacy combines set a departure from the traditional extraction and export of raw mineral to building infrastructure for process of the minerals in Nigeria thereby creating jobs, foreign exchange earnings and eventually driving innovations in electric cars and other equipment. This approach has reflected that, China's broader geostrategic aim is securing critical minerals for its EV and renewable energy industries, which has accounted for 54% of global EV sales in 2023 (O'Donovan, 2024).

However, this engagement has raised critical questions about mutual energy security benefit for Nigeria and its economic diversification from the oil dependence, which constitutes over 80% of its export revenue (Akintayo, 2022). Thus, this chapter examine China's lithium diplomacy in Nigeria and energy security competition within the international political economy while reflecting on the socio-economic and environmental impacts of the lithium mining activities. Hence, the role of China in Nigeria's lithium mining and processing is discussed and assessed the balance between China's geostrategic goals and Nigeria's national interest.

1. LITHIUM IN THE GLOBAL ENERGY TRANSITION

Lithium serves as critical mineral for electric vehicle (EV) batteries and other electronic devices. The rise of lithium is key to the global energy transition efforts for renewable energy storage systems. This has induced global scrambling and competition with powerful states like the US and China doubling efforts to increase their sphere of influence lithium mining. The high-energy-density properties and its lightweight makes it very essential for lithium-ion batteries, which grid-scale storage globally and power over 80% of EVs (IEA, 2021). Lithium has become a source of green energy for decarbonizing transportation systems as well as for renewable energy grids. Additionally, the net-zero emissions in lithium aligned with the Paris Agreement.

The global demand for lithium is driven by the switch to electric vehicle (EV) and the renewable energy infrastructure. By 2040, the International Energy Agency projects a 42-fold because of increased demand in lithium, with EVs accounting for 90% of this growth. In 2023, reports indicate that global EV sales has reached 14 million units, with battery production requiring approximately 700,000 tons of lithium carbonate equivalent annually (Rathi, 2024). The policy provided incentives such as the EU's Green Deal and the US Inflation Reduction Act further stimulates the demand by providing financial incentive for EV adoption and renewable energy projects (US DOE, 2022; Neshat, Kaya, & Zare, 2023). However, there have been challenges because the supply chain bottlenecks and limited refining capacity which intensify competition for lithium resources. For instance, competition between Telsa and China on the exploitation of lithium in Nigeria. Nigeria rejected Telsa's offer to export raw lithium from Nigeria but offered China the license for lithium production and processing (McFall, 2023).

Geopolitically, the scarcity of lithium has sparked a global rush for the mineral among global powers. China has dominated other western powers in lithium processing, especially in developing countries. China controls 60% of global refining capacity, with the US and EU countries' aim at reducing dependency through increased domestic production and strategic partnerships (Hund, La Port, Fabregas, & Laing, 2020). The Belt and Road Initiative of

China has been used by China to increase access to lithium in resource-rich regions, while the EU's Critical Raw Materials Act gives its priority to supply diversification (European Commission, 2023). This competition has underscored the role of lithium as a geopolitical asset, which China understood the use of diplomacy to challenge Western powers by offering a different model of extraction and processing of lithium instead of the traditional approach of exporting the raw minerals.

China underscore the strategic relevance of lithium and the need to strengthen diplomatic ties with African states for sustainable supply chain. African hold a significant lithium reserve which positions her as a key player in the lithium global supply chains. The deposit of untapped lithium are in countries like Nigeria, Zimbabwe, and the Democratic Republic of Congo (DRC) with these attracting foreign investment in its lithium mining sectors. For instance, the Nigeria's north-central lithium fields, are estimated to rival the reserves of Bolivia, and substantial to attract major players like Chinese firms in the race to secure lithium supply for their EV industry (Nazor, 2025). However, weak governance has complicated efforts to deal with associated challenges like illegal mining and environmental concerns, which has challenged sustainable resource development. Africa's lithium deposits will shape the energy transition's geopolitical landscape as global demand grows.

2. NIGERIA'S LITHIUM RESOURCES AND NATIONAL INTERESTS

In Nigeria, lithium deposits are domicile in Kwara, Kaduna, Nasarawa, and Plateau states particularly the north-central regions and other states like Oyo, Osun, Ekiti, and Kebbi. These states host significant lithium deposits, thereby positioning the country as a potential key player in the global energy transition. With the lithium prices reaching $70,000 per ton in 2022 due to global demand, the economic potential is very substantial (BloombergNEF, 2022). These deposits would not only generate billions in revenue but will support Nigeria's industrial growth and its foreign exchange earnings. This will also help Nigeria's economic diversification initiatives from oil dependency. For instance, in 2022, 85% of Nigeria's export revenue came from crude oil sales (Akintayo, 2022). Therefore, strategically, lithium offers a pathway to diversify Nigeria to a value-added lithium industry. The local processing is expected to create jobs, stimulate manufacturing, and reduce Nigeria's reliance on the volatile oil markets. Conversely, lithium processing which could mirror South Africa's manganese processing success story which contributes 8.3% to South Africa's GDP annually (González & Wilde-Ramsing, 2021). Therefore, Chinese investment in the lithium sector is expected to contribute to Nigeria's GDP and drive further investments in technology transfer and infrastructure.

On energy security, lithium is pivotal to the renewable energy of Nigeria and the electric vehicle (EV) ambitions, which aligns with the country's National Renewable Energy and Energy Efficiency Policy (NREEEP) of 2017 and has targeted 30% renewable energy by 2030 (Energy Commission of Nigeria, 2022). Nigeria grapple with poor electricity which make energy unaffordable and difficulty to access by small and medium business for production. Prospectives for lithium-ion batteries to grid storage for solar and wind projects, which is critical to solving Nigeria unreliable electricity access for over 43% of its population is anticipated (World Bank, 2022). Additionally, the development of a domestic EV industry could reduce the dependence on fossil fuel vehicles, support Nigeria climate change policy and energy security. However, the limited local processing capacity can hinder these prospects, as most lithium is exported raw. China's recent investment in processing lithium is the only initiative which is not enough to drive Nigeria's green economic drive amid the vast lithium deposit reserves.

Despite the economic potentials for Nigeria in the emerging lithium industry, there is a national security risk. The unregulated lithium mining sector, which is dominated by foreign firms, posed a significant risk. In Nasarawa the illegal mining has led to environmental degradation and community displacement, which has fueled social unrest (The Nation, 2024). Concerns have been raised about the sovereignty of the economy particularly by Chinese firms, foreign control as profits are being repatriated rather than reinvested locally. The weak regulatory frameworks have worsened the vulnerabilities, with artisanal mining linked to child labor and smuggling (Jamiu, 2024). Additionally, illegal Chinese aliens have been arrested in Nigeria for illegal mining. These issues threatens the national security of Nigeria and its sustainable development. As the industry continue to growth, China's hegemonic control over the lithium industry will be challenged and may induce geopolitical tensions between China and other rival states and their firms. Therefore, robust governance mining regime to protect local stakeholders and Nigeria's national interests is pertinent.

3. CHINESE LITHIUM DIPLOMACY IN NIGERIA

Chinese lithium diplomacy in Nigeria embodies China's strategic efforts to strengthening its dominance in electric vehicle (EV) and renewable energy markets. China employs economic and diplomatic tools to secure critical mining concessions in Nigeria. Since 2017, Chinese firms like Ganfeng Lithium have invested heavily and over $500 million in Nigeria's north-central lithium deposits, in aiming to supply China's EV industry, which in 2023 is consumed by 60% of global lithium. Additionally, for long-term resource access, China invested in infrastructure projects, such as a $200 million road in Nasarawa through the Belt and Road Initiative to seal mining concessions while ensuring long-term resource access (Inokotong, 2024).

While Chinese lithium set a new trajectory in the sector, it encourages the local lithium processing to the creation of jobs and support Nigeria's economic diversification, issues of transparency, technology transfer and weak governance remain a big challenge. Unlike in the EU and US, which prioritized the private-sector partnerships and its sustainability (European Commission, 2023), the rapid infrastructure-driven of China model, has raised concerns about the environmental degradation, illegal mining, and its limited local benefits, which spark debates over the sovereignty and sustainable development of Nigeria. In leveraging its global leadership in critical mineral markets, China has emerged as a major dominant player in the lithium sector of Nigeria which is expected to create geopolitical competition with the US recently launched Commercial Diplomacy Strategy as a new focus of the US engagement with Africa (US Department of State, 2025).

Chinese companies such as Ganfeng Lithium and Tianqi Lithium are playing dominant role in the sector, particularly in Nasarawa and Plateau in the north-central states, where the high-grade spodumene deposits are abundant. China is a strategic player Nigeria's lithium sector, it mining output is projected to reach 50,000 tons annually by 2030 (BloombergNEF, 2022). The lithium diplomacy of China is part of the agenda of Belt and Road Initiative (BRI) strategy which drives the raw lithium to processing innovation for battery-grade lithium in Nigeria, thereby stamping its dominance in the industry.

3.1 Challenges and Controversies in Lithium Extraction

While Chinese significant investment in Nigeria's lithium sector has enormous potentials to drive innovation in electric vehicle technology, renewable energy and industrial development, illegal mining by local artisanal mining supported by illegal and unscrupulous Chinese miners threatens the sector. This illegal mining is particularly common in the north-central states like Nasarawa and Plateau, where these Chinese firms have been implicated in unauthorized dealings. Illegal lithium mining is a wide-spread concern in Nigeria. Reports have indicated that Chinese companies, such as Xinfeng Investments, have taken advantages of the weak regulations governing mining to extract lithium without proper permits, costing Nigeria an estimated $9 billion annually in lost revenue (Ecofin Agency, 2024). For instance, the Economic and Financial Crimes Commission (EFCC) arraigned two Chinese citizens, Zhang Hong Lin and Zhao Pei Hai for illegal lithium mining and export in 2025 (Dania, 2025). These activities have undermined the economic potential of Nigeria and worsened its environmental and social livelihood.

The extraction of lithium contributes to environmental degradation in Nigeria. Deforestation is caused by artisanal and illegal mining operations, with over 17% of forest reserves in mining regions been destroyed annually, leading to the disruption of the ecosystems and carbon sinks. Another major concern that has been raised is the contamination of water, as these mining processes releases toxic chemicals like sulfuric acid into rivers, thereby affecting local water supplies and biodiversity. Lithium mining has led to the erosion of soil and the ecological toxicity, which has threatened the sustainable development, where Studies have drawn its parallels with other African contexts, such as the DRC (Otorkpa, Alao, & Emmanuel, 2024).

Social issues are also associated with mining such as labor exploitation practice and child labor as seen in other jurisdictions where Chinese companies operates. Children as young as 10 have been found to work in dangerous mining conditions, in Nasarawa State, Nigeria, often are under the control of these unregulated operators linked to Chinese firms mining lithium (Adebayo, 2024). Displacement of families from their ancestral lands without adequate or proper compensation in connivance with local political elite. This community displacement is motivated by greed and land grabbing as seen in places like Zimbabwe and the DRC echoing patterns of green extractivist (Global Witness, 2024). Local resistance is expected to increase awareness on exploitation leading to community protests in these mining regions and subsequently disrupt the investments. The locals have blockaded the Chinese-operated mines, in Nasarawa citing its environmental damage and lack of economic benefits. The negative perceptions about Chinese exploitation and cheap labor practices may fuel resistance, and the complication of Nigeria's lithium development (Shobayo, 2024).

The mining governance of Nigeria suffer regulatory weaknesses including the lack of enforcement of the Nigerian Minerals and Mining Act of 2007. Lack of coordination has enabled illegal mining and overlapping regulatory bodies to undermine mining governance in the lithium sector. Corruption and collusion between local officials and foreign miners continue to complicate enforcement of regulations. Additionally, inadequate licensing processes has further enabled foreign firms to bypass environmental and social safeguards. These weaknesses have hindered the ability of Nigeria to harness lithium for a sustainable development.

3.2 Comparative Case Study: Chinese Lithium Operations in the Democratic Republic of Congo (DRC)

China's lithium diplomacy in the Democratic Republic of Congo (DRC), has mirrored its approach in Nigeria, by emphasizing its infrastructure-for-resources deals under the initiatives of Belt and Road Initiative (BRI). Since 2017, these Chinese firms, such as China Molybdenum and Zijin Mining, have invested over $2 billion, in DRC's lithium and cobalt mines, securing access to 60% of the country's critical mineral output (Global Witness, 2024). For example, Chinese companies have invested heavily in lithium mining in DRC such as the Zijin Mining Group Company. It is one of the largest Chinese firms which operates in the southeast DRC mines with deposits of the battery metal considered one of the largest in the world. Transport infrastructure projects, in

Katanga which includes a $456 million railway funded by the Chinese, has enabled these mineral exports while strengthening control over supply chains for its electric vehicle (EV) industry, which consumed 60% of global lithium in 2023 (Liu & Njini, 2023). However, these mining deals often prioritized the interest of Chinese, with limited technology transfer to the DRC.

Lithium mining is considered as an economic gain in the DRC and touted to have created approximately 20,000 jobs in the sector and the earnings of foreign exchange contributed about 12% of its GDP in 2022 (World Bank, 2022). Despite the incredible success story, it comes with social and environmental costs. Artisanal mining have been linked to Chinese mining operations in the region, which has led to the engagement of child labor, with over 40,000 children in hazardous conditions. Environmental degradation of local water sources, including water contamination and deforestation, which has displaced communities and polluted rivers (Global Witness, 2024). These outcomes have been highlighted by the trade-offs of China's resource-driven model.

The DRC experience can offer critical lessons for both Nigeria and China. Nigeria can strengthen its weak regulatory oversights to avoid corruption, exploitative practices, enforce environmental standards and encourage local stakeholders to invest in mineral processing for value addition and economic sustainability (Associated Press, 2024). Unlike the ongoing conflicts of the DRC, the engagements of the community and transparency in contracts can mitigate social unrest. While China can provide oversight on Chinese firms operating in Nigeria while sustaining strong public diplomacy to improve perception about its mining activities. On a broader note, Chinese companies' mining in Africa follows a consistent pattern across Africa, as seen Zimbabwe's lithium mines and in the sector of Zambia's copper. Although infrastructure investments and resource access has provided benefits to host countries, however, environmental damage and dependency are common. Nigeria can learn from these cases to invest wisely in value-added industries and negotiate a win-win partnerships that aligns with the tenets of sustainable development goals.

3.3 Geopolitics of Africa's Energy Rush

Africa enjoy vast deposits of lithium. This situates the continent as a very critical frontier in the global energy competition, with countries like Nigeria, the Democratic Republic of Congo (DRC), and Zimbabwe holding huge reserves of lithium mineral that is vital for electric vehicle (EV) batteries and its renewable energy storage. By 2030, it is estimated that Africa could supply 20% of global lithium according to the International Energy Agency (IEA) because of the rising demand. The demand is projected to grow 42-fold by 2040 (IEA, 2021). This underscores Africa's strategic importance in the chess board of geopolitical race to secure energy supply chains expected to reach $7 trillion in the EV market. However, Nigeria's ability to capitalize on this huge investment opportunity is challenge by weak governance and infrastructure.

China's geostrategic objectives in lithium mining and process is not hidden. China controls 60% of global lithium refining. Its lithium diplomacy pursues an aggressive acquisition of African lithium mining licenses for its EV and renewable energy sectors, which has accounted for 54% of global EV sales in 2023 (BloombergNEF, 2023). Competing powers such as the US and EU are strengthening its efforts in the opposition of the dominance of China in Africa's rare mineral such as the lithium by supporting the private sector investments like the exploration of Albemarle's in Nigeria and through the US' Minerals Security Partnership. The EU's Critical Raw Materials Act projected to invest $100 million in African lithium but lags behind the China's billions in lithium investment (European Commission, 2023). Other players, like Australia and Canada, focus on technical expertise with minimal presence in Nigeria. Nigeria's Tinubu government advances policies on mining to diversify the economy and improve foreign exchange earnings after removing oil subsidy and floating the currency of Nigeria. Therefore, strengthening Nigeria's mining regulatory frameworks can aid in ensuring economic benefits from lithium extraction. Nigeria can emulate Chile's lithium model, by prioritizing local processing and transparent contracts, domestically which retains economic value, by avoiding the DRC's pitfalls

3.4 Balancing China's Energy Security and Nigeria's Economic Interests

In Nigeria, the China lithium diplomacy is driven by its quest to secure an unwavering lithium supplies for its green energy ambitions to sustaining its dominance in electric vehicle (EV) and renewable energy markets. In 2030 alone, China consumed 60% of global lithium in, and necessitating a robust supply chain to meet its 2060 carbon neutrality goal as the world's largest EV producer (IEA, 2021). With over $500 million in Chinese lithium investments in Nigeria, China prioritize Nigeria as a strategic energy security partner in EV and renewal energy battery industry (Nazor, 2025).

This strategy has ensured dominance of China's energy security in Nigeria lithium but often sidelines local stakeholders. While Nigeria aims in leveraging its lithium deposits to achieving energy security, economic diversification, and a sustainable development. Nigeria targets that by 2030, lithium can support its National Renewable Energy and Energy Efficiency Policy which targets to achieve 30% in renewable energy to enhance grid stability and EV adoption (Energy Commission of Nigeria, 2022). Economically, Nigeria lithium processing could reduce its 85% reliance on oil exports, in creating jobs opportunities and foreign exchange provided some of the challenges are mitigated. Environmental and social harms impedes sustainable development, such as those seen in illegal mining operations by Chinese and local miners (Otorkpa, Alao, & Emmanuel, 2024). Therefore, these rises questions as to whether Chinese lithium investments has mutual energy security and economic benefits for both China and Nigeria or it is another conduit for the exploitation of Nigeria's rare minerals. In cases like the DRC, where Chinese firms extracted 60% of minerals with minimal benefits for the local communities. Nigeria risk becoming a supplier of raw materials without finished products made in Nigeria from the lithium (Global Witness, 2024).

CONCLUSION

By and large, the China lithium diplomacy in Nigeria presents a dual-edged sword. On one hand it comes with huge energy transition investment and economic diversification opportunities, on the other hand, it poses socio-economic and environmental challenges. The chapter examined the Chinese lithium investments in Nigeria its potential for job creation and economic development but interrogated China's energy security over Nigeria's long-term national interests. It reflected on the dangers and patterns of exploitation seen in raw mineral exports and illegal mining in Nigeria. Environmental degradation, child labor abuses, and community displacement has underscored the urgent need for Nigeria in asserting the control over its lithium resources.

The switching from raw exports to the local processing, the lithium's potential to power electric vehicles and renewable energy systems in Nigeria can be harnessed by, reducing its 85% reliance on oil and fostering sustainable growth. In ensuring the economic benefits, Nigeria must prioritize its sustainable and inclusive lithium policies to uplifting local communities while safeguarding the ecosystems. Additionally, in terms of policy, Nigeria must strengthen its mining regulations and environmental protection mechanism. Develop local lithium processing capabilities by investing in refineries. Foster equitable and transparent partnerships with foreign investors ensure mutual benefits for both parties. Therefore, Nigeria must act decisively, as it stands at a crossroads in transforming its lithium wealth into a catalyst for equitable development. In investing in local processing, the right time is now for Nigeria to enact a well meaningful robust regulation, and forge equitable partnerships to securing a sustainable future.

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