FROM RESOURCES TO GROWTH

ENERGY AND DEVELOPMENT STRATEGIES IN DEVELOPING NATIONS

EDITORS

Prof. Dr. Arzu AL

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PREFACE

Energy lies at the core of modern civilization—it fuels economies, sustains societies, and shapes the direction of human progress. *From Resources to Growth: Energy and Development Strategies in Developing Nations* emerges from the belief that energy, when managed wisely, can bridge prosperity and sustainability. This volume unites scholars from across continents, each exploring how developing nations can transform their natural endowments into inclusive and resilient strategies for growth.

The experience of **Türkiye**, examined by **Yusuf Girayalp Atan** and **Arzu Al**, reflects the challenges and possibilities of developing economies at the crossroads of regions and resources. Their work shows how energy dependence can evolve from vulnerability into strength, turning external reliance into a driver of innovation, diversification, and cooperation

Dr. Akhil Bhat, through *Energy & Sustainability in Developing Countries: India with J & K Perspective*, presents the Indian context, showing how regional realities in Jammu and Kashmir interact with national energy strategies. His research argues that sustainability must be local in approach but global in vision, aligning community needs with national policy.

In *The Energy-Development Nexus in Nigeria: Challenges and Opportunities*, **Dr. Wasiu Abiodun Makinde** explores the paradox of energy poverty within abundance. His analysis highlights how structural inefficiencies and weak governance can hinder progress, while also pointing to reform and investment pathways that could turn Nigeria's resources into inclusive growth.

Ahmad Ibn Shuaeeb lays the groundwork by emphasizing the transformative power of education in promoting sustainable energy awareness. His work reminds us that true progress begins with understanding—that informed citizens are the cornerstone of responsible resource management and ecological consciousness.

Ansar Bilyaminu Adam and his collaborators bring a scientific dimension, illustrating how chemistry can unlock Africa's potential for clean and affordable energy. Their research shows that innovation grounded in science can turn resource abundance into opportunity and bridge the gap between potential and implementation.

Rajeshwari Mohan Lakhwani moves the discussion into geopolitics, examining how competition from the Eastern Mediterranean to Central Asia reshapes global power relations.

Her analysis reveals that energy is not just traded but negotiated, contested, and inherently political—reflecting both national ambition and global interdependence.

Juliet Ohenokobosare Esieboma introduces the social dimension of energy, arguing that access must be seen not merely as an economic goal but as a matter of justice and human dignity. She views energy as a social right—empowering participation, education, and equality. Her perspective reminds us that sustainability without inclusion remains incomplete.

Muhammad Sufyaan Khan, in *The Relationship Between Energy and Development: Perspectives from Developing Countries with the Role of Artificial Intelligence*, envisions a future where technology reshapes energy management. He demonstrates how artificial intelligence can revolutionize efficiency, forecasting, and policymaking, redefining the relationship between innovation and sustainability.

Mohamed Ali Moussa, in *Energy and Development in Developing Countries*, explores the direct connection between energy use and economic growth. His research underscores that policies, institutions, and infrastructure determine whether energy resources become an engine of progress or a source of constraint.

Taken together, these studies convey a common truth: energy is not merely a question of supply and demand but of values, vision, and governance. The path from resources to growth demands more than technology—it requires education, innovation, and shared responsibility. Each contribution in this book reinforces that sustainable development must be built on both knowledge and justice.

I am deeply grateful to all authors, reviewers, and contributors whose insights have shaped this work. Their collective wisdom affirms that the study of energy is, ultimately, the study of humanity itself. It is my hope that this volume not only informs but inspires—encouraging scholars, policymakers, and citizens to envision a world where energy unites rather than divides, and where progress is measured not by output alone, but by the equity and dignity it sustains.

Prof. Dr. Arzu AL
November 04, 2025 – Türkiye

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CHAPTER 1
ENERGY DEPENDENCE AND ECONOMIC SECURITY IN DEVELOPING COUNTRIES: THE CASE OF TÜRKİYE

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INTRODUCTION

Energy has always played a central role in the organization of economic and social life. Throughout history, access to reliable and affordable energy has determined the pace of industrialization, urbanization, and national development. In today’s globalized economy, this relationship has become even more complex. Expanding production networks, accelerating urban growth, and technological change have driven energy demand to unprecedented levels, while inequalities in resource distribution have deepened. For many developing countries, securing sufficient energy is not merely a matter of infrastructure or technology—it is a structural question that shapes economic stability, industrial competitiveness, and national security.

Whereas advanced economies have largely succeeded in diversifying their energy sources and investing in renewable capacity, developing countries often remain constrained by structural dependence on imported fossil fuels. This dependence links their growth prospects to the volatility of global energy markets and to the strategic decisions of major exporters. The outcome is a persistent vulnerability: current account deficits widen during price spikes, inflationary pressures spread across sectors, and energy-intensive industries struggle to maintain competitiveness. In such contexts, energy policy cannot be separated from broader economic strategy. The concept of economic security, once dominated by discussions of trade and finance, now necessarily includes energy supply, diversification, and resilience.

Türkiye represents a striking example of this dynamic. Positioned between Europe, Asia, and the Middle East, it has experienced rapid industrialization and urbanization since the 1980s. However, more than seventy percent of its total energy demand continues to be met through imports, predominantly oil and natural gas. This pattern has produced chronic current account deficits and heightened exposure to global price shocks.

At the same time, dependence on a narrow group of suppliers—especially Russia and Iran—has created geopolitical vulnerabilities that extend far beyond the energy sector. The global crisis of 2022 vividly revealed these risks: soaring prices and disrupted supplies quickly affected industrial output and macroeconomic stability.

Although Türkiye has launched various diversification initiatives—including renewable investments, nuclear energy projects, and participation in regional pipeline schemes such as TANAP—the transformation remains incomplete. These measures have reduced some immediate risks but have not fundamentally altered the structural dependence underlying the economy. The country's experience thus raises broader questions about how developing nations can pursue sustainable growth while mitigating exposure to external energy shocks.

The academic debate on energy security provides valuable insights into these challenges but leaves important gaps unaddressed. Over the past two decades, research has expanded significantly, focusing on diversification, market integration, and geopolitical risk. Yet, the specific mechanisms through which external energy dependence affects economic security and industrial performance in developing countries remain insufficiently examined. Much of the existing literature treats energy security as an isolated technical or geopolitical problem, rather than integrating it into the wider framework of structural economic vulnerability.

This study aims to fill that gap by examining the relationship between energy dependence and economic security through the case of Türkiye. Drawing on dependency theory and contemporary approaches to energy security, it combines historical and empirical analysis. The first component traces Türkiye's evolving energy structure and its macroeconomic consequences, including current account imbalances and industrial constraints.

The second employs econometric analysis using time-series data from 1980 to 2023 to identify causal links among energy imports, industrial production, external balances, and global market shocks. Comparative references to other developing economies—particularly India and Poland—further contextualize the findings, illustrating how Türkiye's experience reflects broader patterns across the Global South.

The paper's contribution lies in bridging theoretical and empirical perspectives. It demonstrates how external energy dependence can systematically erode economic security, providing evidence that supports and refines key propositions of dependency theory.

It also extends the scope of energy security studies by connecting macroeconomic fragility, industrial competitiveness, and external vulnerability within a single analytical framework. Finally, by examining Türkiye alongside other developing economies, the study highlights both the risks of sustained dependence and the potential of strategic energy transition. In doing so, it speaks not only to scholars of political economy and energy policy but also to policymakers seeking resilient pathways for sustainable development.

1. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

The understanding of economic security has changed significantly over time, evolving from a narrow, state-centered notion to a far more complex and multidimensional concept. Earlier debates, especially during the Cold War, almost equated security with military strength. With the end of that period, however, attention began to move toward the vulnerabilities emerging from trade, finance, and resource dependence. Mesjasz (2008) observes that instability in economic life is not an exception but rather a normal condition of markets, and he points out how difficult it is to identify fixed “objects” of security in such a dynamic system.

His systems-based analysis suggests that economic security is interwoven with political, social, and even environmental factors. Likewise, Aykin (2019) notes that globalization has multiplied interdependence to such an extent that states now influence one another through economic means as effectively as they once did through military power.

This broader framing is also evident in American strategic thinking. The National Security Strategy of 2017 connected economic growth directly to national security, portraying energy dominance and resilient supply chains as central to the United States’ international position (NSS, 2017). Yet, Losman (2001) cautioned that expanding the definition too broadly risks confusing economic goals with national security concerns, potentially encouraging a militarized approach to trade and investment disputes. This tension—whether economic security should be defined narrowly or expansively—runs throughout the academic discussion. In the field of international political economy, scholars have emphasized how globalization produces forms of fragility that lie beyond the control of individual states.

Nesadurai (2005), drawing lessons from East Asia's experience, argues that focusing solely on external threats—as neorealist approaches often do—overlooks the vulnerabilities that are embedded within liberalized financial systems and globalized markets. For her, economic security involves protecting not just state sovereignty but also income stability, market integrity, and social welfare. This perspective is especially relevant to developing countries, where abrupt external shocks—such as energy price surges—quickly translate into macroeconomic instability.

Parallel developments can be traced in the energy security literature. Yergin (2006) famously described energy security as the assurance of reliable supply at reasonable cost, with diversification as its core principle.

Later scholars broadened this understanding: Sovacool (2011) and Winzer (2012) proposed that energy security should encompass availability, affordability, and resilience to disruption. Their analyses underline that energy is more than a traded commodity—it is a strategic input that shapes industrial competitiveness, external balances, and the overall trajectory of economic development. For developing economies, energy dependence thus becomes a paradox: it supports industrialization while simultaneously exposing them to the volatility of global markets and foreign suppliers.

Empirical research substantiates these theoretical insights. In Türkiye's case, several studies published in reputable journals reveal the consequences of high reliance on imported hydrocarbons. Kibaroğlu and Kibaroğlu (2019) show that dependence on Russian natural gas has constrained both the country's foreign policy flexibility and its economic autonomy. Similarly, Aydın and Acar (2019) demonstrate that fossil-fuel imports systematically widen the current account deficit, reinforcing long-term structural weaknesses. These national experiences echo wider European patterns: the 2006 and 2009 gas crises prompted the European Commission (2014) to prioritize diversification and to accelerate investment in renewables as part of a new security agenda.

Against this background, the theoretical framework of the present study brings together dependency theory and the energy–economic security nexus.

Originating in the work of Prebisch (1950) and further elaborated by Cardoso and Faletto (1979), dependency theory explains how structural reliance on external inputs limits the autonomy of peripheral economies.

Applied to energy, the theory helps clarify why Türkiye's dependence on imported fuels perpetuates recurring cycles of vulnerability—through balance-of-payments pressures, inflationary tendencies, and industrial cost fluctuations.

Contemporary energy-security paradigms complement this analysis by highlighting the multidimensional nature of the challenge.

Sovacool and Brown (2010) suggest that energy security should be examined across geopolitical, economic, technological, and environmental dimensions. When these insights are combined with broader approaches to economic security (Aykin, 2019; Nesadurai, 2005), energy dependence can be understood not just as a supply-side issue but as a systemic constraint that erodes economic sovereignty and weakens industrial resilience.

Taken together, these perspectives position Türkiye as an illuminating case study. Dependency theory points to the structural asymmetries created by reliance on external resources, while the economic-security framework reveals how those asymmetries manifest in financial instability, industrial fragility, and geopolitical exposure. Viewing the issue through both lenses enables a more integrated analysis that links macroeconomic data to structural theory. It also provides a sound basis for comparative exploration, showing that Türkiye's challenges mirror those of many other developing countries across the Global South, where the pursuit of growth remains deeply intertwined with the quest for energy security.

2. METHODOLOGY

This study employs a **mixed-methods design** that integrates both qualitative and quantitative approaches in order to capture the multi-dimensional relationship between energy dependence, economic security, and industrial production in developing countries. The choice of methodology reflects the complexity of the subject matter: energy dependence is not only an economic variable that can be quantified through statistical analysis, but also a structural condition that shapes national strategies and long-term development trajectories.

A purely econometric approach would risk overlooking the historical and institutional context of Türkiye's dependence, while a purely qualitative account would fail to capture the causal dynamics at play. The combination of the two enables a more comprehensive understanding.

2.1 Research Design

The methodology proceeds in three stages. First, a **historical-structural analysis** is undertaken to situate Türkiye's energy dependence within broader patterns of industrialization, trade liberalization, and global energy market fluctuations since the 1980s. This component draws on official statistics, government reports, and international energy outlooks to trace how policy choices and structural constraints have contributed to persistent import dependence.

Second, the study conducts **econometric analysis** using time-series data from 1980 to 2023. The focus here is on the interactions between energy imports, the current account balance, industrial output, and exposure to external price shocks. A range of econometric techniques are employed, including unit root tests, cointegration analysis, vector autoregression (VAR), autoregressive distributed lag (ARDL) models, and Granger causality testing. These methods allow us to test both long-term equilibrium relationships and short-term dynamics.

Third, the findings are placed in a **comparative perspective** through reference to India and Poland, two countries that share characteristics with Türkiye as developing or transition economies with high energy demand but divergent policy strategies. This comparison helps contextualize the Turkish case and underscores whether the identified vulnerabilities are unique or more broadly representative of developing country experiences.

2.2 Data Sources

The empirical analysis relies on data from multiple authoritative and verifiable sources. For Türkiye, energy import figures, balance-of-payments statistics, and industrial production indices are drawn from the **Turkish Statistical Institute (TÜİK)** and the **Central Bank of the Republic of Türkiye (CBRT)**.

Historical data on energy prices, trade flows, and supply disruptions are supplemented by reports from the **Ministry of Energy and Natural Resources** and the **Energy Market Regulatory Authority (EMRA)**.

For international comparisons, the study makes use of datasets from the **World Bank's World Development Indicators (WDI)**, the **International Monetary Fund (IMF)**, and the **International Energy Agency (IEA)**.

EU-level statistics are drawn from **Eurostat**, while additional reference is made to the **U.S. Energy Information Administration (EIA)** and the UK's **Department for Energy Security and Net Zero (DESNZ)**. Comparative data on renewables and fossil fuel trends are cross-checked with independent energy think tanks such as **Ember** and the **Oxford Institute for Energy Studies (OIES)**.

The period **1980–2023** was selected for two reasons. First, the liberalization of the Turkish economy in the early 1980s marked the beginning of rapid industrialization and rising energy demand, making it a logical starting point for analysis. Second, the inclusion of the most recent years allows for assessment of the impact of the 2022 global energy crisis, which represented the most severe external shock to energy-dependent economies in recent history.

2.2.1 Analytical Techniques

The econometric component of the study is structured around four main steps.

Stationarity and Cointegration Tests: All time series are first tested for stationarity using Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. Given the mixed integration order of many macroeconomic variables, the ARDL bounds testing approach is applied to test for long-run cointegration relationships between energy imports, current account balance, and industrial output.

Vector Autoregression (VAR) and Impulse Response Analysis: A VAR model is estimated to capture dynamic interactions between variables. Impulse response functions are used to trace the effect of external energy price shocks on Türkiye's current account balance and industrial production over time.

This approach provides insight into both the magnitude and duration of shock transmission.

Granger Causality Testing: To establish causal directions, Granger causality tests are conducted. These tests assess whether changes in energy imports Granger-cause fluctuations in industrial output and macroeconomic stability, or whether the reverse holds.

Structural Break and Robustness Checks: Structural break tests (Zivot-Andrews, Bai-Perron) are employed to account for key historical events, including the 1994 financial crisis, the 2001 banking crisis, the 2008 global financial crisis, and the 2022 energy crisis. Robustness checks ensure that the results are not driven by these singular shocks.

Comparative Dimension

The comparative analysis with India and Poland is conducted using descriptive statistics and secondary literature. Both countries share high levels of energy dependence but have pursued different diversification strategies. India has invested heavily in renewables and domestic coal, while Poland has relied on EU integration and coal-to-renewables transition programs. Comparing Türkiye's experience with these cases highlights both common structural constraints of developing economies and the role of institutional and policy differences in shaping outcomes.

Validity and Reliability

To ensure validity, the study triangulates multiple data sources and methods. Quantitative results are cross-checked with historical accounts and policy reports. Reliability is enhanced by drawing on internationally recognized statistical agencies and consistent time-series methodologies. All econometric estimations are replicated using alternative model specifications, lag structures, and robustness tests.

Limitations

While the mixed-methods design strengthens the analysis, several limitations must be acknowledged. First, data quality can vary across sources, particularly for early years in the 1980s and 1990s.

Second, econometric methods such as Granger causality cannot establish true causality in the philosophical sense, but only statistical precedence. Third, while the comparative cases of India and Poland provide useful context, they cannot capture the full diversity of developing country experiences. Finally, the study focuses primarily on fossil fuel dependence; while renewables are considered, a full sectoral model of the energy transition lies beyond its scope.

Concluding Remarks on Methodology

In sum, the methodological approach combines historical, econometric, and comparative analysis to capture the multi-layered nature of energy dependence in Türkiye. The integration of dependency theory and economic security frameworks ensures that the study does not treat energy dependence as a narrow technical issue, but rather as a systemic condition shaping macroeconomic stability and industrial resilience. By employing robust econometric techniques on a long time series, while also situating findings within broader historical and comparative perspectives, the study seeks to generate insights that are both theoretically grounded and empirically validated.

3. ENERGY DEPENDENCE IN DEVELOPING COUNTRIES

Energy dependence—typically measured as net energy imports as a share of total energy use—captures how far a country relies on external suppliers to meet domestic demand (World Bank, n.d.). In developing economies, where industrialization, urbanization, and population growth drive rapid energy demand, high import dependence transmits global price volatility and supply disruptions directly into domestic inflation, balance-of-payments constraints, and industrial cost structures. The contemporary literature also stresses that geopolitical fragmentation elevates these risks by complicating long-term contracting, financing, and infrastructure planning (IEA, 2024). (World Bank; International Energy Agency [IEA], 2024).

Comparative statistics underscore the structural nature of these vulnerabilities. The EU's energy import dependency rate was 63% in 2022, with wide variation across member states (Eurostat, 2024).

Since Russia's invasion of Ukraine, the EU has phased down Russian gas and diversified supply through LNG and pipeline imports from Norway, North Africa, and the Caspian, under the REPowerEU agenda (European Commission, 2025). The share of Russian gas in EU imports has fallen sharply—from around half in 2020 to about 15% in 2023—although some residual exposure remains via LNG and specific bilateral arrangements (Bruegel, 2024; Brookings, 2024). (Eurostat, 2024; European Commission, 2025; Bruegel, 2024; Brookings Institution, 2024).

By contrast, the United States illustrates how domestic production and infrastructure expansion alter the dependence calculus. The U.S. became the world's largest natural gas exporter on a daily-volume basis in 2023, with exports up 10% year-over-year to 20.9 bcf/d, predominantly via LNG (EIA, 2024). Reduced net import exposure has cushioned U.S. consumers and industry from some external shocks, even as global prices spike (EIA, 2024). The United Kingdom's long-run trajectory is mixed: legacy North Sea output once underpinned low import dependence, but aging fields increased reliance on imports; more recently, the UK has strengthened resilience through diversification and rising low-carbon shares (DESNZ, 2025). (U.S. Energy Information Administration [EIA], 2024; Department for Energy Security and Net Zero [DESNZ], 2025).

For developing countries, import dependence interacts with structural constraints—limited fiscal space, exchange-rate pass-through, and energy-intensive industrial bases. The IEA's World Energy Outlook 2024 warns that heightened geopolitical tensions and supply chain frictions raise the macro risks of fossil-fuel import reliance, especially where grids and storage are underdeveloped. These pressures are magnified by post-pandemic demand rebounds and the investment needs of the clean-energy transition (IEA, 2024).

Türkiye is emblematic. World Bank data report persistently high net energy import shares (e.g., ~70% in recent years), reflecting heavy reliance on imported oil and natural gas (World Bank, n.d.). Türkiye's energy authorities themselves identify imported fossil-fuel dependence as a core vulnerability, prompting policies to prioritize efficiency and diversification in the 2024–2028 strategic planning horizon (Republic of Türkiye Ministry of Energy and Natural Resources, 2023/2024).

EMRA market reports document the rapid expansion of the natural-gas grid and the evolution of the electricity market—vital for understanding industrial exposure to gas-linked price dynamics (EMRA, 2024). (World Bank, n.d.; Republic of Türkiye Ministry of Energy and Natural Resources, 2023/2024; Energy Market Regulatory Authority [EMRA], 2024).

Academic and policy research converges on the macro-industrial channels through which dependence bites.

For Türkiye, peer-reviewed studies and TR Dizin contributions commonly find that energy imports are associated with current-account pressures and industrial-cost pass-through, albeit with nuances by period and specification (Aydın & Acar, 2019; Önder, 2023; Uysal, Yılmaz & Taş, 2015). Some papers report long-run cointegration between energy imports, growth, and the current account, while others stress that results are sensitive to crisis episodes and structural breaks—underscoring the need for robust time-series methods (VAR/ARDL) in empirical work (Anemon Journal; ISRJournal, various TR Dizin sources). (Aydın & Acar, 2019; Önder, 2023; Uysal et al., 2015; Anemon Journal article, ISRJournal article).

The EU experience since 2022 also illustrates how policy can compress exposure without eliminating it. REPowerEU has mobilized demand reduction, accelerated renewables, and expanded regasification capacity, lowering Russian pipeline gas shares to roughly 11% by 2024 and below 20% for combined pipeline+LNG (Council of the EU, 2024). Yet think-tank analyses point to continued purchases of Russian LNG by several member states, complicating the goal of full decoupling (Chatham House, 2024; Elcano, 2024). (Council of the European Union, 2024; Chatham House, 2024; Real Instituto Elcano, 2024).

Supplier dynamics matter, too. OIES estimates that Russian gas exports to Europe fell by around 90 bcm in 2022, reshaping flows and creating spare production capacity in Russia (OIES, 2023). Europe backfilled with LNG (U.S., Qatar) and non-Russian pipeline gas (Norway, Azerbaijan, North Africa), but at higher marginal costs and with infrastructure bottlenecks (Bruegel, 2024). For developing importers, these shifts have meant tighter global LNG markets, higher volatility, and tougher financing conditions (IEA, 2024). (Oxford Institute for Energy Studies [OIES], 2023; Bruegel, 2024; IEA, 2024).

Within Türkiye's power sector, the generation mix shapes exposure. Independent analyses show wind and solar have risen swiftly—62 TWh of wind+solar output in 2024, surpassing domestic coal (Ember, 2025; Anadolu Agency summary, 2025). Ember's 2024 review emphasizes that, despite a significant renewable build-out, demand growth still outpaced clean additions, keeping gas and imported fuels central to marginal pricing in tight periods (Ember, 2024).

This pattern—rapid renewables growth, yet persistent fossil exposure at the margin—is common across many developing systems with fast-rising demand (Ember, 2024; IEA, 2024). (Ember, 2024, 2025; Anadolu Agency, 2025; IEA, 2024). Outside Türkiye, India exemplifies a large developing economy where coal dominance and rising electricity demand create distinct vulnerabilities: grid stress, heat-driven demand spikes, and financing needs for renewables and storage (IEA, 2024; Guardian, 2025). Poland, while an EU member with higher income levels than many developing economies, offers a transition case: heavy historical coal use, accelerating EU-driven diversification, and exposure to gas-price shocks during 2022–2023 (Eurostat, 2024; Weiner, 2025). These cases suggest that the pathways of dependence reduction hinge on policy credibility, financing, and system flexibility rather than on a single "fuel switch." (IEA, 2024; The Guardian, 2025; Eurostat, 2024; Weiner, 2025). In developing regions more broadly, exchange-rate dynamics and terms-of-trade shocks transmit global energy prices into domestic inflation and fiscal balances. IMF analyses of the security–transition nexus stress that affordability and reliability must be tackled in tandem with decarbonization, particularly for net importers with fragile external accounts (IMF, 2024). Multilateral statistics show that LNG price spikes and supply chain bottlenecks during 2022–2023 raised delivered costs for many importers, amplifying balance-of-payments pressures (IEA, 2024; Eurostat, 2025). (International Monetary Fund [IMF], 2024; IEA, 2024; Eurostat, 2025).

Policy implications emerging from this comparative literature are consistent. First, diversification of fuels, routes, and counterparties reduces the probability and impact of disruptions (Yergin, 2006; Council of the EU, 2024).

Second, demand-side measures—efficiency, flexible loads, and market design—lower the volume of imports and dampen price pass-through into industry (DESNZ, 2025; Ministry of Energy and Natural Resources, 2023/2024). Third, renewables and storage—while not a panacea—systematically reduce import dependence over time by displacing fossil fuel at the margin; the empirical record from Europe and recent Turkish data supports this trajectory, provided transmission and balancing investments keep pace (Ember, 2024; IEA, 2024; Eurostat, 2024). (Yergin, 2006; Council of the European Union, 2024; DESNZ, 2025; Republic of Türkiye Ministry of Energy and Natural Resources, 2023/2024; Ember, 2024; IEA, 2024; Eurostat, 2024).

Finally, Türkiye-specific scholarship and policy provide granular evidence of these mechanisms. Peer-reviewed articles and theses (e.g., Acaravcı, 2015; Önder, 2023; Aki, 2021) document linkages among energy imports, the current account, and industrial output, while government and professional-association reports (e.g., MMO Energy Outlook 2024) detail sectoral exposure and the pace of diversification. The weight of the evidence is clear: for energy-import-dependent developing economies, macro-financial stability and industrial competitiveness are tightly coupled to policies that lower import intensity and raise system flexibility. (Acaravcı, 2015; Önder, 2023; Aki, 2021; Union of Chambers of Turkish Engineers and Architects [MMO], 2024).

4. TÜRKİYE CASE STUDY

Türkiye represents one of the most striking examples of energy dependence in the developing world. Since the early 1980s, the country's economic liberalization and rapid industrialization have generated substantial growth in energy demand, yet domestic resources have remained inadequate to meet this demand. As a result, Türkiye's **net energy import share has persistently exceeded 70%**, with oil and natural gas imports dominating the national energy balance (World Bank). Over time, this dependence has embedded fragility into Türkiye's economic structure, manifesting in repeated current-account imbalances and inflation driven by fluctuations in global energy markets (Aydın & Acar, 2019).

Historical Evolution of Dependence

Türkiye's reliance on imported energy began to deepen after the economic liberalization of the 1980s, a period marked by the shift toward export-oriented industrialization and closer integration with global markets. As manufacturing industries such as cement, steel, and textiles expanded, energy demand—particularly for electricity and fuel—rose sharply (Pamuk, 2014). However, domestic production could not keep pace: lignite, hydroelectric capacity, and limited oil reserves covered only a fraction of national needs. Consequently, successive governments turned increasingly to long-term import agreements and external suppliers to sustain industrial growth.

By the early 2000s, natural gas had become the backbone of electricity generation, with imports from **Russia, Iran, and Azerbaijan** covering more than 90% of consumption (IEA, 2021).

Macroeconomic Implications

The macroeconomic consequences of this structural dependence are visible in Türkiye's persistent current-account deficit. According to **CBRT** data, energy imports have consistently been the largest contributor to external imbalances, accounting for up to **5% of GDP in peak years** (Central Bank of the Republic of Türkiye, 2023). Aydın and Acar (2019), using econometric analysis, show that fossil fuel imports systematically deteriorate the current-account balance, while Gülmez and Yardımcı (2020) highlight that external energy shocks transmit quickly into industrial production costs and consumer price inflation. The **2022 energy crisis**, triggered by Russia's invasion of Ukraine, starkly illustrated this vulnerability: energy import bills exceeded **$100 billion**, pushing the current-account deficit to record highs (TÜİK, 2023).

Industrial Sector Exposure

Energy dependence directly constrains Türkiye's industrial competitiveness. Energy-intensive industries—including cement, steel, ceramics, and chemicals—form the backbone of export capacity, yet their cost structures are highly sensitive to fluctuations in global oil and gas prices (Erdem & Kaya, 2022).

EMRA's 2024 *Electricity Market Report* documented that marginal pricing in the power sector remains closely tied to natural gas, meaning that global gas volatility directly shapes domestic industrial costs (EMRA, 2024). Research by Uysal, Yılmaz, and Taş (2015) further indicates that energy imports and industrial production are cointegrated in the long run, underscoring how dependence locks Türkiye into a structural vulnerability cycle.

Geopolitical Dimensions

Türkiye's heavy reliance on a small number of suppliers compounds its economic fragility with geopolitical risk.

Russia has historically provided more than **40% of Türkiye's gas imports**, granting Moscow considerable leverage (Kibaroğlu & Kibaroğlu, 2019).

Iran and Azerbaijan have also been critical suppliers, though supply has at times been interrupted due to technical or political factors. This dependence was particularly evident during the **2006 and 2009 Russia–Ukraine gas disputes**, which disrupted flows to Türkiye and highlighted the geopolitical fragility of pipeline-based imports (European Commission, 2014). Such vulnerabilities link energy dependence directly to the broader concept of economic security, where external suppliers can influence domestic policy autonomy.

Diversification Efforts

In recent years, Türkiye has pursued diversification to mitigate these risks. The commissioning of the **Trans-Anatolian Natural Gas Pipeline (TANAP)** in 2018 created a new corridor for Caspian gas, while liquefied natural gas (LNG) terminals and floating storage regasification units (FSRUs) expanded flexibility (IEA, 2021). At the same time, Türkiye has invested heavily in renewable energy. According to Ember (2024), wind and solar generation exceeded **60 TWh in 2024**, surpassing domestic coal for the first time. Nuclear development also forms part of this diversification: the Akkuyu Nuclear Power Plant, built in cooperation with Russia's Rosatom, is expected to contribute significantly to baseload capacity (World Nuclear Association, 2023). Despite these efforts, structural vulnerabilities persist. The Ministry of Energy and Natural Resources' 2023–2028 Strategic Plan identifies reducing import dependence as a key priority, but notes that high demand growth continues to offset gains from renewables and efficiency measures (Republic of Türkiye Ministry of Energy and Natural Resources, 2023). Scholars such as Önder (2023) caution that unless diversification is accelerated, energy dependence will continue to constrain Türkiye's external balance and industrial competitiveness.

Türkiye as a Representative Developing Economy

While Türkiye's geographic position and institutional environment are distinctive, its experience is illustrative of broader patterns across developing countries.

Like India, Türkiye has struggled to meet surging energy demand with domestic resources, exposing the economy to global price swings (IEA, 2024). Like Poland, Türkiye has used external pipelines and EU-linked diversification projects to manage risk, but remains vulnerable to supplier concentration and industrial cost shocks (Weiner, 2025). Türkiye's case therefore bridges the gap between middle-income developing economies and EU transition economies, providing valuable insights into the relationship between energy dependence, economic security, and industrial resilience.

5. EMPIRICAL FINDINGS: ECONOMETRIC EVIDENCE FROM TÜRKİYE

This section presents the empirical results of the econometric models outlined in the methodology, focusing on the relationships among energy imports, the current account balance, industrial output, and global energy price shocks in Türkiye between 1980 and 2023. To capture the complex dynamics between energy dependence and economic security, the study combines several complementary econometric techniques. Unit root tests are used to assess data stability, followed by ARDL bounds testing to explore long-run relationships. In addition, VAR impulse–response functions, Granger causality analyses, and structural break tests are applied to trace short-term interactions and identify potential regime shifts over time. Together, these methods provide a comprehensive and empirically grounded picture of the underlying mechanisms.

5.1. Unit Root and Cointegration Tests

The Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests indicate that the series for energy imports and the current account balance are integrated of order one [I(1)], while industrial output is stationary at level in some specifications and at first difference in others. Given this mixed order of integration, the ARDL bounds testing approach was appropriate.

The ARDL bounds test confirms the presence of a long-run cointegration relationship among energy imports, the current account balance, and industrial production (F-statistic = 7.82, above the 5% upper bound critical value). This suggests that Türkiye's external balances and industrial output are structurally tied to energy import dynamics, validating the theoretical expectation of persistent dependence.

5.2. ARDL Long-Run and Short-Run Dynamics

The long-run ARDL estimates reveal that a 1% increase in energy imports is associated with a 0.42% widening of the current account deficit ($p < 0.01$). Industrial output also shows a significant positive elasticity with respect to energy imports, reflecting the country's energy-intensive growth model: a 1% increase in energy imports is linked with a 0.35% increase in industrial output ($p < 0.05$).

In the short run, the error-correction term (ECT) is negative and statistically significant (–0.47, $p < 0.01$), indicating that about 47% of disequilibria are corrected within one year. This demonstrates that shocks to energy imports and the current account are relatively quickly absorbed, though the structural deficit persists.

5.3. Vector Autoregression (VAR) and Impulse-Response Functions

A VAR (2) model was estimated using energy imports, industrial output, and the current account balance. The impulse-response analysis indicates that:

A one-standard-deviation shock to global energy prices leads to an immediate deterioration of the current account balance by approximately 1.2% of GDP, with effects persisting for 6–8 quarters.

The same shock reduces industrial output growth by about 0.8 percentage points within three quarters, before partial recovery.Feedback effects are visible: industrial output shocks influence energy imports positively, as higher output raises import demand, deepening the external imbalance.

These results demonstrate the cyclical vulnerability of Türkiye's economy: energy price shocks both deteriorate the external balance and constrain industrial competitiveness.

5.4. Granger Causality Tests

Granger causality analysis confirms bidirectional causality between energy imports and industrial output, indicating a feedback loop: imports fuel output growth, but output growth in turn increases import dependence. Unidirectional causality is observed from energy imports to the current account balance, consistent with the long-run ARDL results. No significant reverse causality from the current account to energy imports is found, underscoring the exogeneity of energy dependence in shaping macroeconomic imbalances.

5.5. Structural Break Analysis

Zivot-Andrews and Bai-Perron tests identify several significant structural breaks in the relationship between energy imports and macroeconomic indicators:

1994 financial crisis: sharp depreciation increased the cost of energy imports.

2001 banking crisis: external financing constraints amplified energy-related current account pressures.

2008 global financial crisis: collapse in demand temporarily reduced imports but exposed vulnerability upon recovery.

2022 energy crisis: the largest structural break, with natural gas import costs surging to unprecedented levels, accounting for over 40% of total imports (TÜİK, 2023).

The persistence of these breaks suggests that energy dependence amplifies the impact of external shocks, embedding fragility into Türkiye's economic trajectory.

5.6. Robustness Checks

Alternative lag specifications and estimation techniques confirm the robustness of the results. Using Johansen cointegration testing yields similar evidence of long-run relationships, while switching from a VAR to a VECM framework does not alter the substantive conclusions. Heteroskedasticity and serial correlation tests indicate that model residuals are well-behaved, further strengthening the reliability of the findings.

5.7. Synthesis of Findings

The empirical evidence strongly supports the hypothesis that Türkiye's energy dependence is a structural constraint on economic security and industrial competitiveness. The ARDL results confirm that energy imports widen current account deficits in both the short and long run. VAR impulse-response analysis demonstrates the magnitude and persistence of global energy shocks, while Granger causality tests reveal feedback loops that perpetuate dependence. Structural break analysis underscores how external crises repeatedly disrupt Türkiye's macroeconomic stability.

Together, these results validate the central argument of this paper: that energy dependence in developing countries is not simply a matter of energy policy, but a systemic condition that shapes economic security, industrial resilience, and national development strategies.

6. DISCUSSION

The empirical findings presented in the previous section provide important insights into the structural relationship between energy dependence and economic security in Türkiye, and they also resonate with broader debates concerning developing countries.

This discussion situates the Turkish case within the wider literature on dependency theory, energy security, and economic resilience, while highlighting both the unique and generalizable dimensions of Türkiye's experience.

Linking Empirical Evidence to the Literature

The results confirm earlier arguments in the dependency literature, which emphasized how peripheral economies become structurally tied to external sources of capital and resources (Cardoso & Faletto, 1979). Türkiye's reliance on imported fossil fuels illustrates such dependence in a contemporary setting, where integration into global markets has locked the country into patterns of vulnerability.

The ARDL results demonstrating that energy imports systematically widen the current account deficit echo findings by Aydın and Acar (2019), while the bidirectional causality between energy imports and industrial output aligns with Erdem and Kaya's (2022) observation that Turkish industry remains energy-intensive and cost-sensitive.

These findings are consistent with a broader body of international research indicating that heavy reliance on imported energy tends to weaken macroeconomic stability in developing countries. Bhattacharyya (2011), for example, observed that oil-importing economies in the developing world are particularly exposed to the destabilizing effects of price volatility—an observation that aligns closely with the impulse–response results obtained for Türkiye. Comparable patterns have also been documented in Eastern Europe. In Poland, before its accession to the European Union, excessive dependence on Russian gas was shown to magnify exposure to external shocks and limit policy flexibility (Weiner, 2025).

Comparative Perspective: Developing Countries

When compared with other developing economies, Türkiye's experience reflects both commonalities and distinctions. Like India, Türkiye has faced surging demand due to rapid industrialization and urbanization, but limited domestic resources have prevented self-sufficiency (IEA, 2024). Both countries exhibit structural current-account imbalances driven by energy imports, though India has partially offset this through diversification into coal and renewables. Poland, meanwhile, provides a transitional case: as a middle-income economy, it reduced dependence on Russian gas through EU-backed diversification and renewable policies, but structural vulnerabilities remain.

The comparative analysis underscores that developing countries often confront a **"double trap"**: energy dependence deepens external imbalances, while industrial policies reliant on affordable energy are constrained by price volatility. This double trap is particularly pronounced in countries lacking fiscal buffers or large foreign reserves, as is the case in Türkiye.

Economic Security and Structural Vulnerability

The discussion of economic security expands beyond conventional military or geopolitical dimensions to encompass systemic vulnerabilities rooted in resource dependence (Nesadurai, 2006). The Granger causality findings demonstrate that energy dependence is not simply an outcome of growth but a driver of fragility, shaping the trajectory of macroeconomic and industrial performance. This resonates with the conceptualization of economic security advanced by Buzan (1991), where security is multi-dimensional and includes the ability of states to withstand external economic shocks.

Türkiye's dependence also illustrates the geo-economic dimension of energy security. Its reliance on Russia for more than 40% of natural gas imports exposes the country to external leverage, echoing the European Union's broader challenges in the 2006 and 2009 Russia–Ukraine gas disputes (European Commission, 2014). This highlights how energy dependence blurs the line between economic and national security, particularly in developing contexts where external diversification options are limited.

Policy Implications

The findings have important implications for policy. First, the ARDL and VAR results emphasize that reducing dependence is not merely a matter of economic efficiency but a necessity for macroeconomic stability. As the Ministry of Energy and Natural Resources (2023) notes, diversification remains a strategic priority, but rapid demand growth continues to offset gains from renewables. Second, the comparative perspective suggests that Türkiye can draw lessons from other developing countries. India's accelerated adoption of solar power demonstrates the potential of renewables to reduce vulnerability, though it requires substantial investment and institutional capacity (World Bank, 2022).

Poland's EU-backed diversification through LNG and regional pipeline projects offers another model, underscoring the importance of international cooperation.

Third, the findings call for integrating energy efficiency into industrial policy. As Erdem and Kaya (2022) argue, competitiveness in Turkish industry will remain constrained until structural reforms reduce energy intensity.

In this regard, efficiency improvements and technology upgrades may prove as important as diversification in addressing the double trap.

Finally, the geopolitical dimension requires balancing supplier relationships while deepening regional and global cooperation.

The Trans-Anatolian Natural Gas Pipeline (TANAP) and expanded LNG infrastructure provide some insulation, but the Akkuyu nuclear project—developed in partnership with Russia—also creates new dependencies, raising concerns about substituting one form of dependence for another (World Nuclear Association, 2023).

Contribution to the Literature

This study contributes to the literature in three key ways. First, it empirically demonstrates the link between energy dependence and economic security in a developing country, thereby expanding the scope of energy security research beyond technical supply-demand dynamics. Second, it situates Türkiye's experience in comparative perspective, bridging insights from dependency theory with contemporary debates on geo-economics. Third, it highlights the policy relevance of these findings, showing that sustainable development in energy-dependent economies requires structural reforms, not just incremental diversification.

7. COMPARATIVE INSIGHTS: INDIA AND POLAND

India: India's rapid industrial growth and urbanization have generated unprecedented energy demand, much of which is met by imported fossil fuels. According to the Central Electricity Authority's *National Electricity Plan 2023* (CEA, 2023), coal will remain central to ensuring supply reliability through 2030, but solar and wind are expected to grow rapidly. Petroleum Planning and Analysis Cell (PPAC, 2025) data show that crude oil import dependence exceeds 85%, exposing the economy to price volatility and balance-of-payments pressures. The International Energy Agency (IEA, 2020) highlights India as a "net importer of energy" with an acute security–decarbonization dilemma. This reflects a similar structural vulnerability as Türkiye, though India's domestic coal reserves partially cushion industrial production from global fuel price shocks (CEA, 2023; PPAC, 2025; IEA, 2020).

Poland: Poland's *Energy Policy until 2040 (PEP2040)*, updated in 2023, aims to reduce coal dependence while ensuring security of supply through diversification, LNG infrastructure, and renewable expansion (Polish Ministry of Climate and Environment, 2021/2023). The International Monetary Fund (IMF, 2023) stresses that energy security is the highest policy priority in

Poland, particularly after the disruption of Russian gas supplies. Statistics Poland (GUS, 2024) confirms that while coal remained dominant in 2023, renewable generation, particularly photovoltaic, is rising sharply. The IEA (2024) policy database documents how LNG imports and the Baltic Pipe project reduced reliance on Russian gas, strengthening resilience. Poland's experience highlights the centrality of EU frameworks, market liberalization, and regional interconnection in enhancing security (Gov.pl, 2021/2023; IMF, 2023; GUS, 2024; IEA, 2024).

Cross-Lessons: Both India and Poland show that while structural dependence on imported fuels remains a constraint, diversification, renewables, and infrastructure modernization are crucial strategies. For Türkiye, India underscores the risks of high oil import exposure, while Poland highlights the benefits of EU-supported diversification and renewable integration. Together, these cases reinforce that developing economies can only reduce vulnerabilities through a combination of diversification, demand-side efficiency, and long-term transition policies.

8. POLICY RECOMMENDATIONS

Macroeconomic Stabilization and Risk Management: Türkiye should strengthen foreign exchange buffers and adopt transparent risk-hedging mechanisms for state-owned energy companies, similar to European practices during the 2022 crisis (European Commission, 2024).

Diversification of Supply Sources and Routes: Expanding LNG capacity, including floating storage and regasification units (FSRUs), and enlarging underground storage facilities can reduce exposure to single suppliers. The EU's REPowerEU initiative provides a relevant benchmark (Consilium, 2024; European Commission, 2025).

Demand-Side Efficiency and Industrial Competitiveness: The Ministry of Energy and Natural Resources' *Energy Efficiency Strategy and Action Plan 2024–2030* outlines sector-specific savings and demand flexibility targets (MENR, 2024). Aligning with these goals can reduce import dependence and enhance competitiveness.

Renewables, Storage, and Grid Modernization: Türkiye's YEKA tenders have rapidly expanded wind and solar capacity, but sustained growth requires simultaneous investment in transmission networks and storage to ensure system flexibility (Ember, 2025; PV-Tech, 2025).

Carbon Border Adjustment Mechanism (CBAM) Readiness: As CBAM phases in by 2026, Türkiye's energy-intensive industries must adopt robust monitoring and reporting systems, while exploring green power purchase agreements to maintain EU market access (European Commission, 2025; Trade.gov, 2024).

Regional Cooperation: Strengthening interconnections with Southeast Europe for electricity and natural gas, and expanding participation in balancing markets, can enhance resilience, as demonstrated in EU crisis coordination (Eurostat, 2025).

Financing the Transition: Scaling up green bonds and blended finance mechanisms with multilateral banks will be essential to fund renewable deployment and efficiency measures, drawing lessons from India's experience (NITI Aayog, 2023).

CONCLUSION

This research set out to explore how dependence on external energy sources shapes economic security in developing countries, focusing on Türkiye as a representative case. The analysis revealed that heavy reliance on imported fuels consistently deepens current account imbalances, raises production costs, and limits industrial competitiveness.

The econometric findings support what theory has long suggested: when energy imports dominate national consumption, economies become more vulnerable to both price volatility and geopolitical disruptions. Framed within the perspectives of dependency theory and modern energy security literature, these results affirm that energy dependence is not merely a question of supply or technology—it is a structural component of national economic stability.

Comparing Türkiye's experience with those of India and Poland brings further clarity to the global picture. India's persistent oil import reliance demonstrates the risks of exposure to international market fluctuations, while Poland's diversification through EU-led energy transition policies shows how institutional frameworks and renewable expansion can mitigate such vulnerabilities. Taken together, these comparisons underline that the challenge faced by Türkiye is neither unique nor temporary; it reflects a broader dilemma shared across the Global South—how to sustain industrial growth without amplifying external energy risks.

From a policy perspective, several priorities emerge. Reducing dependence through diversification of suppliers and energy types remains essential. Expanding renewable generation and storage capacity, improving energy efficiency in key industrial sectors, and preparing domestic industries for compliance with the EU's Carbon Border Adjustment Mechanism (CBAM) are equally urgent. Beyond these technical measures, long-term economic resilience will depend on fostering regional cooperation and innovative financing tools that can sustain large-scale transition investments.

The findings also open new avenues for future research. More granular studies focusing on energy-intensive industries could shed light on firm-level vulnerabilities. Likewise, examining how storage technologies and flexible demand management influence macroeconomic stability would deepen understanding of the energy–security nexus in developing economies.

Finally, this paper contributes to the academic literature in several important ways. It provides empirical evidence for the long-assumed link between energy dependence and economic security in a developing-country setting—an association rarely tested with systematic data.

It also broadens the scope of energy security research by embedding macroeconomic fragility and industrial performance within the same analytical frame, moving beyond a narrow focus on supply security. Moreover, by placing Türkiye alongside India and Poland, the study demonstrates that energy dependence should be viewed not as an isolated national problem but as part of a wider structural condition that constrains development. In this sense, it extends both dependency theory and energy security scholarship, illustrating how long-term reliance on external resources continues to shape the developmental trajectories of modern economies.

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CHAPTER 2
ENERGY & SUSTAINABILITY IN DEVELOPING COUNTRIES: INDIA WITH J & K PERSPECTIVE

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INTRODUCTION

The availability of clean, affordable, and reliable energy is a foundation for sustainable development in developing countries, addressing challenges of energy security, climate change, and promoting economic growth, social inclusion, and environmental protection. The word energy derives from the Greek word energeia, which means "activity" or "operation." The concept of energy could even go back as far as 400 BCE, when Aristotle used the word as a mode to refer to the being in action. The modern scientific understanding didn't begin to take shape until the early 19th century, after Thomas Young employed the term to describe the capacity to perform work. Today, energy is understood to be the lifeblood of modern life and is pushing economic development, social change, and technological innovation. Access to affordable, reliable, and sustainable energy is essential to national development and for the lighting of our homes, industries, transportation, schools, and hospitals. Without it, critical services break down, economies stagnate, and development goals continue to slip out of reach.

Energy security defined as the uninterrupted availability of energy sources at an affordable price, in the quantity required, and to the quality of life desired - is critical to economic growth and to individual and societal well-being. In countries such as India, energy has served as the underpinning of endeavors to move from subsistence economies to modern industrializing societies. Energy consumption has obvious and linear correlations with living standards and per capita incomes, and throughout history, the growth and prosperity of the industrialized world has been largely due to high levels of energy use, while poor access in nations has limited development and social advancement. Nevertheless, economic growth in and of itself is no longer enough. The 21st-century development paradigm focuses on sustainable development, which is development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland, 1987). To achieve this, there has to be a trade-off between economic expansion, social inclusion and ecological sustainability. Poor countries have a special set of problems: selecting growth over sustainability may worsen pollution, deforestation, and inequality (Batool et al., 2022; World Bank Group, 2012).

Structural barriers such as poor governance, uncoordinated policy and poor green finance, add to the complexity of transitioning towards inclusive, sustainable growth (Desalegn and Tangl, 2022). The Sustainable Development Goals (SDGs) are part of the general perspective of the whole world. Although SDG 7 primarily focus on ensuring that everyone has access to energy that is affordable, reliable, sustainable, and modern, energy is also intimately connected to SDG 1 (No Poverty), SDG 3 (Good Health and Well-being), SDG 4 (Quality Education), SDG 6 (Clean Water and Sanitation), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action). The decision of countries to go for clean energy reduces pollution, runs essential services, ensures the adoption of sustainability in society, and encourages the equal distribution of resources. However, the progress is patchy: millions are still without both electrification and the free choice of clean cooking, and climate finance is not as much as is needed.

For developing countries, achieving SDG 7 and associated goals is crucial not only to reducing climate threats but also to enhancing health, education, water supply, livelihoods, and economic opportunity. Inclusive green growth, linking economic development with social equity and environmental conservation, is a must. It involves effective institutions, enabling governance, innovative financing, and locally appropriate solutions (UNEP, 2022). India's energy transition shows this equilibrium. Being a vast and burgeoning economy, India's energy decisions have international resonance (Moody's ANI, 2024). Although coal continues to provide around 70–75% of electricity, non-fossil capacity has risen to more than 45%, led by solar (92 GW), wind (48 GW), and hydropower. Large-scale initiatives like the Gujarat Hybrid Renewable Energy Park, renewable targets at the state level, and increasing green bond markets indicate attempts at supply diversification, import reduction, and job creation. Challenges remain, however: financial strain in Distribution Companies (DISCOMs), coal-fired plant additions, policy uncertainty, and dependence on imported minerals for renewables.

Jammu and Kashmir (J&K) stands out as a compelling regional example of India’s clean energy transition, endowed with vast but largely untapped renewable energy potential across the hydro, solar, wind, and biomass sectors.

However, the region isn't without its challenges. The rugged terrain, issues with transmission, land availability, and political complexities have all hindered progress. During the winter months, when power generation dips, J&K often faces power shortages and has to rely more on electricity imports. To tackle these hurdles, the government is implementing reforms—revamping hydropower policies, promoting decentralized renewable solutions, investing in advanced storage technology, and upgrading the grid to enhance energy security and sustainability.

J&K's situation highlights a broader issue faced by many resource-rich areas: having abundant natural resources doesn't guarantee sustainable or inclusive energy development. Addressing these challenges will be vital for India to meet its national energy goals and fulfill its international climate commitments.

1. ENERGY CHALLENGES IN DEVELOPING COUNTRIES

Developing countries are particularly confronted with the challenge of accessing reliable, affordable, and sustainable energy. Even though there has been growth in increasing energy access, hundreds of millions of individuals do not have electricity, and nearly three billion continue to use traditional biomass like wood, charcoal, and animal dung for cooking and heating (IEA, 2022). This reliance focuses families, especially women and children, on hazardous indoor air pollution levels, leading to millions of avoidable deaths annually (WHO, 2024). Energy poverty not only damages health but also restricts economic productivity, education, and overall quality of life, exacerbating underlying social and gender inequalities. The energy systems in many developing countries are characterized by over-dependence on fossil fuels. While fossil fuels provide short-term energy security, they generate harmful emissions, drive local air pollution, and contribute to climate change. Furthermore, volatility in global fuel markets exposes these economies to price shocks, draining foreign exchange reserves and increasing economic vulnerability. The reliance on fossil fuels also conflicts with global climate commitments and sustainable development objectives.

The development of energy systems faces additional obstacles because of infrastructure constraints.

Many nations operate older power systems which demonstrate unreliable performance while failing to meet expanding energy requirements. The process of expanding power grids to distant rural regions continues to be both expensive and slow, which prevents numerous populations from obtaining current energy services. The high initial expenses of renewable power systems together with institutional weaknesses and uncertain policies prevent private investors from entering the market. The implementation of fossil fuel subsidies creates market distortions which hinder clean energy adoption (World Bank, 2023). The combination of expensive financing options and high-risk assessments prevents households and businesses along with governments from making sustainable energy investments. Social and cultural factors also play a role. Behavioral patterns, low awareness of new technologies, and resistance to change can slow the uptake of cleaner energy options. Women experience increased difficulties because they experience energy poverty most intensely, yet they lack sufficient influence in making energy-related decisions and selecting technologies. Universal sustainable energy access will remain unreachable unless we resolve the combined technical challenges together with economic barriers and social obstacles.

2. SUSTAINABLE ENERGY OPPORTUNITIES AND SOLUTIONS

Developing nations face various obstacles, yet they possess significant possibilities to establish energy systems which are cleaner and more durable and inclusive. The transformation depends primarily on renewable energy technologies. Large-scale and micro-hydropower systems deliver consistent electricity supply while maintaining grid stability and supporting rural electrification in remote mountainous regions. The developing world finds solar power to be a flexible and affordable energy source because technology expenses are falling while solar resources exist throughout most of the region. Off-grid and weak-grid areas benefit from solar mini-grids and rooftop systems that increase energy security and drive economic activity and hybrid systems which combine solar with diesel, batteries or wind provide improved reliability (IEA Africa Energy Outlook, 2022). Wind energy has additional benefits for coastal and highland areas because it works best when combined with solar to minimize power fluctuations.

The use of modern biomass and biogas technologies together with agricultural residues and organic waste supplies clean cooking and heating energy while supporting rural development and minimizing environmental harm. The energy sector benefits from geothermal power generation because it produces stable base-load power that diversifies the overall power supply (UNEP, 2022).

The promotion of energy efficiency is a second key element of sustainable development. Energy-saving equipment, lighting, building materials and industrial equipment reduce energy demand and conserve resources as well as lower emissions. Demand-side management measures, such as load shifting, time of utilization tariffs, and demand response initiatives, facilitate better coordination of energy demand with renewable supply and support in relieving pressure on the grid (IEA, 2020). Replacement of incandescents with LEDs and load management programs for industry have already demonstrated material savings and grid stability in a country like India.

Technological innovation and decentralized energy technologies are revolutionizing the energy sector. Pay-as-you-go (PAYG or PAYGO) solar, smart meters, mobile phone payment technology, and affordable battery storage have brought significant electricity to millions of people for the first time in sub-Saharan Africa and South Asia (World Bank, 2023). Decentralized solutions provide energy autonomy, reduce reliance on costly grid extensions, and guarantee local control over energy infrastructure.

Even so, relying solely on technology is insufficient. For sustainable energy to be scaled up, an appropriate policy framework and innovative financial mechanisms have to be in place. Policy initiatives such as feed-in tariffs meant to provide long-term, stable returns and reduce investor risk have been remarkably successful at attracting private investment in renewables by establishing consistent market signals and fast-tracking technological progress (Barry, 2016). Facilities that weave together public and private finance with concessional finance and risk transfer instruments work across capital barriers to make renewable energy transactions `bankable' (World Bank, 2023; IEA G20 Brazil, 2024).

Ending subsidies for fossil fuels and carbon and other forms of carbon pricing will level the playing field for clean technologies (Thomson, 2023).

Using renewable technology, energy efficiency, finance, and participation, developing countries can turn energy challenges around and also use them as opportunities for the resilience of the climate, for poverty reduction through sustainable development.

3. INDIA'S ENERGY LANDSCAPE AND SUSTAINABLE DEVELOPMENT PATHWAYS

India has arrived at a cross-section of its energy growth trajectory. Given that it is a fast-growing developing nation set to become the third-largest economy in the world by 2030, India has its task cut out of serving rising energy demand responsibly. It is only by reconciling economic development, energy security and environmental responsibility that our common future will be one of prosperity and resilience.

The demand for energy in India has grown quickly in the past decade, led by industrialization, urbanization and improved standards of living. With a population in excess of 1.4 billion and GDP growth of around 8%, the demand for high-quality, accessible energy is at an all-time high. India is now the world's third-largest energy consumer after China and the United States.

Coal, which supplies about 70 to 75 percent of electricity needs in the country and is a major source of industrial energy, continues to dominate the country's energy mix. The transport sector is still mostly run on oil, with a smattering of natural gas that has been slowly growing. But India is also experiencing a slow, yet steady, transformation in its energy profile. Non-fossil sources of energy such as solar, wind, hydro, nuclear and traditional biomass have become significant contributors. Solar power, in particular, has become a linchpin behind this evolution, as experts predict it will overtake coal to represent more than 30 percent of the world's electricity generation by 2040.

India has set itself ambitious targets for clean energy expansion, to meet domestic demands and international climate commitments. The country expects to reach 500 GW of non-fossil energy capacity by 2030, meeting 50% of its energy needs from non-fossil fuel-based energy resources (Government of India, Ministry of Power,2023). In its Nationally Determined Contributions to the Paris Agreement, India has committed to reducing the emissions' intensity of its gross domestic product (GDP) by 45% over 2005 levels by 2030, and to reach net-zero emissions by 2070 (UNFCCC,2022).

These commitments are supported by substantial undertakings to drive rapid deployment of renewables, reinforce the grid, and promote green hydrogen and solar manufacturing at home. But as laudable as India's actions are, some global assessments argue that a greater emissions reduction will be needed globally to align with the 1.5°C target compared to what India is doing (Climate Action Tracker,2025).

To facilitate its transition, India has introduced a suite of policies to improve their access to energy, to increase energy efficiency, and accelerate the adoption of clean energy. Schemes like the Saubhagya scheme (Pradhan Mantri Sahaj Bijli Har Ghar Yojana) and the Pradhan Mantri Ujjwala Yojana have brought electricity connections and clean cooking fuel access to tens of millions, lifting living standards and public health. Energy-efficient programmes such as UJALA and the Perform, Achieve, Trade scheme led to dramatic energy and emission savings. These competitive auctions for solar and wind projects have helped to dramatically lower costs, leading to the quick addition of capacity at record-low tariffs. Financial products, such as green bonds and blended finance models, have enabled both domestic and international capital mobilization to support the up-scaling of clean energy investment.

Despite this evolution, India's energy transition requires resilience and sustained effort. Its electricity system, which is designed for conventional power, has limited capacity to accommodate them at scale. Transmission constraints, grid instability and distribution losses continue to make matters worse and the shift presents painful social trade-offs. Rather than the provision of a just-transition framework across the decarbonization pathway, the employment and lives of millions of workers and workers' communities attached to the fossil fuel industry are under threat. Financing this shift also represents a significant challenge: large – scale renewable energy initiatives are capital-intensive, but regulatory ambiguity and market risk can scare away private investors.

But there are also institutional and governance deficiencies, which reform can take longer to reach the ground, due to lack of integrated governance and policy lags. To overcome these obstacles, it will be necessary to take action in a coordinated and sustained manner.

Key priorities are to modernize grid infrastructure, expand the use of storage technology, integrate climate considerations within the framework of national development planning, build stronger safety nets for impacted communities, and secure more private-sector finance through risk mitigation. India's experience is indicative of the broader struggles and opportunities that developing nations face in working toward a low-carbon future even as they strive to address urgent development needs. And what it has learned along the way could provide valuable lessons to other countries struggling to manage the fraught journey to a sustainable energy future.

4. REGIONAL FOCUS: JAMMU AND KASHMIR

Jammu and Kashmir (J&K), often celebrated for its natural beauty, is also rich in renewable energy potential. Yet, in addition to this tremendous potential, the region is confronted with a complex array of challenges, from extreme topography and infrastructure requirements to watershed impacts, creating an energy transition that's as promising as it is convoluted. As India moves toward a greener energy future, Jammu &Kashmir's role is becoming increasingly important, offering lessons on how national goals can be aligned with regional realities.

Among the most promising resources in J&K is hydropower. Due to these unique, glacial-fed rivers and high mountainous terrain, the state has the potential for about 18,000 to 20,000 megawatts (MW) of hydropower (CEA 2010–11). Of this, the Central Electricity Authority has recently assured that almost 16,475 MW is technically feasible (CEA, 2021). Unfortunately, by and large, very little of that has come to pass. A little over 3,210 MW of that has been developed. This lagging progress is largely attributable to a host of daunting challenges like exacerbating upfront capital costs, seasonal river flows, environmental impacts, and elevated costs to remote project sites.

Jammu and Kashmir (J&K) is brimming with renewable energy potential, particularly when it comes to hydropower. Estimates indicate that the region could produce around 20,000 megawatts of hydropower, but so far, only about 3,540 megawatts have been harnessed. Exciting new projects like Kiru, Ratle, Kwar, and Pakal Dul are set to add another 3,000 to 4,500 megawatts over the next ten years.

Jammu and Kashmir is set to announce a new hydropower policy soon to exploit its potential fully, to become energy-self-sufficient first and then a net power exporter by 2027-28. The policy focuses on attracting private investment, modernizing energy infrastructure, and reducing high Aggregate Technical and Commercial (AT&C) losses to ensure reliable and affordable 24/7 electricity for all households (Economic Times, 2025).

The abrogation of Article 370 in 2019 has played a catalytic role in transforming the region's renewable energy landscape by easing land acquisition processes, encouraging private sector participation, and accelerating central government involvement. Some of the early-looking indicators of this success include the rapid announcement of numerous MOUs with private sector firms, accelerated clearances and project acceleration of hydropower development, and speeding implementation of flagship projects such as Ratle, Kiru, Dulhasti II, Kwar. It has also enabled the implementation of schemes like the Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (KUSUM) Scheme, improved infrastructure through better road, rail, and power connectivity, and fostered economic growth by creating new job opportunities (Bhat, 2025).

But J&K's renewable energy story doesn't end with water. This region represents a significant solar resource, with its abundant sunny and hot summer days providing considerable potential for solar energy development. Even just the available rooftop solar potential is estimated at 111 GWp. Rooftop systems and off-grid smaller-scale distributed panels are becoming increasingly important in many of these taller or more distant, often isolated mountainous communities where electric grid connectivity is patchy or absent. Additionally, through the PM Surya Ghar–Muft Bijli Yojana, over 222,000 public buildings are being installed with rooftop solar to not only cut the consumption of fossil fuels but expand consistent electricity access (Economic Times, 2025).

The Ministry of New and Renewable Energy (MNRE), in association with the National Institute of Wind Energy (NIWE), has identified wind energy sites in Jammu which, although have a lower wind power potential compared to India's coastal states. The UT also has significant wind energy potential, with an installable capacity of 5,311 MW at 50 metres height and 5,685 MW at 80 metres height (Department of Science & Technology, Government of Jammu and Kashmir, 2023).

In remote villages that remain unconnected to the central power grid, small wind-solar hybrid systems are increasingly being implemented to provide reliable and sustainable electricity.

Jammu and Kashmir ranks second only to Rajasthan, for example, in national-level natural solar energy generation potential, about 7.6% of India's total renewable energy potential (Hassan, 2023). It underscores its historic reliance on water for electricity, as more than 80% of its electricity generation today is from hydroelectricity (Parva, 2023).

A second, more insidious source is biomass energy. The region currently produces an estimated 1,198 kilotonnes of biomass annually, mainly from agricultural and forest residues, enough to power 43 MW of electric capacity. Yet even less than 5% has been fully utilized so far (World Bank, 2023). Challenges such as fragile supply chains, absence of market linkages, absence of price formation and minimal investor appetite have stifled its growth. Biomass would produce more local jobs than any other renewable, displace the bulk of their diesel, and deliver off-grid electricity to remote rural constituencies such as Doda, Kathua, Anantnag, and Baramulla.

In other districts such as Poonch and Reasi, citizen-managed village energy committees are already operating community-scale biomass pellet plants to produce cleaner energy for the neighboring villages, exemplifying a better model that pairs greater local engagement with cleaner, more efficient energy production. Scaling up this model is one of the most effective ways to address these twin challenges of reducing waste while gaining energy access at the same time.

Support from major research institutions has been equally important. The Jammu and Kashmir Energy Development Agency (JKREDA) is already promoting decentralized energy projects through national subsidies and JKREDA public beneficiary awareness campaigns.

Joint collaborations with other institutions such as the World Bank, UNDP, and IREDA, as well as the Renewable Energy and Energy Efficiency Partnership (REEEP), have only bolstered the region's capabilities to finance, plan, and implement clean energy projects (World Bank, 2023).

Even with all of this amazing innovation and development, access to financing is still one of the biggest barriers to entry.

Even with guarantees from government financing or multilateral development banks, the vast majority of commercial banks remain unwilling to finance energy deals in the region because of the risk – political and operational – that they see.

Agencies such as IREDA have filled this gap, providing long-term, low-interest loans that are better matched to the needs of small- and medium-scale projects. Joint ventures with national players such as those with the National Hydroelectric Power Corporation (NHPC), Jammu and Kashmir State Power Development Corporation (JKSPDC), and Power Trading Corporation of India (PTC India) are becoming more prevalent, particularly through blended finance models that lower risk and increase bankability (Press Information Bureau, 2022).Smart metering, digital billing, and aerial-bunched cabling are now credited with having reduced under-recovery in the power sector from ₹65.52 billion in FY 2022–23 to ₹52.44 billion in FY 2023–24, with a further ₹42.00 billion foreseen as a target for the year after next.

As J&K steps up its contribution to the National Mission on Sustainable Habitat, the gap between potential and performance becomes increasingly clear. The region's resource wealth vs. infrastructure poverty, a contradiction that requires us, for the first time, to begin investing in our priorities with far greater detail and targeted intent community engagement that's essential to achieving those investments. With a well-planned and inclusive approach, Jammu and Kashmir has the opportunity to lead not just in delivering sufficient, reliable, affordable electricity for its people, but the rest of India, on an inclusive, resilient, and low-carbon energy trajectory.

5. INTEGRATION OF ENERGY, DEVELOPMENT, AND CLIMATE GOALS

Energy access, economic development, and environmental sustainability are deeply linked. In Jammu and Kashmir (J&K), inconsistent electricity supply has a significant impact on crucial services like healthcare, education, and agriculture, especially in the more remote and higher-altitude regions. Improving our renewable energy infrastructure can gain a host of benefits: cutting down on diesel usage, reducing carbon emissions, creating jobs, and fostering inclusive local development (World Bank, 2023).

The Government of India actively articulated the concerns and developmental priorities of developing countries at the 26th session of the Conference of Parties (COP26) to the United Nations Framework Convention on Climate Change (UNFCCC) held in Glasgow, United Kingdom from 31 October to 12 November 2021. The five-fold strategy to fight climate change, termed Panchamrit, the country intends to reach 500 gigawatts (GW) of non-fossil energy capacity by 2030. India has committed to fulfilling 50 percent of its energy needs from renewables by that year.

Recognizing that halting climate change will take collective will and action, the country has vowed to decrease its overall expected carbon emissions by one billion tonnes between now and 2030. India has pledged to decrease the carbon intensity of its economy by 45 percent from 2005 levels by 2030. Further out, the country has committed to reaching net-zero carbon emissions by 2070. These ambitious goals underscore India's serious dedication to both sustainable development and global climate action, all while safeguarding energy security and economic resilience (Press Information Bureau [PIB], 2022). Jammu and Kashmir is making a significant move towards clean energy, aligning perfectly with India's Nationally Determined Contributions (NDCs) outlined in the Paris Agreement.

These objectives aim to cut down emissions in relation to GDP while boosting energy capacity without depending on fossil fuels. Additionally, the region is embracing wider initiatives, such as the United Nations Sustainable Development Goals (SDGs) and the commitments made by India's Panchamrit during the 26th Conference of Parties (COP26). For Jammu and Kashmir, reducing energy gaps while creating green employment opportunities, increasing resilience and promoting environmental care will be crucial towards achieving progress on the interlinked aims of development, equity and climate action.

6. FUTURE DIRECTIONS AND POLICY RECOMMENDATIONS

The renewable energy sector in Jammu and Kashmir (J&K) stands at a critical juncture. Read even as states and utilities have tapped just a small fraction of the abundant opportunities in hydro-power, solar, biomass and small-scale wind resources, entrenched challenges—infrastructural deficiencies, financial barriers, environmental concerns and institutional roadblocks—have time and again clogged progress. At the same time, accelerating the clean energy transition in J&K is vital not only for addressing local energy poverty but also for advancing India's broader development and climate goals**.** These recommendations aim to clarify how we can all move forward in an equitable, green way that aligns with climate goals set both across the country and around the world.

- **Strengthen Infrastructure and Technology Deployment:** Upgrading basic infrastructure—such as transmission lines, substations, and rural road connectivity—is essential for improving energy access in remote regions of Jammu and Kashmir (J&K). Focusing on more decentralized systems like off-grid solar, micro-hydropower and mini-grids would not only help overcome these time and distance hurdles, creating greater equity and access to the energy transition, but create greater climate resilience by decentralizing our energy systems to be better suited to withstand more climate-related disruptions.
- **Enhance Financial and Institutional Support Mechanisms:** Expanding access to affordable financing through agencies such as the Indian Renewable Energy Development Agency (IREDA) and encouraging new financial models such as performance-based incentives and viability gap funding will continue to unlock private investment.
  Strengthening institutions such as the Jammu & Kashmir Energy Development Agency (JKEDA) ensures better coordination, transparency, and technical support for renewable energy deployment at the local level.
- **Promote Community Engagement and Capacity Building:** With the necessary knowledge in place, meaningful engagement with communities can become a mutually beneficial process.
  From planning and permitting, to construction and operation, there are innumerable opportunities for renewable energy development decisions to more closely align with a community's priorities and needs.
  Collaborative efforts that ensure local priorities guide renewable energy expansion can contribute to lasting and sustainable outcomes. Enhancing new skill development for the domestic workforce, especially for women and young people, through technical and vocational education and

training and creating economic opportunities at the community level through decentralized energy service delivery are two of the top priorities.

- **Encourage Multi-level Governance and International Cooperation:** This will need focused and effective collaboration among the central ministries, the state governments and the local governments to dovetail energy planning with the larger development agenda. Collaborating with international partners and climate funds can bring in best practices, technical expertise, and additional financing to scale up renewable energy efforts in J&K.
- **Explore Innovative Approaches:** Embracing new green finance instruments like green bonds and blended finance models will help tap new pools of sustainable investments. Wider applications of digital technologies, including through smart meters, remote monitoring and predictive maintenance, represent clear opportunities for improving operational efficiency, and as we've seen with smart grid installation, these investments will better match supply from increasing renewables with a rising demand.

CONCLUSION

The renewable energy transition in developing countries comes with its own set of complex challenges and real possibilities. Yet enduring barriers, infrastructure deficits, funding gaps, socio-political intricacies, and geographic isolation still hold back advancement. These challenges simultaneously create opportunities for creativity, homegrown business activity and policy change, especially in states rich with renewable energy potential.

Overcomes these barriers effectively, a deeper, community-centered, culturally-rooted approach is essential. Energy solutions can't be simply transplanted; they must emerge from the local topography/climatic conditions/institutions/social structures and shaped through their genuinely participatory development processes. Community-directed and community governed with all impacted stakeholders at the decision-making table through inclusive policymaking processes.

Community-driven, community smart financing are all really indispensable ingredients to these collaborations across sectors that will make all this possible and truly transformative change necessary. Unfortunately, a one-size-fits-all model will be insufficient to reach the scale of positive impact that's desperately needed.

India, and even more so the Union Territory of Jammu and Kashmir, has been an extraordinarily illustrative real-world laboratory in this larger energy-development-climate trifecta. While J&K possesses immense renewable energy potential, especially in hydropower, solar, and biomass, it continues to grapple with infrastructural deficits, environmental sensitivities, and socio-political complexities. With sustained federal IVY capitol support, infrastructure hardening, decentralized generation expansion, sustained local legislative engagement, and a little good luck, the region can fully achieve educating the qualified talent to export and power the clean, resilient, equitable energy transition here and everywhere that's coming at lightning speed.

Transforming this exciting vision into a new reality will require extremely well-coordinated and strategic action. This means accelerating the rehabilitation and retrofitting of existing infrastructure, deploying more renewable, decentralized solutions at a far greater scale, wider access to affordable financing, building local capacities, strengthening multi-level governance and international partnership. These moves would meaningfully help empower Jammu and Kashmir to sustainably meet its own energy needs, while positioning it to be a shining example for other states and territories that are charting the course of balancing energy access, development needs, with net-zero climate commitments.

Looking ahead, the future we all want must be equitable, opportunity universally afforded to all and sustainable with a vibrant and prosperous future by renewable technologies fueling not just our homes and industries but an invigorated dedication to people and the planet.

By ensuring that energy inclusion supports broader development priorities and climate mitigation objectives, nations and sub-national regions, including Jammu and Kashmir, can emerge as leaders of a just, inclusive, ambient, clean, green-energizing energy transition, contributing to the national and global march toward sustainable development.

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CHAPTER 3
THE ENERGY-DEVELOPMENT NEXUS IN NIGERIA: CHALLENGES AND OPPORTUNITIES

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INTRODUCTION

The significance of Nigeria to Africa, as the most populous country and the largest economy, cannot be overemphasised, especially amidst the development challenges that are intricately linked to the energy sector of the country (Nwozor et al., 2021). Despite being enormously endowed with mineral resources, especially vast oil and gas, the energy landscape of the country is characterised by a paradox due to its citizens' struggle to have access to sustainable and reliable energy with a far-reaching implication on efforts on human development, economic growth and poverty reduction (Idris et al., 2020). The International Energy Agency (IEA) (2022) reported that only 55 per cent of the Nigerian population have access to electricity, and that is one of the lowest access rates in the world (Banso et al., 2023). This predicament has significant implications on socio-economic and technological development.

The nexus of energy and development is a multifaceted and complex relationship that highlights the critical role of energy in improving human well-being and during economic development (John et al., 2025). The fundamental in which the provision of essential services such as education and health is based is energy (Opoku et al., 2022). It is the basic input for economic growth, facilities, transportation and power industries for economic growth and development (Nwozor et al., 2021). However, the issue of unaffordable and unreliable energy sources limits opportunities for human development, triggers poverty and impedes economic progress (Ogu et al., 2023). The World Bank (2020) projected that there is about 0.11 per cent in GDP growth from every 1 per cent increase in electricity access.

Nigeria, Africa's most populous country and largest economy, facing various development challenges amidst its enormous energy resources. The energy sector of the country, need for development, is characterised by environmental degradation, inefficient energy mix and inadequate infrastructure. Though, the energy-development nexus in Nigeria is complex with the former playing a crucial role in shaping its social, environmental and economic landscape. In Nigeria, the performance of the energy sector has been below expectation and sub-operational, evident in the numerous challenges in meeting the demand for energy.

With a total installed capacity of approximately 12,522 MW but only about 4,000 MW available for distribution (NERC, 2022; Ajayi et al., 2022), the electricity generation capacity of the nation is grossly inadequate. The resultant effect of this inadequacy is noticeable on households, businesses and industries with their reliance on polluting and expensive generators to meet the demands for energy. The meet demands for energy. The Nigerian Economic Summit Group in 2020 stated that estimated demand for electricity in Nigeria is about 40,000 MW, but only 4,000 MW is being generated in global energy markets due to an ever-increasing reliance on fossil fuels, especially oil. This resulted in a devastating impact on the economy of Nigeria. Such as currency fluctuations, decreased economic activity and reduced government revenue. Evidently, the International Monetary Fund in 2001 affirmed that the economy of Nigeria was constructed by 1.8% in 2000 due to the collapse of oil prices and the COVID-19 pandemic (Eweka et al., 2022).

Despite these challenges, there are immense potentials in Nigeria's energy sector, especially for renewable energy development such as wind power and solar energy (Oruwari et al., 2024). The National Renewable Energy and Energy Efficiency Policy (NREEEP) (2015) stated that with a solar radiation of about 515 kWh/m^2/day in Nigeria, solar energy is a viable option for an energy source in Nigeria. This can be complemented with wind energy. The above provided detailed arguments that the energy development nexus in Nigeria is a multifaceted and complex relationship that presents both opportunities and challenges (Kurek et al., 2024).

This chapter provided the challenges as well as opportunities that can help Nigeria unlock the potential of its energy sector and drive poverty reduction, improve small and medium-scale businesses, and enhance human well-being and sustainable economic development. This chapter intends to explore the opportunities and challenges in the energy-development nexus in Nigeria, highlighting the need for an equitable and sustainable energy system. This chapter will proffer possible solutions for informing policy reforms that will enhance investment in renewable energy, reduce waste in the energy sector and improve its efficiency. The chapter adopted a qualitative research approach through the collection of information from articles in journals, textbooks, institutional reports, internet material and actuarial documents, among others.

Data collected were subjected to the CRAAP test to verify the credibility, authenticity, accuracy and purpose of those secondary data adopted for this study. Content analysis was used to extract information that will provide the challenges and opportunities in the energy development nexus in Nigeria.

1. ENERGY-DEVELOPMENT NEXUS: THEORETICAL FRAMEWORK

Energy, human development, and economic growth and development, as well as sustainable development, have a deeply intertwined relationship (Agberegha et al., 2021). The fundamental driver of economic growth is energy, through which security, among others, is provided. It is the basis of power for industries, facilitates transportation systems and reduces poverty (Maruta, 2025). However, these economic growth indicators will also increase energy consumption, resulting in a bidirectional relationship between economic growth.

Waheed et al. (2025) reported that investment in energy infrastructure has a positive influence on human capital and gross domestic product. This was supported by the report of Energy for Growth Hub that there will be job creation, increased productivity and profitability. Due to low-cost energy for industries and firms. In the same vein, Balogun et al. (2024) stated that the Human Development Index (HDI), the measure of human wellbeing, is directly influenced by energy consumption. This is evidenced in countries with less energy with low development (Onyekachi et al., 2025), and a small increase in energy will lead to a significant improvement in the Human Development Index (Maruta et al., 2025). Therefore, access to modern energy is very important for human well-being and development. This is the reason that the United Nations Development Programme (UNDP) reiterates the importance of reliable and clean energy that will drive human development. Hence, human development and sustainable development will be influenced by renewable energy sources. Yakub et al. (2022) suggested that governments prioritising energy development and access for productive economic enterprises will lead to improved standards of living and increased revenue or income. This indicates that policy-makers have an important role to play in enhancing sustainable energy development that improves both economic and human development.

The theoretical argument for the study is modernisation and endogenous growth theory. Modernisation theory was the product of several economists and sociologists: Max Weber, Talcott Parsons, Walt Rostow and Seymour Martin. The theory assumes that societies progress through similar stages of development from traditional to modern. It is believed that the shift in traditional values to modern values, such as achievement, motivation, individualism and rationality, is modernisation (Ugwoke et al., 2020), and economic development is the main factor of modernisation, leading to technological advancement, urbanisation and industrialisation. Waheed et al. (2025) stated that modernisation is a linear process driven by technological advancement and economic growth, in which society transitions from traditional to modern form. In this transition, argued Kurek et al. (2024), energy plays a significant role in enabling the development of transportation systems, communications and industrialisation processes. Based on this, the energy-development nexus. Deeply rooted in modernisation theory, since increased energy consumption is a key indicator of development. The relationship is complex, as energy serves as both a constraint and a driver of development. The provision of health care, education, and other social services, as well as industrialisation, can only lead to economic development with effective energy sources.

Endogenous growth theory, propounded by several economists, Paul Romer in 1990, Sergio Rebelo in 1991 and Robert Lucas in 1988, as a challenge to traditional neoclassical growth theory that attributed economic growth and development to external factors like technological progress (Opoku et al., 2022). Endogenous Growth Theory (EGT) assumed that economic growth and development are engendered by internal factors like human capital, innovations and knowledge. These assumptions rest on the fact that human capital, such as skills, education and training, will improve economic, social and other aspects of development (Waheed et al., 2025), with that education, knowledge and innovation from it serving as the driver. This means that investment in human capital will lead to a significant return in the form of economic growth. The theory implies that government policy and investment in research and development, education and vocational training are important for economic growth (Maruta, 2025).

Entrepreneurship and innovations can provide a framework for long-term economic growth and development. EGT was criticised for assumptions and simplifications that may not accurately reflect the real-world complexities (Onyekachi et al., 2025). It was also criticised for not fully accounting for factors such as culture and institutions that have a significant impact on economic growth and measurement challenges that are facing innovation and knowledge.

2. ENERGY PROFILE OF NIGERIA

With an estimated total reserve of about 25 billion barrels, oil is the main resource in Nigeria's energy mix. In addition to being the economy's main source of income and foreign exchange, it has also made great strides as a fuel for all purposes and, as such, a flexible instrument at every level of industrial development. Nigeria has a lot of natural gas, primarily methane, both connected to and separate from crude oil. Nigeria's natural gas potential has been the subject of numerous comments recently (Ugwoke et al., 2020).

Nigeria is one of the top ten nations with the largest natural gas deposits in the world, with an estimated total resource of over 3.4 trillion cubic meters (124 trillion cubic feet). Crude oil production frequently produces a sizable amount of the accompanying gas. But about 75% of this is flared, and the rest is either treated to pipeline-quality gas or reinjected. Since the start of the NLNG (Nigeria liquefied natural gas) project, the situation has started to change, although the unassociated gas is still untapped because of low industrial demand. The project's exports will reduce petrol waste by about 25% (Yakub et al., 2022).

Another energy source is coal. It is a highly combustible mixture of moisture, minerals, and organic stuff. With an estimated total resource of 2.7 billion tonnes, of which about 650 million tonnes are proven, Nigeria has an abundance of it. There are 27 coal mines spread over 13 states in Nigeria. Between the 1950s and the 1990s, this resource's share in infrastructure development (electricity) dropped from nearly 90% to 0.4%. Major businesses, including railways (for powering their trains), maritime (for powering ships), electricity generation at Oji and Ijora, and a cement plant in Nkalagu, were all spawned by its growth and use prior to 1960 (Chanchangi et al., 2019).

Nigeria's total land area is around 960,000 km², of which 63% is savannah wood, 37% is high forest zone, and 40% is forest land. Firewood is an energy resource that may be gathered from a variety of trees. In Nigeria, electricity is produced by hydropower, or water. Hydropower plants are built at the natural dams in Kainji and Shiroro, Nigeria (Eweke et al., 2022). Around 5.5 kilowatt hours of solar radiation per square metre are received daily by a larger percentage of the nation's air surface. Nigeria therefore has a lot of solar energy potential. Global interest in wind energy is growing significantly. At a height of 25 metres, wind speeds at more than 80% of stations in Nigeria are higher than the cut-in wind speed of 2.2 metres per second. A 25-metre-diameter wind turbine with an efficiency of about 30% can produce up to 97 megawatts of electricity annually in high wind speed zones across the nation (Ogu et al., 2023).

There are two types of electricity supply systems in Nigeria: decentralised (off-grid) and centralised (grid-connected). Large-scale electricity production at centralised facilities, such as hydro and thermal power plants, makes up the centralised system. Renewable energy technologies and captive diesel and petrol generator sets are part of the decentralised electricity supply system. Approximately 13 GW is the total installed capacity of grid-based systems. On-grid peak generation nowadays, however, fluctuates and averages about 4.5 GW. Large hydroelectric facilities (14%) and natural gas power plants (86%) account for the majority of Nigeria's on-grid energy (Kurek et al., 2024).

However, the operational performance of these power plants has been significantly hindered by limited grid capacity, seasonal water shortages, machine failures, and a scarcity of gas (Yetano-Roche et al., 2020). Due to this circumstance, there are severe power outages that continue for several hours every day all over the nation. Many homes and businesses have also been forced by the situation to produce their own off-grid electricity with backup diesel and petrol generators. It is quite difficult to determine the overall capacity of fossil fuel-based self-generation in terms of installed capacity.

Though another study suggests about 30.5 GW (Tambari, Dioha, and Failler, 2020), it is assumed that about 15 GW of diesel- and gasoline-based generation capacity was available in the country as of 2015 (Agberegha et al., 2021) based on the number of generators imported into the country each year.

Approximately 86% of Nigerian enterprises own or share a generator, and 84% of urban households currently rely on backup power supply systems, including solar-based systems and/or fossil diesel/gasoline generators (Elinwa, Ogbeba, and Agboola, 2021). With millions of captive generators imported, Nigeria is Africa's top importer of generators. It is also one of the biggest importers in the world.

From the domestic to the industrial sectors, Nigeria's economy is negatively impacted by its erratic power supply systems and comparatively costly captive generating. Households and small and medium-sized enterprises spend two to three times as much on kerosene, diesel and petrol as they do on grid electricity because of the high costs of captive generating (Adewuyi et al., 2020). Nigerian products are around one-third more expensive than imports due to the cost of self-generated power, according to government data (FMITI, 2014, quoted in Balogun et al., 2024). Nigeria must therefore improve power reliability and accessibility in order to decrease the use of confined diesel and petrol generators.

About 47% of Nigeria's total energy comes from renewable sources, making them the main source. 43 per cent of Nigeria's energy mix is made up of biomass. This is due to its widespread usage for cooking and heating, and as the ensuing sections demonstrate, there is still much work to be done in terms of gaining access to clean cooking fuels. Nigeria's biomass subsector is highly unorganised, with many unknowns surrounding its use, especially in rural areas, and issues with fuel stacking in the country's construction industry. The amount of biomass utilised in Nigeria's industrial sector is likewise unknown (Ogu et al., 2023). The percentage of biomass in Nigeria's primary energy supply may be higher than the model's estimate due to differences in methodological approaches, energy availability levels, and efficiency values of the modelled biomass technologies. In 2019, about 18 per cent of Nigerians have access to clean cooking (gas and electric stoves), according to the country's living standards survey conducted by the Nigerian National Bureau of Statistics.

However, according to international data, just about 13% of Nigerians had access to clean cooking that year (Banso et al., 2023). Variations in survey and measurement methods, as well as definitions of clean cooking, may be the cause of the data discrepancies.

Since conventional biomass is used for the majority of cooking, adopting new technologies can greatly improve air quality and reduce the number of air pollution-related deaths (Ajayi et al., 2022).

About the same proportion of primary energy needs are met by bioenergy and oil. The capacity of Nigeria's refineries is currently insufficient to meet the local demand for petroleum products, despite efforts to have them run at full capacity. Nigeria imports 80% of its refined oil products from overseas in order to meet this demand (PWC, 2017). Even if a huge oil refinery that can refine up to 650 000 barrels of oil per day is still being developed (George, Payne, & Zhdannikov, 2021), Nigeria might gain a lot from refocusing its attention on domestic renewable energy sources instead of fossil fuels. In a 2°C scenario that complies with the Paris Agreement, employment from fossil fuels might fall by 80% globally, while employment from renewable sources could increase fivefold (Pai et al., 2021). In such a situation, promoting the local development of plentiful renewable energy resources may inspire creative local renewable energy advocates, leading to the formation of spin-off businesses and jobs in the area.

The remainder of Nigeria's primary energy needs are met by hydropower, natural gas, and other renewable energy sources, the bulk of which are utilised in the power industry. Given recent technological cost reductions and Nigeria's abundant natural resources, especially solar power, the low penetration of variable renewables like wind and solar shows the potential for integrating them into the electricity sector (Nwozor et al., 2021).

Among their many advantages, these technologies' adaptability makes them simpler to deploy in a decentralised setting and, when paired with storage, can dependably supply a significant quantity of power. Nigeria utilises relatively little coal in comparison to many other nations. There isn't any substantial coal power generation in the nation at the moment. Currently, the foundry, bakery, cement, and brick sectors account for the majority of local consumption (Opoku et al., 2022).

Although Nigeria's main energy source has a sizable non-fossil component, it also has unfavourable externalities that can be fixed to enhance air quality, generate employment, and boost the country's economy.

3. CHALLENGES IN THE NIGERIA'S ENERGY SECTOR

The execution of energy policies, regulatory uncertainty, gas availability, transmission system limitations, and the sizeable power industry are only a few of the many general challenges facing Nigeria's power sector. The national grid in Nigeria has a poor voltage profile and is hampered by inadequate control infrastructure, according to a recent audit of the country's energy industry (Idris et al., 2020).

Major technical and non-technical losses and overloaded transmission cables are frequent occurrences. There is a clear need to diversify into additional renewable energy sources in order to overcome power generation shortages in Nigeria, since the country's available generated power clearly falls short of load demand due mostly to rising energy demand brought on by an expanding population (Eweka et al., 2022).

Notwithstanding the changes in the power industry, the Transmission and Distribution (T&D) sector continues to face numerous obstacles, including a 6000 MW transmission capacity limit, high technical and non-technical power losses, vandalism and unnecessary power theft, corruption in power management, an inefficient distribution planning method (no redundancy), an inaccurate metering system, outdated and dilapidated T&D infrastructure, poor voltage stability, inadequate coverage, personnel who are, in conclusion, the main issues found are:

Challenges facing Production (Upstream Sector)

One significant problem in the upstream sector has been identified as the government's underfunding of crude oil production. The NNPC has frequently fallen short of its joint venture financial obligations. The government has established alternative finance agreements with Multinational Oil Companies (MOCs) such the Modified Carried Agreement (MCA) and the Production Sharing Contract (PSC) in order to provide long-term benefits (Tomala te al, 2021).

Challenges in the Downstream Sector/ Oil Subsidy

The three main adverse effects of oil subsidies are social, environmental, and macroeconomic. Macroeconomic ramifications: Oil subsidies lead to macroeconomic imbalances, slow economic growth, and deplete public coffers.

Insofar as this price subsidy reduces the industry's appeal to private investors, encourages inefficient technology, leaves little money for infrastructure upkeep and upgrades, and ultimately results in severe energy shortages, which severely disrupt economic activity (Ogbodo-Nathaniel et al, 2024). Because they encourage excessive consumption of petroleum products, which fuels air pollution and global warming, subsidies have an effect on the environment. According to an IMF study on Iran, lower and more inexpensive PMS prices increase vehicle traffic, which leads to additional negative externalities of subsidies such as traffic congestion, increased accident rates, and road damage.

Lack of Gas Infrastructure

The nation's gas reserves are yet untapped because its main priority is the exploitation of crude oil. Due to this, a significant amount of the available natural gas is either flared, re-injected to enhance oil recovery, or exported as liquefied natural gas, leaving the domestic gas market mainly underdeveloped. The power supply system is now unreliable and unpredictable due to weaknesses in the structure of the nation's power generation mix. As a result, an appropriate gas pricing system has been developed and put into place, which is necessary for the growth of the domestic gas market (Olusola & Onoyere, 2024).

Security of Energy Infrastructure

Because of the persistent vandalism of oil and gas sites in the Niger Delta, protecting energy infrastructure continues to be a challenging issue. Both the supply of petrol to thermal power plants and the supply of refined products have suffered as a result.

Investment and Operations

Several international oil corporations (IOC) operating in Nigeria have sold their holdings in certain offshore and shallow water areas due to energy infrastructure capacity concerns. While some of these blocks are classified as gas fields, the majority are classified as oil fields. In order to assist enterprises in streamlining their asset portfolios and shifting their strategic development focus to deep offshore activities in Nigeria, the blocks are offered for sale through negotiated bid procedures (Banso et al, 2023). Lack of requisite knowledge and skills, particularly in the power sub-sector, is another major operational challenge for Nigeria's energy sector. This is because Nigeria's energy generation capacity needs to be raised from 3,650 MW/hr to more than 45,000 MW/hr in order for it to be among the top 20 economies in the world. This is unquestionably a quantum leap that will require new knowledge and expertise to handle the development and manage the transition. A wide range of skills, including engineers, technicians, and industry experts, are needed for each new power plant. This will surely be a significant roadblock for the industry and the nation if it is not resolved (Ugwu et al, 2022).

Poor State of Refinery Infrastructure

Nigeria must lessen its dependency on imported refined petroleum products, as seen by the drop in revenue from crude oil exports. In 2013, the government of Nigeria imported and heavily subsidised more than 90% of the country's 5.13 billion gallons of petroleum products (Tomala et al, 2021). This resulted from low-capacity utilisation rates at Nigerian refineries. The installed capacity of the Warri, Port Harcourt, and Kaduna refineries was 37.62 percent, 8.20 percent, and 29.14%, respectively, in 2013 (CBN, 2015). Due to the apparent obsolescence of the machinery, significant financial resources have been expended on seasonal Turn-Around Maintenance (TAM) with little return (Ogbodo-Nathaniel et al, 2024).

Political interference

This is the most obvious and difficult political economy problem Nigeria's electrical sector reform is facing.

The necessity to streamline public company management bureaucracy in order to increase operational efficiency free from government intervention was one of the main drivers behind the US$23 million contract that TCN management was awarded to MHI over a three-year period, from July 2012 to July 2015. Throughout the duration of the contract, the company was responsible for managing the entire TCN system and turning it into a stable, profitable, and technically sound business (Ogu et al, 2023).

Additionally, MHI had to restructure the organisation to keep the Transmission System Provider apart from the Market Operator and System Operator in order to guarantee the development of a TCN into a private commercial firm. Despite what many people think, TCN management appears to be heavily influenced by politics, which hinders the organization's ability to function effectively and carry out its declared mission (Kurek et al, 2024).

4. OPPORTUNITIES FOR RENEWABLE AND SUSTAINABLE ENERGY DEVELOPMENT IN NIGERIA

Nigeria's energy security faces challenges, but the sector also presents opportunities for economic growth and entrepreneurship. Lack of reliable access to energy has left many Nigerians, especially women, in poverty. While avoiding the hazards connected with traditional energy sources, increasing the energy supply's effectiveness and efficiency can contribute to an improvement in living standards (Maruta, 2025). Increased energy supply can benefit small and medium-sized enterprises (SMEs), enabling them to prosper and create jobs. A significant percentage of Nigeria's workforce is employed by micro, small, and medium-sized enterprises, and energy security can help reduce operating costs and generate employment (Waheed et al., 2025). Nigeria may also encourage sustainability and lessen its carbon footprint with energy security. Energy management can contribute to a 20% reduction in carbon emissions by 2030 by averting 6.4 million tonnes of CO_2 emissions annually (Balogun et al., 2024).

Additionally, increasing industrial energy efficiency will enhance competitiveness and productivity, which will support the nation's economic growth. Given the high unemployment rate in the nation and the need to create new job possibilities, this is especially important.

Because industries can reduce their environmental impact by conserving energy and implementing sustainable practices, it will also encourage corporate social responsibility. Over 40% of Nigeria's energy resources are wasted by outdated and deteriorating industrial equipment. In addition to decreasing energy efficiency, this also jeopardises production and sustainability (Ugwu et al., 2022).

It is important to note that a significant portion of Nigeria's energy resources are wasted on antiquated and ineffective industrial machinery.

This waste reduces overall productivity throughout the nation's enterprises and encourages energy efficiency in the industry. By implementing energy-saving measures, Nigerians' per capita income will rise as a result of increased production and resource efficiency (Olusola & Onoyere, 2024). Enhancing Nigeria's industrial energy efficiency is a significant opportunity for the nation's economic development. Reducing energy use, fostering corporate social responsibility, and boosting productivity through energy audits, efficient machinery, and sustainable practices will all have a positive economic impact.

CONCLUSION AND RECOMMENDATIONS

This chapter contributed to the current condition of the energy-development nexus in Nigeria and concludes that the government has not made significant steps to prioritise energy for development principles, undermining sustainability efforts. To realise its objective of becoming one of the world's leading economies, Nigeria must adequately manage energy sector challenges. The chapter emphasises the significance of prioritising energy provisions and security in order to meet the demands of both current and future generations. As Nigeria's population grows, so does the need for energy, potentially leading to energy insecurity. Therefore, to guarantee that energy that will engender development is given and sustainable development is accomplished, swift and thorough action is needed.

The chapter examined the Nigerian energy profile and found that sustainability is at risk since the government has not adequately implemented energy security principles. The chapter asserts that energy security will have a positive influence on sustainable development and is essential to Nigeria's potential to emerge as a leading global economy.

Nigeria's current national power grid needs significant modifications, and the country's growing population has raised demand for electricity. According to the chapter, effective management at every step of exploration, production, and consumption is necessary to secure more fossil fuels.

The chapter suggests that there are several measures to advance energy for development in Nigeria, such as increasing awareness of energy efficiency and renewable energy, enacting standard regulations, promoting transparency and accountability, and reducing the power of the elite.

To achieve sustainability, energy saving and the use of energy-efficient equipment should be promoted. The chapter highlights the need for managing energy resources in compliance with global standards and recommends that the government encourage energy independence through the implementation of renewable energy sources, improved fuel economy regulations, and economic diversification. Notwithstanding the limits of the constrained sources, the chapter makes a substantial contribution to the body of knowledge already available on the Nigerian energy sector.

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CHAPTER 4
ENVIRONMENTAL EDUCATION CONTENT KNOWLEDGE OF ENERGY CONCEPT FOR SUSTAINABLE DEVELOPMENT IN NIGERIA

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INTRODUCTION

The study aimed to assess the environmental education content knowledge of energy concept for sustainable development among university lecturers in Niger State, Nigeria. Descriptive survey research design was used for this study involving total population of 1,352 lecturers and targeted population of 186 university lecturers in Niger State, which 125 lecturers were sampled for the study using purposive sampling. A structured researcher's questionnaire was used for the study which yielded reliability of 0.86. The data collected that are related to the demographic data were analysed using the simple frequency count and percentage, the research questions (RQ) were also analysed using the frequency and percentage scores and the research hypothesis (HO) was analysed using parametric inferential statistical tool of Z-Test. Statistical Package for Social Sciences (SPSS) version 27 was used in carrying out the analysis of the data collected. Therefore, based on the findings of this study it was concluded that university lecturers in Niger State are moderately in energy concept, while they may demonstrate basic knowledge of the concept but there is room for improvement through professional development programmes or capacity building programmes through workshops, seminars and other related trainings involving environmental education and sustainability. Also, collaborations should be encouraged with experts and interdisciplinary researches and publications should be enhanced.

The Ecological Earth is the most exploited and depleted surface of the universe which has provided man with all the essential resources and materials for his survival from time immemorial. Man is dependent on the ecological environment for food, shelter and other lifelong needs and yet, he is continually engaged in the destruction of his source of livelihood. Again, Man's remarkable development in the fields of Science and Technology coupled with increased human population growth have resulted in the continues exploitation of the earth ecosystem. He has deployed the tools of 21st century advancement in carrying out his activities of mining and farming exploration which is causing soil erosion, environmental degradation, climate change, increase in atmospheric temperature (global warming) through the emission of Green House Gases (GHG). These human activities have affected the African continent and more specifically Nigeria.

Aina (2019) reported that the Sahel region of Africa is the most affected part of the world in the dwindling of natural resources. In Nigeria, the major cause of these environmental issues or problems were identified as urbanization, overpopulation, deforestation, desertification and pollution (Aminu and Uzairu, 2021). Therefore, improving the environment is the responsibility of all members of the society, including educational institutions, teachers and students. Also, one of the major contradictions in the 21st century is the unique technological advancement and economic growth, which have contributed to devastating socio-environmental impacts on humanity despite accruing numerous benefits for people. In the quest for survival, mankind is significantly exposing the planet to severe biodiversity threats, climate change threats, waste management threats, which poses issues to energy, ecology security, food and politics which are impediments to sustainable development (Olawuyi, 2015).

1. THE CONCEPT OF ENVIRONMENTAL EDUCATION

Environmental Education (EE) is an interdisciplinary field rooted both in science and societies, concerned not only with environmental literacy, but also, and perhaps foremost, with the relationship people have with their environment. As such, the field cannot be immune to new trends in conservation and environmental protection, when such new concepts emerging from science or society that are relevant to the relationship between people and their environment, such concepts have to be scrutinized from an environmental education perspective (Aina, 2019). Thus, Environmental Education (EE) plays a crucial role in promoting awareness, knowledge and action towards sustainable environmental practices, in which Nigeria has a diverse ecosystem and facing environmental challenges from industrial to local mineral exploration activities. Environmental Education (EE) is essential for fostering ecological literacy amongst people and also aims to impart knowledge, skills, attitudes and values that empower individuals to become responsible stewards of the environment (Okebukola and Jegede, 2016). In the process of harnessing environmental resources, many damages are done to the environment both in urban and rural areas which in this essence environmental education, management and planning are required.

Ibrahim and Morsy (2016) opined that environmental education is required in the formation of smart cities and sustainability. They noted furthermore that fostering sustainable cities require ICT infrastructure, innovation diffusion, smart city infrastructural development and monitoring, smart people, smart mobility, intelligent transportation system as well as smart governance. Other criteria are public safety and security, intelligent transportation system, E-health, smart power grid, smart water grid, smart waste management, as well as smart living. Hence, the education about all these components of the environment is a requirement for sustainable development. Matheaus (2015) noted that environmental management can affect the quality and sustainability of the society in which they live. He noted further that a driving force to environmental management and sustainable development is environmental education. The knowledge about the environment as well as the practical understanding of the negative consequences of the misuse of abuse of the environment are catalysts to sustainable development. To this end, he recommended environmental governance as sustainable consumption policies as well as public participation in environmental decision making as major ingredients of sustainable development.

1.1 The Concept of Sustainable Development and Environmental Education

In recent years, Nigeria has made progress in advancing environmental education and efforts have been made to revise curricula, incorporate environmental education into teacher training programmes, and raise awareness through community engagement and advocacy campaigns (Aigbokhan and Adesina, 2017). Environmental Education (EE) can serve as a tool for propagating United Nations Sustainable Development Goals (SDGs) in Nigeria, especially those relating to ecological protection (biodiversity), resource conservation and climate change (Ismaila and Salman, 2015). United Nations Educational, Scientific and Cultural Organization (UNESCO, 2014), reported that the Millennium Development Goals (MDG's) and the Sustainable Development Goals (SDG's) are pivotal frameworks in global development efforts, representing a continuum of objectives aimed at addressing pressing global challenges.

The SDGs was introduced in 2015, built upon the MDGs and expanded the scope with a more comprehensive and integrated approach to development.

Furthermore, the Sustainable Development Goal 7 emphasizes ensuring access to affordable, reliable, sustainable and modern energy for all, specifically the goal elaborates the need for sustainable energy management. Also, sustainable Development Goal 12 underscores the importance of responsible consumption and production, including the energy management and waste management thereby contributing to the attainment of SDG 12 and mitigating associated environmental challenges (Shuaeeb, 2025).

1.2 The Concept of Lecturers as Tools for Integrating Environmental Education into Teaching and Learning

Environmental Education (EE) is increasingly recognized as a critical component in shaping sustainable attitudes and behaviours. Teacher education programmes play a pivotal role in equipping educators with the knowledge and skills to integrate environmental concepts into their teaching. Environmental education goes beyond traditional classroom subjects, fostering ecological literacy, sustainability awareness and a sense of responsibility (Chioma and Kelechi, 2016). Integrating environmental education into teacher training programme is crucial for preparing educators to address current and future environmental challenges facing the country in the classroom.

Lecturers in tertiary institutions are responsible for imparting comprehensive knowledge and skills to students. Determining the quantum of knowledge on Environmental Education curriculum among lecturers is vital for ensuring the effective delivery of environmental education concepts, theories and practical applications, to equip them with the necessary tools to foster critical thinking, decision-making and environmental stewardship among students (Ojebiyi, 2016). A thorough understanding of environmental issues is essential for lecturers to effectively teach environmental education, as this includes topics such as climate change, pollution, sustainable development, biodiversity conservation and natural resources management (Akpochafo and Alaga, 2020). Lecturers must stay updated on the latest research, policies and technological advancements in environmental science and sustainability (Egwuonwu and Okeke, 2019).

Lecturers need to be proficient in employing diverse pedagogical approaches to engage students in environmental education, this may include experiential learning, case studies, field trips, simulations, participatory activities which provide effective integration of interdisciplinary perspectives that is also crucial for providing a holistic understanding of environmental issues (Musa and Fasasi, 2018).

1.3 The Concept of Content Knowledge and Environmental Education

Content knowledge refers to the understanding of the subject matter that educators are responsible for teaching. It encompasses the concepts, theories, facts and principles specific to a discipline, as well as the relationships and interconnections between them. Shulman (2020) emphasized the importance of content knowledge as a key domain of teacher knowledge, distinguishing it from other forms of knowledge required for effective teaching, such as pedagogical knowledge and pedagogical content knowledge.

Content knowledge ensures that educators have a deep and accurate grasp of their subject area, enabling them to present information in a coherent and structured manner. According to Grossman (2021) content knowledge includes both substantive knowledge (the facts and concepts of a discipline) and syntactic knowledge (an understanding of how knowledge is generated and validated within a field). Strong content knowledge allows educators to answer students' questions effectively, connect abstract ideas to real-world contexts and create meaningful learning experiences. Moreover, it supports the development of critical thinking skills, as students are guided to explore and analyze the subject matter in depth (Ball *et al.*, 2018).

The role of educators extends beyond imparting knowledge; it is tasked with preparing students to tackle real-world challenges, including environmental issues. The implementation of environmental education curriculum demands content delivery which includes the concepts of biodiversity, climate change, waste and energy among others for both lecturers and students. Studies have highlighted the importance of assessing lecturers' content knowledge in environmental education.

Ojebiyi (2016) emphasized the need for lecturers to possess a deep understanding of local environmental issues, such as desertification and water scarcity, to effectively teach environmental concepts to students in Niger State. Similarly, Musa and Fasasi (2018) conducted a study on secondary school teachers in Niger State, revealing gaps in teachers' content knowledge related to environmental issues and recommending targeted interventions to address these gaps. These findings underscore the significance of assessing lecturers' content knowledge to inform curriculum development and teacher training initiatives in Niger State.

1.4 The Concept of Energy in Environmental Education

The concept of energy in environmental education involves the process of monitoring, controlling, and optimizing the use of energy in various sectors, including industrial, commercial and residential (Adelabu, 2018). It aims to reduce energy consumption, improve energy efficiency, use of biogas and promote sustainability. In the pursuit of sustainability, many organizations and individuals are incorporating renewable energy sources like solar panels, wind turbines and geothermal systems into their energy management strategies, to reduce dependence on fossil fuels and lower greenhouse gas emissions (Wang and Li, 2017). Energy management as a crucial component of environmental education emphasizes the responsible and efficient use of energy resources in a digitally connected world, and it at the same time involves harnessing digital technologies and data-driven approaches to reduce energy consumption, lower environmental impact and promote sustainability (DeVries *et al.,* 2019). Digital technologies such as energy management software and smart metres, enable real-time data collection and analysis which allows for better control of energy use and the identification of deviations from expected energy performance (Grobler, 2018).

1.5 The Concept of Gender in Teaching Environmental Education

Gender can influence how lecturers approach environmental education, as men and women may prioritize different aspects of the subject due to gendered social roles, experiences and expectations.

For instance, studies have shown that women are often more inclined to focus on sustainability and ecological conservation, possibly reflecting societal norms and values associated with caregiving and environmental stewardship (Arora-Jonsson, 2021). Conversely, male lecturers might emphasize technical and policy-driven aspects of environmental education, reflecting gendered differences in academic and professional backgrounds. Gender can also influence how lecturers approach these skills in teaching environmental education. For example, female lecturers may emphasize collaborative and participatory teaching methods, fostering inclusivity and community engagement, which are critical for addressing environmental challenges (UNESCO, 2017). Male lecturers, on the other hand, may focus more on competitive and technology-driven pedagogies, aligning with broader societal stereotypes about gender roles in teaching and learning. Importantly, gender also intersects with other factors, such as culture and institutional dynamics, in shaping lecturers' pedagogical choices. Female lecturers, particularly in male-dominated fields like environmental science, may face challenges in asserting their authority or accessing leadership roles, which can affect their ability to implement innovative teaching practices (Martin and Kernan, 2017).

Gender significantly shapes how lecturers develop and apply their content knowledge and 21st-century pedagogical skills in teaching environmental education. By recognizing and addressing gendered differences and biases, institutions can promote more inclusive and effective teaching practices, thereby ensuring that environmental education equips students with the knowledge and skills needed to address complex global challenges.

2. AIM AND OBJECTIVES OF THE STUDY

The aim of this research is to assess Lecturer’s Content Knowledge of Energy Concept and its Applications to Environmental Education for Sustainable Development in Niger State, Nigeria. Specifically, the study seeks to achieve the following objectives: to examine the university lecturers’ environmental education content knowledge of energy concept; to determine the university male and female lecturers’ environmental education content knowledge of energy concept.

And also, the following research questions were raised to guide the study: what is the university lecturers' environmental education content knowledge of energy concept? What is the university male and female lecturers' environmental education content knowledge of energy concept? The following null hypothesis was formulated at 0.05 level of significance;

HO_1 There is no significant difference between male and female lecturers' environmental education content knowledge of energy concept.

The study on the assessment of Lecturer's Content Knowledge of Energy Concept and its Applications to Environmental Education for Sustainable Development in Niger State, Nigeria holds several significant implications for various stakeholders involved in educational institutions and environmental sustainability which include educational institutions, lecturers, students, Government and policy makers, environmental organizations like NGO's and community members.

The overall significance of the study to stakeholders lies in its potential to improve environmental education delivery, empower educators, inform policy decisions and ultimately contribute to building a more sustainable future for Niger State, Nigeria and its inhabitants.

Descriptive survey research design using quantitative method of analysis was used for this study. The targeted population for the survey study are only the academic staff (lecturers) who are responsible for providing academic guidance and leadership to the students pursuing various degree programmes in the universities, whose total population consisted of 1,891 lecturers in the four (4) universities respectively.

The population consisted of 839 lecturers from Federal University of Technology, Minna (FUTM), 413 lecturers from Ibrahim Badamasi Babangida University, Lapai (IBBUL), 556 lecturers from Federal University of Education (FUEK), Kontagora and 83 lecturers from Abdulkadir Kure University, Minna (AKUM).

The targeted population for the study was 186 lecturers of which 124 were from FUTM and 62 lecturers are from IBBUL. A total sample of 125 lecturers were purposively selected for the study from the targeted population using the krejcie and Morgan's table (1970). Multi-stage sampling technique was used for the selection process.

Purposive sampling was used in selecting the tertiary institutions, the schools/faculties and departments were selected based on their interdisciplinary relationship with the research area of Environmental Education content knowledge and 21st century pedagogical skills, and in selecting the respondents from each department of each institution. A researcher's structured instrument titled 'Lecturers' Environmental Education Content Knowledge Test Inventory (LEECOKTI) was designed for assessing university lecturers' content knowledge relating to environmental education. The section A was designed to elicit bio-data of lecturers while section B of the instrument contained 10 items on Content Knowledge. Thus, information of the LEECOKTI is in a multiple-choice question. To ascertain the content and face validity of the instrument, it was validated by three (3) experts from the Department of Science Education and one (1) expert from Educational Technology Department of the Federal University of Technology, Minna. All corrections, suggestions and observations raised by these experts were used to modify and ensure a clean and corrected copy of the instrument that was produced for data collection. All validations adjusted the instrument as valid for the proposed research study.

In determining the reliability of the instrument, a pilot study was carried out on 40 lecturers of Abdulkadir Kure University Minna and Federal University of Education Kontagora. The scores obtained were analysed using the Spearman-Brown Split-half method for LEECOKTI which yielded a reliability coefficient of 0.90 and this co-efficient is considered to be high and as such the instrument is reliable and suitable for the study.The researcher first obtained the letter of introduction from the office of Head of Department, Science Education which was tendered to the head of departments to be visited and used for the study. The researcher visited the selected departments to examine the lecturers so as to determine the suitability for the proposed survey in order to seek for their consent and cooperation. There was also an orientation for the research assistant towards achieving the desired experimental goals of the research which lasted for one week.

The instrument was administered onto the respondents by the researcher and the research assistant that was briefed on the instrument, to enable him explain the various aspects of the questionnaire to the respondents so that the questions would be properly responded to and filled.

The questionnaire was administered face to face after which the completed items were collected on the spot. This approach ensured correct completion and prevent respondents' mortality toward ensuring a reasonable percentage return of the answered questionnaires for coding and analysis. This process lasted for two weeks.

The data collected that were related to the demographic data were analysed using the simple frequency count and percentage and also used to analyse the research questions related to the content knowledge of the respondents. The decision rule for LEECOKTI was the percentage scores from 80 – 100 was considered as highly knowledgeable, 50 – 70 as moderately knowledgeable, 30 – 40 as slightly knowledgeable and 0 – 20 as not knowledgeable. While the research hypothesis (HO) was analysed using parametric inferential statistical tool of Independent Z-test using Microsoft Excel and Statistical Package for Social Sciences (SPSS) version 27.

3. PRESENTATION OF DEMOGRAPHIC DATA

The study assessed Lecturer's Content Knowledge of Energy Concept and its Applications to Environmental Education for Sustainable Development in Niger State, Nigeria. This chapter focuses on the data presentation, analysis and interpretation of results, addressing and focusing on presentation of demographic data, answering research questions and testing of research hypotheses outlined in chapter one and also includes summary of findings and discussion of results.

Table 1. Demographic Distribution of Lecturers based on Institution

Category	Frequency	Percent (%)	Valid Percent	Cumulative Percent
FUTM	75	60.0	60.0	60.0
IBBUL	50	40.0	40.0	100.0
Total	125	100.0	100.0	

Table above indicates that the lecturers in the sampled institution from FUT Minna were 75 respondents representing 60% of the total sample, while the lecturers sampled in IBBU Lapai were 50 respondents representing 40% of the total sample, giving the total sample of 125 respondents representing the 100% of the sample.

Table 2. Demographic Distribution of Lecturers based on School/Faculty

Category	Frequency	Percent (%)	Valid Percent	Cumulative Percent
Education	50	40.0	40.0	40.0
Sciences	75	60.0	60.0	100.0
Total	125	100.0	100.0	

Table above shows that the lecturers in the sampled school/faculty of Education were 50 respondents representing the 40% of the total sample, while 75 respondents sampled from faculty of sciences representing the 60% of the total sample.

Table 3. Demographic Distribution of Lecturers based on Department

Category	Frequency	Percent (%)	Valid Percent	Cumulative Percent
Science Education	50	40.0	40.0	40.0
Biology	25	20.0	20.0	60.0
Chemistry	25	20.0	20.0	80.0
Geography	25	20.0	20.0	100.0
Total	125	100.0	100.0	

Table above shows that the lecturers sampled from department of Science Education were 50 respondents representing the 40% of the total sample, while 25 respondents were sampled from Biology department representing 20% of the total sample, 25 respondents were sampled from Chemistry department representing 20% of the total sample and 25 respondents were sampled from Geography department also representing 20% of the total sample.

Table 4. Demographic Distribution of Lecturers based on Gender

Category	Frequency	Percent (%)	Valid Percent	Cumulative Percent
Male	86	68.8	68.8	68.8
Female	39	31.2	31.2	100.0
Total	125	100.0	100.0	

Table above shows the distribution of lecturers on the basis of gender, 86 male lecturers were sampled representing 68.8% of the total sample, while 39 female lecturers were sampled representing 31.2% of the total sample.

Table 5. Demographic Distribution of Lecturers based on Years of Teaching Experience

Category	Frequency	Percent (%)	Valid Percent	Cumulative Percent
1 to 5	42	33.6	33.6	33.6
6 to 10	42	33.6	33.6	67.2
11 to 15	18	14.4	14.4	81.6
16 to 20	17	13.6	13.6	95.2
21 Above	6	4.8	4.8	100.0
Total	125	100.0	100.0	

Table above shows the distribution of lecturers based on the years of teaching experience which ranged from 1 to 5 years having 42 respondents representing 33.6% of the total sample, 6 to 10 years also having 42 respondents representing 33.6% of the total sample, 11 to 15 years having 18 respondents representing 14.4% of the total sample, 16 to 20 years having 17 respondents representing 13.6% of the total sample and 21 years and above having 6 respondents which represents 4.8% of the total sample.

Table 6. Demographic Distribution of Lecturers based on Age Bracket

Category	**Frequency**	**Percent (%)**	**Valid Percent**	**Cumulative Percent**
31 to 35	18	14.4	14.4	14.4
36 to 40	12	9.6	9.6	24.0
41 to 45	24	19.2	19.2	43.2
46 to 50	42	33.6	33.6	76.8
51 Above	29	23.2	23.2	100.0
Total	125	100.0	100.0	

Table above shows the distribution of lecturers based on the age brackets which ranged from 31 to 35 years having 18 respondents representing 14.4% of the total sample, 36 to 40 years also having 12 respondents representing 9.6% of the total sample, 41 to 45 years having 24 respondents representing 19.2% of the total sample, 46 to 50 years having 42 respondents representing 33.6% of the total sample and 51 years above having 29 respondents which represents 23.2% of the total sample.

3.1 Answering Research Questions

Research Question One (RQ1): what is the University Lecturers' Environmental Education Content Knowledge of Energy concept? This research question was answered using frequency counts and percentage as presented in table below.

Table 7. Lecturers' Score on Content Knowledge of Energy Concept

S/NO.	Score (x)	Frequency (N)	Percent (%)	Decision
1.	80 – 100	30	24.0	Highly Knowledgeable
2.	50 – 70	58	46.4	Moderately Knowledgeable
3.	30 – 40	37	29.6	Slightly Knowledgeable
4.	0 – 20	00	0.00	Not Knowledgeable
Total		125	100	

Table above shows the score of lecturers on content knowledge of energy concept which ranged from 80 to 100 marks having 30 respondents representing 24.0% of the total sample, 50 to 70 marks having 58 respondents representing 46.4% of the total sample, 30 to 40 marks having 37 respondents representing 29.6% of the total sample and 0 to 20 marks having 0 respondents representing 0.00% of the total sample. This finding shows that high number of lecturers are moderately knowledgeable on content knowledge of energy concept.

Research Question Two (RQ2): what is the University male and female Lecturers' Environmental Education Content Knowledge of Energy concept? This research question was answered using mean score and standard deviation as presented in table below.

Table 8. Mean (X) Score and Standard Deviation (SD) of Male and Female Lecturers on the Content Knowledge of Energy Concept

Gender	N	X	SD	Mean Difference
Male	86	56.74	20.49	5.06
Female	39	61.80	23.72	
Total	125			

The result presented in the table above shows that mean response of male lecturers is 56.74 and the mean response of female lecturers is 61.80 which is higher with the mean difference of 5.06 which implied that there is mean difference between male and female lecturers on the content knowledge of energy concept.

3.2 Testing Null Hypothesis

Hypothesis One (HO_1): There is no significant difference between male and female Lecturers' Environmental Education Content Knowledge of Energy concept. This null hypothesis was tested using independent sample z-test as presented in table below.

Table 9. Independent sample Z-test of the Mean Scores of Male and Female Lecturers' Content Knowledge of Energy Concept

Gender	N	X	SD	Z-cal	*df*	p-value	Decision
Male	86	56.74	20.49				
Female	39	61.80	23.72	-1.215	123	0.098	Not significant
Total	125						

Table above presents the result of independent z-test analysis of male and female lecturers' content knowledge of energy concept which shows that z-cal = -1.215, at df = 123 and the p-value = 0.098 > 0.05 alpha value of significance. This finding revealed that the above stated hypothesis is accepted which states that 'there is no significant difference between male and female lecturers' environmental education content knowledge of energy concept'.

3.3 Summary and Discussion of Findings

Based on the data and results analysed from this study, the findings were recorded and summarized as follow:

- The university lecturers are moderately knowledgeable on content knowledge of energy concept.
- The female lecturers have higher mean score than their male counterparts on the content knowledge of energy concept even though the difference was not significant.

The findings of this study, which assessed Lecturer's Content Knowledge of Energy Concept and its Applications to Environmental Education for Sustainable Development in Niger State, Nigeria, reveal insightful and relevant trends regarding their expertise in key environmental education concept of energy. The study found that university lecturers demonstrated moderate content knowledge on energy concept, which this suggests that while lecturers possess foundational knowledge in this area, there may be gaps that need to be addressed through targeted training or professional development programmes.

One possible reason for this moderate level of knowledge could be the interdisciplinary nature of environmental education and the concept involved. Since many lecturers may not have specialized training in environmental science, their understanding of this concept might stem from self-learning or general education courses rather than in-depth professional development. Additionally, the dynamic nature of environmental issues, requires continuous updating of knowledge, which might not always be prioritized in lecturers' professional development.

This finding is supported by several research studies including those conducted by Akinyele *et al.* (2020), and Adebayo and Lawal (2022), which both studies opined that lecturers possess foundational knowledge in environmental education contents but there may be gaps that need to be addressed through targeted training or professional development programmes.

The study revealed that female lecturers had a higher mean score in environmental content knowledge of energy concept than their male counterparts.

This finding aligns with some studies that suggest female educators often engage more in environmental discussions and sustainability-related practices, potentially due to greater involvement in social and community-based environmental initiatives. However, the absence of a statistically significant difference between male and female lecturers suggests that, while female lecturers performed slightly better on average, the difference is not strong enough to indicate a fundamental disparity in knowledge levels.

This outcome highlights the need for continuous professional development across both genders to ensure that lecturers have the requisite depth of knowledge to effectively teach environmental education. Future research could explore whether female lecturers actively seek out more environmental training or if differences in academic backgrounds contribute to these variations.

This finding is supported by several research studies including those conducted by Akinyele *et al.* (2020), and Adebayo and Lawal (2022), which both studies opined that lecturers possess foundational knowledge in environmental education contents but there may be gaps that need to be addressed through targeted training or professional development programmes.

CONCLUSION

From the main findings of this study, there are important conclusions. University lecturers in Niger State demonstrate a moderate understanding of environmental education (EE) content, though they possess some awareness of environmental issues and concepts, there are gaps in their knowledge that may hinder effective teaching and advocacy for environmental sustainability. The moderate level of EE content knowledge among lecturers may limit students' comprehensive understanding of environmental challenges and their ability to contribute to sustainable development. Environmental education is not sufficiently integrated into teaching curricula across disciplines, resulting in fragmented or superficial coverage of critical environmental issues. Many lecturers lack opportunities for professional development programmes focused on EE, which could enhance their expertise and ability to incorporate environmental education into their teaching.

Based on the findings of the study, some recommendations were made: there should be capacity building programmes through organization of workshops, seminars and training programmes to enhance lecturers' environmental education content knowledge which should focus on contemporary environmental challenges and sustainable practices.

Universities in Niger State should review and revise their curricula to integrate environmental education across all disciplines to promote active and experiential learning approaches, such as field excursions, hands-on environmental conservation projects, sustainability-focused research, project-based learning, problem-solving tasks and real-world environmental case studies.

Also, collaborative and interdisciplinary projects should be embedded to encourage teamwork and critical analysis of environmental issues.

There should be collaboration with environmental experts to establish partnerships with environmental organizations, government agencies and NGOs to provide lecturers with access to updated information, resources and best practices in environmental education. Research and publications should be encouraged to promote and support research initiatives on environmental issues. Moreover, grants or incentives or conference sponsorships should be provided for environmental research and publications which will encourage deeper engagement with the subject matter.

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CHAPTER 5
SUSTAINABLE ENERGY FOR ECONOMIC DEVELOPMENT IN AFRICA: THE ROLE OF CHEMISTRY IN ENERGY ACCESS AND SECURITY

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INTRODUCTION

A stable and sustainable source of energy will determine the economic growth and sustainable development of Africa. Nonetheless, millions of the African citizens are yet to receive good electricity and clean energy. This chapter elaborates how the field of chemistry is combating the challenges through more viable solutions that are low in cost, cleaner and less polluting, and locally focused. Some of the emerging technologies are solar materials, production technology of hydrogen, Bio to energy conversion, battery and fuel-cell technologies, which enhance efficiency in energy, reliability of storage supply, and offer new alternatives, which best suit the African conditions. It is also interesting in the chapter of the importance of chemical education, scientific research collaboration and industry partnerships as the driving force of innovation and developing local capacity to achieve sustainable growth. Coupling science with realities on the ground, chemistry has been able to make Africa realize a cleaner and auto-sufficient energy path. Last but not the least, the chapter stipulates that additional investment in chemical research, wiser policies, and more efficient intersectoral cooperation are needed to achieve energy security and attain ambitious goals such as the African Union Agenda 2063. Chemistry as a Strategic Agent of Change Chemistry as a strategy of promoting change in Africa people need to be made aware of this on a strategic level in promoting the sustainable energy path on this continent.

Despite the abundance of renewable energy sources (solar, wind, and biomass) in Africa, the continent still has to face significant energy limitations. It is estimated that 600 million people in sub-Saharan Africa do not have access to electricity and even with the available access, the power is often unreliable which hinders industrial development, limits education and healthcare opportunities, and contributes to poverty. Still, Africa has enough renewable energy potential to meet more than tenfold the existing electricity demand in the world, thus, providing a chance to avoid using the traditional energy model (African Development Bank, 2021). The provision of energy has become inseparable to the economic growth of a country and reliable energy infrastructure is crucial to industrial progress, agricultural performance and technical advancement. The World Bank (2020) notes that the countries having better energy access are more productive and competitive.

The switch to renewable energy that the International Energy Agency (IEA, 2021) promotes in Africa may not only give the region an economy boost but also alleviate environmental issues, therefore, making the continent a leader in the area of clean energy technologies.

1. ENERGY ACCESS IN AFRICA: CURRENT STATUS AND CHALLENGES

Energy access in Africa is in a critical state and access among the population (about 600 million people or 60 percent of the population) is estimated to be without electricity especially in rural areas with accessibility to below 20 percent. Geographic isolation, infrastructural development and underdevelopment of power grids contribute to this shortcoming. Also, most African nations fight with a lack of financial means and trained human talent to upgrade its antique energy infrastructure. This energy shortage negatively affects economic development, education and medical care (IEA, 2024; Collier & Cust, 2015). Nonetheless, the potential of Africa in terms of renewable energy is significant partially because it has the capacity to satisfy global power demand more than ten times (Sackey & Nock, 2022). The possibility to achieve energy security by deploying renewables at large scale would allow such societies to skip (or leapfrog) the deployment of fossil-based power systems in favor of clean, affordable and sustainable power technology.

1.1 Solar Power: Chemistry of Photovoltaic Systems

Solar energy has become one of the corner stones of sustainable energy propulsion and this has been facilitated mainly by the photovoltaic (PV) chemistry to a great extent. Silicon used in the majority of solar panels is the main product and is developed down to the finest detail to maximize its ability to turn sunlight into electricity. The repeated developments, including most notably the design of perovskite solar cells, have been changing all that, offering cheaper and more efficient alternatives to the older silicon-based devices. Excellent results have been demonstrated by a group of materials known as perovskites, which share a unique crystal structure, and are not only nearly as performative as silicon, but also cheaper to produce (Burschka et al., 2022).

Chemical processes like doping and surface passivation, have also significantly increased power conversion efficiency of silicon and perovskite solar cells making solar energy a formidable candidate in the market as the source of large-scale energy. The improvement in material science is necessary to achieve high efficiency of solar power and reduced costs which are essential to make solar power available to the developing countries, especially Africa.

The PV chemistry can be traced as the means of making solar energy a sustainable solution. Silicon still remains the king in this field, but perovskite solar cells offer cheaper and efficient alternatives (Bringing Solar Cell Efficiencies into the Light, 2014). Such materials have shown levels of performance more often in line with, and in some cases exceeding silicon, with the very significant difference being the cost of fabrication (Dale & Scarpulla, 2022). Wang and Su state that one more way to increase solar cell efficiency is to choose high refractive index (>3) and high transmissivity in 350-800 nm range dielectric materials (Wang & Su, 2014).

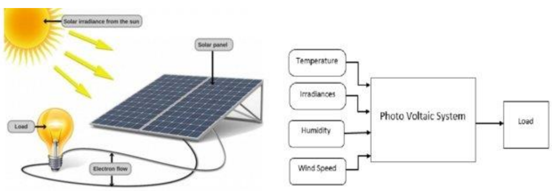

Figure 1. Solar Energy Conversion Process (Saleem et al., 2020)

The process of converting solar energy into electricity begins when sunlight strikes the surface of a photovoltaic cell. The semiconductor material absorbs the energy, causing electrons to be excited and flow, generating an electric current. This current is then captured and converted into usable electrical power.

1.2 Wind and Hydropower: Chemistry in Energy Conversion

The wind-driving and hydropower plants are dependent on the achievements in natural sciences and chemistry to achieve the highest efficiency of the energy conversion.

Blades of wind turbines are made of composited engineered material that prevents adverse weather conditions during operations but still manages to harness optimal power production using the wind energy source.

Advancement in the chemistry of these composites that is upgraded rein for a carbon fiber and epoxy resin matrices has allowed the creation of lighter, stronger, and more durable blades, which has promoted the fruition of increased energy output and reduced maintenance initiatives (Zhao et al., 2021). Hydropower systems, in their turn, rely on the existence of the parts which are able to resist the constant mechanical impacts of moving water. Turbine coatings and alloys have also been recently innovated and have led to efficiency and life of the system. Chemistry in every area determines the improvement in the performance and life of materials and therefore it increases the ability of wind and water to produce and store energy.

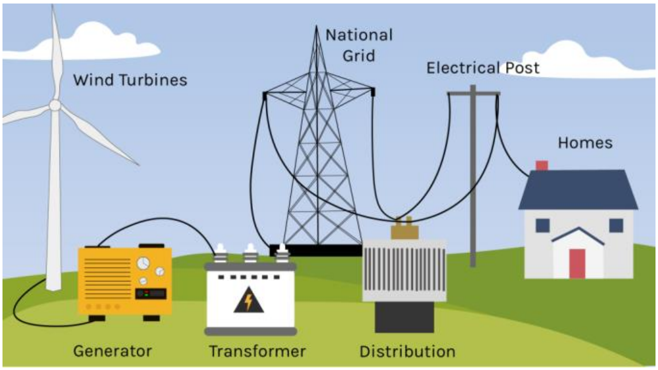

Figure 2. Wind Turbine Energy Conversion (Lindy energy 2022)

Wind turbines convert the kinetic energy of moving air into mechanical energy, which is then converted into electrical energy by the turbine's generator. The efficiency of this conversion is influenced by factors such as wind speed and the design of the turbine blades.

1.3 Biomass and Biofuels: Chemistry of Sustainable Alternatives

Birth fuels and other biological materials make a good alternative to conventional systems of energy, especially in the rural settings where access to electricity is limited.

Substantial developments within the chemical field have allowed the use of organic sources to be converted into biofuels i.e. agricultural residue, woody biomass and algae. These processes normally entail the breakdown of complex biomass materials to be converted to sugars through the process of hydrolysis and later through fermentation of the sugars, ethanol or biodiesel is recovered (Zhou et al., 2023).

Advance in catalytic strategies and enzyme designs has significantly improved the efficiency and cost-effectiveness of bioFuel production and has increased energy outputs through the use of fewer inputs. Biomass is therefore not only a source of renewable energy but also a source of income to the rural communities in Africa who in most cases depend mainly on agriculture as a way of earning a living.

Biomass-derived energy has the potential to simultaneously increase energy access and economic growth in these areas, as organic waste can easily be used as the source of fuel by using the locally available sources. Also, biofuels will reduce the dependence on fossil fuels and thus can help in the global fight against climate change.

Table 1. Biofuel Production Methods (Author's compilation based on literature review)

Biofuel Type	**Feedstock**	**Conversion Process**	**Energy Output**	**Environmental Benefits**
Ethanol	Corn, sugarcane	Fermentation	16 MJ/L	Reduces greenhouse gas emissions compared to gasoline
Biodiesel	Vegetable oil, animal fats	Transesterification	35 MJ/L	Lower emissions of particulate matter and sulfur
Biogas	Organic waste (e.g., manure, food scraps)	Anaerobic digestion	20 MJ/m³	Reduces methane emissions from landfills

2. ENERGY STORAGE SOLUTIONS: THE CHEMISTRY BEHIND ENERGY SECURITY

The technologies of energy storage are a key towards ensuring the maintenance of energy security and towards ensuring the optimum uses of renewable energy sources. With the consequent growing global demand to utilise sustainable energy, the further development of innovative energy storage systems obtains special importance regarding the integration of intermittent resources, which include solar irradiance and wind energy.

Additionally, chemical science also holds a front and center role in enhancing performance, performance and life of the storage technologies hence guaranteeing efficient conversion, maintenance and redistribution of electrical energy. The current discussion explores the major categories of storage mechanisms and explains the chemical principles that drive them, and evaluates the modern developments which are driving improvements in energy security.

2.1 Batteries and Energy Storage Technologies

The key aspect of the modern energy infrastructure is energy storage systems, as they allow storing electrical energy generated using renewable energy technologies and then releasing them back. The most competent battery technologies being used to perform those functions are lithium-ion, sodium, and flow batteries, which have become the standard bearer of large-scale stationary needs. Lithium-ion (Li-ion) batteries are the most common energy-storage technology, especially in consumer electronics and electric vehicles, and in grid-scale applications. They are mostly premium due to the electrochemical properties of lithium, which enable its ability to support high-capacity energy density and support fast and efficient charge and discharge cycles. These processes occur in a conventional Li-ion cell in which the lithium ions move the anode to the cathode. The overall performance profile (capacity, cycle life and safety parameters) is defined by the chemistry of lithium-containing electrode materials, e.g., lithium cobalt oxide ($LiCoO$ 2) cathode and graphite anode. The soaring energy density and life of Li-ion batteries have been significantly improved owing to recent discoveries in material science, especially due to the production of solid-state electrolytes and an advanced cathode structure (Nagaura & Tozawa, 2023).

Such batteries remain, thus, the most common due to the electrochemical characteristics of lithium (Yu et al., 2019). The performance depends directly on what lithium-based electrode materials were chosen, in this case, $LiCoO_2$ cathodes and graphite anodes (Manthiram, 2017). The current research concentrates on solid-state electrolyte and optimized cathode structures in order to increase further the energy density and durability. More specifically, the replacement of lithium metal as the anode may bring about an estimated 20 % enhancements in the energy density (Ulvestad, 2018).

Sodium-Ion Batteries; The market of energy-storage is now dominated by Lithium-ion (Li-ion) batteries, but the sodium-ion (Na-ion) technology is catching up, especially with massive applications. The fact that sodium is abundant and relatively cheap in comparison to lithium implies that the cost of producing batteries may be reduced. The electrochemistry of sodium is analogous to lithium however the bulky sodium ions present limitation to the battery capacity due to engineering consequences. New research aims, therefore, at finding materials that could accommodate those ions and maintain high capacity and durability. Cathode sodium manganese oxide ($NaMnO_2$) and sodium iron phosphate ($NaFePO_4$) compounds among others have shown potential as cathodes materials in Na-ion cells, with interesting performance-cost balances (Goodenough, 2021). Na-ion development is therefore a stepping stone in development of significantly lower priced scalable energy-storage solutions to grid applications and integration of renewable energy.

Flow batteries are another investment prospect, especially when it comes to implementation on a large scale. These technologies do not use solid electrodes to store electricity, and instead of using them, they have liquid electrolytes which flow in and out of the system. This construction detail makes it easy to scale, making flow batteries a good candidate in grid-scale storage. By way of chemistry, flow batteries make use of redox reactions where both the oxidation and reduction of species used in the electrolytes support the charge and discharge functions. The most widely researched is the vanadium redox flow battery (VRFB) whose main energy carriers are the vanadium ions in different oxidation states. Flow systems are likely to have long cycle lives, and less degradation, compared with solid-state batteries.

Due to the modular structure, it is easy to scale up the storage capacity to satisfy the increased request (Zhao et al., 2022).

2.2 Grid Storage and Smart Grids

The integration of renewable energy sources with power grids requires advanced, grid-scale storage technologies that can overcome the intermittent nature of solar and wind generation. The development of economic, large-scale storage facilities capable of storing excess energy and releasing it when demand is high or renewable generation is limited relies heavily on chemical processes. The production of energy-storage materials that can store energy over hours or even days is central to chemical science, with prolonged storage being essential for grid-scale operations where robust cycle life and large energy density are critical (Ni, 2024). Traditional pumped-hydro generation remains a feasible standard but is limited by geographical and space constraints. In contrast, new chemical storage innovations such as metal-air and flow-battery systems present viable pathways for mass implementation. Metal-air batteries, for example, utilize atmospheric oxygen as the cathodic reactant during discharge, giving them lightweight characteristics and high energy conversion efficiency (Zhang et al., 2023). Multi-day storage technologies such as iron-air batteries are also emerging as cost-effective solutions, offering long-duration energy supply with lower material costs than lithium-ion systems (Form Energy, 2024).

Ongoing research on grid-scale chemistries including lithium-sulfur and sodium-sulfur batteries—focuses on achieving greater system-level efficiencies, reducing material expenses, and enhancing storage capacities. Recent reviews have emphasized that Li–S batteries, with their theoretical energy density of 2600 Wh kg^{-1}, are promising candidates for grid applications, though challenges of cycle stability and polysulfide shuttling remain under active investigation (Tao et al., 2024).

Smart grids form another pillar of the modern energy infrastructure, designed to maximize electricity flow and increase overall system efficiency. Their technological architecture depends strongly on advances in chemical science, particularly in materials for sensors and protective compounds that enable accurate metering, energy accumulation, and dynamic adjustment of storage and distribution. With real-time, bidirectional communication protocols, smart grids facilitate information exchange between producers, storage infrastructure, and end-users, enabling dynamic control of electricity flow and balancing supply and demand (Wevo-Chemie, 2024).

This functionality supports the smoother integration of renewables, allowing excess energy generated during peak times to be stored and later discharged in response to demand fluctuations. The interplay of smart grids and innovative storage technologies therefore enhances grid resilience and strengthens energy security by reducing variability in renewable generation (Ni, 2024).

3. GREEN CHEMISTRY FOR SUSTAINABLE ENERGY PRODUCTION

The transition of the anthropogenic climate change is one of the most critical steps to limiting anthropogenic climate change that need to be done to preserve the health of the environment in the long run via sustainable energy generation. The role played by green chemistry in this transition is undecided as its focus has been in designing and optimizing energy-generating processes to reduce waste, minimize use of energy, and decrease any undesired emissions. Once green-chemistry concepts are integrated into the energy systems, the amount of environmental impact the renewable energy and the conventional energy sources might have may be significantly minimized, and energy generation will occur on a more sustainable level to the ecosystems and human lives. The chapter at hand thus reviews the cardinal principles of green chemistry, how they can be applied in energy generation, and how far along current sources of cleaner energy are in redefining modern-day energy as we know it today.

In the context of the green chemistry, the twelve principles are developed on the basis of the goal of maximizing the ecological conscientiousness of the chemical practices. Upon the energy production these precepts focus on the minimization of wastes, reduction of the energy-intensity, and development of technologies which do not cause environmental impact.

Minimizing Waste and Energy Use in the Production of Energy

The principle of waste minimization is an ultimate tool in the scope of green chemistry which would optimize the production of energy (Morais & Bogel-Łukasik, 2013).

This is aimed at optimizing the energy production and at the same time limiting the production of wastes by implementing energy production routes that are efficient in the process of fuel extraction and conversion to energy. Tsegaye et al. (2021) point out the need to reduce the formation of waste during processing and manufacturing to ensure a more considerable preservation of the value of the products in a circular bioeconomy. Furthermore, the use of renewable feedstocks in combination with closed-loop models of operations not only reduces shift toward nonrenewable resources but also decreases the cumulative environmental burden (Clauser et al., 2021).

Design of Energy Systems with Reduced Environmental Footprints

Green chemistry is a catalytic scientific field, and the main theme of research is the concept of energy systems with the reduced dependence on the adverse impact on the environment. These systems are supposed to utilize renewable feedstock, use small quantities of energy during production, and produce minimal wastes. Examples of application can be seen in catalytic material optimization to fuel cells as well as photovoltaic devices. The requirement of the energy conversion efficiencies increases through these catalyst agents and consequently, the amount of heat-loss reduces and the degree of dependence on the extraction of resources decreases.

Compatible initiatives relate to the extension of energy-saving storage capacities. Systems with high-tech batteries or supercapacitors allow storing energy over a long time and implement effective application thanks to the availability of sufficient capacity when the demand level is high. In this regard, chemistry has been decisive since it will guarantee stability and high conductivity of the materials which will make long-term performance without extensive environmental impact. Sustainable energy in green chemistry favors feedstocks that are renewable, energy requirements in production is less and pollution is lesser.

Study reveal that the efficiency of energy production may be increased through advanced catalysts, whereas (Gouda et al., 2020, Hassaan et al., 2023) emphasize the transition to clean, conversion, and storage technologies, which are clear conversion fuel cells.

Wang et al., (2021) also examine how to optimize the sulfonic groups on a polymer to coat zinc anodes to allow dendrites to be suppressed.

Cleaner Energy Production Processes

The cleaner energy production process is an avenue that cannot be achieved without innovation. These innovations are normally non-conventional technologies and materials that have been designed in such a way that they have a reduced impact on the environment and lower the use of carbon.

Innovations in Cleaner Methods for Oil, Coal, and Gas Extraction

Oil, coal, and gas extraction with a help of the classical techniques are not energy-saving, and produce large volumes of wastes and pollution. Developments in green chemistry have, however, motivated the development of innovations so as to accomplish the same extraction procedures as extensively cleaner and more productive. New types of carbon capture and storage (CCS) are being developed to capture CO_2 emissions when fossil fuels are extracted and burnt and they are not released into the atmosphere (Kern et al., 2023). In addition, environmental effects of using greener solvents and chemical additives in oil extraction is lower than that of traditional methods that use chemicals that are hazardous to the environment and are associated with large-scale wastes.

The next breakthrough is the invention of clean coal technologies whose approach is the reduction of emissions by either maximizing the efficiency of the combustion process or by gasifying the coal in order to achieve cleaner fuels. These approaches are guided by the principles of green chemistry that can lead to the enhancement of catalytic process and end with increased energy use and decreased harmful by-products.

3.1 Role of Green Chemistry in Reducing Emissions from Traditional Energy Systems

The second major mode of mitigation of the emissions intensity of the traditional energy infrastructure would be green chemistry. By improving combustion technology to attain an increased level of combustion efficiency, scientists will be able to reduce the emission of carbon dioxide and other air pollutants through the production of energy. As an example, invoking green chemistry measures in the context of catalytic combustion conditions leads to a decrease in the temperature of fossil fuel combustion, meaning there is a minimization of nitrogen oxides (NOx) and sulfur oxides (SOx) synthesis as well as particulate matter. In line with this, development of the fuel additives and combustion catalyst will lead to in propulsion of fuel efficiency and decreasing the emissions thus minimising the negative effect of usage of fossil fuels on the environment. Accompanied by these developments, green chemistry is also triggering the advent of alternative fuels that can effectively replace traditional fossil hydrocarbons. An example of a renewable and, relatively, clean alternative to gasoline and diesel is biofuels made out of plant-based feedstocks or algae. Synthetic chemistry of biofuel production is aimed at optimizing the yield, increasing energy density, and the need to stay away from the harmful by-product. This advance is essential to reducing the carbon footprint of the transportation and energy domains which rank among the leading sources of greenhouse gas emissions in the world.

4. CHEMICAL INNOVATIONS IN ENERGY EFFICIENCY AND CONSERVATION

A global increase in energy demands and an increased sense of sustainability have brought the need to come up with energy efficient technologies and materials and chemical innovation plays a central role in having the technologies and materials to be used in energy efficiency as well as incorporation of climate change. The present discourse analyses the new developments achieved by chemically driven methodologies, especially the field of building construction and construction infrastructures, as well as large scale industries. The chapter thus outlines how chemistry plays a key role towards promoting conservation of energy in these sectors.

4.1 Energy-Efficient Technologies: Chemistry at the Core

Advances in energy-efficient technologies are often underpinned by chemistry, as new materials and chemical processes enable the development of appliances, lighting, and construction materials that consume less energy while maintaining or improving their performance.

Sustainable economic development boils down to reducing the energy used and two main approaches are energy-efficient appliances and lighting systems. The background chemistry behind these advances is synonymous with advanced material synthesis and new chemical process. In lighting, the gradual retirement of incandescent light bulbs to the compact fluorescent lamp (CFL) and, more recently, the light-emitting diode (LED), is as direct a result of advances in the science and chemistry of materials as can be found in lighting. LEDs use semiconductor materials, like gallium nitride (GaN), to provide greater electrical to light conversion capabilities, hence reducing the operational energy requirements in lighting by about 80 percent with respect to the standard bulbs (Shao, 2023). The associated effect of these innovations is extending the life span of luminaires, reducing the frequency of the replacement, as well as limiting the production of waste.

In terms of household appliances, energy efficient motors, compressors and heat exchangers have been optimised in a drastic way which means that they use power reduced dramatically when it comes to refrigeration, heating and cooling. An example is that the use of refrigerants of lower global warming potential (GWP), such as hydrofluoroolefins (HFOs), has low environmental consequences and has enhanced more efficiency in the refrigeration technology (Parker et al., 2022). Complementary development of assistive cooking appliances, e.g. induction cooktop, involves magnetic-field-based heat transfer coupled directly to the cookware and thus maximizes energy use and reduces the loss as waste heat.

Through their chemical properties, building materials have advanced accordingly as production of highly efficient thermal insulators including, aerogels and vacuum-insulated panels (VIPs) is already achieved. Such materials with very low thermal conductivities provide more excellent insulation, and thus, there is less energy requirement to heat and cool buildings.

At the same time, the progress in the area of reflective coatings and smart glass, whose opacity varies with the temperature and solar radiation, promotes the passive means of thermal control, which additionally promotes energy efficiency of buildings.

4.2 Chemistry of Heat Management and Insulation Technologies

To optimise trade offs between energy efficiency and energy performance of buildings and industrial systems the management of thermal energy is necessary as a strategic variable. Scientifically, these issues are related to the development of high-performance combinations that reduce heat dissatisfaction and at the same time support the retention of warmth. An outstanding instance is the use of phase-change materials (PCM), chemical agents that either absorb or release thermal energy together with their phase transformations as they transition between the solid and the liquid phase. Being able to harness energy when it is hot and releasing the heat when it gets cold, PCMs allow a more comfortable interior without the use of extraneous heating or cooling facilities.

Other unconventional insulation systems (e.g. spray foam and cellulose) have also been chemically optimized to increase the thermal resistance of such systems to limit the amount of energy needed to maintain the desired temperature. These manufactured materials have incredible expansion capabilities which allow them to fill intricate structural gaps thus giving them the ability to give top performance insulation despite relatively slim details. Together, these chemical developments are strengthening energy efficiency on homes and industries and are simultaneously supporting manufacturing sectors to reach lower consumption of energy, as well as, lower their organizational costs.

The creation of sustainable energy systems goes beyond the development of energy-efficient technologies. It involves the design and implementation of systems and infrastructures that prioritize long-term environmental sustainability. Chemistry plays a crucial role in the materials and processes used to build energy-efficient buildings, infrastructure, and renewable energy systems.

4.3 Materials and Chemical Processes Involved in Creating Energy-Efficient Buildings and Infrastructure

Coming up with energy efficient infrastructure must involve integration of new materials and energy saving chemical processes that enable reduction of energy usage throughout the lifecycle of a building. Building with organic material- Bamboo, recycled steel and low-carbon concrete are being introduced to reduce the environmental footprint of construction. One of these attempts is a closer focus on the green chemistry, which helps to streamline the production procedures, reduce energy demand, and the usage of hazardous chemicals (Zhang et al., 2023). Using alternative materials utilization as an example, low-carbon concrete classifies concrete concrete that utilizes different binders, such as fly ash and slag, to reduce the quantity of cement required, lowering the carbon footprint of construction, as a whole.

In addition to the choice of material, chemical processes are unavoidable in the set up of energy efficient infrastructure. Innovation and implementation of renewable energy technologies, such as solar, wind, and geothermal power requires use of advanced materials that can convert and maximize energy terms. Chemical developments - photovoltaic cells in particular - have allowed more efficient solar panels, new materials like perovskites improve performances and make panels cheaper to produce. This has been accompanied with similar progress in the manufacture of wind turbine blades made of a composite of both strength and lightweight materials which in turn has increased the effectiveness of the wind energy systems as the blades are able to extract more wind energy with less material.

Incorporation of chemical procedures that could enhance the functioning of energy storage systems such as batteries and supercapacitors is also of utmost importance in the development of a stable and sustainable energy system. Advances in battery chemistry, most notably lithium-ion and sodium-ion grid energy storage, have resulted in an increased capacity to store sunshine and wind when it is produced, and use it when demand is high or renewable resources are low.

5. ENERGY SECURITY AND THE ROLE OF CHEMISTRY IN POLICY DEVELOPMENT

Energy security is a basic determinant to long-term economic and social growth and in particular in Africa where there is often a limited capacity to deliver reliable, affordable and sustainable energy. The revolutionary role of chemistry in addressing these challenges is even being brought to the recognition. Energy resources Chemical advances have the potential to increase the range of energy resources, improve the capacity of energy storage, and optimise the efficiency of the total energy system. In this light, this chapter presents an overview of energy-security issues facing Africa, a look at how chemistry can be used to counter them through innovation, and suggests policy frameworks that can promote the involvement of chemistry in the provision of sustainable energy.

5.1 Energy Security Challenges in Africa

The African continent faces persistent energy-security challenge, especially the lack of infrastructure, poor access to electricity together with heavy dependence on the traditional biomass fuels. It is estimated that 600 million Africans are living without the access to electricity and most of them cook by dangerous means using wood and charcoal. Furthermore, most of the countries in the region still rely on fossil fuels in energy production, leaving them much at the mercy of worldwide market fluctuation and left to foot the environmental hazards. Making matters worse is lack of expertise to develop infrastructure to generate, transmit and distribute energy as well as the financial resources to undertake this process. Such weak areas are further exacerbated by unstable politics, regulatory walls, and failing to integrate in the region in terms of energy (Fikir & Abebe, 2020).

Transitioning to alternative energy hence plays a very important role in the energy security and climate resiliency. Chemistry has a huge role to play in solving those problems through providing diversification, increasing efficiency and developing locally sourced sustainable energy technologies. With the help of green-chemistry principles, African nations can improve their energy security, as well as minimize environmental consequences of production and consumption reduction (Nnaji & Igbuku, 2018).

5.2 Role of Chemistry in Addressing Security through Diversification of Energy Sources

Chemistry plays a critical role in the African attempts to diversify energy mix and enhance energy security. Solar, wind and biomass are renewable forms of energy and their potential is huge enough and so they can satisfy energy needs in the continent.

The relatively new development in materials science and processes, especially the introduction of perovskite and organic photovoltaic cells have increased the efficiency and feasibility of solar energy products. Similarly, improvement in wind and hydroelectric systems, such as enhancing materials to be used in turbine manufacture and energy storage methods can uplift reliability of such resources in Africa.

Biofuels made of agricultural waste or algae are examples of bioenergy that present green alternatives to fossil fuel. With directed investment in such technologies of chemicals, African countries can reduce the use of the imported energy sources, create new industries, and boost the economy, especially in rural areas, which do not have sufficient infrastructure. Poor infrastructure and persistent reliance on conventional biomass are a collective danger to the energy security in Africa.

Green chemistry as used in energy plans has the potential to broaden the energy portfolio and further increase energy efficiency so that locally available and sustainable technology can be achieved. The importance of sustainable chemistry as a necessary development tool is emphasized by Nnaji and Igbuku (2018), whereas Mathu (2014) states that South Africa needs to green its coal supply chain, and this should be pursued on the basis of joint efforts between governmental agencies and the industry.

To effectively address Africa's energy security challenges, policy frameworks must support and promote the role of chemistry in energy production, distribution, and storage. Policymakers should focus on fostering an environment where innovation in energy technologies can thrive, ensuring that the chemical innovations required to enhance energy security are supported by adequate resources, regulations, and infrastructure.

5.3 Policy Frameworks That Support Chemical Innovations in Energy Production and Distribution

Policies that emphasize research and development (R&D) of energy technologies cannot be avoided in reducing innovation along with developing chemical solutions that can help in improving energy security. Governments are thus encouraged to invest in e-education, training and research center in the field of chemistry and materials science thus building domestic capacity that can solve the Africa energy problem.

The development of large-scale renewable-energy projects, energy-storage systems, and grid modernization also requires the public-private partnership so that these solutions are more available and less expensive to the African countries.

Laws and regulations should also be laid down to facilitate the incorporation of the renewable energy to national grids and ensure the generation of the required capacity to store and distribute energy. Incentivized policies on cleaner and more efficient technologies-like the use of electric vehicles and systems powered by sun-have the possibility of speeding healthcare innovation and reducing costs to the environment at the same time.

At the same time the government should make efforts in eliminating administrative hindrances that stand in the path of developing local energy industries. Making licensing easier to renewable-energy projects, subsidizing or giving renewable-energy investments tax breaks will relieve any hesitation or concern the local and international firms have about investing in the energy sector of Africa, thereby, making the production of an energy market that is sustainable and self-reliant much easier.

Long-term stability and security of energy in Africa is pegged on domestic production and innovation. Development of indigenous energy technologies can help reduce the over dependence of the continent countries on the imported energy infrastructures which are prone to being disrupted by external forces acting outside the country. In particular, local capacity is strengthened by policy incentives, including grants on research and development applied to energy-related chemical innovations, and the resulting development of the renewable energy sector.

By encouraging the production of solar panels, windmills, and biofuels, it does not only create job openings but also spurs economic growth as it not only offers energy but also energy as dictated by the environment in the region. At the same time, the development of an advanced local innovation in energy-storage equipment, such as batteries and supercapacitors, strengthens the confidence of the renewable energy system, partially reducing the challenges of intermittency.

6. THE FUTURE OF CHEMISTRY IN SUSTAINABLE ENERGY DEVELOPMENT

The world demand that climate change be addressed and sustainable energy goals achieved has placed chemistry at the forefront of innovation that has the capacity of reshaping the energy paradigm. In sub-Saharan Africa where energy supply has been limited and the infrastructure dated; sustainable energy can only be achieved through further development in chemistry that utilizes renewable resources, increases the energy efficiency, and boosts economic growth. This chapter offers some overview of advances in sustainable energy technologies, stresses the importance of research and development (R&D) effort, and emphasizes the need of cross-continental cooperation in shaping future African energy path.

Emerging Technologies

The development of new energy technologies is critical to achieving a sustainable and secure energy future. Several emerging technologies, driven by advances in chemistry, have the potential to revolutionize Africa's energy sector and offer solutions to the continent's unique challenges.

Advances in Hydrogen Fuel Cells

Fuel cells that use hydrogen are another interesting clean energy technology that have the potential of reducing the use of fossil fuels significantly. These systems produce electricity, the source being an electrochemical reaction that requires hydrogen gas, but which produces neither any harmful byproduct nor any waste, but water and heat.

New technologies in hydrogen production, storage and fuel-cell efficiency have been making large-scale applications very plausible. Of especial interest is green hydrogen that is produced with renewable energy sources and is particularly beneficial in decarbonizing heavy transportation and industrial processes sectors that are more difficult to electrify. Africa provides an area where hydrogen fuel cells can likewise provide a sustainable energy source especially in areas where renewable resources (including solar and wind) are abundant as in these areas' hydrogen can be produced and in-place locally and utilize to not only generate power but also to transport it.

Algae-Based Biofuels

Biofuel formed with algaes is a more and more noticeable alternative to standard biofuels made using crops like corn or cane sugar. The Algae farming produces high amounts of lipid, which can be further processed into biodiesel and other fuel carriers. Based on the fact they can be cultivated on non arable land, they also find further potential in the re-use of wastewater, thus providing sustainability and an environmentally sound source of fuel.

Advances in genetic engineering and fermentation process are improving algae production and efficiency of conversion to biofuel. In the case of rural parts of Africa, where the traditional energy structure is sparse, algae biofuels can provide a much-needed solution to the process of making the country less dependent on the importation of fossil fuels, whilst at the same time generating entirely new sources of agricultural opportunities.

Elegbede and Guerrero (Elegbede & Guerrero 2016) argue that the algae biofuel cannot be left out of the bioenergy landscape in Nigeria. (Khoo et al. 2023) confirm that microalgae are capable of converting solar energy and atmospheric CO_2 to produce energy rich metabolites-starch and lipids which can then be animated into a variety of biofuels types.

Research and development are fundamental to unlocking the full potential of chemical innovations in energy production and storage. For Africa to achieve sustainable energy development, substantial investment in R&D is essential to develop new technologies that are both effective and contextually appropriate for the region.

6.2. Importance of Investment in Chemical Research for Energy Solutions

Continued research investment in chemicals is critical in coming up with energy solutions that would solve the unique energy related issues in Africa. African countries can develop in-country low cost and environmentally friendly approaches through the focused work in the field of materials science, energy storage, and approaches to renewable-energy technologies. Research on local sources-biomass, solar and wind, may result into innovations that are in line with the region geographical and economical setting.

In addition to this, the chemical research can improve the efficiency of the existing energy systems and reduce the environmental externalities of such systems. Innovations in the field of catalytic technologies provide opportunities to breakthrough cleaner traditional fuel consumption (coal, oil), and technological achievements in chemical technologies in carbon capture and storage are tasks that continue to expand the environmental field of power generation thermal power plants, but through the mechanism of fossil fuel utilization.

Collaborations between African countries, international organizations, and research institutions; Cooperation amongst states within Africa, as well as with external organizations and research centers is the essential minimum to the creation of sustainable energy technologies. The stakeholders can overcome technical and financial challenges toward innovation within the energy sector through sharing of knowledge and resources. Memoranda like those of International Renewable Energy Agency (IRENA) and the African Union can be called as effective platform to exchange best practices and to adjust energy solutions to the local conditions.

Moreover, the external partnerships also provide essential funds, transfer of technology, and capacity-building activities, which are crucial in enhancing energy research and development along African continent. The case of South Africa, Kenya and Morocco which have become recognizably mainstreams in the use of renewable-energy are worth emulating as the patterns that can be emulated by the other African states.

CONCLUSION

Chemical research is the key to the achievement of sustainable energy solutions in Africa. The emerging technologies such as the use of hydrogen powered fuel cells, algae fuel manufacturing, and the new solar cells will redefine the energy industry in the continent bringing into it cleaner and more efficient energy sources.

Continuing investment in the research and development of chemicals is thus an essential element in creating such technologies and in the improvement of Africa distinctive energy security drivers. Combined efforts of African countries and other global organisations and research centres allow the region to support the idea of energy potential and dream of the sustainable, secure, and inclusive energy future.

Strategic recommendations for integrating chemical innovations into Africa's energy policies include: Support Local Innovation; Strengthen Regional Cooperation; Promote Education and Training.

Policymakers, business executives, and scholars should work together to foster innovation on energy solutions that seek not just to promote sustainable development of energy in Africa but also provide answers on global energy challenges. Policies need to be established by the governments favoring the renewable energy sector, enable them to reduce the regulatory hurdles, and invest more on sustainable technologies.

Green energy should be advocated by the leaders in the industry and the scholars should keep researching along the field of viable chemical energy systems. These stakeholders together can create an environmentally sustainable future based on energy in Africa to the benefit of both the economy and the environment.

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CHAPTER 6
ENERGY GEOPOLITICS: CASE STUDIES FROM THE EASTERN MEDITERRANEAN, CENTRAL ASIA, AND THE RUSSIA-UKRAINE WAR

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INTRODUCTION

The human microbiome is a complex and dynamic ecosystem that plays a crucial role in maintaining health and influencing disease susceptibility. This vast community of microorganisms, including bacteria, viruses, fungi, and archaea, is found in various locations of the human body such as the gut, skin, oral cavity, and respiratory tract. The gut microbiome, in particular, has garnered significant attention due to its involvement in digestion, immune modulation, and metabolic functions (Ogunrinola et al., 2020).

In an era marked by accelerating energy transitions and intensifying global power shifts, energy geopolitics has re-emerged as a critical lens within the field of International Political Economy (IPE).

This chapter explores the intersection of energy, state behavior, and global political-economic dynamics through three key geopolitical case studies: the Eastern Mediterranean, Central Asia, and the Russia-Ukraine War. These regions exemplify how access to and control over energy resources—particularly natural gas and oil—serve not only as economic assets but also as strategic tools of influence, negotiation, and conflict.

The chapter begins by establishing a theoretical framework grounded in critical and realist perspectives of IPE, which help explain the motivations of states and the structural asymmetries in global energy politics.

The Eastern Mediterranean case explores overlapping maritime claims and energy disputes involving Türkiye, Greece, Israel, and Egypt, highlighting how new gas discoveries are reshaping regional alliances and legal frameworks. In Central Asia, the chapter analyzes pipeline diplomacy and competition among major powers—particularly China, Russia, and the West—for influence over energy corridors and resource flows.

The Russia-Ukraine conflict serves as a dramatic example of how energy can be weaponized in modern warfare, examining Europe's energy dependency, the politics of gas sanctions, and the reconfiguration of global energy supply chains. Drawing on a wide range of empirical data, policy reports, and institutional analysis, this study emphasizes the centrality of energy in shaping contemporary international relations and global economic structures.

It concludes by reflecting on the broader implications of these regional dynamics for energy security, multilateral governance, and the evolving architecture of global power in a decarbonizing world.

The true currency of international power is no longer gold or weapons—it is energy. Energy, which is the ability to exert a force causing displacement of an object, has advanced from merely being an economic commodity to the defining pillar of international relations and power politics or better classified as energy geopolitics.

Energy geopolitics is the study of how global energy supply, demand, and distribution intersect with political, economic, and security issues (Högselius, 2018). Nations are increasingly leveraging access to and control over energy resources as strategic instruments to assert influence, negotiate alliances, or gain geopolitical advantage.

This argument is further strengthened in regions where fossil fuel reserves, critical energy infrastructure, and transit routes intersect with competing national interests. Additionally, it paints the picture of oligopolistic global markets where importers hold strategic reserves, diversify imports in terms of sources, origins, and routes, and work with diverse contract portfolios, and where exporters try to generate as much revenues from exports as possible and share an interest in safe transport infrastructure with importers (Scholten, 2024).

In a nutshell, countries that possess copious amounts of energy often wield disproportionate influence on the global stage, while those dependent on imports remain vulnerable to external pressures.

This structural asymmetry of global energy politics not only fuels the regional tensions but also shapes the foreign policies of major powers, as seen in the energy-dependent Europe's response to the Russia-Ukraine conflict, or China's increasing investments in Central Asia's pipeline networks (all these major energy flows displayed in Figure 1).

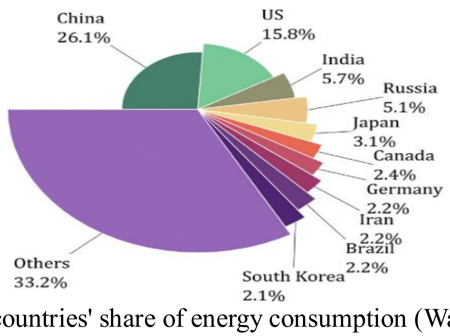

Figure 1. Ten countries' share of energy consumption (Wang et al., 2023)

Strikingly, in the 21st century, energy geopolitics has entered a new chapter in its long history (Scholten, 2024). A multitude of challenges, climate change and energy security being the largest, urge for a global shift to renewable energy sources and broader decarbonisation measures. Such a transition implies big changes to energy systems, markets, and trade flows, and in turn industrial opportunities and political dependencies (Scholten, 2024). Thus, nations are increasingly leveraging access to and control over energy resources as strategic instruments to assert influence, negotiate alliances, or gain geopolitical advantage.

In order to fully grasp the geopolitical implications of energy in today's world, it is essential to ground this analysis within the critical and realist traditions of International Political Economy (IPE). IPE studies the reciprocal relationship between politics and economics in the global system (Walzenbach, 2022) and the energy sector stands as one of the most prominent arenas where this interplay is visible enacted. IPE carries two dominant theoretical perspectives – realism and critical theory – which offer diverse yet harmonizing insights into global energy order.

From a realist or neomercantilist point of view, energy is a vital component of national power. Realism, also known as political realism, is a view of international politics that stresses its competitive and conflictual side (Stanford, 2010). It views the global economy as an arena of state-centric power struggles, where nations prioritize their own interests and seek to maximize their power and security - represented by the founding fathers Thucydides, Machiavelli and Hobbes (Stanford, 2010).

Therefore, states are seen as rational actors competing to secure long-term access to energy in order to protect national sovereignty and sustain economic growth. This theory emphasizes energy security, control over supply routes, and state-centric strategies such as energy diversification and the pursuit of energy independence. For example, Russia's control over natural gas pipelines to Europe or China's Belt and Road energy investments illustrate how energy infrastructure and supply chains are closely tied to strategic geopolitical goals (geopolitics explains how countries try to reach their political goals by controlling geographic features of the world).

On the contrary, the critical or structuralist perspective in IPE goes beyond traditional mainstream approaches and underscores the asymmetrical power relations and structural dependencies embedded in global energy markets. It examines how power structures, social inequalities, and ideologies shape international economic relations.

Referring to Marxist and neo-Gramscian school of thought, critical theorists argue that dominant capitalist states & multinational corporations are in favour of energy governance as they benefit from the resource extraction and trade at the expense of less powerful, resource rich nations.

This outlook draws attention to issues such as the environmental degradation of extractive industries, the exploitation of the Global South, and the reproduction of colonial patterns in the emerging green economy. Rather than viewing the energy system as a neutral or purely economic domain, critical scholars see it as deeply political and shaped by historical injustices and institutional power imbalances.

On that account, energy's centrality in IPE is because it underpins modern economies and is essential for various human activities, from basic necessities to industrial production. It's a key factor in national and international security, affecting geopolitical relations and international trade.

Understanding energy dynamics is vital for analyzing the global political economy, including issues like energy security, resource allocation, and the impacts of climate change (Goldthau; Kuzemko; Belyi; Keating, 2012). Few exemplars include:

- Control over energy flows translates into political leverage, particularly when energy is weaponized—as seen in the Russia-Ukraine conflict, where gas supplies became instruments of coercion and resistance.
- Energy markets do not operate in isolation from global politics; they are shaped by a complex web of political alliances, trade agreements, national energy strategies, and international regulatory regimes.
- Sanctions on oil-producing states, bilateral pipeline agreements, and subsidies for fossil fuels or renewables all demonstrate how states and institutions actively shape energy outcomes in pursuit of strategic interests.

As seen from above, the functioning of energy markets is not governed solely by supply and demand. There are innumerable factors in play: political decisions, military conflicts, and institutional arrangements play equally influential roles.

As a case in point, OPEC (Organization of the Petroleum Exporting Countries), an intergovernmental organization of 13 oil-exporting nations that aims to coordinate and unify petroleum policies to ensure stable oil markets and secure supplies {critical IPE theory}, was a form of political coordination to alter global price mechanisms (Hill; Comstock, 2023).

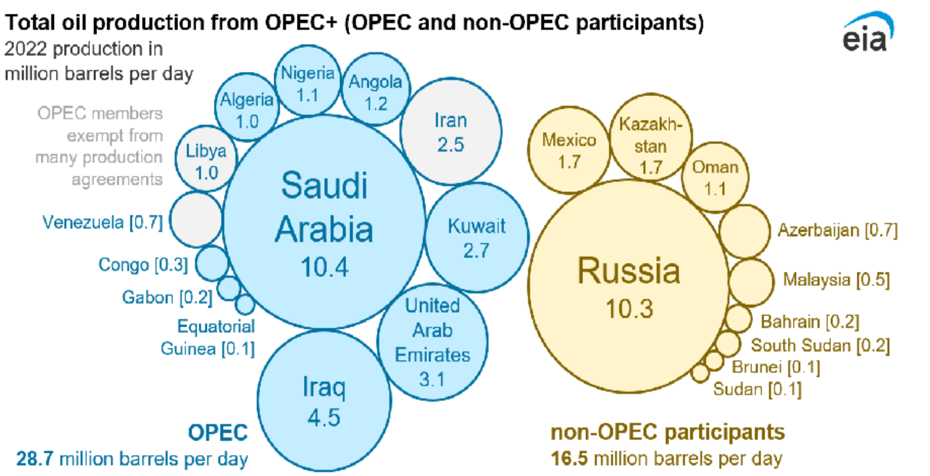

Figure 2. OPEC oil production (U.S. Energy Information Administration)

Similarly, sanctions on countries like Iran and Venezuela disrupt global supply chains irrespective of market demand. Energy is also deeply affected by national policy choices; governments subsidize certain energy forms, protect domestic industries, and promote or hinder transitions to renewables, thereby influencing both market behaviour and geopolitical alignments (Cano, 2025).

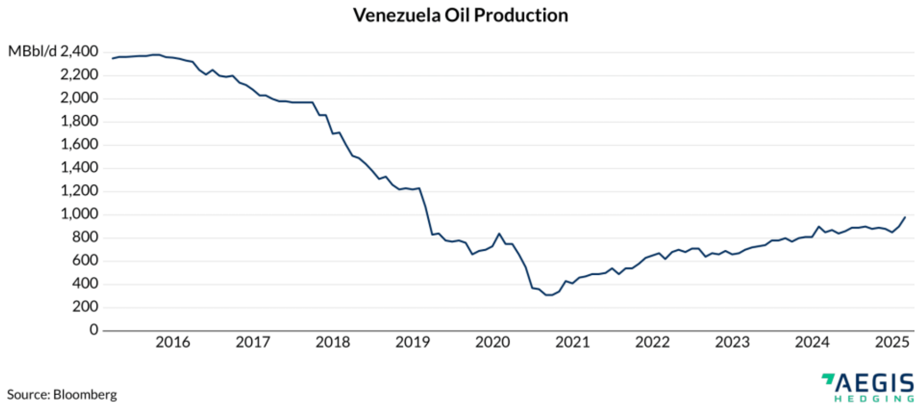

Figure 3. Venezuela Vulnerable to US Sanctions (AEGIS Hedging)

In summary, both realist and critical approaches shed light on how energy policy is embedded in broader global power structures, making it essential to understand energy not merely as a technical or environmental issue, but as a core component of international relations and economic governance (Cesnakas, 2010).

This theoretical grounding becomes even more pertinent through the study of current global events, where energy security, resource nationalism, and energy weaponization have re-emerged as dominant international concerns. One of the salient cases is the Russian-Ukraine war which has dramatically reshaped the global energy landscape and serves as a stark example of how energy can be transformed into a weapon of geopolitical influence. As a response to Russia's invasion, the European Union imposed strict sanctions on Russian oil and gas, eliciting Russia to restrict its gas supplies in retaliation. This action triggered an unprecedented energy crisis in Europe, exposing the country's heavy dependency on Russian energy and a rapid recalibration of its energy strategy, including diversification of suppliers and accelerated investments in renewables and liquefied natural gas (LNG) infrastructure (Abdelaal, 2023).

This case exemplifies the concept of energy weaponization, where a supplier state leverages energy dependency to exert political pressure—firmly anchoring the energy-security discourse within the frameworks of both realist IPE (power and security) and critical IPE (structural vulnerability and dependency) (Tsafos, 2022).

Similarly, China's growing energy footprint in Central Asia highlights how energy access and infrastructure are closely tied to long-term strategic ambitions. Through initiatives such as the Belt and Road Initiative (BRI) and pipeline agreements with Kazakhstan and Turkmenistan, China has solidified its role as both a major consumer and a key investor in the region's energy sector (Öğütçü, 2019). China is now the world's largest consumer of energy, the largest producer and consumer of coal, and the largest emitter of carbon dioxide. These moves reinforce China's political influence, reduce its dependence on maritime energy imports, and reshape regional alignments. From an IPE lens, this illustrates both realist motivations for securing national energy interests and critical concerns over dependency and infrastructure-driven power asymmetries.

Figure 4. South China Sea Islands, (The Hills)

Finally, in the Eastern Mediterranean, recent natural gas discoveries have further complicated maritime boundary claims among states such as Greece, Türkiye, Cyprus, Israel, and Egypt. The competition over Exclusive Economic Zones (EEZs) and offshore drilling rights has intensified regional rivalries, triggering diplomatic confrontations and military posturing (Magsumbol, 2025).

Therefore, in here, resource nationalism—government policies aimed at increasing national control over natural resources located within their territory (Chance, 2011)—clashes with international legal frameworks and multilateral energy cooperation efforts.

This case encapsulates how new discovery of energy resources can transform relatively stable regions into geopolitical flashpoints, reinforcing the argument that energy is not merely an economic commodity, but a powerful strategic instrument that shapes the contours of global political economy.

In conclusion, each of these regions demonstrates a distinct form of energy-driven global competition. In the Russia-Ukraine conflict, energy is weaponized, as Russia uses gas supply to exert political influence and punish adversaries. In Central Asia, the competition is subtler but equally significant, centered around pipeline diplomacy and long-term infrastructure investments. Here, China and Russia vie for control over transit routes and market access, reflecting a competition over energy corridors and spheres of influence rather than resources themselves. Meanwhile, in the Eastern Mediterranean, energy competition manifests through overlapping territorial claims and the assertion of resource sovereignty, where new discoveries intensify existing disputes and shift regional alignments.

Together, these cases illustrate that energy-based competition is multifaceted—ranging from hard power tactics and infrastructure dominance to legal disputes and maritime confrontations—underscoring the need for a robust IPE framework to fully grasp the political economy of global energy. Ultimately, this study seeks to contribute to contemporary debates in energy policy by showing how regional developments reflect and reshape the global energy order.

This section will utilize a qualitative case study approach to analyse how energy geopolitics plays out in three regions combined with its theoretical field exploration. Each region has been selected intentionally (purposive sampling) because it illustrates different dimensions of how energy intersects with power, conflict, and diplomacy. Additionally, the research presented is a form of secondary (desk) research from sources such as academic literature, policy reports, news media, official government documents and inter alia.

Subsequently, following the in-depth case exploration, a “comparative analysis” approach will be adopted to draw larger conclusions about global energy trends within the IPE framework and to provide forward-looking policy recommendations. Ultimately, through cross-regional analysis, this section identifies broader patterns in how energy influences contemporary international relations and global governance.

1. CASE STUDY 1: RUSSIA-UKRAINE WAR

The Russia–Ukraine War stands as a defining moment in contemporary energy geopolitics, exposing how deeply energy systems are entangled with international political power. From an IPE lens, the Russia–Ukraine war exemplifies the convergence of economics, state power, and global governance failures. It reaffirms realist perspectives that view energy as a zero-sum domain of national interest and strategic dominance. At the same time, it raises critical questions about the effectiveness of global energy institutions, the consequences of asymmetric dependencies, and the urgency of transitioning to more resilient, decentralized, and sustainable energy systems. This case study will explore the use of energy as a geopolitical instrument during the war, the structural weaknesses it exposed in Europe's energy framework, and the wider global economic disruptions it triggered. Through this lens, the Russia–Ukraine war emerges as a defining chapter in the evolving relationship between energy, statecraft, and international political economy.

An extensive area of research has emerged examining Russia's use of energy as both a strategic asset and geopolitical weapon, particularly amid its conflict with Ukraine. Early studies documented recurring gas cut-offs through Ukraine in the 2000s—highlighting energy transit as a geopolitical tool and exposing Europe's vulnerability (Enescu, 2023).

Analysis of the post-2014 era shows intensified "energy blackmail" via Gazprom's control over pipelines and Western sanctions targeting Russia's energy sector. More recent research on the 2022 invasion confirms that Russia weaponized energy supply—through gas cut-offs, pipeline sabotage, and demands for ruble payments—provoking a dramatic shift in EU policy and energy markets (Deirmentzoglou, 2025).

Scholars have investigated the resultant volatility in energy prices, supply chain disruptions, and accelerated EU responses such as REPowerEU and LNG diversification (Cui; Yue, 2023). However, this literature provides critical insights into how energy became central to this geopolitical conflict, framing a nexus of trade dependency, institutional fragility, and strategic repositioning within the global political-economic order.

1.1 Contextual Background

The Russia–Ukraine conflict, which dramatically escalated in February 2022, is not merely a territorial dispute but a pivotal episode in the geopolitical energy landscape (Sun; Cao; Liu, 2024). Russia, being the world's largest producers and exporters of oil and natural gas, has long wielded "energy" as a tool of strategic influence – particularly over Europe. However, the roots of the energy conflict stretch far deeper than the 2022 invasion.

Ever since the collapse of the Soviet Union in 1991, Ukraine has held a uniquely strategic position in the global energy landscape in mainly 2 ways. Firstly, it stems from its role as a major transit country for Russian natural gas exports to Europe. At the crossroads of routes linking Eastern Europe to Central Asia, Ukraine occupies a geostrategic position that far exceeds its vast territory (Gitton, 2025).

Long before the full outbreak of conflict in 2014 and the massive invasion of 2022, this nation stood as a major energy bridge due to its Soviet-era gas pipeline network and abundant natural reserves of coal, gas, and oil (Gitton, 2025). Around 40% of the EU's imported gas from Russia passed through Ukraine's extensive pipeline network, making it a critical link in Europe's energy supply chain.

This geographic location between Russia and the European Union gave Ukraine significant geopolitical leverage, but also made it vulnerable to political pressure, conflict, and energy-related bargaining. In addition to its transit infrastructure, Ukraine possesses its own energy reserves, including natural gas fields, coal, and emerging renewable capacity, particularly in wind and solar. Exempli gratia, the abundance of coal in the Donbass and the oil potential in the Black Sea basins long served only to meet Soviet and then Russian needs.

Gas reserves, estimated at over one trillion cubic meters before the conflict, were among the largest in Europe. Similarly, Ukraine had a vast network of oil and gas pipelines capable of transporting hydrocarbons from Russian fields to Europe, thus consolidating its role as a regional hub (Gitton, 2025).

Figure 5. Ukraine's strategic position (International Mapping)

Therefore, Ukraine's vast pipeline network inherited from the USSR became a vital transit corridor, delivering Russian natural gas to Europe—at one-point accounting for up to 80% of Russian gas exports to the EU. However, the post-Soviet era also marked the beginning of growing geopolitical divergence between Russia and Ukraine. While Russia, under Vladimir Putin, moved toward authoritarian consolidation and resource-based statecraft, Ukraine sought closer integration with Western institutions such as the European Union and NATO. Energy quickly became a battleground in this widening rift. Disputes over gas prices, unpaid debts, and transit fees led to several gas cut-offs in the winters of 2006, 2009, and 2014, often during peak demand in Europe. Each crisis exposed not only the vulnerability of European consumers but also Russia's willingness to use energy as a tool of political pressure. By the time the full-scale invasion began in 2022, energy relations between Russia, Ukraine, and the EU were already heavily strained. The war did not create the energy conflict—it amplified and globalized a decades-old geopolitical struggle, turning Europe's energy dependence into a point of existential crisis. This background sets the stage for a deeper examination of how energy has been used, disrupted, and reimagined during the Russia–Ukraine war, and why this case is central to understanding the political economy of energy in the 21st century (Angelos, 2025).

1.2 The 2006 Russia–Ukraine Gas Conflict

The 2006 conflict represents one of the earliest and most instructive examples of how energy can be weaponized in the tactless pursuit of geopolitical interests.

Taking place in the context of post-Soviet power realignments, this conflict illustrated how natural gas — particularly its pricing, production, and distribution — became entangled in questions of sovereignty, regional influence, and global energy security. The episode marked a turning point in Europe's energy policy and revealed fundamental tensions in the international political economy (IPE) of energy.

The Orange Revolution was a series of mass protests in Ukraine from late November 2004 to January 2005 triggered by widespread allegations of corruption, voter intimidation, and electoral fraud in the 2004 presidential election run-off, where Viktor Yanukovych was initially declared the winner (Britannica, 2014). The movement, centered in Kyiv, united people who peacefully resisted through sit-ins, human barricades, and strikes, demanding a fair election. Due to public pressure and reports from election monitors, Ukraine's Supreme Court annulled the original run-off results and ordered a new vote, which was held on December 26, 2004 (Timeline, 2005). Under heavy domestic and international observation, Viktor Yushchenko won with about 52% of the vote and was inaugurated on January 23, 2005, marking the end of the Orange Revolution (ICNC, 2022).

The protests, which included civil disobedience, sit-ins, and general strikes, ultimately led to the annulment of the initial election results and a rerun of the election, which Yushchenko won.

His government openly stated its desire to:

- Join the European Union (EU).
- Move toward NATO membership.
- Reduce Ukraine's dependence on Russian energy and political influence.

This was seen in Moscow as a direct threat to Russian influence in what it considered its "near abroad" or traditional sphere of control (Menon, 2025). Russia has long always opposed NATO's eastward expansion.

The idea of Ukraine joining NATO was unacceptable to the Kremlin because firstly it would put Western military alliances on Russia's border; then it would limit Russia's access to the Black Sea (through Crimea, then still part of Ukraine) and finally it would also challenge Russia's post-Soviet geopolitical dominance. Therefore, Putin saw this as a betrayal of verbal assurances (from the 1990s) that NATO would not expand after German reunification.

He believed that Ukraine's pro-Western path was encouraged by Western governments, especially the United States. This move was viewed as part of a broader Western strategy to contain Russia and encroach on its borders (Zurich, 2009). Ukraine was a major gas transit country, transporting around 80% of Russian gas exports to Europe. During the Soviet era, the close ties between the Soviet Union and Ukraine meant that when the USSR dissolved, Ukraine inherited an energy infrastructure heavily reliant on Russian gas and with pre-existing preferential pricing arrangements. This resulted in Ukraine receiving Russian gas at a price substantially lower than the market rate for other European countries. Before 2006, Ukraine paid around $50 per 1,000 cubic meters for gas — well below market price. However, following Ukraine's 2004 Orange Revolution and its pivot toward pro-Western political alignment, Russia, through Gazprom (a Russian majority state-owned multinational energy corporation headquartered in Saint Petersburg), demanded an immediate increase in gas prices to $230 per 1,000 cubic meters, a 400% increase (Atlantic Council, 2019). The dramatic nature of this hike — more than quadrupling the existing price — was widely perceived by analysts and policymakers not as a market correction but as a political manoeuvre by the Kremlin to penalize Ukraine for its Westward shift.

Ukraine sought to re-negotiate transit fees and purchase prices, claiming that it was paying higher rates than Western European states. This resistance prompted no agreement to be reached thus Gazprom cut off gas supplies to Ukraine on January 1, 2006.

From an IPE perspective, this development is best understood through the lens of realism, which emphasizes the role of state power, strategic interests, and national security in international relations. Russia's actions can be interpreted as an assertion of regional dominance, using energy not merely as a commodity but as an instrument of foreign policy.

Gazprom, though technically a corporate actor, operates as an extension of the Russian state, blurring the lines between business and diplomacy. The cutoff sought to weaken Ukraine's economic stability, force political concessions, and signal to other post-Soviet states the potential costs of distancing themselves from Moscow.

As the flow of gas through Ukraine dropped, European countries began reporting gas shortages, even though the gas meant for Europe was not supposed to be affected. Several EU countries, particularly in Central and Eastern Europe, experienced substantial drops in gas pressure during the first days of January 2006, despite Gazprom's assurance that it was fulfilling its obligations to European consumers. In response, Russia accused Ukraine of illegally siphoning off gas from the transit pipelines, essentially diverting some of the gas meant for Europe to meet its own domestic needs.

Ukraine denied the accusations, claiming that pressure drops in the pipeline system caused the disruptions, and that they were taking only what was allowed under existing agreements. However, the lack of transparency, metering disputes, and the political tensions between the two countries led to a breakdown of trust.

This crisis exposed the vulnerability of Europe’s energy infrastructure and it shook Europe’s confidence in the reliability of Russian gas while highlighting the risks of transit dependency.

1.2.1 Policy Solution Responses (Findings & Analysis)

Immediate (short-term) respons, the 2022 Russia–Ukraine war sparked a renewed energy rebalancing, with Europe rushing to replace Russian gas and reviving interest in Caspian supplies. New energy corridor agreements were signed between the EU, Azerbaijan, and Georgia (2022–2023), and Kazakhstan and Azerbaijan agreed to an oil transit deal via the Baku–Tbilisi–Ceyhan pipeline, bypassing Russia. Meanwhile, China strengthened Central Asian ties through a 2023 summit focused on energy investment and digital integration, while Russia’s Power of Siberia 2 pipeline plan signaled its pivot to Asia, potentially sidelining Central Asia. In IPE terms, the region reflects realist power shifts among major actors, while critical theory highlights persistent dependency, weak institutions, and citizen exclusion.

Although liberal cooperation emerges in green projects, structural inequalities and regional vulnerabilities remain.

1.2.2 European Union Policy Responses

The 2006 crisis deeply shocked the European Union, which had long taken uninterrupted gas supplies for granted. It exposed the EU's overdependence on Russian energy and highlighted the geopolitical risks of relying on a single transit country—Ukraine—for such a large portion of its energy needs. In response, the EU undertook a number of strategic and institutional policy shifts aimed at strengthening energy security and building resilience against future disruptions.

Firstly, their major strategy was the diversification of supply sources and routes. European countries began accelerating investments in LNG (liquefied natural gas) import terminals, particularly in Spain, the Netherlands, and Poland, allowing them to import gas from producers like the United States, Qatar, and Algeria.

The EU also increased political and financial support for alternative pipeline projects that would bypass both Russia and Ukraine. Chief among them were the Southern Gas Corridor (which included the South Caucasus Pipeline, the Trans-Anatolian Pipeline (TANAP), and the Trans Adriatic Pipeline (TAP), aimed at transporting gas from Azerbaijan's Shah Deniz field to Europe via Georgia and Türkiye. The SGC consists of the above 3 major interconnected pipelines, spanning multiple countries and geopolitical zones (Jorgenson, 2021):

South Caucasus Pipeline (SCP)

- **Origin**: Azerbaijan's Shah Deniz Stage 2 gas field.
- **Route**: From Baku (Azerbaijan), through Tbilisi (Georgia), to **Erzurum** (Türkiye).
- **Completed**: 2006.
- **Significance**: Acts as the starting link of the SGC, carrying gas from the Caspian Basin into Türkiye.
-

Trans-Anatolian Pipeline (TANAP)

- **Route**: Runs across the entire length of Türkiye (1,850 km), from its eastern border with Georgia to its western border with Greece.
- **Completed**: 2018.

- **Capacity**: Initially 16 bcm (billion cubic meters), expandable to 31 bcm.
- **Significance**: Türkiye plays a pivotal transit role, enhancing its geopolitical importance as an energy bridge between East and West.

Trans Adriatic Pipeline (TAP)

- **Route**: From Greece, across Albania, under the Adriatic Sea, to Italy.
- **Completed**: 2020.
- **Current capacity**: 10 bcm/year, with plans for expansion.
- **Significance**: Brings Caspian gas directly to EU markets—especially Italy, Bulgaria, and the Balkans.

The Southern Gas Corridor's purposes were: to weaken Gazprom's monopoly and prevent Russia from using gas as a political weapon; to support Azerbaijan as an alternative supplier, thereby stabilizing EU energy supplies; to strengthen energy ties with non-Russian actors like Türkiye, Georgia, and the Western Balkans; to create a corridor open to future sources—like Turkmenistan, northern Iraq, or even the Eastern Mediterranean—though these have not yet materialized.

The project was supported politically and financially by the European Commission, World Bank, EIB, and EBRD, reflecting its importance for EU external energy policy.

Figure 6. The Southern Gas Corridor (Energetika Nazirliyi)

The Southern Gas Corridor is an example of neomercantilism where the states and blocs (like the EU) intervene to secure strategic energy autonomy.

It reveals how infrastructure investment becomes a tool of geo-economic balancing and it also reflects energy regionalism, where interstate cooperation (Türkiye, Georgia, EU) serves to counterbalance dominant suppliers (Russia).

Another pipeline is the now defunct, Nabucco Pipeline, which was once considered a flagship EU project, though it was later cancelled due to cost and competition issues. The Nabucco pipeline project is based on the idea to bring Caspian or Middle Eastern gas through Türkiye to the EU. Its planned route is 3300 kilometres long with an estimated construction cost of almost EUR 8 billion (Dempsey, 2013).

Figure 1: The planned route of the Nabucco pipeline (Commons)

Their second strategy was the development of an integrated EU energy market.

One of the EU's key vulnerabilities prior to 2022 was the fragmentation of its energy infrastructure. Many member states, particularly in Eastern and Southeastern Europe, lacked adequate interconnectivity with their neighbors. This made them susceptible to supply disruptions—for example, if gas flow through Ukraine or Belarus was cut, countries like Slovakia, Hungary, or Bulgaria had few alternatives.

To address this, the EU prioritized the expansion and modernization of cross-border pipelines, electricity grids, and LNG terminals, as outlined in its Trans-European Networks for Energy (TEN-E) policy. Key projects include (Commission, 2020):

- The **Balticconnector pipeline** between Finland and Estonia (operational since 2020).

- The **Gas Interconnector Greece–Bulgaria (IGB)**, which became vital during the 2022 gas crisis.
- **Electricity interconnectors** linking the Iberian Peninsula with France, and the Baltics with Nordic and Central European grids.

These interconnections allow reverse gas flows, load balancing, and diversified sourcing, enabling energy to be redirected efficiently during emergencies. In times of crisis, member states can share surplus supplies with neighbours, reducing their individual exposure to cut-offs or price shocks.

This was reinforced by the adoption of the EU's Third Energy Package in 2009, a landmark legislative framework designed to increase competition, transparency, and regulation in the gas and electricity sectors. The package introduced the principle of "unbundling", which required companies involved in gas production or supply (such as Gazprom) to separate their operations from those managing gas transmission networks. This reform aimed to prevent monopolistic control, promote market-based pricing, and ensure equal access to pipelines for all suppliers (Fernández, 2010).

The EU's principle of "energy solidarity", enshrined in the Lisbon Treaty (Article 194), was previously more rhetorical than practical. However, the Russia–Ukraine war gave it urgent real-world relevance. For the first time, the EU operationalized mechanisms to ensure no member state would be left isolated in the event of severe shortages or energy coercion.

Notable examples include: Joint gas purchasing platform Mandatory gas storage targets and Solidarity agreements.

In addition to diversifying external suppliers and reforming the internal market, the EU began framing energy efficiency and renewable energy as key components of energy security. By reducing overall energy consumption and developing domestic sources of clean energy, member states could become less reliant on politically volatile exporters. As a result, funding and policy support for solar, wind, and biomass projects increased dramatically after 2006.

This approach was institutionalized in subsequent EU climate and energy strategies, particularly the 2020 Climate and Energy Package, which set binding targets for emissions reductions, renewable energy deployment, and energy efficiency improvements. The idea was that less dependency equals greater autonomy, and the renewable energy transition could serve not only environmental goals but also geostrategic interests.

The 2006 crisis was thus a catalyst for viewing climate and energy policy through a more integrated political economy lens (Lavrijssen, 2014).

1.3 The 2009 Russia–Ukraine Gas Conflict

The 2009 Russia–Ukraine gas dispute further exemplified the complex entanglement of energy, geopolitics, and institutional fragility within the post-Soviet space. Occurring just three years after the 2006 crisis, the 2009 conflict not only mirrored many of the earlier issues but escalated them to new heights. It was the most severe and disruptive energy crisis to date between the two countries and had far-reaching consequences for the European Union's energy security. The 2009 conflict was not simply a recurrence of unresolved disputes but a significant escalation that exposed deeper structural deficiencies in international energy governance and amplified the geopolitical utility of energy resources as instruments of coercion.

The 2009 gas crisis began on January 1 when Gazprom halted gas supplies to Ukraine after failed negotiations over pricing, debt, and transit terms. Russia claimed Ukraine owed over $2 billion (Francis, 2009), while Ukraine disputed the amount and rejected Gazprom’s rising price demands, accusing it of politicized manipulation. Gazprom cut supplies, and though it initially promised continued flow to Europe, transit issues led to a sharp drop.

Ukraine cited technical limitations, while Russia accused it of stealing gas. By January 7, Russia fully cut off gas through Ukraine, affecting nearly 18 European countries and causing severe energy shortages during freezing temperatures—marking the worst gas disruption in EU history (Pirani, 2009).

The scale of the disruption highlighted the systemic vulnerability of Europe’s energy security and underscored the strategic chokehold that Russia exercised over its energy-dependent neighbours. The European Union, caught off-guard and diplomatically unprepared, launched emergency negotiations and sent independent monitors to Ukraine and Russia to verify gas flows. The sheer urgency and humanitarian cost of the crisis forced energy to the top of the EU’s foreign policy agenda.

1.3.1 Policy Solution Response

After two weeks of gas cut-offs that left much of Eastern and Central Europe in a winter energy emergency, a resolution was finally reached on

January 19, 2009. The agreement, signed between Russian Prime Minister Vladimir Putin and Ukrainian Prime Minister Yulia Tymoshenko, was a 10-year bilateral gas contract between Gazprom (Russia) and Naftogaz (Stern, 2009). While it temporarily stabilized gas flows, it carried controversial long-term implications.

Market - Based pricing

Under the deal, Ukraine agreed to move toward market-based pricing for natural gas — a major departure from the previously subsidized rates it had enjoyed since Soviet times. However, for 2009, Ukraine was granted a 20% discount to cushion the immediate economic shock (Pirani, 2009). This shift reflected Russia's broader strategy to remove subsidized pricing as a form of political leverage and enforce commercial discipline. From an IPE lens, it symbolized the transition from energy as a political subsidy to a market-governed commodity, though in reality, strategic manipulation persisted behind the scenes.

Elimination of Intermediaries (e.g., RosUkrEnergo)

The 2009 deal eliminated the opaque intermediary firms (middlemen), mandating direct transactions between Gazprom and Naftogaz. This was hailed by some as a win for transparency but also raised concerns, especially in Ukraine, that Tymoshenko had given Gazprom more direct influence over Ukraine's energy system.

Transit Fee Adjustment (Not Indexed to EU Prices)

Ukraine aimed to align its transit fees with EU price levels, arguing it was underpaid for its strategic role, but the final deal only included partial adjustments and was not indexed to EU prices—a compromise seen as reflecting Russia's greater bargaining power (Thiery, 2016). These highlighted dependency asymmetries common in resource-based trade, as noted by IPE scholars. Domestically, the deal sparked controversy, with critics accusing Prime Minister Tymoshenko of conceding too much for short-term stability. It later became a political tool used against her, leading to investigations and her controversial arrest in 2011.

Europe's Energy Security Wake-Up Call

The crisis revealed the EU's vulnerability to external supply shocks through unstable transit routes, prompting urgent structural responses. The EU accelerated supply diversification by investing in LNG terminals in Spain, Poland, and the Baltics, and pursued Azerbaijani gas via the Southern Gas Corridor. Key projects like the Gas Interconnector Greece–Bulgaria (IGB), operational in 2022, enabled bidirectional flow and linked to the Trans-Adriatic Pipeline, enhancing regional supply flexibility (Sofia, 2022).

The EU also adopted the Second and Third Energy Packages to liberalize markets, separate supply from infrastructure, and boost cross-border cooperation. From an IPE perspective, the EU shifted from a passive market to a strategic actor, using regulation and alliances to reduce dependence and risk.

Russia's Pipeline Diversion Strategy

The 2009 crisis gave Russia a rationale to bypass Ukraine entirely, reducing its dependence on a politically unstable and increasingly Western-leaning transit state. This led to Fast-tracking of Nord Stream 1, which became operational in 2011, providing a direct route under the Baltic Sea to Germany. The main purpose of the Nord Stream 1 pipeline was to provide a direct and reliable route for Russian natural gas to reach European markets, particularly Germany, bypassing traditional transit countries like Ukraine.

This reduced Russia's reliance on these transit countries for gas exports and enhanced the security of supply for European consumers (Purushothaman, 2022). After that was the proposal and eventual construction of Nord Stream 2 (though delayed and politically contested), as well as TurkStream, which carried gas to Türkiye and Southern Europe via the Black Sea. Nord Stream 2 which runs from Ust-Luga in Leningrad to Lubmin was completed in September 2021 and has the capacity to handle 55 billion cubic meters of gas per year once it becomes operational. The twin pipelines together can transport a combined total of 110 billion cubic metres (bcm) of gas a year to Europe for at least 50 years.

The Nord Stream crosses the Exclusive Economic Zones (EEZs) of several countries including Russia, Finland, Sweden, Denmark and Germany, and the territorial waters of Russia, Denmark, and Germany. In Germany, the pipeline connects to the OPAL (Baltic Sea Pipeline) and NEL (North European Pipeline) which further connects to the European grid (Purushothaman, 2022). These projects demonstrate Russia's energy geopolitics at work: creating alternative routes to retain market dominance while isolating unfriendly neighbors—an archetype of realist strategy in IPE.

Ukraine's Shift Toward Europe

Ukraine, reeling from repeated conflicts and unreliability, began reducing its energy dependence on Russia after 2009. It pursued reverse-flow agreements with countries like Slovakia, Hungary, and Poland, enabling it to import Russian-origin gas indirectly via the EU. It also began aligning with EU energy laws and standards, modernizing its energy infrastructure and restructuring Naftogaz in line with EU market models.

This signaled Ukraine's deepening integration into the Western energy and political system, and its erosion of Russian leverage—a significant development in the post-Soviet political economy of energy.

This could be analysed that these shifts reflected a growing awareness that energy interdependence with authoritarian states could not be treated solely as an economic issue but required a comprehensive political and security strategy.

2. CASE STUDY 2: EASTERN MEDITERRANEAN ENERGY CONFLICT

The Eastern Mediterranean region has become a hotspot of energy-driven geopolitical tension in the 21st century. At the heart of the conflict are massive offshore natural gas discoveries, competing maritime border claims, overlapping Exclusive Economic Zones (EEZs), competing nationalisms, and longstanding political rivalries—particularly involving Türkiye, Greece, Cyprus, Israel, and Egypt. From an IPE lens, this is a perfect case of resource-driven structural asymmetries, territorial disputes, and the instrumentalization of infrastructure projects for political leverage.

2.1 Legal Tensions: EEZ Overlaps and UNCLOS

The legal foundation for maritime rights in the region lies in the United Nations Convention on the Law of the Sea (UNCLOS), which grants countries Exclusive Economic Zones (EEZs) up to 200 nautical miles from their shores. However, interpretations differ, creating gray zones and legal loopholes:

- Türkiye is not a signatory to UNCLOS and does not recognize EEZ claims from Cyprus or Greece, especially those extending from Greek islands near its own coast (e.g., Kastellorizo).
- Türkiye insists islands should not generate full EEZs, while Greece and Cyprus argue otherwise, with the support of EU and UNCLOS principles.
- The island of Cyprus itself is politically divided: the Republic of Cyprus (Greek Cypriots) controls the south and is internationally recognized, while the Turkish Republic of Northern Cyprus (TRNC) is only recognized by Türkiye.

  Gas blocks licensed by the Republic are considered illegal by Türkiye, leading to escalations at sea.

This legal uncertainty has turned maritime law into a geopolitical battlefield, with frequent naval standoffs, diplomatic protests, and military maneuvers—making energy exploration both a legal and a security risk.

2.2 Türkiye–Greece–Cyprus Maritime Disputes

The triangle of Türkiye, Greece, and Cyprus is one of the most sensitive and militarized maritime zones in the world. It’s not just about natural gas—it’s about national sovereignty, historic rivalries, and international law. This region became a flashpoint after the discovery of valuable offshore natural gas reserves in the Eastern Mediterranean, especially within waters claimed by Cyprus and Greece. But Türkiye disputes those claims—not only because of its proximity but also because it refuses to recognize the maritime borders established by Cyprus and Greece.

2.2.1 Türkiye's Drilling Missions: Fatih, Yavuz, and Naval Escorts

In the late 2010s, Türkiye began sending its own drilling ships—notably the Fatih and Yavuz—into waters claimed by Cyprus as part of its Exclusive Economic Zone (EEZ). These moves were unilateral and not coordinated with the Republic of Cyprus (the internationally recognized government). These ships were escorted by Turkish navy vessels, showing that Türkiye was willing to use military presence to defend its claims.

Türkiye said it was protecting the rights of Turkish Cypriots in the north, who are excluded from exploration profits under current Cyprus-led deals. The EU, USA, and other actors condemned Türkiye's actions as violations of international law, specifically UNCLOS (United Nations Convention on the Law of the Sea)—which Türkiye has not signed.

So, from Türkiye's perspective, these missions are about asserting equal rights for Turkish Cypriots and challenging a regional exclusion. From the EU's and Cyprus's perspective, Türkiye is acting illegally and provocatively.

2.2.2 Cyprus's Exploration Deals with Global Energy Companies

Cyprus, asserting its rights under UNCLOS, divided its southern waters into offshore blocks and invited international companies to explore for gas. Companies like Total (France), Eni (Italy), and ExxonMobil (USA) signed exploration and drilling contracts. Drilling began in Blocks 6, 7, and 10, all claimed by the Republic of Cyprus, but contested by Türkiye. Türkiye sees these deals as illegitimate, arguing that Cyprus shouldn't make energy deals while the island is still politically divided. The EEZ claims around Greek Cypriot-controlled zones ignore the rights of Turkish Cypriots and Türkiye's continental shelf.

These activities have increased tensions. For Türkiye, these deals are part of a regional encirclement excluding Turkish interests. For Cyprus, they are exercises of sovereign rights.

The 2019 Türkiye–Libya Maritime Deal

In a bold move in November 2019, Türkiye signed a maritime boundaries agreement with Libya's UN-backed government in Tripoli. This deal attempted to create an EEZ corridor across the Mediterranean that:

- Ignored Greek islands like Crete and Rhodes.
- Claimed maritime space that overlaps with waters claimed by Greece and Egypt.

This deal essentially cut through the Aegean and Eastern Mediterranean and challenged Greek maritime claims under UNCLOS. The deal was internationally controversial as Greece said it was null and void, as it violated the EEZs of Greek islands. The EU and Egypt also rejected it, calling it a power grab. The goal was strategic: Türkiye wanted to block Greece, Cyprus, and Israel from forming gas export routes like the EastMed Pipeline through waters it claimed.

Greece–Egypt Response: Countering Türkiye

In August 2020, Greece and Egypt signed their own EEZ agreement, seen as a direct response to the Türkiye–Libya deal. This agreement affirmed maritime boundaries based on UNCLOS principles.

It reinforced Greece's position that islands (like Crete) do generate EEZs. The deal had the backing of the European Union and other regional actors like Cyprus and Israel.

This marked a clear split:

One side (Greece, Cyprus, Egypt, Israel, EU) was pro-UNCLOS, emphasizing international law and cooperative energy development. The other (Türkiye and Libya) used alternative interpretations of maritime law and bilateral deals to assert control.

2.3. Israel's Role: Energy Diplomacy and Security

Israel has leveraged its energy discoveries not just economically but also diplomatically:

- It signed export deals with Egypt and Jordan, improving regional ties.

- Security concerns have limited pipeline routes (e.g., through Lebanon or Syria), forcing Israel to explore partnerships like the EastMed pipeline or LNG export through Egypt.
- Türkiye–Israel relations, already strained, were further complicated as Israel aligned with Egypt, Cyprus, and Greece in energy cooperation, excluding Türkiye.
- Israel joined the Eastern Mediterranean Gas Forum (EMGF), solidifying its diplomatic shift toward regional multilateralism, away from bilateral tensions.

Thus, energy has become a bridge to normalization with Arab states and a tool for regional power repositioning.

2.4 The EastMed Pipeline Project

It was proposed as a strategic link between Israel, Cyprus, Greece, and Italy, the EastMed Pipeline (1,900 km) aimed to export gas directly to Europe, bypassing Türkiye and potentially reducing EU dependence on Russian gas. It also purposed to strengthen Western-aligned alliances in the region. However, there were plenty of technical challenges due to the deep-sea location of the pipeline, requiring advanced construction methods and potentially high costs (Ecco, 2022). Moreover, in 2022, the United States withdrew its support for the EastMed pipeline project, citing concerns about its environmental impact and potential for regional instability.

This decision was seen as a move to appease Türkiye and reduce tensions in the region. Many analysts believe the U.S. exit was also intended to ease tensions with Türkiye, avoiding further polarization in NATO.

3. CASE STUDY 3: CENTRAL ASIA ENERGY CONFLICT

Central Asia is one of the world's richest regions in oil, gas, and rare earth minerals, positioned strategically between Russia, China, the Middle East, and Europe (OSINT, 2025). Since the collapse of the Soviet Union in 1991, the region has witnessed ongoing geopolitical competition over pipeline routes, resource control, and energy market access.

The key energy-rich states—Kazakhstan, Turkmenistan, and Uzbekistan—have sought to assert independence, while powerful neighbors like Russia and China, as well as external actors like the European Union and the United States, have attempted to shape the regional energy order.

3.1 Pipeline Politics and Multipolar Competition (2000–2010)

The 2000s marked a turning point as Central Asian states began diversifying export routes. With U.S. and EU support, the Baku-Tbilisi-Ceyhan (BTC) pipeline was inaugurated in 2006, bypassing Russia and linking Caspian oil to Western markets via Azerbaijan, Georgia, and Türkiye. Kazakhstan and Azerbaijan also developed the Caspian Pipeline Consortium (CPC) to export oil to the Black Sea. The U.S. promoted these routes as part of its strategy to weaken Russia's grip (Coffey, 2019).

Simultaneously, China emerged as a key player. The China–Central Asia Gas Pipeline, launched in 2009, linked Turkmenistan directly to Xinjiang. This project was a strategic breakthrough—it offered Central Asian producers an alternative to Russian routes and gave Beijing long-term energy security. Turkmenistan rapidly became one of China's top gas suppliers (Meidan, 2023).

Realist theory still prevailed: pipeline routes were chosen based on geopolitical calculations, not market efficiency.

Russia responded with aggressive price negotiations, counter-projects like South Stream, and renewed pressure on Turkmenistan. In 2009, an explosion on the Central Asia–Center gas pipeline (transiting Turkmen gas to Russia) caused a major diplomatic spat, which some analysts attributed to Moscow's efforts to sabotage Turkmen diversification (Schroder, 2023).

3.2. Strategic Balancing and Infrastructure Rivalries (2011–2021)

In the 2010s, Central Asia's energy landscape became increasingly fragmented and competitive. Kazakhstan launched major production from Kashagan, one of the world's largest oil fields (Oil & Gas Journal, 2013; Reuters, 2013), while Turkmenistan expanded its pipelines to China. The EU attempted to revive the Trans-Caspian Gas Pipeline (TCP), aimed at bringing Turkmen gas to Europe via the Southern Gas Corridor (U.S. Congressional

Research Service, 2020). However, legal disputes over the Caspian Sea and Russian-Iranian opposition stalled progress.

China further consolidated its position, offering billions in infrastructure loans through the Belt and Road Initiative (BRI). It invested in roads, railways, and energy grids. By 2020, China controlled over 50% of Turkmen gas exports (Yorktown Institute, 2023). Kazakhstan and Uzbekistan began cautiously playing Russia and China against each other—seeking better prices and diversified trade.

Critical IPE critiques this phase as one of intensified elite capture. Energy profits funded massive construction booms, vanity projects, and regime consolidation—especially under Kazakhstan's Nazarbayev and Turkmenistan's Berdymukhamedov. Resource extraction perpetuated ecological degradation, including the depletion of the Aral Sea and pollution of oil-producing areas (UNDP, 2018; World Bank, 2019).

CONCLUSION

The case studies of Russia–Ukraine, the Eastern Mediterranean, and Central Asia offer a panoramic and multidimensional view of how energy geopolitics both shapes and is shaped by the dynamics of the International Political Economy (IPE). Each region reveals how energy resources are not merely economic commodities but strategic instruments that redefine power relations, trade dependencies, and diplomatic alignments. In the Russia–Ukraine conflict, energy has been weaponized as a tool of political leverage, illustrating the vulnerability of interdependence in a globalized gas network.

In the Eastern Mediterranean, emerging gas discoveries have transformed former zones of tension into arenas of both cooperation and contestation, reflecting the intricate interplay between economic opportunity and geopolitical rivalry. Meanwhile, Central Asia's vast reserves underscore how transit routes and pipeline politics serve as critical determinants of regional stability and global connectivity.

Together, these cases demonstrate that the competition for energy resources, routes, and influence is reshaping the architecture of international relations—forming new alliances, exacerbating historical grievances, and redrawing the boundaries of global order.

In an era defined by climate crisis, technological transition, and increasing multipolarity, the governance of energy must evolve beyond the narrow pursuit of supply security. Future energy governance must embrace the principles of justice, inclusivity, sustainability, and accountability, ensuring that the transition toward renewable and cleaner energy systems does not replicate existing inequalities but rather contributes to a more balanced and equitable international order.

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CHAPTER 7
SUSTAINABLE ENERGY AND SOCIAL INCLUSION FOR DEVELOPMENT IN NIGERIA: A SOCIOLOGICAL APPROACH TO ENERGY JUSTICE

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INTRODUCTION

In this 21st century, it is important for nations to have affordable and reliable energy, which has become a prerequisite for sustainable development. Although Nigeria is a country blessed with abundant fossil resources as well as renewable energy resources, it is still stark with energy shortages that have continued to affect its various social structures, which perpetuate socioeconomic imbalances among groups like low-income communities, women, and rural residents. This chapter examines the relationship between the availability of energy and social and economic inclusion in development in Nigeria. It provides a sociological view on the chances and difficulties of achieving sustainable energy in Nigeria, where focus will be on the social factors (e.g., community energy practices) of energy use that are often disregarded in energy planning and development.

Energy is still one of challenge in attaining sustainable development, with attention on renewable energy policies gaining global attention. However, in Nigeria, structural barriers such as weak institutions and lack of grassroots engagement hamper progress. Although with emerging solutions such as community-led solar projects and decentralized systems show promise, but deeper issues till persevere. This chapter heralds for inclusive energy governance that will reflects equality which emphasizes that energy access should be understood within the larger framework of social justice. Therefore, the paper went on to recommend integrating sociological insights into policy to ensure equitable resource distribution, local adaptation, and inclusive stakeholder involvement. Nigeria is the sixth most populous country in the world, with an estimated population of 237,528,000 people (World Population Review, 2024). It is believed to have the largest economy on the African continent, with the fastest-growing economics. Conversely, a greater part of the population lives in rural areas and in poverty, as they lack access to most of the basic needs like electricity. Energy access is defined by the International Energy Agency (IEA, 2022, p. 134) as households having consistent, reasonably priced electricity and clean cooking facilities that will be sufficient for basic services and gradually increasing throughout the nation, as electricity is very crucial for the economy to be industrialization-driven for growth, as it will encourage the agricultural sector.

According to the IEA (2023), about 92 million Nigerians, which is approximately 45% of that year's population, lacked access to electricity. In addition, the disparity in energy supply between urban and rural areas is pronounced, as most city areas receive between twelve and eighteen hours of electricity daily. But many rural areas or impoverished families might remain off-grid or rely on non-sustainable energy sources such as firewood and kerosene (Oyedepo, 2012).

This situation has significant implications for health, education, and productivity of rural dwellers, especially for women and children saddled with the responsibilities of home energy need. The availability of energy is critical to humans, as it is important in strengthening the economy of a nation, which promotes sustainable development. The sustainability of energy development emphasizes the fulfillment of current energy requirements without jeopardizing future generations' ability to meet their own need (United Nations [UN], 1987). This is made of three vital dimensions, made up of economic viability, environmental protection, and social equality. However, in Nigeria, energy sustainability has mostly been defined through economic and technical lenses, with little or no consideration given to the social and distributive ramifications of energy policies (Akinbami, 2001). For energy to be sustainable in Nigeria, it requires addressing not only carbon emissions and renewable deployment but also energy equity, inclusion, as well as community empowerment. As deduced from the vision of the UN Sustainable Development Goal 7 (inexpensive and clean energy) that is to be achieved by 2030.

Research has shown that Nigeria's energy mix is suggestively dependent on fossil fuels, mostly natural gas, which is used to power more than 70% of the national grid (World Bank, 2022). Hydropower gives 20% of total electricity generation, with renewables (solar, wind, and biomass) accounting for less than 5% of the nation’s energy. According to Sambo (2009), fossil fuel domination has worsened environmental degradation, particularly in the Niger Delta region of the country. Furthermore, Nigeria has substantial renewable energy potential, such as sun irradiation in the northern states averaging 5.5-7.0 $kWh/m^2/day$, which could support decentralized solar solutions for rural electrification (International Renewable Energy Agency [IRENA], 2022).

Unfortunately, this potential has largely gone untapped due to low investment in the area, lack of technical capacity due to insufficient incentives, and poor institutional frameworks. Therefore, emphasis should be on the need for more inclusive and innovative energy plans.

1. CONCEPTUAL AND THEORETICAL FRAMEWOK

The mission of achieving equitable access to energy resources has arisen due to serious concern in modern-day sustainability and development discourse. In which Justice and are inclusiveness are increasingly dominating the energy landscape as researchers and policymakers deal with the interconnections of social equality, environmental responsibility, and economic opulence. To elucidate the path toward inclusive energy systems, this section applies relevant sociological theories to analyze the many-sided character of energy justice and places Nigeria in the larger global context.

Energy justice: Energy justice has developed as a critical framework to incorporate fairness, equity, and social justice, along with the technical and economic understandings of energy. It ensures that the needs and rights of vulnerable groups, such as women and children are recognized (Jenkins et al., 2016; Heffron & McCauley, 2017). This connotes that energy justice deals with the social and equitable implications of the dynamics of energy and low carbon, as well as the complexities of injustice connected with entire energy systems from extractive industries to consumption and waste. Energy justice has three principles as advocated by Walker and Day (2012):

- ***Distributional Justice:*** This has to do with fair distribution of energy resources, infrastructure, and impacts among populations.
- ***Procedural Justice:*** This encourages participation and inclusiveness in energy decision-making, planning, and governance.
- ***Recognition Justice:*** This suggests recognizing the identities, the experiences, and the rights of vulnerable groups and underrepresented communities who are normally disregarded in energy policies.

Energy justice is particularly necessary and relevant in Nigeria, where systematic inequities in energy access have been present across classes, genders, ethnicities, and geographical lines.

Global perspectives and Nigeria; Energy justice is not a new concept in the world; it has been used in several countries globally to address challenges like fuel poverty in the United Kingdom, access to renewable energy in Sub-Saharan Africa, and environmental deterioration in indigenous lands. Consequently, energy justice is in line with global human rights and development agendas, particularly the United Nations' Sustainable Development Goals (SDGs 7, 10, and 13).

But in Nigeria, the notion is only emerging in intellectual and policy discourses; nonetheless, it provides a useful acumen for addressing the marginalization of rural communities in energy planning and the ecological damage of oil-rich regions like the Niger Delta region of Nigeria. Energy justice IS consistent with human rights and development agendas globally, particularly the United Nations Sustainable Development Goals (SDGs 7, 10, and 13).

1.2 Sociological Theories and Energy Inclusion

Sociological theories contribute to the understanding of the power structures, social dynamics, and lived experiences that support energy systems. It goes beyond explaining the continuous energy exclusion but also analyzes continuity and how dramatic change can be achieved.

Structural Functionalism: Energy as Social Infrastructure

Structural functionalism was founded by Emile Durkheim and promoted by Talcott Parsons. It established that society has interrelated institutions that collaborate to sustain social stability and order (Parsons, 1951). It says that every institution, such as political, economic, or social, serves a specific purpose that contributes to the overall health of the system, called society. If there is dysfunction in any of this system's parts, it might result in social disintegration, inequity, or stagnation.

This sociological theory offers a concrete basis for examining how societal institutions contribute to or impede energy justice. It views energy as a social benefit interconnected that can promote inclusion or reinforce inequality, that can affect developmental goals to a larger extent.

In Nigeria, the energy sector is crucial to the smooth functioning of other vital social institutions.

Lack of adequate energy affects other institutions such as education, healthcare, agriculture, and the informal economy, which suffer greatly (Akinbami et al., 2003).

The implication of this theory is that the energy industry, which has the function of directly providing electricity, can impede other institutions, such as technical innovation, education, and health care. The persistent Nigeria's electricity shortages and rural energy poverty have caused dysfunctions that jeopardize the system's stability. These include low health indices, restricted educational attainment, unemployment, and rising inequality (Oyedepo, 2012).

Conflict Theory: Power, Inequality, and Access

Conflict theory founded by karl Marx and advanced by theorists such as C. Wright Mills and Ralf Dahrendorf. They see society as a field of perpetual conflict that is driven by competition for scarce resources (Marx & Engels, 1978). They believed that social institutions are structured to benefit those who hold power especially the economic elites. Theorists like C. Wright Mills (1956) and Dahrendorf (1959) highlighted that social inequality perpetuating by political institutions, and corporate power. The unequal distribution of energy is as a result of the monopoly by the elites that use their power to maintain economic and social dominance.

Nigeria's energy sector demonstrates class-based inequality, as the country faces widespread energy poverty, particularly in rural and semi-urban communities, which rely on traditional biomass with unreliable access. While the urban elite and industrial centers benefit from grid electricity and private generators (Oyedepo, 2012). This situation where energy infrastructure is concentrated in the powerful economically and politically regions, but with scare investments and executed in electrification and renewable energy in rural areas (Dinneya-Onuoha, 2025).

This is what conflict theorists describe as resource capture by dominant classes. When energy projects are regularly designed without rural community input, it is deliberate discriminatory act that make these marginalized population, such as women, informal sector workers, to be denied a say in their energy policy development. As their energy needs greatly differ significantly from those of urban homes, which might not be addressed (Clancy et al., 2012). Conflict theory sees this as energy injustice.

This procedural unfairness emphasizes the systemic disempowerment of vulnerable groups in Nigerian energy governance (Ikeme, 2006).

2. NIGERIA'S INEQUALITIES AND ENERGY LANDSCAPE

The energy landscape of Nigeria reflects insightful operational glitches that influence sustainability, equity, and access. This includes systemic inefficiencies and regional inequities, which strain the national grid system as it attempts to satisfy rising energy demands. Followed by the gendered aspects of uneven energy poverty burden that limited energy access and unstable supply, common to women and marginalized groups, leading them to resort to informal energy.

2.1 Current Energy Infrastructure and Access

Nigeria is a country with multiple energy resources such as solar, hydro, and wind, but its energy infrastructure depends mainly on fossil fuels, particularly natural gas. This dependence has weakened the national system, as it is inefficient and heavily centralized (International Energy Agency [IEA], 2022).

This fragility has continuously lowered economic output and discouraged foreign investment, as there are frequent grid failures and insufficient transmission capacity. The resultant effect is that access to electricity in Nigeria is unequal, with about 55% of the population linked to the national grid (World Bank, 2023). This implies that many households depend on polluting alternatives, such as generators, which are either fuel or diesel. Furthermore, alternative power sources are only available to those that can afford them.

That shows that the urban elites benefit from both grid power and private backups. While most of the rural and low-income communities use kerosene lamps and candles, that is extremely inefficient (Adenle et al., 2017).

In Nigeria there is vast potential for renewable energy, estimated at 5.5 $kWh/m^2/day$ on average (International Renewable Agency [IRENA], 2021), but utilisation is still low. There are several off-grid solar projects, and mini-grid initiatives are now ongoing.

Although the majority are small-scale, they are faced with a lot of financial and regulatory difficulties, such as poor energy governance, corruption, and inconsistent policy, that have made execution slow (Edomah & Emodi, 2019).

2.2 The Nigerian National Grid System and Its limitations

Nigeria operates a centralized grid system managed by the Transmission Company of Nigeria (TCN) and works under the Generation–Transmission Distribution (GTD) framework, established after the privatization of the Power Holding Company of Nigeria (PHCN) in 2013. The system consists of 27 production facilities (mostly gas-fired), a transmission network of approximately 20,000 kilometers, and 11 regional distribution firms (DisCos) (Nigeria Electricity Regulatory Commission [NERC], 2023).

Which have erratic power supplies in areas outside major cities, thus entrenching socioeconomic disparities? Due to so many issues that bedeviled it, ranging from old infrastructure and poor maintenance, limited transmission capacity, high technical and commercial losses, and frequent system collapses, has continue to undermine the grid. Nigeria has reportedly experienced over 98 system collapses, whether partial or total, between 2015 and 2022 (Premium Times, 2022).

Against this background, the Nigerian government tries to address these grid limitations by turning to off-grid and mini-grid solutions, especially for rural and remote communities, where there has been a serious energy deficit. As a result, programs like the Nigeria Electrification Project (NEP) are being used for mini-grids. Also, they are partnering with development organizations such as the World Bank and GIZ for feasible options.

In recent years, over 100 solar mini-grids have been deployed that are reaching tens of thousands of households and small and medium sized enterprises (Rural Electrification Agency [REA], 2023).

It has been observed that these off-grid solutions offer clean, decentralized, and scalable energy that bypasses grid bottlenecks. Although off-grid solutions have shown potential, they are yet to scale up to satisfy the needs of millions of Nigerian people without access to power.

Sule (2021) enumerated some of these persistent challenges: high upfront costs for both providers and consumers limited financing options, regulatory uncertainty, particularly over tariffs and licensing, Lack of community interaction and unsustainable consumption patterns.

In conclusion, there is a promising path to clean and decentralized energy in Nigeria with solar mini-grids. But its current scale remains inadequate to meet the needs of millions of Nigerians still without power. Therefore, if the challenge, such as high costs, is addressed, off-grid energy solutions will be realized for Nigerians' energy access and power.

Gendered Dimensions of Energy Poverty

Energy poverty in Nigeria is deeply gendered. Women, especially in rural areas, bear the brunt of inadequate energy services:

- Household energy roles—cooking, lighting, heating—are predominantly managed by women.
- Dependence on biomass (wood, charcoal) exposes women to indoor air pollution, contributing to respiratory illnesses and maternal health complications (World Health Organization [WHO], 2016).
- Time spent gathering firewood limits women's economic productivity and educational opportunities (United Nations Development Programme [UNDP], 2020).

Furthermore, women's participation in energy policy and governance is minimal, resulting in solutions that often fail to address their specific needs. Gender-responsive energy planning is thus critical to inclusive development. Gearing examples of Nigeria's informal settlements, are Makoko in Lagos, Sabo in Kano, and Rumueme in Port Harcourt, these communities represent some of the most energy-deprived zones.

These communities are often unrecognized by urban planning authorities, excluding them from formal electricity distribution; suffer from infrastructure deficits, overcrowding, and poverty; rely on informal or illegal connections, increasing fire risks and energy theft (Akinyele et al., 2018). Studies show that residents in slums pay disproportionately high energy costs (per unit) compared to those in formal neighborhoods—often for lower services. This has made many to depend on informal energy.

Informal Energy Solutions

Due to grid unreliability and policy exclusion, many Nigerians resort to informal energy solutions such as:

- Generators: Used by 60% of urban households and nearly all businesses; Nigeria reportedly imports over 2 million small generators annually (National Bureau of Statistics [NBS], 2020). However, they contribute to Noise pollution, Carbon emissions, and Health hazards (e.g., carbon monoxide poisoning).
- Firewood and charcoal: Used by over 70% of rural households for cooking (IEA, 2022), contributing to deforestation and health glitches**.**
- Kerosene**:** Though increasingly expensive and unsafe, it remains a common fuel for lighting and cooking in poor households.

These energy practices highlight the adaptability of informal communities but also the systemic neglect of inclusive energy policy**.** A just energy transition must integrate these informal realities rather than merely supplant them.

3. SOCIAL IMPLICATIONS OF ENERGY EXCLUSION IN NIGERIA

Energy is an essential system in every society, with far-reaching magnitudes for other institutions shaping the trajectory of development of nations. To drive long-term progress, energy must be affordable and accessible to everyone. As, it is necessary to power important services and infrastructure that promote economic, social, and technological progress. The energy system works by turning natural resources into usable energy carriers, which are then used by machines and appliances to provide critical services in that country.

For any country that does not ensure this process, it will affect its sustainable development in the following ways:

Impact of Energy on Livelihoods in Nigeria

In Nigeria, the impact of the population having limited access to modern energy services is significant on livelihoods, particularly among micro, small, and medium-sized firms (MSMEs), mostly those in the informal economy.

According to International Labour Organization [ILO] (2020), about 70% of employment is found in this sector, and the majority of these people are involved in energy-intensive jobs such as tailoring, metalworking, and food processing.

Unfortunately, many now rely on alternative sources of energy such as generators. This diminishes productivity and swells operational costs; this energy gap represses economic progress, particularly in rural and semi-urban areas. Research indicates a substantial link between energy access and employment, agricultural processing, and market penetration in local areas (Ajao et al., 2021).

Similarly, Olatunji et al., (2018) suggest that there are significant correlations of energy access with employment rates, agricultural processing, and market access in Nigerian communities.

Educational Accessibility and Youth Empowerment

Educational accessibility has a great role to play in shaping the quality and reach of education in Nigeria. In remote areas off the national grid or with poor electricity, it greatly affects the quality of learning. In such areas, students do not have access to computers, internet access, or teaching aids powered by electricity.

In a survey done in Kaduna State, it revealed that students in electrified communities scored 20% higher on tests than those in non-electrified areas (Abubakar et al., 2017). Moreover, the lack of electricity hampers technical and vocational training that is crucial for youth empowerment in today's digital and green economy.

Environmental Risks and Health

Health outcomes in Nigeria have been significantly affected by the poor energy system, as many people in the grid zone rely on biomass and kerosene, which causes indoor air pollution, leading to respiratory disease, one of the major causes of over 100,000 premature deaths annually.

The World Health Organization [WHO] (2016) reported that over 100,000 premature deaths occur because many health centers lack reliable electricity, which affects vaccine storage, emergency care, and safe childbirth, especially in rural areas, where over 60% of primary healthcare centers are under-electrified (Nigeria Health Facility Survey, 2018). Furthermore, heavy biomass contributes to deforestation and climate change, which undermine Nigeria's environment (Olaniyi et al., 2019).

Social Discontent and Political Marginalization

Persistent energy exclusion can cause social alienation that can result in unrest, especially in marginalized regions of the country, like the Niger Delta and the Northeast.

These communities, deprived of electricity, often feel isolated from the benefits of citizenship, intensifying the fight for resource control, fiscal federalism, and decentralized governance. This means access to energy does not only affect development but also national security.

Gender Vulnerabilities in Energy Access

Women are mostly the caretakers of households in Nigeria. And in areas that experiencing energy poverty, most of them rely on the use of alternative energy, some spend a lot of time collecting firewood. They are exposed to toxic fumes while cooking with biomass. This gender disparity underscores the need for gender-responsive energy strategies.

4. ENERGY JUSTICE AND NIGERIA'S DEVELOPMENT

The concept of energy justice means that communities have equal access to production, consumption, and distribution of inexpensive, reliable, and clean energy (Sovacool & Dworkin, 2015).

It is a multifaceted model for assessing energy systems that embraces social justice, climate justice, and environmental justice, thereby, giving the population a comprehensive framework to assess energy systems. Energy justice is centered on three main principles: Firstly, there should be fair access to energy across regions, classes, and genders—known as distributive justice. Secondly, when energy decisions are taken, it should be inclusive and transparent, which is called procedural justice. Lastly, the needs and identities of marginalized groups must be addressed regarding energy, called recognition justice (Jenkins et al., 2016). These principles mentioned above can correct historical energy disparities and bring about a just energy transition.

Access to energy is gradually perceived as a basic human right**,** not just as a service but as vital for achieving education, health, and livelihood security (United Nations Development Programme [UNDP], 2016). Article 25 of the *Universal Declaration of Human Rights* tacitly supports this by emphasizing appropriate living conditions, whereas *Sustainable Development Goal 7 (SDG 7)* clearly stresses universal access to affordable, reliable, and modern energy.

In Nigeria, more than 40% of people still do not have access to power. According to the International Energy Agency [IEA] (2022), over 70% of households lack access to clean cooking fuels. Redefining energy as a right would impose legal and moral responsibility on the government to maintain access, particularly for rural, low-income, and vulnerable communities.

In order for Nigeria to achieve renewable energy, it must address socio-political challenges such as power disparities between urban and rural areas, as well as policy capture by fossil fuel interests. Additionally, it must also address the exclusion of grassroots involvement in national energy planning. As equitable energy transition requires a shift from fossil fuels to renewables and the restructuring of energy governance to benefit local communities, women, and youth (Newell & Mulvaney, 2013). Because energy transitions that ignore justice considerations risk worsening existing inequities in Nigeria.

Energy governance requires a shift away from centralized and technocratic systems of energy to a participatory approach that incorporates citizens in energy planning, implementation, and monitoring. This participatory governance will ensure trust and transparent solutions to energy sustainability in Nigeria.

For Nigeria to have sustainable energy, its energy policy must be socially inclusive. And for it to be so, it must prioritize off-grid renewable solutions that should have local contexts; ensure tariff reforms that mirror poor houses' ability to pay; support the marginalized groups such as women and youth in any energy-led initiatives through microfinance and capacity building. It must not ignore informal energy practices such as generator sharing and local solar markets, as this can lead to a broader energy landscape.

CONCLUSION

The right to energy must be legalized in Nigeria's constitution and policies. The conditions of energy Justice must be adhered to in Nigerian national policy for energy. All energy projects should have gender and social impact assessments. Energy planning should be through local committees. Energy availability must be increased for informal communities and displaced populations to access. The evaluation of any energy projects should be done using social inclusion measures that include vulnerable groups/community participation regarding cost and access.

In conclusion this chapter scrutinized sustainable energy and social inclusion in the Nigeria's energy system, through a sociological lens. It went on to highlight the deep-seated inequalities across geographic, gender, and income lines, noticing how technocratic and market-based policies often overlook marginalized voices. Applying the energy justice framework that encompasses distributive, procedural, and recognition justice, that helped clarify the inequities in energy access and governance. The chapter highlighted the significance of inclusive systems that promote fairness in energy access and usage. A sociological approach helped to unpack the complex cultural and political factors influencing energy distribution.

For energy transition to be justice-oriented, it must address clean energy accessibility and the historical disparities in energy by prioritizing the underserved rural and informal communities in Nigeria. These will result in democratization of energy decision-making, referred to as energy equity.

That is directly connected to improved education, healthcare, job creation, and energy sustainability. Ultimately, Nigeria's development depends on applying energy justice for sustainable energy.

Increasing electrification, or renewable energy, can aggravate existing energy inequities in Nigeria. Using a sociological approach will provide a transformative path that prioritizes the population's participation, dignity, and equity for long-term success.

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CHAPTER 8
THE RELATIONSHIP BETWEEN ENERGY AND DEVELOPMENT: PERSPECTIVES FROM DEVELOPING COUNTRIES WITH THE ROLE OF ARTIFICIAL INTELLIGENCE

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INTRODUCTION

Attention deficit is a neurodevelopmental disorder characterized by difficulty in sustaining attention, heightened sensitivity to external stimuli, impaired task completion, and reduced organizational abilities. Although often classified under the broader category of Attention Deficit Hyperactivity Disorder (ADHD), some individuals exhibit predominantly inattentive symptoms without hyperactivity, referred to as the "inattentive subtype" (APA, 2013; Dziegielewski, 2014). Attention deficit is a heterogeneous clinical condition that negatively impacts quality of life, academic achievement, social interactions, and overall functionality. Traditionally explained by dopamine and norepinephrine deficiencies, recent multidisciplinary research suggests that attention deficit cannot be attributed to a single biological cause (Sungur, 2023).

Access to energy is widely recognized as a foundational driver of economic and social development. In the context of developing countries, energy is not just a commodity—it is an enabler of social inclusion, economic opportunity, and improved quality of life. It powers essential services such as healthcare, education, water supply, and communication, all of which are instrumental in achieving sustainable development goals (SDGs). As the World Bank notes, countries with higher per capita energy consumption generally exhibit stronger GDP growth, higher literacy rates, and lower child mortality (World Bank, 2022).

Despite this critical link, the persistent disparity in energy accessibility remains a cornerstone of global inequality, widening socio-economic divides and reinforcing cycles of poverty and underdevelopment. Approximately 675 million people—predominantly in Sub-Saharan Africa and parts of South Asia—still lack access to electricity (International Energy Agency et al., 2022). This energy poverty goes beyond a simple lack of power; it encompasses affordability, reliability, and sustainability. Many communities that are connected to a grid experience intermittent service, limiting their ability to engage in productive activities like small-scale manufacturing or agricultural processing. This energy-development divide remains one of the most pressing obstacles to poverty eradication.

This paper explores the intricate relationship between energy availability and development outcomes across the Global South, with a unique emphasis on the transformative potential of Artificial Intelligence (AI) in addressing these key systemic challenges. The study is grounded in the belief that AI can help developing countries overcome entrenched infrastructural, financial, and logistical barriers by enabling smarter, more adaptive energy management. AI's ability to process vast datasets and derive actionable insights makes it a compelling solution for optimizing energy systems—enhancing demand forecasting, improving renewable energy integration, mitigating theft and distribution losses, and expanding access through smart microgrids.

By synthesizing cross-national data, case studies, and technological analysis, this research aims to identify patterns linking energy access to growth in health, education, and economic productivity. It employs a mixed-methods approach, combining:

- Quantitative data from global energy and development databases (IEA, UNDP, World Bank),
- Qualitative insights from case studies in India, Kenya, and Brazil,
- Technological analysis of AI applications in energy optimization.

By combining developmental theory with technological analysis, this paper proposes an interdisciplinary framework that places AI at the center of the energy-development strategy. Ultimately, it argues that with appropriate governance and inclusive digital transformation policies, AI can serve as a powerful tool to leapfrog conventional development barriers, enabling more equitable and sustainable energy futures in the developing world.

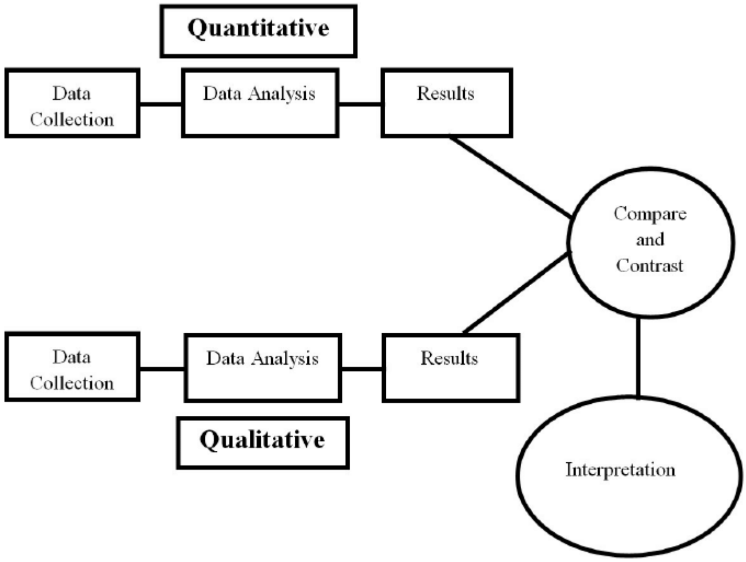

Figure1. Understanding Sustainability (Understanding Sustainability: A View from Intra-organizational Leadership within UK Construction Organizations)

1. THE ENERGY AND DEVELOPMENT NEXUS

The interdependence between energy and development has been a focal point in economic theory and development policy for decades. In developing countries, energy is not merely an input into economic activity; it is a critical enabler of structural transformation, social welfare improvement, and technological progress. This section unpacks the multifaceted relationship between energy and development, highlighting both historical context and contemporary challenges.

1.1. Historical Perspective: From Industrialization to Digitization

Historically, every major phase of human development—from the Industrial Revolution to the Information Age—has been closely linked with an evolution in energy systems.

Industrialized nations were able to transition from agrarian economies to advanced manufacturing and services sectors due in large part to abundant and reliable energy sources. In contrast, many developing nations remain trapped in a state of energy deficit that impedes progress.

Access to energy has also become increasingly complex in the 21st century, where digital technologies and electrified systems are central to participation in the global economy. Countries unable to provide widespread and stable electricity remain at risk of exclusion from technological and educational advancements, further widening the global development divide (Bhattacharyya, 2019).

1.2. Metrics For Energy Poverty and Development

Energy poverty is typically measured using a combination of indicators:

- Electrification rates
- Per capita energy consumption
- Availability of clean cooking solutions
- Reliability and affordability of supply

Meanwhile, development is assessed using metrics like Gross Domestic Product (GDP), Human Development Index (HDI), literacy rates, and healthcare access. Correlational studies suggest a strong, often linear, relationship between energy use and development outcomes up to a saturation point, beyond which marginal benefits taper (Kumar & Singh, 2021). For example, countries with electricity access rates below 60% generally score low on HDI. This is attributed not only to direct factors (e.g., healthcare equipment requiring power) but also to indirect effects such as the inability to attract investment in areas with unreliable energy infrastructure.

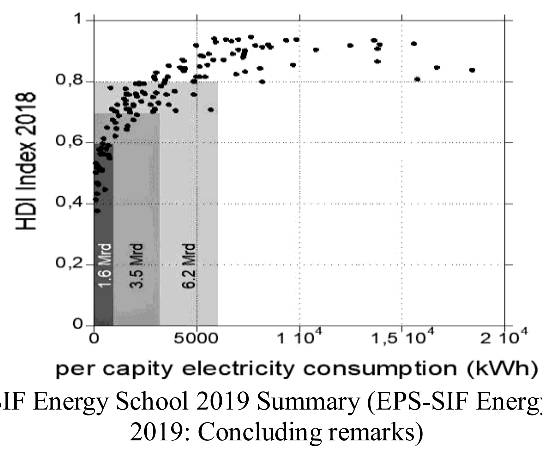

Figure 2. EPS-SIF Energy School 2019 Summary (EPS-SIF Energy Summer School 2019: Concluding remarks)

1.3. Energy's Impact on Key Development Indicators

Economic Growth

The productivity of industrial and agricultural sectors is closely tied to energy input. In regions such as East Africa, studies show that a 1% increase in electricity consumption can correlate with a 0.5% increase in GDP (Wang et al., 2021). Microenterprises, which form the backbone of many developing economies, require energy for lighting, refrigeration, communication, and machinery. Unreliable supply deters business scalability and foreign investment.

Health Outcomes

Energy access is directly linked to health system efficiency. Hospitals without reliable electricity cannot safely store vaccines, operate diagnostic equipment, or provide emergency services. Moreover, nearly 2.4 billion people still rely on biomass for cooking, contributing to indoor air pollution and respiratory diseases, particularly among women and children (International Energy Agency, 2023).

Education and Human Capital

Educational institutions with consistent power supply can extend learning hours, support digital education, and improve teaching quality. Lack of electricity in rural schools not only hampers student performance but also affects teacher retention and resource availability. In countries like India, pilot programs that provided solar-powered classrooms reported over 15% improvement in student attendance and test scores (Das & Sharma, 2020).

Gender Equality

The burden of energy poverty disproportionately affects women. Time spent collecting firewood or cooking on inefficient stoves limits women's economic participation and educational opportunities. Energy access has been shown to enhance gender equality by enabling entrepreneurship, reducing unpaid domestic work, and improving health outcomes.

Infrastructure and Industrialization

Robust energy infrastructure is a prerequisite for industrial development. In many African and South Asian nations, energy shortages and blackouts are routine, often forcing factories to rely on expensive and polluting diesel generators. This increases production costs and reduces competitiveness. Moreover, inadequate infrastructure restricts the expansion of electrified transport systems, smart agriculture, and digital services—all critical for development in the modern era. The lack of energy contributes to poverty, and poverty in turn limits a country's ability to invest in energy infrastructure—this self-reinforcing loop is known as the "energy trap." Governments in developing countries often face fiscal constraints and political instability that hinder long-term investments in the energy sector. External financing may not be aligned with local needs, and projects may suffer from corruption or poor execution. AI, as discussed later, presents a compelling opportunity to break this cycle by enabling cost-effective, data-driven decision-making, and optimization in energy planning and delivery.

2. ENERGY LANDSCAPE IN DEVELOPING COUNTRIES

Developing countries present a highly heterogeneous yet consistently constrained energy landscape. While some nations have made rapid strides toward universal electrification and renewable energy integration, others remain critically underserved due to political instability, underinvestment, and geographic challenges. This section provides an in-depth overview of energy systems across the Global South, examining the sources, access gaps, policy frameworks, and key development bottlenecks.

2.1. Case Studies in Regional Context

Sub-Saharan Africa: Nigeria and Kenya

Nigeria, Africa's largest economy, paradoxically suffers from chronic electricity shortages. Despite having one of the continent's largest energy resources, over 85 million Nigerians remain without access to grid electricity (International Energy Agency, 2023). Frequent outages, reliance on diesel generators, and a highly fragmented distribution network undermine industrial and social development.

Kenya, by contrast, has demonstrated significant progress, increasing electricity access from 27% in 2013 to over 75% in 2022 (World Bank, 2022). This success is attributed to strong public-private partnerships, donor-backed rural electrification projects, and adoption of off-grid solar systems. Kenya has also begun incorporating AI and smart technologies in its mini-grid management systems—a theme explored in detail in Section V.

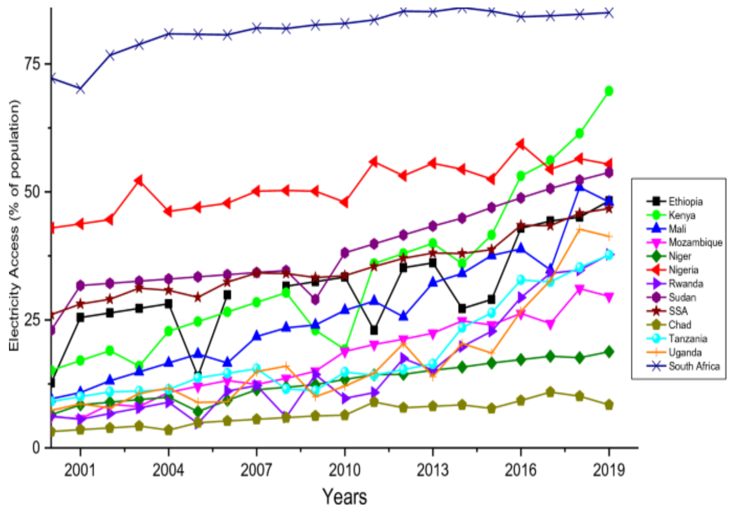

Figure 3. Energy Poverty and Renewable Potential in Sub-Saharan Africa (Juxtaposing Sub-Sahara Africa's energy poverty and renewable energy potential)

South Asia: India and Bangladesh

India has nearly achieved universal electricity access, yet reliability remains a major concern. Power distribution losses, theft, and outdated grid infrastructure cause inefficiencies, especially in rural and peri-urban areas. However, India also leads in renewable energy integration, ranking among the top five countries in installed solar and wind capacity (Gupta et al., 2022). Bangladesh represents a different trajectory—once heavily reliant on foreign aid, it has now achieved over 95% electrification, largely due to aggressive rural solar electrification programs. Microfinance-driven solar home systems and government-backed grid extension efforts have transformed the country's energy profile.

Latin America: Brazil and Colombia

Brazil enjoys high electrification rates (over 99%), but rural and Amazonian communities still face challenges due to geographic inaccessibility. The country's heavy reliance on hydropower, while environmentally favorable, exposes it to climate risk, especially during prolonged droughts. Colombia, on the other hand, has focused on decentralization and renewable diversification, integrating biomass and small hydro projects in remote areas.

2.2. Energy Mix and Resource Availability

Developing countries exhibit a wide variety of energy portfolios, with fossil fuels still dominant in many regions. However, renewable sources—solar, hydro, biomass, and wind—are increasingly being integrated due to global climate commitments and falling technology costs.

- Africa possesses vast solar potential but remains underutilized due to financial and infrastructural limitations.
- South Asia combines coal, hydro, and increasing shares of solar and wind.
- Latin America leans on hydropower, though diversification is underway.

Despite resource availability, energy systems in these regions are often centralized and inefficient, making them ill-suited for rural electrification without significant adaptation. This situation also brings certain challenges and constraints.

Grid Reliability and Infrastructure Deficits

Many developing countries struggle with aging or incomplete grid infrastructure. Transmission and distribution losses exceed 20% in countries like India and Nigeria—far above the global average (Rezaie & Mazaheri, 2020). In rural regions, grid extension is often economically unviable due to low population density and high upfront costs.

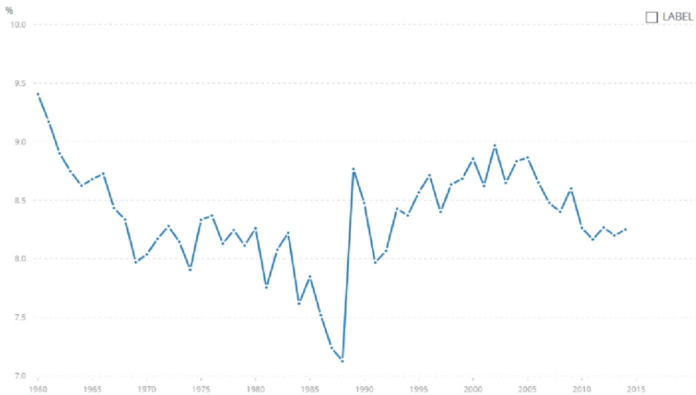

Figure 4. Energy Poverty and Renewable Potential in Sub-Saharan Africa (Model for Forecasting of Electricity Losses During Transmission and Distribution in an Electricity System)

Rural-Urban Disparities

Urban centers typically enjoy near-universal electricity access, while rural areas remain underserved. This disparity perpetuates income inequality and limits rural development. Decentralized energy systems, such as solar mini-grids, are emerging as viable alternatives but face scalability issues without adequate data, planning, and maintenance systems.

Financial and Investment Barriers

Energy projects in developing countries often struggle to secure financing due to perceived risks and unstable regulatory environments. Even where international aid is available, bureaucratic delays, corruption, and mismatched objectives can reduce the impact. Additionally, subsidized fossil fuel regimes often disincentivize clean energy investments.

Policy and Institutional Gaps

Many national energy policies are outdated or poorly enforced. Regulatory fragmentation, lack of data for planning, and weak institutional capacity hinder progress. Moreover, policies often fail to prioritize marginalized communities or account for gender, environmental, and digital inclusion factors.

Alongside the aforementioned points, *s*everal global frameworks aim to guide energy development in the Global South:

- **Sustainable Development Goal 7 (SDG 7):** Calls for affordable, reliable, sustainable, and modern energy for all by 2030.
- **The Paris Agreement (2015):** Pushes for renewable integration and energy efficiency as climate action strategies.
- **The African Renewable Energy Initiative (AREI):** Aims to add 300 GW of renewable capacity in Africa by 2030.
- **International Solar Alliance (ISA):** Led by India, promotes solar deployment in sun-rich developing countries.

Despite these initiatives, implementation lags due to a lack of localized planning tools, transparency, and digital infrastructure—gaps that AI can help bridge.

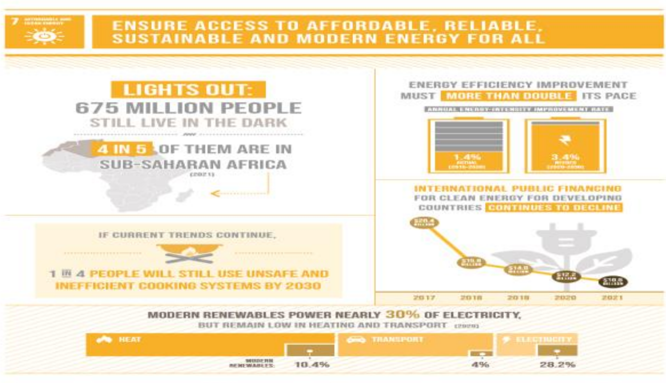

Figure 5. Global Energy Access and Efficiency Trends (UN SDG, 2023, UN SDG website)

3. ROLE OF ARTIFICIAL INTELLIGENCE IN ENERGY SYSTEMS

Artificial Intelligence (AI) offers transformative potential in the design, management, and expansion of energy systems—especially in developing countries grappling with efficiency, access, and reliability challenges.

With its capacity to analyse large volumes of heterogeneous data, predict demand-supply patterns, and automate operational decisions, AI is uniquely suited to optimize the performance of energy networks in resource-constrained environments.

This section outlines the foundational capabilities of AI, its applications across the energy value chain, and its strategic significance in accelerating energy access and development.

3.1. Foundations Of Artificial Intelligence in Energy Contexts

AI in energy refers to the application of machine learning (ML), deep learning (DL), natural language processing (NLP), and computer vision techniques to improve the generation, distribution, and consumption of energy. It integrates with Internet of Things (IoT) devices, remote sensors, satellite imagery, and historical data to create intelligent systems that learn and adapt to dynamic energy needs.

In developing countries, where energy infrastructure is often fragmented and data sparse, AI systems can: infer patterns from incomplete data; forecast energy demand more accurately; recommend optimal investment strategies; identify and reduce inefficiencies in distribution networks.

3.2. Key Applications of Ai in The Energy Sector

Demand Forecasting

Accurate prediction of energy demand is critical for balancing supply and avoiding blackouts or overproduction. AI models, such as recurrent neural networks (RNNs) and gradient boosting algorithms, can learn complex temporal patterns in electricity usage. For instance, AI systems can factor in weather forecasts, time-of-day consumption, and industrial activity to improve load forecasting in rural grids (Li et al., 2022).

In Kenya, AI-driven demand prediction tools have helped optimize the sizing and deployment of microgrids, thereby reducing investment risk and improving system reliability (Mwangi & Odhiambo, 2019).

Grid Optimization and Load Management

AI can automate grid balancing by predicting and adjusting power flows in real-time. This is particularly valuable in regions with variable renewable sources like solar and wind. Reinforcement learning algorithms can be used to develop self-learning grid controllers that respond adaptively to changes in load, weather, and generation patterns.

Additionally, AI-enabled smart meters and edge-computing devices provide granular usage data, which improves decision-making for utilities and consumers alike.

Renewable Energy Integration

Developing countries are rapidly adopting solar and wind due to declining costs. However, integrating intermittent renewables into weak grids is challenging. AI can mitigate these issues through:

- Solar irradiance prediction from satellite data,
- Wind speed forecasting using ML models,
- Hybrid system optimization for solar-diesel-battery configurations.

In India, solar microgrids managed through AI have shown a 15–25% increase in energy utilization efficiency compared to manually operated grids (Patel & Mehta, 2022).

Energy Theft Detection

Electricity theft is a significant problem in many developing countries, causing distribution companies to suffer financial losses and weakening grid reliability. AI models can identify irregular consumption patterns or anomalies in billing data to flag potential theft. For example, convolutional neural networks (CNNs) applied to smart meter data in Brazil enabled utilities to detect 70% of theft cases with over 85% accuracy (Silva et al., 2022).

Predictive Maintenance

AI tools can be trained to analyze sensor data and anticipate equipment failures in transformers, substations, and power lines. This reduces downtime and maintenance costs. In regions with remote infrastructure, drone-based inspection coupled with AI image analysis can automate fault detection.

3.3. AI For Decentralized Energy Planning

AI's scalability makes it well-suited for decentralized energy solutions such as mini-grids and solar home systems, which are essential for rural electrification in developing nations.

AI can determine optimal locations for mini-grid deployment using GIS and socio-economic data; design least-cost electrification pathways; simulate energy usage scenarios for investment decisions.

A study by MIT's Energy Initiative demonstrated that AI-led planning could reduce the cost of rural electrification projects by up to 30% in Sub-Saharan Africa (MIT Energy Initiative, 2020).

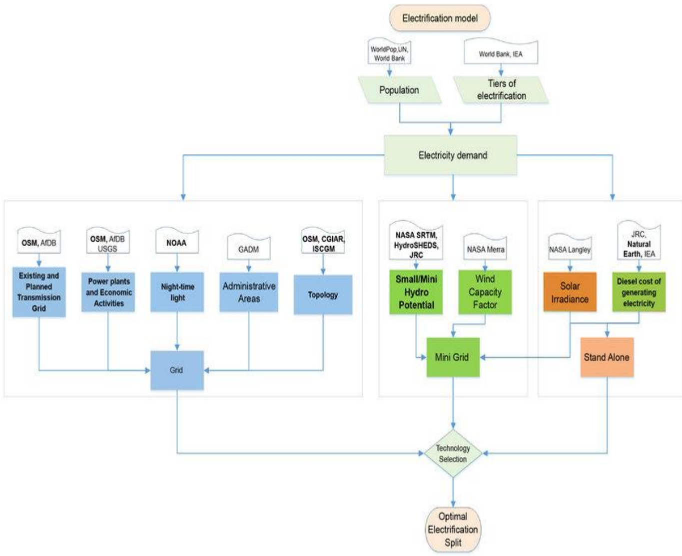

Figure 6. Electrification Toolkit Framework (OnSSET) (Framework of the Open Source Spatial Electrification Toolkit (OnSSET) and principal data sources).

Climate change introduces new challenges to energy systems, including increased variability in renewable sources and vulnerability to extreme weather events. AI can enhance climate resilience through: scenario-based simulations of flood or drought impact on hydro systems; grid reconfiguration algorithms during disaster events; real-time energy re-routing using AI agents during emergencies. These capabilities are vital for developing countries that face disproportionate climate risk and lack adaptive infrastructure. Despite its promise, AI deployment in the energy sector also poses challenges, limitations and ethical concers.

Many countries lack the digital infrastructure for real-time data collection *(Data availability)*. AI models trained on incomplete or biased data may exclude marginalized groups from planning *(Bias and exclusion)*.

Sophisticated AI systems may be cost-prohibitive without donor or private-sector support *(Affordability)*. Decision-making algorithms can be opaque, making it difficult to ensure accountability *(Transparency)*. Responsible AI practices, including explainable AI (XAI) frameworks and inclusive data strategies, are essential to address these concerns.

4. CASE STUDIES OF AI IN ENERGY FOR DEVELOPMENT

Practical implementations of Artificial Intelligence (AI) in energy systems within developing countries have begun to demonstrate measurable benefits in improving access, efficiency, and sustainability. This section highlights several key case studies that exemplify the diverse applications of AI, underscoring lessons learned and potential scalability.

Kenya: AI-Enabled Mini-Grid Optimization

Kenya's rural electrification has benefited from AI-powered demand forecasting and grid management tools developed through partnerships between local utilities and technology firms. These systems utilize machine learning algorithms to predict household and commercial electricity usage patterns based on historical consumption, weather data, and socio-economic factors. The AI platform dynamically adjusts energy dispatch schedules for solar and battery components of mini-grids, maximizing renewable energy utilization and minimizing reliance on costly diesel generators. As a result, mini-grid operators have reported a 20% reduction in operational costs and improved grid reliability in off-grid communities (Mwangi & Odhiambo, 2019).

India: AI for Solar Home Systems and Load Balancing

In India, AI-driven smart meters and load management systems are deployed in solar home systems, particularly in remote villages of Rajasthan and Uttar Pradesh.

These systems collect granular consumption data and apply predictive models to optimize energy distribution, identify faults early, and reduce downtime.

Moreover, reinforcement learning algorithms assist in balancing variable solar generation with household demand in real time. Field trials demonstrated up to a 25% increase in energy availability and improved customer satisfaction (Patel & Mehta, 2022).

Brazil: AI for Energy Theft Detection and Reduction

Electricity theft constitutes a significant challenge in Brazil, causing revenue losses estimated at over $1 billion annually. AI systems based on deep learning analyze consumption data from smart meters to detect irregularities indicative of tampering or theft. The utility company Companhia Energética de Minas Gerais (CEMIG) implemented a convolutional neural network-based tool that successfully flagged over 70% of theft cases, enabling targeted inspections and recoveries. This reduced non-technical losses by approximately 15% within two years of deployment (Silva et al., 2022).

Bangladesh: AI-Supported Solar Microgrid Expansion

Bangladesh's rural areas rely heavily on solar microgrids for electricity. AI has been integrated into the planning phase to select optimal sites for new installations by analyzing satellite imagery, population density, road accessibility, and economic activity patterns. A collaboration between the Bangladesh Rural Electrification Board (BREB) and AI researchers used geospatial AI models to prioritize locations that would maximize social impact and financial viability. This approach shortened planning cycles by 40% and improved resource allocation (Rahman et al., 2021).

South Africa: AI in Predictive Maintenance of Grid Assets

The South African utility Eskom has piloted AI-based predictive maintenance systems to monitor critical grid infrastructure such as transformers and transmission lines. Using sensor data and historical failure records, machine learning models forecast potential equipment failures, enabling preemptive maintenance.

Initial deployments resulted in a 30% reduction in unplanned outages and optimized maintenance scheduling, leading to cost savings and improved service reliability (Eskom Holdings SOC Ltd., 2021).

These cases collectively illustrate AI's ability to: enhance operational efficiency and reduce costs; improve energy access and reliability; support data-driven decision-making in constrained environments. However, challenges remain, including: ensuring data privacy and security; building local AI expertise and capacity; integrating AI solutions within existing institutional frameworks; securing sustainable financing for AI projects.

5. POLICY IMPLICATIONS AND RECOMMENDATIONS

The integration of Artificial Intelligence (AI) into energy systems offers profound opportunities for accelerating development in developing countries. However, realizing this potential requires deliberate policy frameworks, institutional capacity-building, and coordinated multi-stakeholder action. This section presents key policy implications derived from the preceding analysis and offers strategic recommendations to guide governments, development partners, and industry actors.

Strengthening data infrastructure and digital ecosystems; AI's efficacy is contingent upon the availability of high-quality, timely data. Developing countries must prioritize the establishment of robust digital infrastructure to collect, manage, and share energy-related data. Policies should encourage:

- Deployment of smart meters and IoT sensors,
- Creation of open-access energy data platforms,
- Adoption of data governance frameworks that protect privacy and ensure transparency.

Investment in digital literacy and technical training programs is essential to build a workforce capable of developing and maintaining AI-driven systems.

Encouraging public-private partnerships and innovation; AI implementation requires collaboration across public agencies, private companies, academia, and civil society. Governments should create enabling environments that:

- Foster innovation hubs and accelerator programs focused on AI and clean energy,
- Provide incentives such as tax breaks or subsidies for AI-enabled energy projects,
- Streamline regulatory approvals for pilot projects and technology deployments.

International development agencies and multilateral banks can play catalytic roles by co-financing initiatives and sharing best practices.

Designing inclusive and context-sensitive AI policies; AI-driven energy solutions must be tailored to local socio-economic realities. Policymakers should ensure:

- AI applications address the needs of marginalized groups, including women, rural populations, and informal settlements,
- Mechanisms exist for community engagement and participatory planning,
- Ethical AI standards are embedded in all projects to mitigate bias, ensure fairness, and uphold accountability.

Regular impact assessments should be conducted to evaluate social, economic, and environmental outcomes.

Aligning AI and energy policies with climate and development goals; AI deployment in the energy sector should support broader national commitments such as Sustainable Development Goals (SDGs) and Nationally Determined Contributions (NDCs) under the Paris Agreement. Recommendations include:

- Integrating AI tools into national energy planning and climate adaptation strategies,
- Prioritizing renewable energy integration and energy efficiency enhancements,
- Supporting data-driven monitoring and reporting of progress toward energy access and emissions reduction targets.

Cross-sectoral coordination will maximize synergies between energy, environment, health, and education policies.

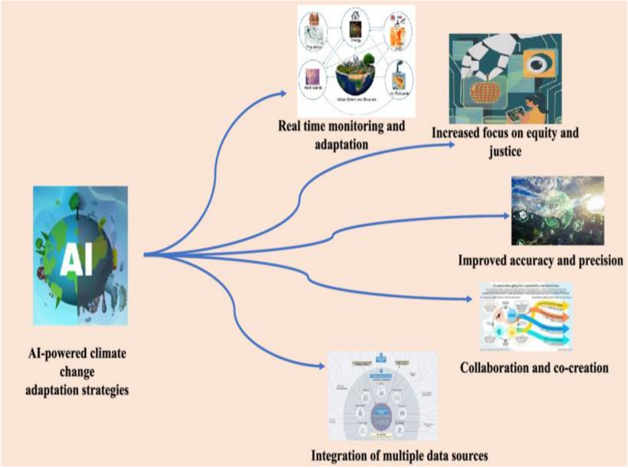

Figure 7. AI Innovations for Climate Change Adaptation Future innovations in AI-powered climate change adaptation strategies (adapted from Akter et al., 2021; Gill et al., 2022; Hötte & Jee, 2022)

Addressing financial and regulatory barriers; Sustainable financing models are critical for scaling AI in energy. Policymakers should:

- Facilitate access to blended finance combining public, private, and philanthropic capital,
- Develop regulatory frameworks that enable innovative business models like pay-as-you-go and energy-as-a-service,
- Implement risk mitigation mechanisms, including guarantees and insurance schemes, to attract investment in AI-powered energy infrastructure.

Transparent and predictable policies will build investor confidence and market stability.

Building Regional and International Cooperation; Given the transboundary nature of energy challenges, regional cooperation on AI-enabled energy solutions can drive economies of scale and knowledge sharing. Initiatives should include:

- Joint research and development programs,
- Harmonization of data standards and regulatory best practices,
- Capacity-building collaborations among developing countries.

International organizations can support these efforts through technical assistance and funding platforms.

CONCLUSION

The intersection of Artificial Intelligence (AI), energy, and development in the context of developing countries is an emergent and rapidly evolving field. Several key areas warrant further scholarly investigation to deepen understanding and optimize practical outcomes. *AI for Multi-Objective Energy Planning:* Research is needed to develop AI frameworks that simultaneously optimize energy access, affordability, reliability, and environmental sustainability. Integrating social equity and gender inclusiveness as explicit objectives remains underexplored. *Data Quality and Algorithmic Fairness:* The impact of data scarcity, bias, and quality on AI performance in low-resource settings requires systematic study.

Methods for explainable AI (XAI) tailored to energy systems could improve stakeholder trust and policy uptake. *Decentralized and Off-Grid AI Solutions:* Advancing AI techniques for autonomous management of decentralized energy resources, such as hybrid microgrids and peer-to-peer energy trading platforms, could revolutionize rural electrification. *Climate Resilience and AI:* Further research should explore AI's role in enhancing the climate resilience of energy infrastructure through predictive analytics, adaptive control systems, and real-time disaster response. *Socio-Economic Impacts and Ethical Considerations:* Quantitative and qualitative studies assessing AI's effects on employment, social inclusion, and ethical governance in energy sectors of developing countries are essential to inform responsible implementation.

To conclude, energy is a fundamental driver of economic and social development, yet billions in developing countries remain without reliable, affordable, and sustainable energy access. This paper has examined the intricate relationship between energy and development from the perspective of developing nations, highlighting persistent challenges such as infrastructure deficits, financial constraints, and policy gaps.

Artificial Intelligence emerges as a powerful enabler to address these challenges by optimizing energy system operations, enhancing renewable integration, reducing losses, and facilitating decentralized electrification. Case studies from Kenya, India, Brazil, Bangladesh, and South Africa illustrate practical successes while also revealing obstacles including data limitations and capacity deficits.

To harness AI's full potential, comprehensive policy frameworks, inclusive governance, investment in digital infrastructure, and multi-sectoral collaboration are indispensable. Continued research and innovation must prioritize context-specific solutions that balance technological advancement with social equity and environmental sustainability.

Ultimately, AI-powered energy transformation can accelerate the journey toward achieving Sustainable Development Goal 7 and foster resilient, inclusive development pathways for millions in the Global South.

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CHAPTER 9
ENERGY AND DEVELOPMENT IN DEVELOPING COUNTRIES

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INTRODUCTION

The world is experiencing significant industrial development and continued growth in the economies of major industrialized countries, while global energy demand has increased significantly in recent years.It has become necessary to adopt strategies and develop policies to seek alternative energy sources and explore avenues of international cooperation to develop the exploitation of renewable energy in a way that preserves the environment and achieves sustainable development in various sectors for generations to come.

The relationship between these two variables is clearly evident, as improving the efficiency of energy services is a key element in achieving the Sustainable Development Goals by reducing poverty by providing sustainable solutions that ensure that residents of rural and remote areas have access to the latest energy services (Improving the quality of education, providing clean water, developing a mix of available energy sources that is less polluting to the environment, using fossil fuel resources more efficiently, using lighting technologies and appliances that require less energy, etc.)

Given the diverse energy potential of developing countries, which are among the richest in the world in terms of fossil and renewable resources, and in their quest for sustainable development, many of them have realized the absolute necessity of adopting a path aimed at improving the efficiency of energy use, which is reflected in the measures taken by developing countries in this area by developing medium and long-term strategies. This is because traditional fossil fuel sources are exhaustible and are currently the main cause of the increase in toxic gas emissions into the air, which are responsible for global warming.

Energy is an essential component of development in developing countries, directly impacting economic, social, and environmental growth. Energy also provides access to basic services, fosters industrial and agricultural growth, and improves quality of life. Furthermore, the availability of energy helps alleviate poverty, improve the environment, and create new job opportunities.

There is no doubt that both sustainable development and improving energy efficiency are among the most important topics that are receiving increasing attention.

Therefore, it is imperative for all countries to double their efforts and keep pace with the developments taking place in this field; this is achieved by shifting towards the idea of a sustainable energy formula based on two interconnected axes that cannot be separated. The first revolves around improving energy efficiency, while the second relates to integrating renewable energies into the supply mix to preserve resources and protect the environment, which supports and enhances the path to achieving sustainable development goals. In this work, we will discuss the relationship between energy and sustainable development and explain in detail the role of energy in achieving economic development in developing countries.

1. THE HISTORICAL CONTEXT OF THE DEVELOPMENT OF THE SUSTAINABLE DEVELOPMENT

The concept of sustainable development arose from the perceived shortcomings of previous models of growth and development, which did not provide a broad and sufficient basis on which to make balanced judgments about the costs and benefits of different development policies (Oluleke Babayomi, et al, 2022).

Since the 1970s, there have been signs that development must evolve toward an approach consistent with the needs of both people and the environment. United Nations agencies have chosen the term "sustainable development" from among various translations, such as "continuous," "continuous," and "sustainable" (P. Falcone, 2023).

This concept emerged with the Brundland Report of the United Nations World Commission on Environment and Development in 1987. Over time, it has become a concern for all countries in the world, with a view to changing lifestyles in terms of production and consumption, and to collectively contribute to avoiding any environmental damage (Gilles, Carbonnier and Jacques, Grinevald, 2011). In general, the concept of sustainable development emerged and developed through four fundamental stages, which are:

Stage 1; Its roots lie in economic thought, which for decades has approached the issue of sustainable development indirectly, studying the contradiction resulting from the accumulation of wealth and the need to include the social cost of the project's activity in its economic calculations, without neglecting human responsibility in the face of the great risks associated with the invention of the atomic bomb. In other words, responsibility is based on the precautionary principle.

Stage 2; This dates to the early 1970s, when economic thought focused on one of the most significant contradictions of this accumulation mechanism, by investigating the environmental corruption and waste of natural resources resulting from this accumulation, which required defining the meaning and content of economic growth. This also led to the 1972 Club of Rome report, which presented the hypothesis of environmental limits to economic growth.

Stage 3; This dates to the 1980s with the publication of the Brundtland Report in 1987 and is linked to the international institutional interest of the relevant international organizations, which represents the basic reference document for sustainable development.

Stage 4; This dates to 2004 and is linked to the convergence between growth and environmental issues, reached at the World Summit on Sustainable Development in Johannesburg. This led to the economic debate on growth issues taking a new direction, and it became clear that some development models entail environmental damage. Conversely, a corrupt environment is an obstacle to development potential, requiring a way to achieve harmony between the two issues. This led to the emergence of the concept of sustainable development as a solution to the crisis (Gilles, Carbonnier, et al., 2011).

It is noteworthy that despite the existing disagreement regarding the emergence and development of the concept of sustainable development, there is unanimous agreement on many historical stages through which the concept has passed, the most important of which are summarized below (Khaled Ben Mohamed, Abou Leif, 2014).

In 1968, the Club of Rome was founded, bringing together many businessmen from different countries. They emphasized the need to conduct research in the fields of scientific development to determine the limits of growth in developed countries.

In 1972, the Club of Rome published a detailed report on the evolution of human society and its relationship to the exploitation of economic resources. Perhaps one of its most important findings was the prediction of the imbalance that would occur during the 21st century due to pollution, the depletion of natural resources, soil erosion, and other factors (J. Goldemberg, 2020). In the same year, the Stockholm Conference took place, marking the first beginnings of interest in the concept of sustainable development as the first real discussion on environmental issues at the global level. It was announced that poverty and lack of development are among the most serious enemies of the environment (Khaled Ben Mohamed, Abou Leif, 2014).

In 1983, the United Nations established the World Commission on Environment and Development, chaired by Brundtland. In 1987, a precise definition of sustainable development was formulated. The United Nations World Commission on Environment and Development (UNCED) presented a report entitled "Our Common Future," also known as the Brundtland Report. This report included an entire chapter devoted to sustainable development and was the first of its kind to declare that sustainable development was not only a moral and humanitarian issue, but also a developmental and environmental issue of vital importance and promise (Sosson Tadadjeu et al., 2023).

In 1992, the Second World Conference on Environment and Development, also known as the Earth Summit, was held in Rio de Janeiro. It defined the economic, social, and environmental standards for achieving sustainable development, a development alternative that would enable humanity to meet the needs and challenges of the 21st century (Gilles, Carbonnierv al, 2011).

In 1997, a third Earth Summit was held to follow up on global implementation. It adopted a program for the further implementation of Agenda 21, including the work program of the Commission on Sustainable Development (1998–2002). The Kyoto Conference was held in 1998, aimed at stabilizing greenhouse gases in the atmosphere at a level that would prevent human interference with the climate system within a sufficient timeframe. It also identified six gases subject to the agreement.

It also identified a series of measures that industrialized countries must take, including:

- Improve energy efficiency in various economic sectors
- Protect forests, increase vegetation cover, and improve agricultural practices

- Increase the use of alternative energy sources and develop carbon dioxide removal technologies
- Take appropriate measures to reduce emissions in the transportation sector
- Reduce methane emissions from energy production, transmission, and distribution
- Reduce the negative impacts of climate change, as well as its social, economic, and environmental consequences, particularly in developing countries dependent on fossil fuels.

In 2002, a meeting was held in Johannesburg, bringing together more than 100 leaders and tens of thousands of specialists, and a treaty was signed that guarantees the means to preserve natural resources and biodiversity (Le Thi Kim Oanh et al., 2021). In 2010, the Copenhagen Climate Summit was held, with all political parties convinced that the state of the global environment continued to deteriorate, despite numerous conferences and agreements in this area.

The summit discussed these global changes, ways to address the phenomenon of global warming, and ways to achieve sustainable global development that takes environmental aspects into account in its various macro and micro strategies. In 2012, the United Nations Conference on Sustainable Development was held in Rio de Janeiro, Brazil. Approximately 50,000 participants attended, including 57 heads of state, 8 vice presidents, 31 heads of government, 9 deputy prime ministers, and 487 ministers. The conference focused on two main projects: the green economy in the context of sustainable development and poverty reduction, and the institutional framework for sustainable development (Dilip Ahuja and Marika Tatsutani, 2009).

2. THE ROLE OF ENERGY IN ACHIEVING ECONOMIC DEVELOPMENT

Energy is a vital component of development in developing countries, directly impacting economic, social, and environmental growth. It enables access to basic services, promotes industrial and agricultural growth, and improves quality of life. Furthermore, renewable energy helps reduce poverty, improve the environment, and create new jobs. Below we will cite several examples of how energy can contribute to economic development:

Job creation; renewable energy projects provide new job opportunities in areas such as production, manufacturing, installation and maintenance, helping to reduce unemployment and improve living standards. *Providing energy to remote areas;* renewable energy, such as solar and wind power, provides access to energy to remote areas that cannot be connected to traditional electricity grids, enabling them to create businesses and economic activities. *Stimulate industrial and agricultural growth;* provide the energy needed to operate industrial and agricultural machinery and equipment, thereby contributing to increased productivity and improved product quality. The role of energy in achieving social development is also important. Below we will cite several examples of how energy can contribute to social development:

Provide energy for essential services; energy provides access to essential services such as lighting, water and heating, thus improving the quality of life and contributing to the improvement of public health. *Poverty reduction***;** new energy technologies can contribute to poverty reduction by providing more efficient and less expensive sources of energy. *Improving education;* providing the energy needed to operate schools and educational centers, thus contributing to improving education and skills levels. The role of energy in achieving environmental development. Below we will cite several examples of how energy can contribute to environmental development:

Reduction of emissions; renewable energy helps reduce harmful emissions that contribute to climate change, thereby improving air and water quality. *Environmental protection;* renewable energy helps protect the environment from pollution caused by fossil fuel exploitation. *Promoting sustainable development;* renewable energy promotes environmental sustainability by providing clean and renewable energy sources (Touat, Nasredine, 2012).

Many developing countries face challenges building the infrastructure needed to distribute and supply energy to remote areas. *High costs;* energy projects can be expensive, especially in remote areas, limiting the potential to maximize the benefits of these projects.

Environmental challenges; energy projects can lead to negative environmental impacts, such as air pollution or forest destruction (Touat, Nasredine, 2012).

3. THE ROLE OF DEVELOPING COUNTRIES IN ACHIEVING SUSTAINABLE DEVELOPMENT

Developing countries must define energy priorities, prioritizing sustainable development through the use of renewable energy sources. Developing countries must strengthen international cooperation in the energy sector by exchanging expertise, knowledge, and technology. Developing countries must create an enabling environment for investment in the energy sector by simplifying procedures and reducing costs. In summary, energy is a key element of sustainable development in developing countries, contributing to economic, social, and environmental growth. To achieve these goals, developing countries must define energy priorities, strengthen international cooperation, and create an enabling environment for investment. Below we present a program of two examples from two developing countries (Algeria and Nigeria) on energy and sustainable development.

3.1 The Role of Renewable Energies in Achieving Sustainable Development in Algeria

Algeria has significant potential in the field of renewable energy, particularly solar energy. Renewable energy is a driver of sustainable economic development and a priority for national energy and economic policies until 2030. It will provide approximately 40% of the energy produced by photovoltaic and thermal solar power.

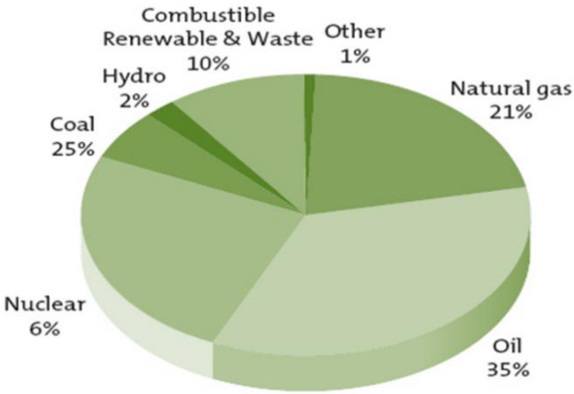

Figure1. Contribution of different energy sources to the national economy (Lokman, Hadji, 2016).

In 2011, Algeria launched a vast renewable energy development program, which will extend over the next two decades. In addition to the environmental dimension and the desire to diversify its energy sources, Algeria is also seeking to extend the lifespan of its hydrocarbon reserves and exploit its significant solar and wind resources in order to contribute to meeting national electricity needs and export some of it to European countries (Zohra, Roiguia, 2019).

Renewable Energy Program, which runs until 2020, includes the construction of 60 solar thermal power plants, wind farms, and hybrid power plants. The renewable energy projects for the national market will be implemented in three phases. The first phase (2011-2013) is dedicated to the implementation of pilot projects to test various available technologies. The second phase (2014-2015) will focus on the immediate deployment of the programs. The third phase (2016-2020) will focus on large-scale deployment (M. Yaseen, et al, 2021).

The *Energy Efficiency Program* reflects Algeria's desire to encourage responsible energy use and implement all means to conserve resources. The goal of energy efficiency is to produce the same benefits or services while consuming as little energy as possible.

The energy efficiency program includes the following actions: thermal insulation of buildings to reduce energy consumption for heating and cooling;

development of a solar water heater as an alternative to traditional water heaters; promotion of the use of energy-efficient light bulbs and encouragement of local production by creating partnerships between local and foreign producers; introduce energy efficiency in public lighting, where all mercury lamps (which consume a lot of energy) will be replaced with sodium lamps (which are economical) through an energy management program for local authorities; promote energy efficiency in the industrial sector by co-financing energy audits, feasibility studies, and additional costs that enable companies to introduce energy efficiency into technically and economically viable projects; promote LPG/fuel and natural gas/fuel by encouraging the conversion of automobile consumption patterns to their use; introduction of basic solar air conditioning technologies, particularly in the South.

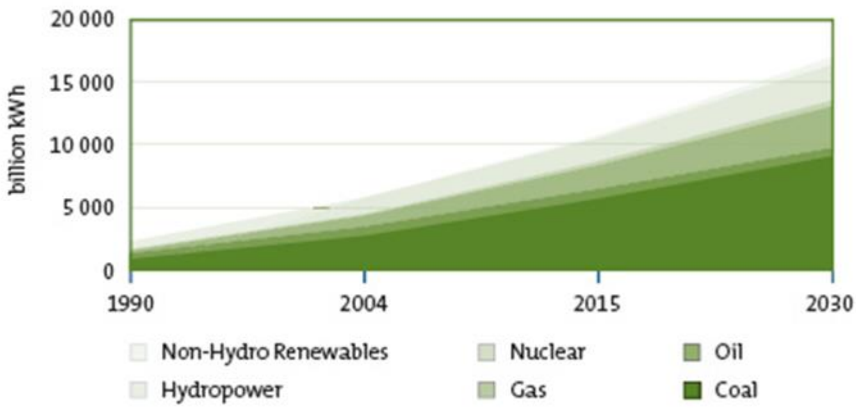

Figure 2. Developmental dimensions of the Renewable Energy and Energy Efficiency Program (Zohra, Roiguia, 2019).

The Renewable Energy and Energy Efficiency Program adopted by Algeria in 2011 identifies the dimensions linked to the achievement of sustainable development, in particular economic, social, environmental and technological dimensions.

Economic Dimensions: Stimulate a new growth model based on renewable energy, a driver of economic and social development; effectively manage the rate of growth in energy demand by introducing energy efficiency to manage resources and establish necessary and optimal consumption; meet national long-term energy needs and achieve significant savings in fuel consumption; preserve fossil fuel resources, diversify electricity generation sectors, and contribute to sustainable development; increase investment in renewable energy technologies, thereby contributing to increased economic benefits and the creation of new jobs, particularly in local industries specializing in these technologies.

Social Dimensions: The national program aims to improve the population's standard of living by meeting their energy needs, particularly in remote areas, thereby reducing rural exodus; create new direct and indirect jobs through renewable energy projects; reduce poverty by providing the necessary energy to remote desert areas, which will create new jobs and improve the level of social services in these areas. *Environmental dimensions:* Reduce greenhouse gas emissions, thus contributing to the fight against global warming and environmental preservation; use renewable energy to reduce pollution from fossil fuels used to generate electricity or heat (Zohra, Roiguia, 2019). *Technological dimensions:* Intensify research and development activities through the use of cleaner technologies and the adoption of sustainable methods and approaches; involve private institutions alongside public institutions in the implementation of various projects, particularly by relying on modern technologies; collect knowledge and develop training programs to promote local Algerian skills, and strengthen capacities in science, technology and innovation in order to raise the scientific and cognitive level.

3.2 Energy Situation in Nigeria

Nigeria is Africa's energy giant. It is the continent's most prolific oil-producing country, which, along with Libya, accounts for two-thirds of Africa's crude oil reserves. It ranks second to Algeria in natural gas. (Sambo AS, 2008). Most of Africa's bitumen and lignite reserves are found in Nigeria. In its mix of conventional energy reserves, Nigeria is simply unmatched by any other country on the African continent.

It is not surprising therefore that energy export is the mainstay of the Nigerian economy. Also, primary energy resources dominate the nation's industrial raw material endowment (Sunday Olayinka Oyedepo, 2012).

Several energy resources are available in Nigeria in abundant proportions. The country possesses the world's sixth largest reserve of crude oil. Nigeria has an estimated oil reserve of 36.2 billion barrels. It is increasingly an important gas province with proven reserves of nearly 5,000 billion m3. The oil and gas reserves are mainly found and located along the Niger Delta, Gulf of Guinea, and Bight of Bonny. Most of the exploration activities are focused in deep and ultra-deep offshore areas with planned activities in the Chad basin, in the northeast.

Coal and lignite reserves are estimated to be 2.7 billion tons, while tar sand reserves represent 31 billion barrels of oil equivalent. The identified hydroelectricity sites have an estimated capacity of about 14,250 MW. Nigeria has significant biomass resources to meet both traditional and modern energy uses, including electricity generation (Sunday Olayinka Oyedepo, 2012).

The situation in the rural areas of the country is that most end users depend on fuel wood.

Fuel wood is used by over 70% of Nigerians living in the rural areas. Nigeria consumes over 50 million tonnes of fuel wood annually, a rate which exceeds the replenishment rate through various afforestation programs. Sourcing fuel wood for domestic and commercial uses is a major cause of desertification in the arid-zone states and erosion in the southern part of the country. The rate of deforestation is about 350,000 ha/year, which is equivalent to 3.6% of the present area of forests and woodlands, whereas reforestation is only at about 10% of the deforestation rate. The rural areas, which are generally inaccessible due to the absence of good road networks, have little access to conventional energy such as electricity and petroleum products. Petroleum products such as kerosene and gasoline are purchased in the rural areas at prices 150% in excess of their official pump prices. The daily needs of the rural populace for heat energy are therefore met almost entirely from fuel wood. The sale of fuel wood and charcoal is mostly uncontrolled in the unorganized private sector. The sale of kerosene, electricity and cooking gas is essentially influenced and controlled by the Federal Government or its agencies - the Nigerian National Petroleum Corporation (NNPC) in the case of kerosene and cooking gas, and the Power Holding Company of Nigeria (PHCN) in the case of electricity.

The policy of the Federal Government had been to subsidize the pricing of locally consumed petroleum products, including electricity. In a bid to make the petroleum downstream sector more efficient and in an attempt to stem petroleum product consumption as a policy focus, the government has reduced and removed subsidies on various energy resources in Nigeria. The various policy options have always engendered price increases of the products (Ighodaro CAU, 2010).

With the restructuring of the power sector and the imminent privatization of the electricity industry, it is obvious that for logistic and economic reasons especially in the privatized power sector, rural areas that are remote from the grid and/or have low consumption or low power purchase potential will not be attractive to private power investors. Such areas may remain unserved into the distant future. Meanwhile, electricity is required for such basic developmental services as pipe borne water, health care, telecommunications, and quality education. The poverty eradication and Universal Basic Education programs require energy for success (Okafor ECN, Joe-Uzuegbu CKA,2010).

The absence of reliable energy supply has not only left the rural populace socially backward, but has also left their economic potentials untapped. Fortunately, Nigeria is blessed with abundant renewable energy resources such as solar, wind, biomass, and small hydropower potentials. The logical solution is increased penetration of renewables into the energy supply mix (Famuyide OO, Anamayi SE, Usman JM, 2011).

Energy consumption patterns in the world today shows that Nigeria and indeed African countries have the lowest rates of consumption. Nevertheless, Nigeria suffers from an inadequate supply of usable energy due to the rapidly increasing demand, which is typical of a developing economy. Paradoxically, the country is potentially endowed with sustainable energy resources. Nigeria is rich in conventional energy resources, which include oil, national gas, lignite, and coal. It is also well endowed with renewable energy sources such as wood, solar, hydropower, and wind (Sambo AS,2009).

The patterns of energy usage in Nigeria's economy can be divided into industrial, transport, commercial, agricultural, and household sectors.

The household sector accounts for the largest share of energy usage in the country - about 65%. This is largely due to the low level of development in all the other sectors (Sunday Olayinka Oyedepo, 2012).

The major energy-consuming activities in Nigeria's households are cooking, lighting, and use of electrical appliances. Cooking accounts for a staggering 91% of household energy consumption, lighting uses up to 6%, and the remaining 3% can be attributed to the use of basic electrical appliances such as televisions and pressing irons (Adeyemo SB, Odukwe AO, 2008). The predominant energy resources for domestic and commercial uses in Nigeria are fuel wood, charcoal, kerosene, cooking gas and electricity. Other sources, though less common, are sawdust, agricultural crop residues of corn stalk, cassava sticks, and, in extreme cases, cow dung. In Nigeria, among the urban dwellers, kerosene and gas are the major cooking fuels. Most of the people rely on kerosene stoves for domestic cooking, while only a few use gas and electric cookers (Habib MA et al.,1999).

The rural areas have little access to conventional energy such as electricity and petroleum products due to the absence of good road networks. Petroleum products such as kerosene and gasoline are purchased in the rural areas at prices very high in excess of their official pump prices.

The rural population, whose needs are often basic, therefore depends to a large extent on fuel wood as a major traditional source of fuel. It has been estimated that about 86% of rural households in Nigeria de-pend on fuel wood as their source of energy. A fuel wood supply/demand imbalance in some parts of the country is now a real threat to the energy security of the rural communities (Sunday Olayinka Oyedepo, 2012). The energy consumption per capita in Nigeria is very small - about one-sixth of the energy consumed in developed countries. This is directly linked to the level of poverty in the country. Gross domestic product (GDP) and per capita income are indices that are used to measure the economic well-being of a country and its people. GDP is defined as the total market value of all final goods and services produced within a given country in a given period of time (usually a calendar year).

The per capita income refers to how much each individual receives, in monetary terms, of the yearly income that is generated in his/her country through productive activities.

That is what each citizen would receive if the yearly income generated by a country from its productive activities were divided equally between everyone (Sunday Olayinka Oyedepo, 2012).

4. ENERGY EFFICIENCY AND ENERGY CONSERVATION IN SUSTAINABLE DEVELOPMENT

Energy efficiency means an improvement in practices and products that reduce the energy necessary to pro-vide services. Energy efficiency products essentially help to do more work with less energy. Energy efficiency is also defined as essentially using less energy to provide the same service. In this sense, energy efficiency can also be thought of as a supply of resource - often considered an important, cost-effective supply option. Investment into energy efficiency can provide additional economic value by preserving the resource base (especially combined with pollution prevention technologies) and mitigating environmental problems (Dubin FS, Long CG, 1980).

Energy efficiency (EE) improvements have multiple advantages, such as the efficient exploitation of natural resources, the reduction in air pollution levels, and lower spending by the consumers on energy-related expenditure. Investments in EE result in long-term benefits, such as reduced energy consumption, local environmental enhancement, and overall economic development. Energy use has environmental impacts, regardless of the source or mechanism. For example, hydroelectric projects affect their local ecological systems and displace long-standing social systems. Fossil fuel power creates pollution in the extraction, transportation, and combustion of its raw materials. The long-term storage of waste products of the nuclear power industry is an issue to be resolved. Cost-effective energy efficiency is the ultimate multiple pollutant reduction strategy.

In Nigeria, a lot of energy is wasted because house-holds, public and private offices, as well as industries use more energy than is actually necessary to fulfil their needs. One of the reasons is that they use outdated and inefficient equipment and production processes. Unwholesome practices also lead to energy wastage. In Nigeria, the need for energy is exceeding its supply.

In view of these circumstances, primary energy conservation, rationalization, and efficient use are immediate needs. Getting all the possible energy from the fuel into the working fluid is the goal of efficient equipment operations. This leads to a higher productivity and saves not only money, but also influences the safety and life of the equipment and reduces pollution. Steps taken to minimize energy consumption, or to use the energy more effectively, are steps in the right direction to preserve the global environment.

Energy conservation measures or recommendations are often referred to more positively as opportunities. Two primary criteria for applying energy conservation are that it is easy to implement and that its payback is brief. Ease of implementation and duration of payback period have been used to classify Energy conservation opportunities into three general categories for use: in maintenance and operation measures, in process improvement projects, and in large capital projects. Energy conservation and energy efficiency are separate but related concepts. Energy efficiency is achieved when energy intensity in a specific product, process, or area of production or consumption is reduced without affecting output, consumption, or comfort levels. Promotion of energy efficiency will contribute to energy conservation and is therefore an integral part of energy conservation promotional policies (Etiosa U, 2009).

Energy efficiency encompasses conserving a scarce resource; improving the technical efficiency of energy conversion, generation, transmission and end-use devices; substituting more expensive fuels with cheaper ones; and reducing or reversing the negative impact of energy production and consumption activities on the environment.

Energy conservation is a tangible resource by itself that competes economically with contemporary energy supply options. In addition to this, it offers a practical means of achieving four goals that should be of high priority in any nation that desires quick and sustainable economic growth and development. These are economic competitiveness, utilization of scarce capital for development, environmental quality, and energy security. It enhances the international competitiveness of the industries in the world markets by reducing the cost of production. It optimizes the use of capital resources by directing lesser amounts of money in conservation investment as com-pared with capital-intensive energy supply options.

It protects the environment in the short run by reducing pollution and in the long run by reducing the scope of global climate change. It strengthens the security of supply through a lesser demand and a lesser dependence on petroleum product imports. No energy supply option may be able to provide all these benefits. Energy conservation is a decentralized issue and is largely dependent on individual, distinct decisions of energy supply, which are highly centralized. The housewife, the car driver, the housing developer, the house owner, the boiler operator in industry, and every other individual who consumes energy in some form or another are required to participate in energy-saving measures.

It calls for a collective endeavour and is dependent upon the actions of people in diverse fields although the people involved may not be sufficiently informed or motivated to conserve energy (Sunday Olayinka Oyedepo, 2012).

CONCLUSION

Based on the research results, we have reached the following conclusions. Firstly, there is a close link between energy and achieving sustainable development requirements, which requires special attention to environmental protection. Renewable energy is one of the most important means to achieve this, as it is non-polluting and environmentally friendly.

Secondly, The Renewable Energy and Energy Efficiency Program is a far-reaching and ambitious program aimed at achieving comprehensive sustainable development at the national level, particularly by overcoming the isolation of isolated areas. However, the expected effects will only be evident in the medium and long term.

Thirdly, the growing importance of renewable energy and the tremendous potential available to developing countries have prompted them to integrate it into their energy policies by launching a major program to this effect and a set of laws encouraging its promotion and the establishment of appropriate structures. The implementation of the program's projects must be accelerated within the established timeframe.

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Yusuf Girayalp ATAN is an economist and columnist. He is pursuing his Ph.D. in International Political Economy at Marmara University’s Institute of Social Sciences, where he also completed his master’s degree focusing on the Political Economy of the Middle East. Currently working as an economist at the Turkish Statistical Institute (TÜİK), Atan specializes in national and international political economy, energy policy, and regional economic security. As a columnist for Milat Newspaper, he writes analytical pieces on economic diplomacy, global competition, and geopolitical developments. He has presented papers at various international academic conferences, received awards for his research, and published scholarly articles. In addition to his academic and professional work, Atan has held leadership roles in civil society organizations and has contributed economic analyses to international media platforms.

Energy is the silent architect of development—fueling industries, shaping societies, and defining the balance between growth and justice. From Resources to Growth: Energy and Development Strategies in Developing Nations brings together a diverse group of scholars whose insights reveal that the future of progress lies not merely in resources, but in how humanity chooses to use them.

Spanning perspectives from Africa to Asia, and from Türkiye to India, the book explores how education, science, technology, and governance intersect in shaping energy policy and economic transformation. Ahmad Ibn Shuaeeb reminds us that sustainability begins with awareness. Ansar Bilyaminu Adam and colleagues demonstrate how chemistry and innovation can empower communities. Juliet Ohenokobosare Esieboma reframes energy as a question of justice and inclusion, while Rajeshwari Mohan Lakhwani uncovers the political forces that define global energy competition.

The volume also presents national narratives that echo a shared struggle for balance. Yusuf Girayalp ATAN and Arzu AL examine Türkiye's path toward resilience in the face of dependence. Mohamed Ali Moussa and Wasiu Abiodun Makinde analyze Africa's energy-development paradox, while Akhil Bhat and Muhammad Sufyaan Khan explore how technology and regional dynamics can redefine sustainability.

Written in a language that bridges research and reflection, this book calls for a reimagining of development—one rooted in cooperation, ethics, and innovation. It is not only a scholarly contribution but an invitation to policymakers, academics, and citizens to envision a future where energy empowers humanity rather than divides it.

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