

## Assessing Energy Flexibility: A Comparative Review of Nigeria and the UK

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### ABSTRACT

This paper provides a comparative analysis of the energy systems in Nigeria and the United Kingdom, focusing on market instruments for energy flexibility to achieve NetZero emissions under the Paris Agreement. Through a systematic review using Scopus database, the study identifies key energy flexibility instruments in Nigeria, including energy efficiency initiatives, smart metering, peer-to-peer energy trading, decentralised energy systems, and independent power plants. Supporting policies include Renewable Energy Master Plan, National Energy Efficiency Action Plan, and National Renewable Energy Action Plan. However, Nigeria faces challenges like low electrification rates, underutilised grid capacity, and fragile infrastructure, resulting in power outages. Conversely, the UK's energy system features advanced Demand-Side Response Programmes, Smart Grid Technologies, Energy Storage Solutions, and Virtual Power Plants, supported by policies and initiatives like Agile Octopus Smart Meters. Learning from the UK's successes evidenced by its high ranking on the World Energy Council Energy Trilemma Index, this study recommends that Nigeria improve its power infrastructure and incorporate energy flexibility instruments. By expanding power capacity, upgrading the grid, enhancing flexibility mechanisms, creating roadmaps, and transparent allocation and use of financial resources. These actions are essential for enhancing the reliability and sustainability of Nigeria's energy system to achieve a Just Transition.

**Keywords:** Energy Trilemma, Renewable Energy, Just Transition, Energy Flexibility, Developing Economy

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## 1. Introduction

The global energy transition has accelerated as nations strive to limit global temperature rise and meet the Paris Agreement's NetZero goals. This transition emphasises the critical need for integrating renewable energy sources, reducing dependence on fossil fuels, and enhancing energy efficiency. To achieve a balance between supply and demand, there is an increasing need for energy flexibility instruments globally (Cruz et al., 2024; Dannheim et al., 2020; Jung & Schindler, 2020; Malaekheh et al., 2022; Neupane et al., 2022; Ofgem, 2021; Paraschiv et al., 2022; Patidar et al., 2022; Vallejo-Díaz et al., 2022; Virtanen et al., 2022; Wang et al., 2024)

Energy flexibility instruments are crucial for ensuring the reliability of power systems, particularly with the growing integration of variable renewable energy sources (RES). Traditionally, supply-side flexibility has played a significant role in stabilising power systems. However, as RES become more prevalent, they displace traditional supply-side flexibility providers and increase generation variability. This shift has intensified discussions on the need for flexibility to support a just energy transition in both developed and developing nations (Ahmadihangar et al., 2020)

The stochastic nature of RES presents operational and security challenges, particularly when their share in the generation mix is significant. The unpredictability of power generation from RES necessitates a greater emphasis on flexibility to maintain power balance. In the ongoing transition towards a decarbonised society, driven by intermittent and non-deterministic renewable sources, flexibility becomes essential for creating resilient, efficient, and sustainable energy systems (Abbà et al., 2024). This need for flexibility extends across global regions, including both the Global North and South (Reiter & Jakob, 2021).

Energy flexibility tools are essential for maintaining the reliability of power systems, especially as variable renewable energy sources, such as solar, wind, hydropower, geothermal, biomass, tidal, and wave energy, are increasingly integrated. Historically, supply-side flexibility has been key to stabilising power systems. However, as the share of these renewable energy sources grows, they start to replace conventional supply-side flexibility options, leading to more variability in power generation. This change has heightened the conversation around the need for flexibility to facilitate a fair energy transition in both developed and developing countries (Ahmadihangar et al., 2020). The unpredictable nature of renewable energy sources, particularly when they constitute a large portion of the energy mix, poses operational and security challenges. The irregularity of power generation from these sources underscores the importance of flexibility in maintaining a stable power balance. As the world transitions to a decarbonised future, driven by renewable sources that are inherently intermittent and unpredictable, the role of flexibility becomes crucial in developing resilient, efficient, and sustainable energy systems (Abbà et al., 2024). The necessity for such flexibility spans across the globe, affecting both the Global North and South.

While regions in the Global North have made progress in developing and advancing both supply and demand-side flexibility (Tziovani et al., 2020), many Global South nations, including Nigeria, continue to face ongoing challenges such as unreliable power supply and unstable grids. For instance, Nigeria's energy sector is characterised by a significant gap between available energy and system capacity. Despite an installed power generation capacity of 15 GW, only one-third operates at peak levels, leaving over 20 million homes without adequate electricity. The country's electrification rate is 56.5%, indicating widespread issues with reliable energy access. Frequent power outages, insufficient capacity, and low levels of renewable energy integration further complicate Nigeria's energy landscape. Socioeconomic factors, such as a 5.75% unemployment rate, a 2.6% population growth rate, and high fossil fuel emissions, further contribute to these challenges (Attabo et al., 2023; Ben et al., 2021; Eweka et al., 2022; IRENA, 2023c; Ndukwu et al., 2021; Olaofe, 2017; Ritchie et al., 2020; Shigenobu et al., 2017; Statista, 2023).

Despite Nigeria's abundant non-renewable and renewable energy resources—including solar PV, hydroelectric, offshore and onshore wind, tidal, and biomass—clean energy sources only

contribute about 26% of the country's annual energy production (Akporhonor et al., 2023; Ben et al., 2021; Climatescope, 2022; Eweka et al., 2022; IRENA, 2023a; Somoye, 2023). Addressing these challenges is crucial for ensuring a just energy transition as Nigeria increases its integration of renewable energy sources. This transition must be accompanied by corresponding advancements in flexibility instruments to improve the country's energy landscape.

In Nigeria, as in many developing countries, load shedding is commonly used to balance energy demand and supply, albeit inconsistently. This approach aims to distribute electricity equitably among users, despite its limitations. However, there is a lack of sufficient knowledge and literature regarding other energy flexibility instruments utilised in Nigeria. A literature review indicated that limited research has focused on this topic, highlighting the need for further study and exploration in this area.

This presents an opportunity to assess and enhance energy flexibility instruments in Nigeria, thereby identifying areas for improvement and better integration.

### **Aim and Objectives**

The primary aim of this study is to investigate and evaluate the existing energy flexibility instruments in Nigeria. The primary aim of this study is to assess the factors affecting the success of energy flexibility instruments in Nigeria. This will involve a comparative review with similar instruments in the United Kingdom to evaluate their effectiveness and identify areas for improvement. This will be done by addressing two main questions:

- (i) What are the existing energy flexibility instruments in Nigeria? and
- (ii) How effective are the existing energy flexibility programs, and how can they be improved, based on lessons learned from the United Kingdom?

To answer these questions, the following objectives have been set:

- To evaluate Nigeria's power system and key policies that support flexibility.
- To evaluate existing market instruments for flexibility within Nigeria's energy system.
- To explore the opportunities and uncertainties for energy flexibility in Nigeria.
- To explore best practices and insights from the UK energy flexibility market that can be applied to the Nigerian context.

## **2. Methodology**

To understand the energy flexibility instruments in Nigeria, a critical evaluation of the country's energy system and supporting policies was conducted. Following this, a systematic review of academic publications was undertaken to address the research questions and objectives outlined above. Following the Collaboration for Environmental Evidence (CEE) Guidelines, a systematic review involves a meticulous data collection process that emphasises thoroughness, transparency, reproducibility, and minimising bias (Gusenbauer & Haddaway, 2020).

Consequently, the following approach was employed:

### **2.1 Database Selection**

The Scopus database was selected as the primary source due to its wide acceptance among researchers and frequent use in systematic and comparative studies in the energy sector.

### **2.2 Search String Development and Search**

The search string was developed in two parts. Primary keywords derived from the study's title were searched under the "Article title" category. Secondary keywords, likely to appear in the study's abstract, were searched under the "Article title, Abstract, Keywords" category. The initial search string (TITLE (energy AND flexibility AND (mechanism OR instrument\*)) AND

TITLE-ABS-KEY (energy AND trilemma OR renewable AND energy OR energy AND transition OR energy AND flexibility OR just AND transition)) yielded two publications. However, applying the exclusion criterion "focus on Nigeria" resulted in zero results, indicating a limited study focus (see Figure 2-1).

To broaden the search, the terms "AND (mechanism OR instrument\*)" were removed, refining the search string to (TITLE (energy AND flexibility) AND TITLE-ABS-KEY (energy AND trilemma OR renewable AND energy OR energy AND transition OR energy AND flexibility OR just AND transition)). Given the low count this adjustment aimed to broaden the scope and increase the relevance of the search results. As indicated in the PRISMA flow chart (Figure 2-2), the revised search yielded 108 publications, when limited to "energy and engineering" 77 and when limited to "focus on Nigeria" the search string resulted in zero publications, indicating a limitation in studies across this topic.

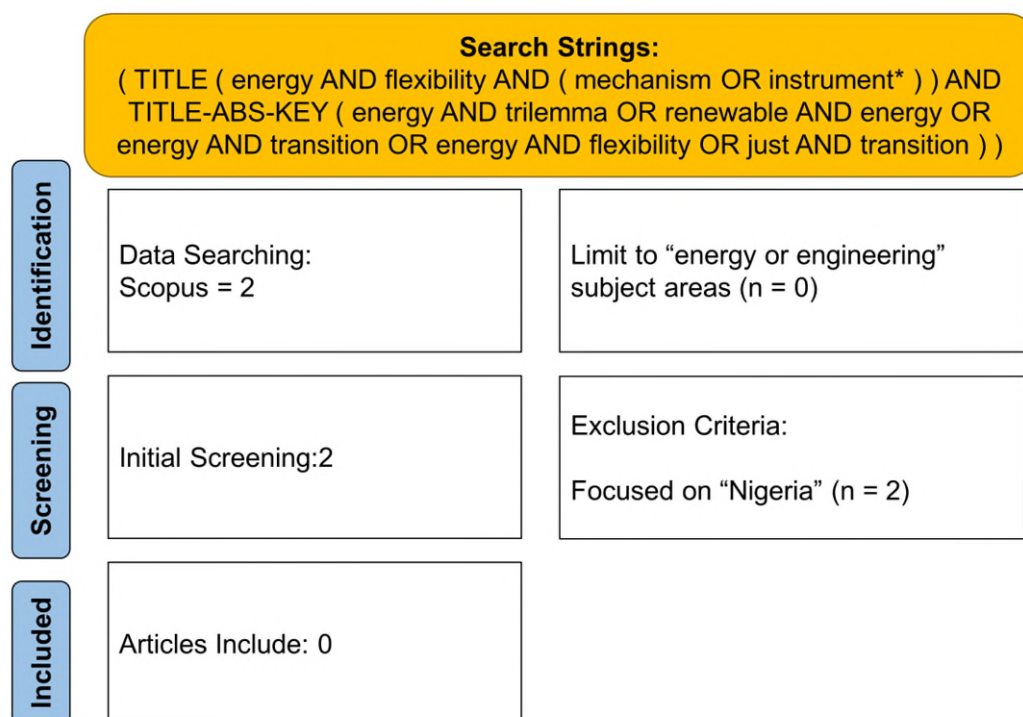


**Figure 2-1 PRISMA flow Chart for Initial Search String**

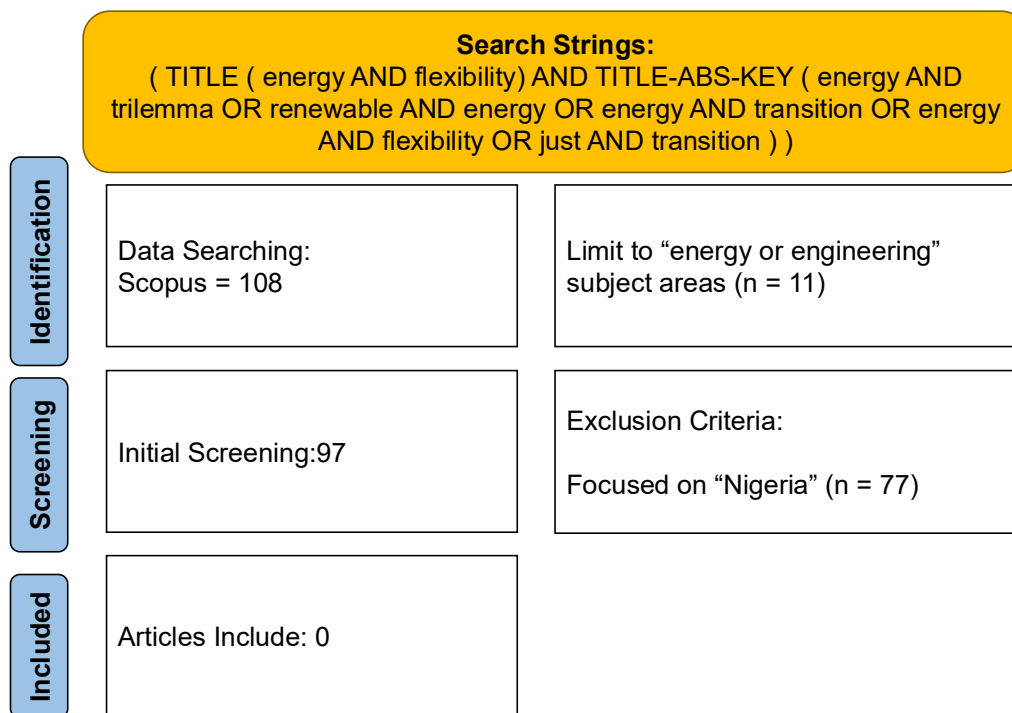


**Figure 2-2 PRISMA flow chart for Second Search String**

### 2.3 Backward Snowballing

Consequently, the backward snowballing was adopted. This method involves the identification, review and adoption of references from selected papers (Wohlin, 2014) Following expert recommendations a study titled "Systematic Review of Demand-Side Management Strategies in Power Systems of Developed and Developing Countries" was reviewed and adopted for its analysis involving the Nigerian energy system focusing on demand-side management as the start-set paper.

### 2.4 Comparative Review

There are no universally established criteria for evaluating the success of energy flexibility mechanisms. Therefore, this study employed a comparative review approach, focusing on Nigeria and a leading nation in the implementation of energy flexibility instruments, particularly demand-side management, such as the United Kingdom. The analysis centred on three key documents: Ofgem's "Transitioning to a Net Zero Energy System: Smart Systems and Flexibility Plan 2021," "Guidance: The Change Process for the Capacity Market Rules" (2023), and the Department of Energy and Climate Change's "Electricity Market Reform Delivery Plan" (2013). These documents were selected for their detailed insights into the UK's strategic, regulatory, and operational frameworks for energy flexibility, providing a basis for comparison and highlighting potential improvements for Nigeria's energy sector.

## 3. Results and Discussion

### 3.1 Relevant Publication

Following the decision to adopt a start-set paper and proceed to employ a backward snowballing process. A total of nine publications were included in this process as indicated in Table 3-1. The inclusion criteria required that the retrieved papers significantly contribute to the initial set and reference the Nigerian energy sector. Among the selected works, were three academic publications including studies by Adewole et al. (2023) on peer-to-peer energy trading, Ikpe and Torriti (2018) on demand-side management, and Nitte and Salahudeen

(2023) on energy transitions. Four of the included papers were Organisational publications including Agosto & Co Store (2023) on Nigerian independent electric power producers, the Energy Commission of Nigeria (2022) with the National Energy Policy, and the Nigerian Electricity Regulatory Commission (2018) discussing MAP regulations. National Energy Policy Revised 2022 by the Energy Commission of Nigeria was adopted as a policy document. Additionally, articles from three websites including The Cable (2023) on NERC licensing, and the IEA (2022) with the World Energy Outlook were the final included papers.

**Table 3-1 Relevant Publications**

| <b>Publication Title</b>                                                                                                                 | <b>Publication Type</b> | <b>Reference</b>                                   |
|------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|----------------------------------------------------|
| <b>2023 The Nigerian Independent Electric Power Producers - Agosto &amp; Co Store</b>                                                    | Report                  | (Agusto & Co Store, 2023)                          |
| <b>A Means to an Industrialisation End? Demand Side Management in Nigeria</b>                                                            | Journal Article         | (Ikpe & Torriti, 2018)                             |
| <b>Demand Response Strategy Management with Active and Reactive Power Incentive in the Smart Grid: A Two-Level Optimization Approach</b> | Journal Article         | (Shigenobu et al., 2017)                           |
| <b>MAP Regulations will Fast-Track Closure of Metering Gap</b>                                                                           | Report                  | (Nigerian Electricity Regulatory Commission, 2018) |
| <b>NERC Licenses 17 Power Distribution Networks, Seeks Unbundling of System Operations</b>                                               | News Article            | (The Cable, 2023)                                  |
| <b>National Energy Policy Revised 2022</b>                                                                                               | Policy Document         | (Energy Commission of Nigeria, 2022)               |
| <b>Peer-to-Peer Energy Trading, Independence Aspirations and Financial Benefits among Nigerian Households</b>                            | Journal Article         | (Adewole et al., 2023)                             |
| <b>Transmission Company of Nigeria</b>                                                                                                   | Organisation Website    | (Transmission Company of Nigeria, 2023)            |
| <b>World Energy Outlook 2022</b>                                                                                                         | Report                  | (IEA, 2022)                                        |

These include nine publications that were adopted to understand Nigeria's entire energy system and key policies that support flexibility, evaluate market instruments for flexibility within Nigeria's energy system, assess the success of the energy flexibility instruments in Nigeria, and explore the opportunities and uncertainties for energy flexibility in Nigeria.

## **3.2 Energy Flexibility and Nigerian Whole Energy System**

### **3.2.1 Energy Policy Targets**

Nigeria's energy policy targets aim to enhance flexibility and sustainability while reducing dependence on non-renewable resources (Usman et al., 2022). The National Energy Policy emphasises conservation and efficient technology adoption, with the Renewable Energy Master Plan (REMP) targeting a 36 % increase in renewable energy production by 2030, focusing on solar, wind, and hydropower (Energy Commission of Nigeria, 2022; Usman et al., 2022). Initiatives like rooftop solar systems and off-grid connections as energy flexibility instruments for five million communities post-COVID-19 are underway. Challenges include

transitioning from non-renewables, rural electrification, and policy implementation inconsistencies (Energy Commission of Nigeria, 2022; Shigenobu et al., 2017).

Nigeria has also introduced various policies like the National Energy Efficiency Action Plan (NEEAP) and the National Renewable Action Plan (NREAP) to advance energy efficiency and increase electricity access. The Nigerian Electricity Regulatory Commission (NERC) has played a role in promoting energy efficiency through initiatives such as energy-efficient lighting and addressing the metering gap. However, challenges remain, including gas supply limitations, distribution network constraints, and infrastructure issues, highlighting the need for comprehensive reforms (Nitte & Salahudeen, 2023)

### 3.2.2 Nigerian Whole Energy System

The Nigerian energy system is categorised by different stakeholders, as indicated by Table 3-2. The Federal Government is responsible for policy and oversight, while the Ministry of Power implements energy policies. The Energy Commission of Nigeria serves as the regulatory and planning authority. The Electric Power Sector Reform Act (ESPRA) 2005 initiated privatisation, leading to Generation Companies (GenCos) for power generation, Transmission Company of Nigeria (TCN) for transmission, and Distribution Companies (DisCos) for electricity distribution. Nigeria Bulk Electricity Trading (NBET) manages electricity trading, and the Rural Electrification Agency (REA) focuses on electrifying underserved communities (IRENA, 2023b; Nigerian Bulk Electricity Trading, 2023; Transmission Company of Nigeria, 2023; Usman et al., 2022).

**Table 3-2 Key Stakeholders in Nigeria's Energy System**

| Stakeholders                                         | Roles and Responsibilities                                                          |
|------------------------------------------------------|-------------------------------------------------------------------------------------|
| <b>Federal Government</b>                            | Oversight and policy-making for the energy sector.                                  |
| <b>Ministry of Power</b>                             | Implementation of government energy policies and regulations.                       |
| <b>Energy Commission of Nigeria (ECN)</b>            | Regulatory and planning authority for the energy sector.                            |
| <b>Electric Power Sector Reform Act (ESPRA) 2005</b> | Legislation leading to energy system privatisation.                                 |
| <b>Generation Companies (GenCos)</b>                 | Responsible for bulk power generation.                                              |
| <b>Transmission Company of Nigeria (TCN)</b>         | Ensures the transmission of High Voltage electricity.                               |
| <b>Distribution Companies (DisCos)</b>               | Responsible for distributing electricity to consumers.                              |
| <b>Nigeria Bulk Electricity Trading (NBET)</b>       | Manages electricity trading across the Nigerian Electricity Supply Industry (NESI). |
| <b>Rural Electrification Agency (REA)</b>            | Focuses on electrification of underserved communities                               |

Sources: (IRENA, 2023b; Nigerian Bulk Electricity Trading, 2023; Transmission Company of Nigeria, 2023; Usman et al., 2022).

## 3.3 Existing Energy Flexibility Instruments in Nigeria and Effectiveness of Market Instruments

In pursuit of enhancing supply and demand equilibrium within the nation, Nigeria has implemented several energy flexibility instruments within its energy sector. The energy flexibility landscape in Nigeria is characterised by a variety of market dynamics as discussed below:

### 3.3.1 Demand Side Management

A key initiative is Demand Side Management, which aims to reduce energy demand by promoting the adoption of energy-efficient technologies such as light-emitting diodes (LEDs) as replacements for incandescent and fluorescent lighting in households. This aligns with the objectives outlined in the National Energy Efficiency Action Plan (NEEAP) 2015-2030 and

poses the potential to reduce peak demand by 3 GW – 4 GW with NEEAP targeting a 40% improvement in lighting efficiency by 2020 and 100% by 2030 (IRENA, 2023b; Nitte & Salahudeen, 2023; Usman et al., 2022).

### 3.3.2 Peer-to-Peer Energy Trading (P2P)

Nigeria has also embraced peer-to-peer (P2P) energy trading as a means to facilitate energy flexibility. This short-term strategy, in line with the National Energy Policy, encourages the sale of excess electricity generated by industries to other users, contributing to improved energy supply (IRENA, 2023b). P2P trading, while conceptually promising, faces significant challenges due to the absence of a grid infrastructure capable of facilitating such transactions (Adewole et al., 2023). This highlights the crucial role that grid development plays in enabling advanced energy trading mechanisms.

### 3.3.3 Decentralised Energy Systems

The integration of decentralised energy systems using renewable energy sources, including isolated microgrids and grid-connected microgrids, serves as a pivotal energy flexibility instrument, particularly in rural and peri-urban areas. These systems, supported by Solar Home Systems, align with the objectives of the National Energy Policy (NEP) to enhance renewable energy integration (Energy Commission of Nigeria, 2022). The adoption of solar home systems (SHS) has seen substantial growth to meet Nigeria's energy demand. REN21's report noted a 5% increase in off-grid solar markets in 2019, and Nigeria stands out with one of the largest mini-grid support programs. This includes notable installations, such as two solar hybrid mini-grids in 2020, facilitated by Nigeria's Rural Electrification Authority (REA) (Ren21, 2021). Presently, over 45 million people in sub-Saharan Africa utilise SHS with a capacity exceeding 11 Watts peak rating (IEA, 2022).

### 3.3.4 Independent Power Plants (IPPs)

Approved by NERC, there are currently 12 IPPs operating in Nigeria, with nine of them supplying power to the grid and three serving off-grid regions without access to the grid (Agusto & Co Store, 2023; The Cable, 2023). These power plants primarily rely on gas as their energy source, enabling them to provide ancillary services due to their black start capability and short response time. Independent Power Plants (IPPs) have gained a strong foothold in Nigeria's energy market, contributing a substantial 31.2% to the total generated power capacity in 2022 (Agusto & Co Store, 2023). This underscores their effectiveness in enhancing the energy supply landscape.

### 3.3.5 Smart Metering

Another notable energy flexibility instrument is the introduction of electricity smart meters under the Meter Provider framework, a strategy aimed at improving demand-side response and providing valuable information to suppliers for optimising energy distribution (Ikpe & Torriti, 2018; Nigerian Electricity Regulatory Commission, 2018). This initiative was part of the efforts of NERC's inter-ministerial committees on renewable energy and energy efficiency strategies (Usman et al., 2022). The Nigerian Electricity Regulatory Commission (NERC) has made significant strides in metering consumers, achieving levels ranging from 80% to 100% for maximum-demand consumers, and considerable coverage for non-maximum-demand consumers as of December 2022 (The Cable, 2023). This progress indicates an improvement in monitoring and management capabilities within the energy market.

## 3.4 Energy Flexibility in the UK

**A world leader in energy systems, the United Kingdom has numerous energy flexibility instruments, like Demand Side Response Programs, Smart Grid Technologies, Energy Storage Solutions, Virtual Power Plants (VPPs), and Market-Based Mechanisms supported by policies like Smart Systems and Flexibility Plan, Electricity Market Reform (EMR), Flexible Power Auctions and Energy Storage R&D Funding etc. as indicated in**

Table 3-3. These instruments are supported by policies like the Smart Systems and Flexibility Plan, Electricity Market Reform (EMR), Flexible Power Auctions, and Energy Storage R&D Funding.

**Table 3-3 Flexibility Instruments in the United Kingdom**

| Energy Flexibility Instrument      | Description                                                                                                              | Corresponding Policies             | Policy Relation to Instrument                                                                                                                           | Reference                                       |
|------------------------------------|--------------------------------------------------------------------------------------------------------------------------|------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|
| <b>Demand Response Programs</b>    | Initiatives incentivising consumers or businesses to adjust energy consumption based on grid needs or price signals      | Smart Systems and Flexibility Plan | Supports the implementation of demand response initiatives by fostering technological advancements and regulatory frameworks for flexible energy usage. | (ofgem, 2021)                                   |
|                                    |                                                                                                                          | Capacity Market                    | Encourages participation in demand-side response by providing financial incentives to reliable energy sources during peak demand periods.               | (Ofgem, 2023)                                   |
| <b>Smart Grid Technologies</b>     | Utilises digital communication and control to manage electricity supply and demand efficiently                           | Smart Systems and Flexibility Plan | Promotes the adoption of smart technologies to enhance grid management and flexibility in handling energy supply and demand.                            | (ofgem, 2021)                                   |
|                                    |                                                                                                                          | Electricity Market Reform (EMR)    | Introduces policies to drive investment in low-carbon electricity generation and grid stability through smart grid technologies.                        | (Department of Energy and Climate Change, 2013) |
| <b>Energy Storage Solutions</b>    | Includes battery storage systems to store excess energy for later use, helping to balance supply and demand fluctuations | Smart Systems and Flexibility Plan | Encourages advancements in energy storage technologies for effective utilisation and storage of excess energy.                                          | (ofgem, 2021)                                   |
|                                    |                                                                                                                          | Electricity Market Reform (EMR)    | Facilitates the integration of storage solutions into the energy market, ensuring better management of supply fluctuations.                             | (Department of Energy and Climate Change, 2013) |
| <b>Virtual Power Plants (VPPs)</b> | Aggregated systems using distributed energy resources to function as a single power plant, enhancing flexibility         | Smart Systems and Flexibility Plan | Supports the development and integration of virtual power plants by enabling coordination among diverse energy resources.                               | (ofgem, 2021)                                   |
|                                    |                                                                                                                          | Electricity Market Reform (EMR)    | Encourages the deployment of aggregated resources to act as a                                                                                           | (Department of Energy and Climate Change, 2013) |

|                         |                                                                                                                              |                                                    |                                                                                                                                                      |
|-------------------------|------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| Market-Based Mechanisms | Systems facilitating trading or exchange of energy between suppliers, consumers, and market players to optimise energy usage | single power source, improving system flexibility. |                                                                                                                                                      |
|                         |                                                                                                                              | Capacity Market                                    | Ensures a competitive market by incentivising the exchange of energy resources and demand response participation. (Ofgem, 2023)                      |
|                         |                                                                                                                              | Electricity Market Reform (EMR)                    | Establishes frameworks for market-based mechanisms to enhance flexibility and optimise energy usage. (Department of Energy and Climate Change, 2013) |

### **3.5 Comparing Energy Flexibility in the UK to Nigeria**

#### **3.5.1 Case Study: UK Agile Octopus Smart Meters**

The strength of the UK flexibility instruments was displayed in a case study in June 2018, when Octopus Energy introduced a pioneering half-hourly time-of-use tariff known as Agile Octopus in Britain. This innovative tariff utilises data from smart meters to reflect the changing price of electricity to customers throughout the day. As a result, customers have the opportunity to benefit from lower electricity costs during periods of low demand or when available electricity generation is abundant. This approach not only allows customers to access affordable electricity but also supports balance and optimisation of the grid for cleaner and more sustainable power sources (ofgem, 2021).

The introduction of Agile Octopus brought to light several key lessons regarding time-of-use tariffs. Firstly, it underscored the critical need for raising consumer awareness about these tariffs, as many customers were unfamiliar with the concept of fluctuating electricity prices throughout the day. Secondly, the inconvenience of strictly adhering to off-peak usage was evident, highlighting the challenges consumers might face in limiting electricity-intensive activities to specific periods. Additionally, the tariff's suitability for families with children, who have varying electricity needs, was called into question, emphasising the importance of tailored tariff options. Moreover, the observation of high tariffs during winter peak times emphasised the significance of budgeting for seasonal variations in energy costs. Finally, the implementation of Agile Octopus revealed that lifestyle changes might be necessary for customers to maximise cost savings, emphasising the need for clear communication and support. In conclusion, Agile Octopus provided valuable insights, emphasising consumer awareness, flexibility, and tailored solutions as crucial considerations for effective time-of-use tariffs (Smart Home Charge, 2021).

#### **3.5.2 Case Study: Nigeria 2022 Power Outage**

The rapid growth of population across the most populous and largest economy in Africa, Nigeria has resulted in an exponential increment in energy demand predicted to unlock the economic development even further (IRENA, 2023b). Consequently, the World Bank approved a \$ 500 million aid to enable the improvement of electricity distribution and energy flexibility across the Nation through large-scale projects (Africa–EU Renewable Energy Cooperation Programme, 2021). Nonetheless today Nigeria is still plagued with insufficient energy generation to meet demand, thus energy flexibility instruments although existing can only contribute little to guaranteeing an energy system equilibrium. For example, the lack of a smart grid system resulted in a significant power outage, across Nigeria in 2022. Due to an explosion and fire at a transmission line connecting power plants in Niger state. The total grid collapse would have been averted if the grid system had been decentralised and flexible. (BBC News, 2022). The employment of a smart grid system creates pathways to overcome single faults.

### **3.6 Measuring Success: Energy Flexibility in the UK vs Nigeria**

The criteria for measuring the success of energy flexibility and balancing mechanisms within global energy systems have not been universally defined. However, an essential indicator in today's energy sector is the ability of an energy system to dynamically adjust the timing and location of energy generation and consumption in real-time. This adaptability should align with the goals of ensuring a secure, sustainable, and equitable energy supply as defined in Figure 3-1, often referred to as the energy trilemma (Ofgem, 2021; World Energy Council, 2022c).

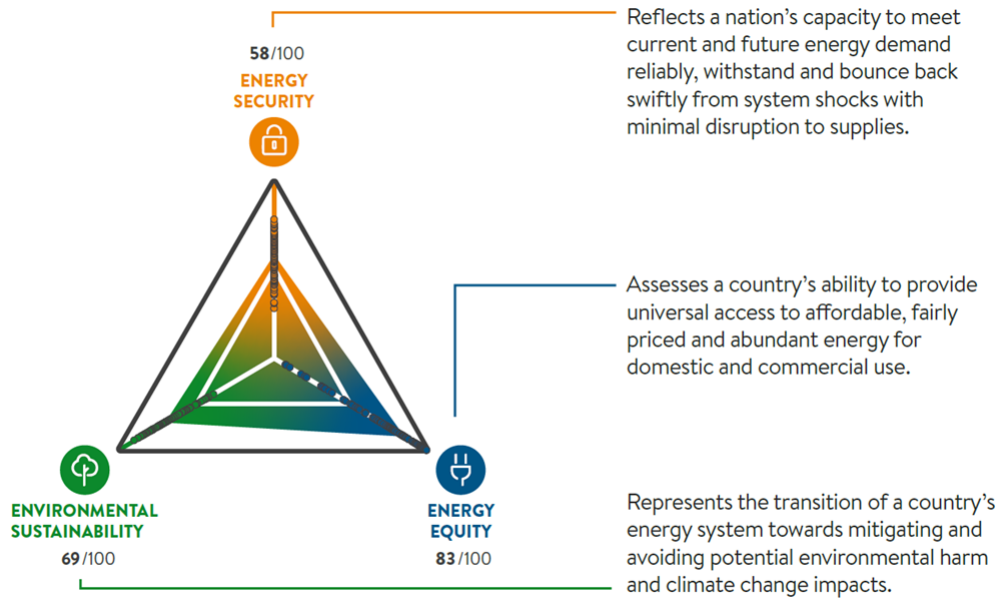


**Figure 3-1 A Generic Diagram of Global Energy Trilemma**

Sources: (World Energy Council, 2022c)

In the 2022 World Energy Council Energy Trilemma Index, the United Kingdom ranked impressively. It secured the 10th position in energy security with a score of 70.8, just 6 points below the top-ranked Canada, highlighting its capacity to manage its energy system effectively. Sustainability ranked 7th, with a score of 83.2, indicating its commitment to minimising environmental impact. Additionally, in providing reliable and affordable energy, it stood 12th with an index score of 96.4. However, concerns emerged regarding energy equity due to inflation and geopolitical tensions. Overall, according to the World Energy Trilemma Index, the UK's energy system demonstrated effectiveness, focusing on balance and environmental sustainability, improving its 2022 ranking to 4th place in 2023 with an index score of 82.4 (World Energy Council, 2022b)

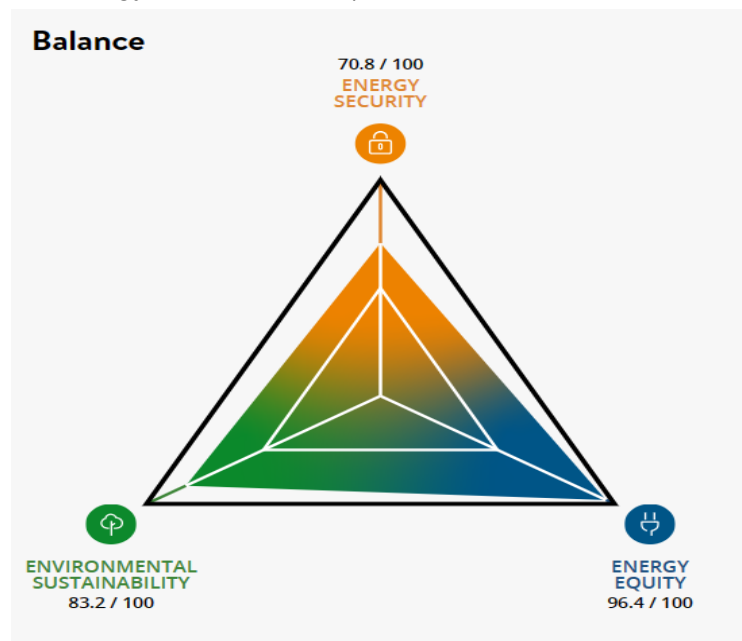


**Figure 3-2 United Kingdom 2022 Energy Trilemma Index**

Sources: (World Energy Council, 2022b)

In contrast, Nigeria's energy system faces challenges in all three areas of the energy trilemma. Nigeria ranked 84th in the 2022 energy trilemma index with a score of 39.1 (grade DDD) across all categories. While energy security improved slightly, sustainability remained stagnant. Energy equity showed some improvement, with a 3.6% increase since previous assessments. However, the trilemma scores for energy security, sustainability, and equity were 46.2, 47.9, and 24.9, respectively, indicating room for enhancement (World Energy Council, 2022a).

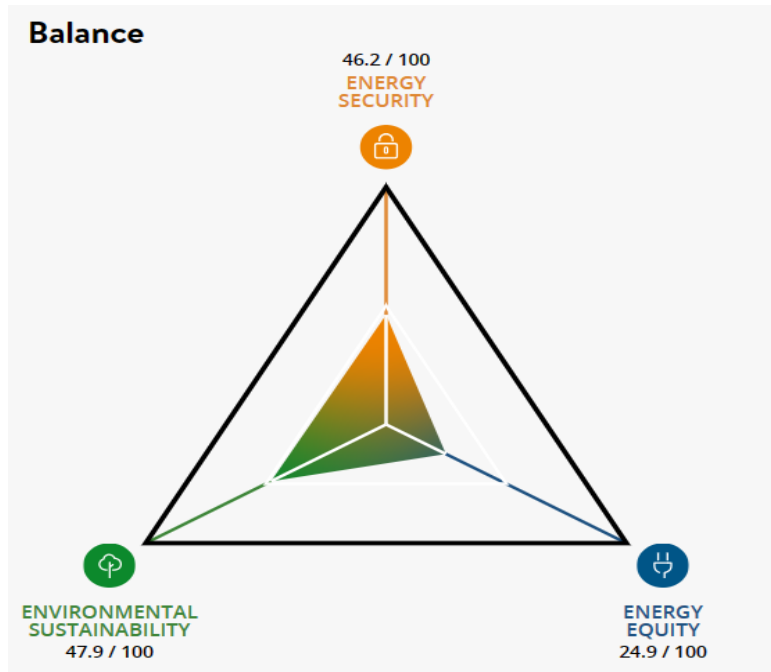


**Figure 3-3 Nigerian 2022 Energy Trilemma Index**

Sources: (World Energy Council, 2022a)

More specifically, the execution of the agile octopus although plagued by behavioural limitations provides reliable and affordable electricity tariffs when used during off-peak hours, encourages the use of cleaner and more sustainable energy by a reduced tariff for greener energy as well as provides secure energy. Consequently, when underpinned below the world energy trilemma criteria for success the case study gets an A in all three grades.

Considering the grid failure in 2022, energy security would get an F, due to the lack of secure power supply, however, the grade for energy sustainability and equity would maintain the general grade for Nigeria "D" by World Energy Council as indicated in Figure 3-3 because it would be difficult to measure the sustainability and equity of energy that was not supplied.

### 3.7 Discussion: Assessing Uncertainties and Opportunities for Flexibility in Nigeria

**Expanding Power Capacity:** Nigeria's current power generation capacity falls short of meeting the needs of its growing population, which exceeds 206 million people. Estimates suggest that around 24 GW of capacity is required to address this demand. To achieve energy security and enhance energy flexibility, substantial investments, and the integration of renewable energy sources, particularly solar and wind, are imperative. The addition of alternative energy sources would help Nigeria move away from load shedding.

**Upgrading the Grid (Smart Grid):** Despite having an installed power capacity ranging from 12 to 15 GW, Nigeria faces challenges with its grid infrastructure. The average power generation of approximately 5 GW falls short of the potential 8 GW due to distribution and transmission losses stemming from an ageing grid. Initiatives like the partnership between Nigeria and Siemens aim to comprehensively enhance the grid in a three-phase approach, increasing the grid capacity from 7 GW to 25 GW (Omonfoman, 2019; Siemens, 2019).

**Poor Policies Implementation:** According to the authors, Governmental policies and initiatives have played a central role in promoting energy efficiency. However, the success of these policies has been mixed, highlighting the need for more targeted strategies and robust implementation (Adewole et al., 2023). Nigeria has devised an array of energy policies, strategies, and plans, yet their actualisation is marred by delays and often unrealised potential. For instance, the Energy Transition Plan, which aspires to achieve universal energy access by 2030 and establish a carbon-neutral energy system by 2060 (Ashurt, 2022). Although great, the plan remains ambitious without a clear roadmap, effective measuring and monitoring to achieving (World Economic Forum, 2023).

**Corruption:** Corruption poses a significant and formidable obstacle to the attainment of energy flexibility, vividly demonstrated by Nigeria's smart metering initiative. Despite securing a substantial \$500 million from the World Bank to advance smart metering, Nigeria's progress remains slow, with smart meter installations around 40%. (Africa–EU Renewable Energy Cooperation Programme, 2021).

**Insecurity:** Insecurity, particularly in Nigeria's northern and eastern regions, has hindered the reach of energy flexibility instruments into these areas. Prolonged conflicts and insurgencies have created an environment of risks, making the deployment of energy infrastructure difficult. This situation severely curtails access to reliable energy services.

**Expanding Energy Flexibility Mechanisms:** To promote energy flexibility, it is essential to extend mechanisms such as improved ancillary services, demand-side response, and energy efficiency to a broader population. Currently, a significant portion of Nigeria's population lacks access to adequate energy flexibility options and remains unaware of their benefits. While efforts are underway to enhance energy supply, exemplified by the construction of power plants in Abuja, further education is necessary to increase awareness and adoption.

Boosting power capacity and modernising the grid are undeniably pivotal endeavours in fortifying energy flexibility within Nigeria. With advancing technology, these goals not only become increasingly achievable but also more imperative in the face of the nation's escalating energy needs. Furthermore, the synchronisation of government policies with international net-zero objectives, placing a significant emphasis on decentralisation, decarbonisation, and digitisation, offers a hopeful path for the enhancement of Nigeria's energy sector. Nevertheless, it is crucial to emphasise that maintaining this trajectory and proactively adapting to forthcoming shifts in energy demand, technology, and policy are imperative prerequisites. This adaptability is vital to establishing a secure, equitable, and sustainable energy landscape that can effectively meet Nigeria's evolving requirements.

#### 4. CONCLUSION

The imperative of limiting global temperature rise and achieving the Paris Agreement's NetZero goal has spurred the global energy transition, emphasising the need to integrate renewable energy sources, reduce fossil fuel dependence, and enhance energy efficiency. This transition demands robust engagement with energy flexibility instruments to achieve supply and demand equilibrium worldwide. Nigeria, with its large population and significant landmass, faces unique energy challenges, including a low electrification rate, underutilised power grid capacity, and a fragile grid. This paper critically evaluates Nigeria's energy system, focusing on market instruments for flexibility by comparing it with the United Kingdom using Agile Octopus Smart Meters as a case study and the energy trilemma as comparison measures.

The UK has effectively implemented various energy flexibility mechanisms such as Demand Side Response Programmes, Smart Grid Technologies, Energy Storage Solutions, Virtual Power Plants (VPPs), and Market-Based Mechanisms, supported by strong policies and innovative projects such as the Agile Octopus Smart Meters. The case study of Agile Octopus Smart Meters showcases the effectiveness of these instruments in promoting time-of-use tariffs and optimising energy usage. It highlights the importance of consumer awareness, flexibility, tailored solutions, and seasonal variations in energy costs as key lessons learned.

Energy flexibility instruments identified in Nigeria include demand-side management, smart metering, peer-to-peer energy trading, decentralised energy systems, and the operation of independent power plants (IPPs). Despite its vast energy potential and investment support from organisations like the World Bank, Nigeria faces a significant energy flexibility shortfall. The country's rapid population growth has led to a substantial increase in energy demand, but insufficient energy generation and infrastructure challenges persist. For instance, Nigeria's recent power outage in 2022, caused by a transmission line explosion, could have been avoided with a decentralised and flexible grid system. Advanced economies like the United Kingdom use grid systems with multiple pathways to ensure continuous electricity supply, reducing dependency on a single point of failure and enhancing overall system resilience. The absence of a smart grid system, coupled with the centralised nature of the energy infrastructure, leaves Nigeria vulnerable to such disruptions.

The UK's efforts in employing energy flexibility instruments have contributed to its high ranking in the World Energy Council Energy Trilemma Index, ranking 4th globally. The UK energy system demonstrates a balanced approach to energy security, sustainability, and equity, ensuring a just energy transition across the nation. In contrast, Nigeria's energy system remains challenged by insufficient infrastructure and centralised energy generation, resulting in frequent power outages and limited energy access. Nigeria ranks 84th with percentage indices of 46.2, 47.9, and 24.9 for energy security, sustainability, and equity, respectively.

Although the UK has successfully implemented several policies to support energy flexibility, such as demand-side response initiatives and advanced grid management technologies, these policies cannot be directly applied to Nigeria without significant adaptation. The primary reasons for this are rooted in the distinct differences between developing and developed economies. The UK benefits from a mature infrastructure, stable political climate, and robust economic frameworks that facilitate the implementation of advanced energy policies. In contrast, Nigeria faces numerous challenges, including underdeveloped infrastructure, political instability, and economic volatility. These factors present substantial barriers to the direct adoption of UK policies.

Implementing similar processes in Nigeria would require significant political and economic changes. This involves not only infrastructural upgrades but also regulatory reforms and substantial investment in technological advancements. Given the current political and economic landscape in Nigeria, such changes may not be feasible shortly. The socio-political complexities and financial constraints create an environment where replicating the UK's energy flexibility measures becomes highly challenging, if not impossible.

In conclusion, while lessons can be drawn from the UK's experience with energy flexibility, any attempt to apply these in Nigeria must be carefully tailored to address the unique challenges of a developing economy. This highlights the need for a customized approach that takes into account Nigeria's specific socio-economic and political context.

Consequently, this study proposes the following recommendations to improve Nigeria's energy system, integrate flexibility instruments and aid a just transition

- **Expanding power capacity and upgrading the grid:** Substantial investments in renewable energy sources and modernising grid infrastructure with smart technologies are essential. These actions will reduce transmission losses, enhance reliability, and support the transition to a more sustainable energy system.
- **Enhancing flexibility mechanisms:** Expanding the integration and implementation of energy flexibility instruments, such as energy efficiency measures, demand-side responses, and ancillary services, can help prevent issues like grid collapse. This approach enhances system flexibility, making the energy infrastructure more resilient and responsive.
- **Creating Strategic Roadmaps and Implementing policies:** There is a need to create strategic roadmaps and implement policies to achieve targets, such as the Energy Transition Plan, which aims for universal energy access by 2030 and a carbon-neutral

energy system by 2060. Achieving these goals requires clear roadmaps and effective implementation strategies

- **Financial allocation and transparency in energy development:** Financial resources should be allocated to enhance the reliability of energy systems by expanding power capacity, improving and expanding the grid, and integrating energy flexibility instruments. It is also essential to establish transparent processes for allocating and using these financial resources, including regular audits and public reporting. As well as creating systems to monitor these projects from conception to completion and during their operation life cycle to ensure the effective use of resources. This transparency will help, prevent misuse and foster accountability.

### Disclaimer:

This paper was curated from an assignment submission made by the Author for the course module "Energy Policy and Economics" delivered at Cranfield University, resulting in a high similarity index. The original submission to Cranfield University received a Turnitin similarity score of 10%, comprising individual components, each contributing 2% or less.

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## **Assessing energy flexibility: a comparative review of Nigeria and the United Kingdom**

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