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Energy Transitions in Nigeria: The Evolution of Energy Infrastructure Provision (1800–2015)

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Academic Editor: Erik Gawel

Received: 9 March 2016; Accepted: 17 June 2016; Published: 23 June 2016

Abstract: The provision of energy infrastructure is essential for economic growth, social cohesion, and environmental sustainability. Understanding the multiple functions and services it provides us requires firstly a deeper understanding of the factors that influence energy infrastructure itself. This paper focusses on the factors that influence the evolution of energy infrastructure in Nigeria. By studying different eras of energy use according to the technologies that were being implemented, resources that were available, and the political practice of the time it is possible to better frame the drivers of energy infrastructure. The paper explores the transitions of how Nigerians managed to obtain the vast majority of energy from food calories and traditional biomass, to the broad portfolio of energy sources that is in use today.

Keywords: energy transitions; energy histories; energy demand; energy efficiency; energy policy; developing countries; Africa

1. Introduction

Energy transition involves "long term structural changes in energy systems" [1] (p. 2) and [2]. Many developed countries have gone through some energy transition, while some are still experiencing some sort of transition [1,3]. All countries undergo transitions as a result of economic and societal change [4–6]. Learning from the experiences of the other countries does not necessarily mean they have to take the same steps as some developed countries did in the past, but they may have to learn to understand the vast processes that are involved in a transition [7]. However, how much knowledge do we have on the historical energy transitions across most developing countries? How many records and research outputs really point to the factors that influenced such transitions? How many studies have been done on the influences of policy practices on energy transitions from a developing economy perspective? These are questions that the current bodies of research have not been able to satisfactorily answer. Addressing these questions is important as a lack of knowledge of a country's energy histories poses challenges in policy governance that can pave the way towards a more sustainable energy future [8].

The case study presented in this paper focused on the Nigerian energy transition. There is currently no known study on the Nigerian historical energy transition [9]. Most transition studies have focused on energy resources [10,11], energy consumption [12], energy production [13], energy poverty, and energy access [14]. Bridge [15] argues that there is a clear need for a more focused study on the geographies of energy transitions in terms of space and place. This is important as the aggregation of knowledge and experiences of the transition histories of different geographies will help different stakeholders in learning from past experiences and ensuring avoidable mistakes are not repeated.

Indeed, the authors have been unable to find academic research on the Nigerian historical energy transition. This is in spite of the importance of understanding historical transitions for enabling new sustainability transitions, as argued by Falcone [16]. It is in this context that this paper explores the past Nigerian energy infrastructure transition, with a focus on the historical development of energy demand and energy infrastructure provisions since 1800. This paper specifically aims to highlight some of the dynamics around the provision of such infrastructure, by answering the question:

- *How has Nigerian energy supply infrastructure evolved over time and what contexts have influenced this evolution?*

In exploring this research question, this paper considers five different energy eras. These eras are characterized by different historical happenings in the life of Nigeria (ns). The core of this paper is structured around these eras, with particular attention given to how infrastructure has evolved alongside societal changes and the role of changing institutions within that [17].

Since energy use co-evolved with advances in technology, the Nigerian energy transition is broken down into different eras of energy use according to the technologies that were being introduced and used at that time, as well as the different primary resources which were being exploited. Typically, those primary resources were successively more energy-dense types of energy resources, e.g., coal, and crude oil. Energy density is essentially the amount of energy per unit volume [18]. The Nigerian energy eras are:

- Pre-industrial (agricultural) era—up to mid-1800s.
- Early industrial (advanced metallurgy) era—late 1800s.
- Industrial (steam engines) era—early to mid-1900s.
- Late industrial (dynamo, internal combustion engines) era—mid to late 1900s.
- Information (microprocessor) era—early 2000s onwards.

In providing an overview of these eras (Section 3), our intention is not to provide an exhaustive history of energy use and technology, but to instead lay the foundation for thinking about the business challenges in developing primary energy resources, as part of enabling a deeper understanding of how energy infrastructure evolved over time [19]. Within this overview of the energy eras, we relate those same eras to the changes in Nigeria's political decision-making institutions, so as to emphasize the historically dominant influence of the British and other foreign envoys in Nigeria. Indeed, and as we will go on to discuss, the development of infrastructure that led to changes in consumption patterns of Nigerian locals (and a corresponding increase in demand for various energy sources) were a result of the various exchanges brought about by the colonialists who tried to continue the lifestyles they were already used to. We finish with a discussion (Section 4) and the conclusion (Section 5) which considers the cross-cutting themes.

2. Materials and Methods

This study employed the use of exploratory documentary research tools by exploring documents, official data and statistics on the different aspects of the life and history of Nigeria in connection with trade, traditional energy use, culture, and norms. Documents and archives from several sources were used in data collection and analysis to have a better understanding of how the historical events of the time influenced and affected energy infrastructure provisions.

Secondary data analysis was used in this research to analyze the data collected from the various literatures and documentary archives. Data used for the analysis of the events from colonial Nigeria (and a little from pre-colonial Nigeria) were sourced from the archives of the Nigerian Railway Corporation (NRC). The NRC is the only organization in Nigeria still in existence today that has a history pre-1900. Also, most events and happenings—particularly trade, movements of goods and agricultural products, initial provision of electrical infrastructure, etc.—were largely made possible by

the provision of rail infrastructure. The planning of most parts of the rail transport infrastructure was highly connected with other infrastructural developmental plans such as electricity, ports and harbours, airports, industrialization, and trade activities. The roles of these various aspects are highlighted in the description of the events of each energy era and how they impacted on increased demand for energy.

The other documentary sources from the International Energy Agency (IEA), Energy Information Administration (EIA), and the World Energy Council (WEC) only have useful evidence and records of Nigeria post-independence (1960 onwards). These agencies have, in their archives, records and data of the Nigerian energy resources, consumption, and production, covering 1970s to present day. As such, these do not provide a reliable means of getting a true historical picture of the Nigerian energy situation pre-1960.

3. Nigeria's Energy Supply Infrastructure: Resource and Political Influences

This section presents the various energy eras for Nigeria with respect to the trimetric parameters of energy demand and use, technology driving demand for energy, and the primary energy resources used in satisfying energy demand within each era. It also discusses the role of institutions, within each era, in effecting changes in energy systems and use. The eras identified are intentionally artificial and have been employed to emphasize salient features of different time periods across the Nigerian energy transition.

3.1. Pre-Industrial (Agricultural) Era—Up to Mid-1800s

The first energy era in Nigeria was the pre-industrial era, which spans several centuries from 1500 up to mid-1800s. In this era, the primary energy resource used was organized (peasant) agriculture. This resource was effective for the kind of work and society that was needed at that point in time, which mostly related to manual work and walking. Manual work was what was needed to produce agricultural products and for transporting goods to markets.

3.1.1. Agriculture as the Main Driver of Energy Demand

Agriculture was the mainstay of the economy of most families, communities and empires during this era [20]. The cultivation of food crops for human consumption was the main agricultural practice. The emphasis was on peasant farming. Families had farmlands where they could cultivate and produce different food crops for consumption throughout the farming year, as well as having enough to trade to earn resources to take care of their other needs. Through this period, agricultural practices evolved and farmers were able to learn from their experience different innovative ways of tilling and cultivating the land to obtain greater yields. This led to the use of semi-mechanized farm tools such as hoes, local ploughs, wheel barrows, and other innovative forms of farm implements.

Through agriculture, other practices evolved, such as those involving arts and crafts. The use of dishes made from wood carvings used exclusively by the kings and the ruling class within some cultures in southern Nigeria dates back centuries [21]. Furniture was made from wood obtained from trees, while cooking and heating requirements were from agricultural by-products. Some cultural festivals considerably depended on agriculture, such as celebrating the new harvest season, which was—and is still—common in parts of southern Nigeria.

Energy (calories) from food was required for both for manual labour and draft animal labour. Energy required for heating and cooking was from wood and agricultural by-products. Oils derived from food and other agricultural by-products were used for oil lamps to serve lighting purposes. The essential factors that influenced the transition to the next energy era during this period were trade and European exploration of Africa.

3.1.2. European Exploration, Trade and Energy Demand

Early contact between Nigeria and the Europeans dates back to 1472 when the Portuguese bought pepper and ivory from Benin City, within the great Benin Empire in Nigeria. Lagos was discovered

in the same year and named by Lancelot de Freitas, the caravel captain, as Lagos de Curamo, finally called Lagos which displaced the Yoruba name, *Eko*, years later resuscitated by the Holiday Inn Group. This happened during the time of the navigator, Prince Henry, grandson of John O'Gaunt, Duke of Lancaster [22].

Trade had been happening since the 15th century and had continued during those periods—particularly through the desert into northern Nigeria with cities like Kano, Katsina and Zaria—as recorded in the book by Leo Africamus on *West African Empires* published in 1526. Most trade continued across the desert until the coast became better known in the 15th century, when contact was further established with Fernando Po and Sao Tome (two islands on the coast of West Africa), so that Nigeria became tapped on its northern and southern limits. Brazil specifically established trade in the 17th century in Badagry area of Lagos. The eastern coastline of Nigeria had been dubbed "*Oil Rivers*" as at 1831 [22].

Alongside trade came knowledge transfer of new techniques and practices, which helped shape early aspects of Nigeria's energy transition. Agricultural activities, arts, and crafts done manually with limited use of tools (particularly in the Benin Kingdom) promoted trade relations with foreign European traders which led to the exchange of ideas and the embrace of better technology in achieving the same work and practices with limited amount of energy. Thus, contact with Europeans through trade led to the next transition in energy use, energy consumption pattern, and energy demand due to new practices embraced from the trade partners over time which were more energy intensive. All of the aforementioned were pointers to an energy intensive future fostered by trade, investment, and cultural exchanges [23].

3.1.3. Influences of Decision-Making Institutions during the Pre-Industrial (Agricultural) Era

This era, which was characterized more by agricultural practices and interventions, saw the extensive use of traditional biomass (mostly by-products of agriculture, such as wood) as the major source of energy. There were two pre-dominant decision-making institutions during this era:

- *Families*: families made decisions based on their needs and available resources. Most families used oils from agricultural by-products for their lamps for lighting needs [24]. Peasant agriculture was the major source of food for most families. Families took decisions in matters concerning their domestic energy needs which had a great impact on the increased energy needs in the forms of food and other agricultural by-products needed for cooking and other (domestic) applications. The impact of the aggregation of the individual family needs led to the increased demand for energy, thus, increasing the need for improved agricultural by-products and the need for better innovation in meeting the new forms of energy demand.
- *Traditional rulers and kings*: traditional rulers played a very instrumental role as much of the trade activities were the results of decisions taken by either the traditional ruler(s), or the traditional ruler(s) together with his council of chiefs (as was the case in some parts of southwest Nigeria) [24]. Trade activities with foreign envoys and partners by some kingdoms and communities—such as the Benin kingdom, Badagry area in Lagos—led to the exchange of ideas and practices that later became energy intensive [25]. Trade activities improved during this era—particularly arts and craft, as well as agricultural produce—which encouraged the increased cultivation of agricultural cash crops for domestic consumption and export [26].

Decisions in (nuclear and extended) family circles, as well as decisions by the traditional rulers and the council of chiefs were the main institutional drivers of the changes that occurred during this era in relation with energy use and demand.

3.2. Early Industrial (Metallurgical) Era—Mid to Late 1800s

During this era, the continued use of wood for heating and cooking was still very pre-dominant. There were really no technologies used to produce energy. The available technologies were still leveraging the older forms of energy which had also been used in the pre-industrial era (food

calories). However, the extensive use of metallurgical interventions added some new dynamics to energy use during this era. Metallurgy is the technology of metals which involves the use of metals for manufacturing and consumption purposes [27,28]. The use of metallurgy does not mean that metallurgy was invented at this point, neither does it mean that metallurgy had not been in existence before then. It only highlights how knowledge of metallurgy helped in extensively mechanizing many industrial processes, not just in agriculture but also in the production of machine and agricultural tools, which helped the local small industries, particularly for transportation needs, such as wheel barrows, bicycles, and other mechanisms used for transportation with draft animals. The following are key highlights of the role metallurgical interventions played in Nigeria's energy transition during this era [28]:

- It led to mechanization of some agricultural processes, which aided the further production of cash crops for export (as noted in parts of northern Nigeria).
- It was very instrumental in the initial survey and development of the railway transport system, which started during this era.
- It played a role in the initial study, survey and justification for future ports, terminals, and harbour infrastructure.
- Knowledge of metallurgy was instrumental to the provision of the first electricity generation infrastructure (mainly for lighting) during this era.

A key development during this period was the provision of transportation infrastructure. Transportation is simply the movement of people and goods through some defined modes (such as rail, road, air, or sea) from one place to another [19]. The extensive use of metallurgical interventions during this era prompted the need for an extensive study on how various transportation infrastructure can be developed to open up the country to socio-economic and political development. This section delves into the pre-historical happenings on how decisions on the various transportation infrastructure started.

3.2.1. Railway Transportation Development in Nigeria

The Nigerian railway was initially pioneered by some private interests, and later taken over by the then Colonial Government as government railway with the main aim of opening up the country and easing the transportation of bulk goods from the hinterlands to the coastal seaports for export, and vice versa. The following were major milestones in the development of rail transportation during this era [22]:

1879–1892	Several applications for concessions were received by the Colonial Government from private interests to construct rail networks.
1879–1892	An initial survey was conducted by Mr. William Shefford, which revealed great potential of rail transport networks for trade in the country.
1895	The then Secretary of State for Colonies, Mr. Chamberlain, gave approval for the construction of 32 km of 1067 mm gauge rail line from Iddo (Lagos) to Otta (Ogun State).
1898	The construction of the first rail line in Nigeria commenced. A 193 km rail line from Lagos to Ibadan. It was completed in 1901.

The later part of this era saw the extensive provision of rail tracks (particularly for the first railway line) for rail transportations.

3.2.2. Ports, Harbours, and Terminals Development

Activities during this era provided the basis for the future development of ports, harbours, and terminals in Nigeria. As of 1863, 99 ships called on the Nigerian coast, 58% of which were British. By 1893, the number had grown to 446, of which 53% flew the British ensign (Figure 1). Nigeria's economic growth was highly influenced by trading of oil palm produce. As of 1900, the total trade had reached £4.0 million, which is worth about £470 million in current estimates [22]. Increased trade activities led to the need for ports and harbour infrastructure.

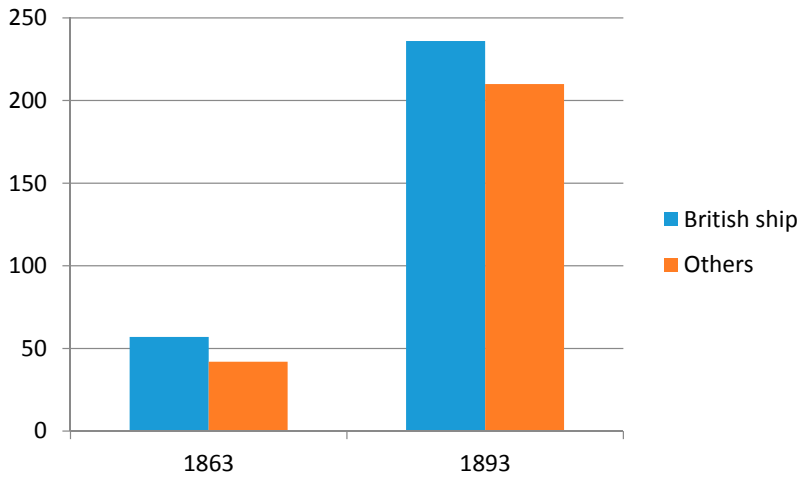

Figure 1. Number of ships that called at the Nigerian coast [22].

3.2.3. The First Nigerian Electrical Power Station

The first Nigerian electrical power plant was built at the cost of £6 thousand (~£702 thousand using current estimates) in Lagos Marina in 1896. As early as 1898, the streets of the Lagos Marina were lit between 6 P.M. and 11 P.M. by series connection. The power plant was built by the Public Works Department (PWD), this same site was taken much later by the Electricity Commission of Nigeria (ECN) as its national headquarter building. The plant comprised of two 30 kW, 1000 V, 80-cycle, single phase supply. The power plant was primarily used for lighting purpose. The government house was first lit, followed by the colonial hospital. As of 1899, most streets on the Lagos Island were lit by glow lamps with maximum demand reaching 24 KW. A third unit was installed in 1902 due to increasing demand for electricity for lighting, which was fast replacing the use of traditional lamps with oil from food sources. By 1909, installed capacity had reached 120 KW, with registered energy demand already reaching 65 KW [22].

Through installation of some underground 10,000 yard-long High Tension (HT) cables that fed 31 transformers (of which the largest was 5 thousand Volt Amps capacity), electricity reached Iddo and Ebute-metta axis of Lagos. In 1901, one of the colonial masters, Lord Lugard, undertook a similar project for the Niger Company and illuminated government house in Zungeru (a small city in North-Central Nigeria). The development of electricity infrastructure was very slow since most of the activities at that time were agriculture, which did not support enough industries to justify the development and provision of an economic power supply. When industries were projected, there were no funds available. The only notable exceptions were the Lagos railway workshops at Iddo, and later at Ebute-metta, which were largely responsible for the replacement of the Lagos steam plants by diesel engines after 1910 in the new distribution of 2-phase, 40 cycles. However, in 1914, the First World War put an end to further development of this power plant, as it was necessary to cannibalize some power plants to provide spares to keep the others working. By 1918, the street lights had to be turned off due to increased energy demand and insufficient supply.

This era heralded the pre-history of many infrastructural provisions in the next energy era which led to a sharp increase in demand for energy. The initial provision of the first electrical power plant, the surveys that led to the extensive provision of rail transport infrastructure, increased trade activities that led to the development of the ports, harbours, and terminals, as well as improved mechanization of agricultural practices increased the pressure for other forms of primary energy resources to meet the growing energy demand.

3.2.4. Influences of Decision-Making Institutions during the Early Industrial (Metallurgical) Era

This era saw the extensive use of metallurgical interventions in energy use. However, the instructional decision-making platforms that were key in shaping this stage of the transition were:

- *Colonial rule and institutions*: decisions during this era were done predominantly by the British colonialists who at that point already had their foot in Nigeria. The regional colonial governors were responsible for decision-making for the northern, eastern, western, and Lagos regions. At this time, the British colonialists started making necessary plans to set up institutions targeted at providing different infrastructural facilities to open up the nation as well as sourcing the necessary resources. During this era, the Nigerian Railway Corporation was formed to open up the nation to rail transportation to ease the movement of agricultural products from the hinterlands to the coastal cities for easy export. In 1896, construction started on the first rail line in Nigeria linking Lagos to Ibadan.
- *Traditional rulers*: traditional rulers continued in their work of governance at the local community level [29]. However, the coming of the British colonialists into the decision-making scene impacted on the kind and manner of decisions taken [26].

This era saw a closer union and more cordial working relationship between the British colonialists and the local traditional rulers in the decision-making process. This cooperation, however, led to some ugly situations in mutual trade such as the slave trade.

3.3. Industrial Era—Early to Mid 1900s

This era saw the use of steam engines in manufacturing to produce mechanical work. The discovery of coal in 1909, led to the increasing use of coal for heating water to run steam engines. Consequently, this era saw the use of dynamos and electric generators in Nigeria. The use of coal for electricity generation was introduced, with the first coal fired power plant in Nigeria commissioned in 1923 in Lagos. As such, coal was not only used to run a steam engine, but also used in electricity generation.

In this era, there were mechanical needs for manufacturing which evolved with more diverse types of manufactured goods; and mass transportation with the introduction of trains and rail transport systems in Nigeria. During this era, steam engines were the main technology driver of energy demand. The gradual embrace and extensive use of steam engines aided the following:

- The provision of the first few electrical power plants, which were used predominantly for lighting within the first two decades of this era.
- The use of steam engines in industrial applications and manufacturing—particularly in agro-food processing—to do mechanical work.

This era saw the initial steps towards the discovery and development of primary energy resources in Nigeria (particularly coal) and their impact on increased energy demand [30]. The following sections highlights the various aspects of steps taken in development of primary energy resources.

3.3.1. Coal Development, Mining Activities, and Energy Demand

Coal was discovered in Nigeria in 1909 in Enugu, eastern Nigeria. It is the oldest commercial fuel in Nigeria with early production dating back to 1916, when 24,500 tonnes of coal was produced. This era saw the increased use of coal for mass (railway) transportation, increased electricity generation, and other industrial application of coal. Figure 2 highlights the growth of coal as the primary energy resource during this era. Despite this growth, between 1944 and 1948, Nigeria started experiencing a decline in the use of coal for electricity generation. This was due to the reduced mining activities impacted by the Second World War, as well as the mini-discoveries of crude oil which led to the commercial discovery of oil in Nigeria in 1956.

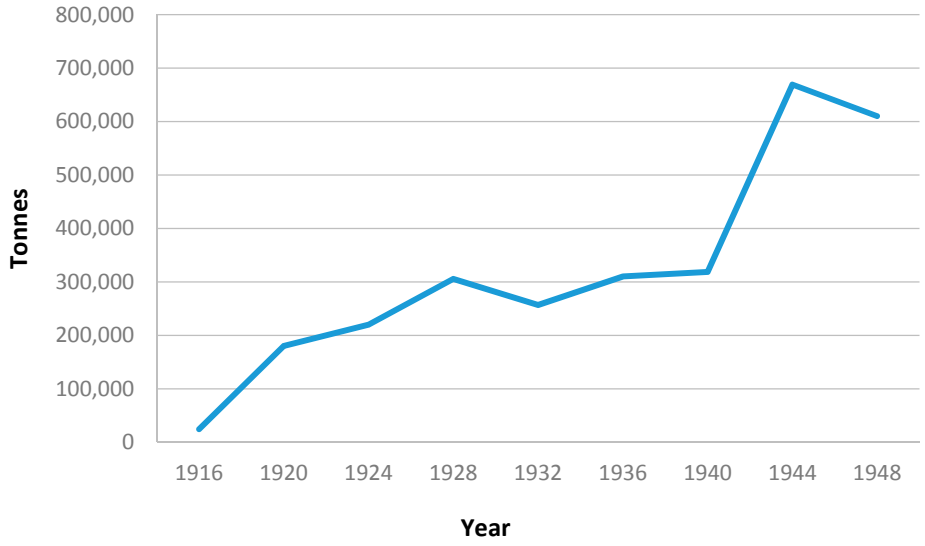

Figure 2. Coal productions in Nigeria over 1916–1948.

During this era, coal was used extensively for thermal and mechanical needs in manufacturing, particularly in fabricating machine tools, metal machines, etc.

3.3.2. Further Development of Electricity Supply Infrastructure

The installed capacity for the Lagos Marina power station was 420 kW as of 1920. Owing to increased load and demand for electricity, it was decided to look for a new site with reserve for expansion. The new power plant, which was the first coal fired power plant in Nigeria, was built and commissioned on 1 June 1923. The Marina site was shut down on 28 November 1923. The new power plant, which was described as the first major landmark in the development of electricity infrastructures in Nigeria, had a total installed capacity of 3.6 MW. In 1924, the 3-phase, 4-wire, 50-cycle system was adopted to achieve an improved load balance [22].

The new power station further grew in installed capacity to 13.75 MW. This development helped in providing the necessary electricity resource required by the Nigerian Railway workshops at the Ebute-metta and Iddo terminuses in Lagos [22].

Following the development of electrical power stations in Lagos, the next obvious place was the Plateau, to take care of the electricity needs of the Nigerian Eastern Railway (NER) workshops and coal mines, both in Enugu. The Plateau supply was a high-head hydro-electric power installation, employing quick start-up low maintenance water turbines. However, there were some initial constraints which included: inaccessibility constraints with remote location; high power transmission cost; and non-continuous river flow in dry season.

The Enugu power station was a coal-fired power plant and comprised of three 350 kW Bellis & Morcom vertical reciprocating direct condensing steam engines steamed by Babcock & Wilcox boilers. The power plant was commissioned on 24 June 1924, while the township was lit on 24 December, 1924. Table 1 shows the electrical balance sheet for Enugu in 1924.

Table 1. Enugu electrical balance sheet 1924 [22].

Electrical Balance Sheet (1924)	Kilowatt Hour (kWh)
Electrical power consumed by power	139,905
Electrical power consumed by lighting	4297
Electrical power lost to transmission	338
Electrical power surplus in consumption	17,020
Total electrical power generated	**161,560**

In 1925–1926, a further 111.5 kW was connected to the Enugu mains. In 1926–1927, the extension was given to the European Hospital, while further extension to the mines had increased the load by 40%, 860 KW for power and 110 kW for lighting. In 1928–1929, a 150 kW AC set with condensing plant and auxiliaries were added, and power was extended to the secretariat, PWD, coal camp, and the Roman Catholic mission. Units generated were over 936 MWh, and a 3.3 kV electrical voltage line connected to residence of the Lieutenant Governor. This was extended to reach the barracks of the Great Royal West African Frontier Force. Units topped the million mark by 1932–1933 when the electrical engineer-in-chief of the Public Works Department took over the Enugu Electric and Power Plant from the railway from 1 November, 1932, and its accounts from 1 April 1933. Figure 3 shows the growth in units of electricity generated (in megawatt hours—MWh)) and installed capacity (in megawatts) from 1900 in Nigeria [22].

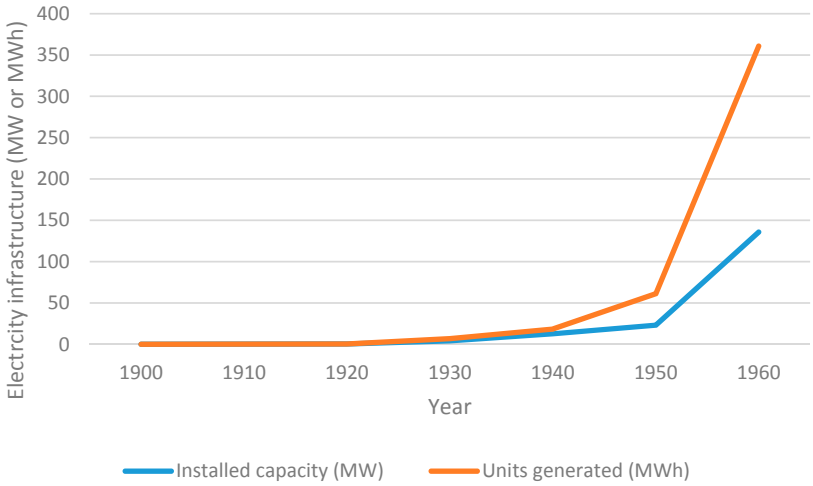

Figure 3. Electricity infrastructure growth in Nigeria across 1900–1960 in Mega Watts (MW) or Mega Watt hours (MWh) [22].

3.3.3. Energy Demand and the Development of Transportation Infrastructure

The discovery of coal led to a rise in economic activities during this era. More coal-fired electrical generation plants were built, more mass railway transportation routes were opened, while other industries that depended on coal for the running of steam engines for other industrial processes sprang up.

Following the initial development of the railway in the previous era (1879–1898), the stage was set for the future development of railway transport, which aided economic development and trade. As of 1912, fourteen ports were operational without wharf or jetty. These were Obokun, Calabar, Bakama, Bonny, Buguma, Degema, Forcados, Koko, Ikang, Brass, Akassa, Lagos, Sapele, and Warri. In 1919, it was decided that Apapa and Iddo (both in Lagos) were to serve as cargo and coal wharves, respectively. In 1923, a 750 feet screw pile wharf was constructed at Iddo (actually Ijora which is close to Iddo) and some eighteen acres of land were reclaimed. The wharf dealt with unloading of coal for railway, Ijora electricity power station, and ship's bunkering. This wharf was later taken over by the railway in 1924–1925.

As of December 1918, the total harbour works expenditure stood at over £862,000, which is approximately £52.0 million using current estimate. As of December 1921, the expenditure had risen to £1.1 million, about £45.0 million using current estimates, which excludes dredger costs. The provision of harbours increased trading activities and imposed the need for bigger and more ports and harbour infrastructure. The movements of goods from the hinterlands to the ports also added to the increased demand for energy infrastructure provisions. As of 1913, trade through Lagos was valued at £13.4 million, which is about £1.4 million using current estimates. By 1923, the value had risen to £19.2 million, which is about £990.1 million using current estimates [22]. This led to the

development of the Apapa ports in Lagos, which started with the construction of three screw pile wharves for the Marine Department in 1925. The trade dynamics and movements of goods at the Lagos ports was quite complex. Table 2 shows some statistics of the complexity of movements in Lagos harbour in 1925–1926 in terms of tonnage of goods. This also shows the complex dynamics of the need for harbour and ports infrastructure, which in turn imposes some pressure on the increased demand for energy.

Table 2. Complex movement of goods at Lagos harbour in 1925–1926 [22].

Movement	Tonnage
Landed at Customs Quay	147,983
Landed at private wharves	142,906
Landed at gun powder magazine	170
Landed at kerosene magazine	7780
Landed at petroleum magazine	7786
Landed at Iddo wharf	55,454
Railway materials landed at Iddo wharf	7167
Landed at Ijora wharf	2362
Coal landed at Ijora wharf	106,219
Imports brought in through Iddo Railway station	49,886
Exports through Iddo wharf	195,603
Export through Apapa wharf	55,786
Aro stone traffic through Apapa	21,730

Road infrastructure came much later in Nigeria owing more to the fact that rail infrastructure was first built before roads were even considered. As such, there was a delay in the provision of road network infrastructure. Most of the road infrastructure network projects were financed in the closing decades of the 20th century by oil revenues and not through taxation. Very little was done to develop road systems until 1925, due to the considerable costs of tackling swamps, bridging, grading the climbs into plateau areas, and proving the spate in the rainy season.

Providing road networks was quite challenging owing to the size of the country and the huge distances between cities. The longest capital-to-capital journey was 1677 km, while the longest road journey was from Badagry on the west of Lagos, to Kukawa, a place of historical importance in Bornu (1922 km). As of 1926, the Public Works Department (PWD) already had responsibility for 2970 miles of road. As of 1930, there was already 3775 miles of bituminous highways. As of 1937, plans were made for trunk road construction at 400 miles per annum. However, the great depression of the 1930s put an end to the scheme. As of 1946, there were 0.07 miles of road per square mile and 0.92 miles per thousand head of population; twelve years later, these figures had risen to 0.10 and 1.07 respectively [22].

While presenting a challenge, the vast distance between cities formed part of the justifications for a need for road infrastructure provisions. The progress made in road infrastructure provision had severe impact on increased fossil fuel consumption, which was mostly imported at this time. Table 3 shows the historical data of commercial vehicle and private car registration from 1937 to 1963 which highlights the transition from mass transportation to individualized transportation.

Table 3. Commercial and private vehicle registration in Nigeria across 1937–1963 [22].

Year	Number of Commercial Vehicles	Number of Private Vehicles (Car/Taxi)
1937	1819	822
1948	1593	2199
1953	4159	5783
1958	7220	7459
1963	5490	11,599

3.3.4. Influences of Decision-Making Institutions during the Industrial Era

This era was dominated by colonial institutions, established to achieve specific infrastructural and policy targets [31]. The Nigerian Electricity Supply Company (NESCO) was established in 1922 and tasked with the responsibility of developing electrical energy supply (generation) infrastructure. NESCO produced and sold bulk power for the townships of Bukuru (in 1936), and Vom (in 1944) which covers a total of 600 square miles (including the mines). The peak load rose to 12 MW with an annual load factor of 60%. As of 1922, the Enugu building of NESCO was already in place, just off the railway workshops. Engines, dynamos, boilers, and a riveted steel chimney were in position at an audited cost of over £103,000, which is worth around £4.6 million in current estimates. This power plant supplied electrical power to the mines from 1924.

3.4. Late Industrial Era—Mid to Late 1900s

This era saw more extensive use of energy, with dynamos and internal combustion engines as the main technology enablers for increased energy use. Indeed, with regards to transportation, there was a shift from mass transportation to individualized transportation. The discovery of crude oil also added a different dynamic in energy use as more infrastructure were provided as a result of the increased country income that came from crude oil.

3.4.1. Dynamos and Internal Combustion Engines as Main Drivers of Energy Demand

Dynamos are the core inventions behind electrical generators, electrical motors, and internal combustion engines. Dynamos were the main technology driver which contributed to increased energy demand in the following areas:

- *Mechanical*: there was increased mechanical needs for manufacturing, with much more diverse types of manufactured products emerging, as well as demand for those products.
- *Electrical:* was being used increasingly in industry for manufacturing goods.
- *Transport:* Individualized transportation with the internal combustion engines which was developing hand-in-hand with automobile.

3.4.2. Primary Energy Resources and Energy Demand

This era saw the gradual decline of the use of coal for electricity generation, which was essentially a result of the discovery of crude oil, and the focus on renewable hydropower generation for electricity. From the 1930s, there were plans to develop the hydropower potential of Nigeria, which led to the later formation of the Niger Dams Authority (NDA) which was charged with developing the hydropower potential of Nigeria. The demand for crude oil was supported by the emerging transportation demand in other countries (petroleum export), as well as electricity generation. The discovery of primary energy sources, such as coal, crude oil, etc., in the first half of the 20th century in Nigeria was fostered by extensive surveys carried out by the British colonialists through the Public Works Department (PWD) to actively search for primary energy resources and minerals within the shores of Nigeria.

Oil and gas operations in Nigeria started in 1956 with the first commercial discovery of oil in Nigeria by Shell D'Arcy. However, in November 1938, a concession was signed with the same company to explore for possible petroleum resources within Nigeria's borders [30]. After the discovery, Shell played a dominant role in the Nigerian oil industry up until 1971 when Nigeria joined the Organization of Petroleum Exporting Countries (OPEC), after which the country began to take a firmer control of its oil and gas resources.

The growing use of petroleum characterized this era due primarily to the penetration and wide spread use of internal combustion engines, as well as the increased use of petroleum (and its by-products) in the petro-chemical industry for production of plastics and other chemicals, which use the energy embedded in this product in form of petroleum. Figure 4 shows crude oil production, 1980–2000.

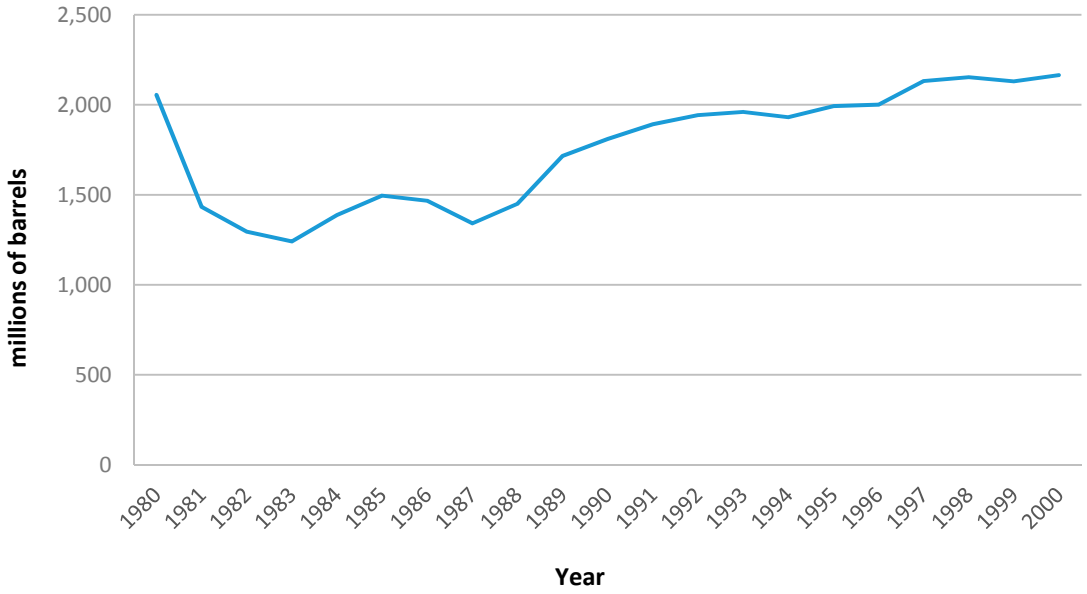

Figure 4. Nigeria's crude oil production across 1980–2000 [32].

Nigeria holds the largest natural gas reserves on the African continent, and was the fourth world leading exporter of liquefied natural gas in 2012 [32]. Nigeria's increased gas production was influenced by the creation of the Nigeria Liquefied Natural Gas Limited (NLNG) on 17 May 1989. The creation of NLNG paved the way for the installation of an LNG plant for production of natural gas to meet local demand for electricity generation, and also to meet export demand. Figure 5 shows the growth in the use of natural gas for electricity generation (1971–2000).

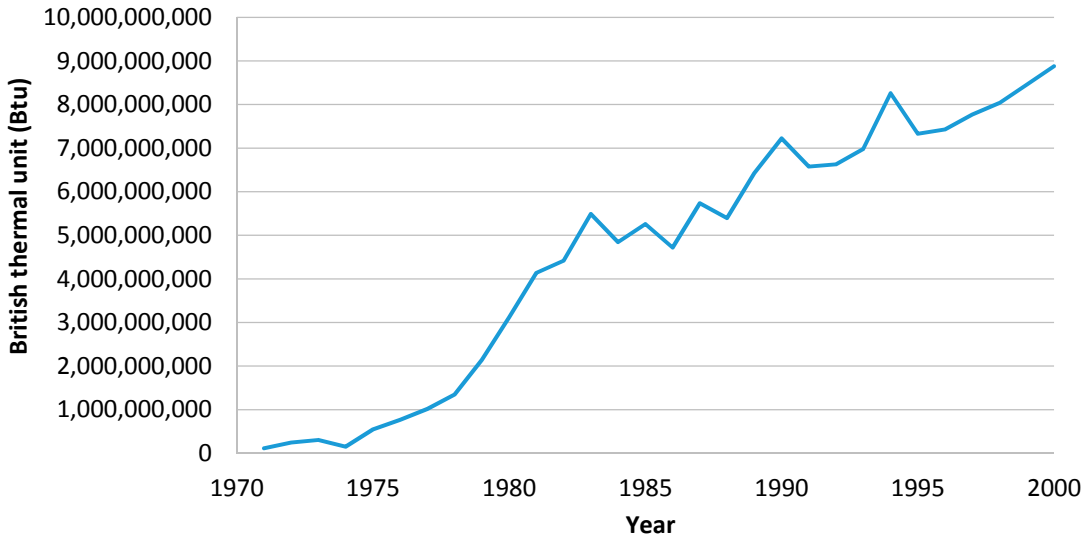

Figure 5. Natural gas for electricity production in Nigeria across 1971–2000 [32].

During this era, there was increased demand for the primary energy resources that can do the kind of work that was required in transportation, electrical generation, and manufacturing. This reflected in:

- The continued use of coal for electricity generation—particularly within the first two decades of this era—and its reduced use for steam engines.
- The discovery and growing use of petroleum in the petrochemical industry, as well as transportation, due to the widespread use and penetration of the internal combustion engines.

The latter part of this era saw some diversification of primary energy resources. The higher demand for electricity warranted that there be diverse sources of energy for electrical infrastructure provisions. Essentially what was needed was electricity from whatever source, which led to the introduction of diverse technologies, such as thermal power plants, and the increasing growth of renewables (hydropower) in electrical power generation.

3.4.3. Industrial Estates Growth and Energy Demand

In the 1970s, there was a reinvigoration of many industrial activities which had slowed down in the late 1960s owing to the Nigerian civil war, which lasted from 1967 to 1970. By the early 1970s, there were more than 2000 industries in Nigeria located across several industrial areas. Table 4 details the Nigerian industrial estates, as well as their average size and principal activities as of 1971.

Table 4. Industrial estates in Nigeria and their principal activities in 1971 (Source: archives of the Nigerian Railway Corporation, 1997).

Estate	Acreage	Principal Activities
Kano	277	Groundnut mills, textiles, perfumery, plastics, tanning, minerals waters, carbon dioxide, Bata shoes, Raleigh Industries, retreading.
Kaduna	550	Textiles, brewing, London Brick pre-cast concrete, ordinance, building materials.
Zaria	145	Oilseed processing, Nigerian Tobacco, toiletries, bicycle assembly.
Jos	60	Tin smelting, pump assembly, twill jute snacks.
Gusau	75	Textiles, rail head for Sokoto cement.
Maiduguri	79	Oilseed processing, abattoir not within the estate, Chad fishery to be developed.
Ilorin	317	Philip Morris Tobacco, United Matches, Tate & Lyle.
Port Harcourt	2000	75% industrial, 25% residential. Alcan Aluminum, paints, enamelware, tyres & tubes, Costain (WA) furniture.
Aba	5	Textiles, soap, pharmaceuticals.
Umuahia	31	Brewing, ceramics, not rail served.
Emene	Unavailable	Turners Asbestos cement paper & sheet, iron & steel mill, Niger gas factory.
Onitsha	1518	Textiles, iron & steel, mineral waters, bus bodies. 50% residential and 50% industrial. Not rail served.
Ikeja	750	40% industrial, 60% residential. Textile, tyres, asbestos cement, enamelware, biscuits, paints, mosaics, Guinness, Aluminium products, drugs, galvanized work, livestock feeds, Bridon Group (Nigeria) wire-mesh and barbed wire, ICI Plastic pipes.
Mushin	230	Milk recycling, bicycle assembly, mattress factory, furniture, metal windows, not rail served.
Ilupeju	67	Light industries, rail served by Oshodi station.
Apapa	230	Established by Lagos Executive Development Board (LEDB), flour milling, automobile assembly, margarine, Sunlight/Lifebuoy/Lux toilet soaps, Nigerian ropes, Metalbox, West African Distillers, West African Cold Store, IBRU Seafoods.
Iganmu	200	Developed by LEDS, Star Brewery.

During this era, there was increased mechanical needs for manufacturing, with more diverse types of manufactured products emerging, and demand for those products. The increase in manufacturing activities led to a corresponding demand for energy required for commercial and manufacturing hubs and estates. Government and policy-makers during this era made some effort in the provision of energy infrastructure to support manufacturing. However, despite this provision, demand kept growing, such that the growth of the manufacturing sector was limited by the insufficient energy infrastructure provision [33].

3.4.4. Influences of Decision-Making Institutions during the Late Industrial Era

After the Second World War, there were increased problems in supply of electricity infrastructure to meet the growing demand. As such, the government had to intervene by creating a new department out of the Public Works Department with the aim of removing inevitable government restrictions and to take care of the essential growing developments. The Nigerian Government Electricity Undertaking

(NGEU) was set up in 1946, to last for a period of five years, to pave the way for a future corporation. During this time, no further undertakings were commissioned but orders were placed and hydrological services were put in hand. The contemporary 10-year plan of 1946–1956 of the sum of £1.7 million, which is about £66.3 billion using current estimates, was designed by NGEU to increase capacity by 200%.

The Electricity Corporation of Nigeria (ECN) was created on 6 July 1950 under the ordinance No. 15 of 1950, charged with the responsibility to plan the development of Nigeria's electrical energy potential in a manner as to provide the cheapest form of energy consistent with continuity of supply.

The first decade of this era saw the gradual and eventual hand over of most institutions controlled by the British colonial administrators to Nigerians [34]. This was in preparation for Nigeria's independence, which took effect from 1 October 1960. A few years after independence, Nigeria experienced a series of military coups and counter coups, which then led to the highly militarized decision-making structure during this era, as most of this era saw military institutions leading the decision and policy-making process [35,36]. Some of these institutions included:

- Niger Dams Authority (NDA) established in 1962 to develop Nigeria's hydropower potential.
- National Electric Power Authority (NEPA) established in 1st April 1972 which is a product of the merger of the Niger Dams Authority (NDA) and the Electricity Corporation of Nigeria (ECN). The merger actually took effect from 6 January 1973.
- Nigerian National Petroleum Corporation (NNPC) established on 1st April 1977 to participate and regulate Nigeria's petroleum industry.
- Energy Commission of Nigeria (ECN) established by Act No. 62 of 1979, as amended by Act No. 32 of 1988 and Act No. 19 of 1989, to strategically plan and coordinate Nigeria's national policies on energy.

The Energy Commission of Nigeria, since its formation, has focused on developing strategies and action plans to address Nigeria's energy challenges through promulgation of policies that can help Nigeria in having a diversified energy mix, improve energy efficiency and management, while encouraging indigenous and private sector participation in Nigeria's energy sector. The aims of the ECN is far from being achieved as there is still a huge gap between the desired objectives and what seems to have been achieved.

3.5. Information (Micro-Processor) Era—Early 2000s Onwards

This era is characterized by the extensive use, and need, of information systems and data storage infrastructure. More organizations have needed data centres and server rooms. Most manufacturing plants have migrated to semi-automated and automated platforms for their manufacturing processes, with the use of Programmable Logic Controllers (PLC) and other associated automation technologies. The need for automation, data storage, and information processing has thus added to increased demand for energy.

Mechanical needs in manufacturing and transportation also continued, with increasing demand for electrical power for the automation of manufacturing processes. A core characteristic of this era is the increasing value creation in the economy through information processing and transmission. This era has additionally seen the increasing use of petroleum products and the growing use of natural gas for electricity generation, as well as the growth of renewable energy generation.

With respect to transportation, this era is seeing an increasingly varied use of different forms of individualized and mass transport systems, which has been a major contributor to increased demand for crude oil. Another major contributor to the increased energy production has been the increased export demand for the primary energy resources, particularly crude oil and natural gas [32] (Figure 6). In addition, the continuous growth in energy demand has been influenced by increased local consumption due to population growth and increased export demand.

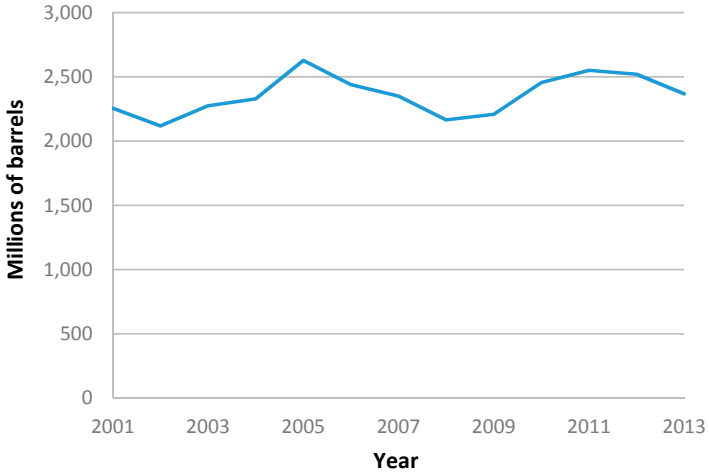

Figure 6. Crude oil production in Nigeria across 2001–2013 [32].

The consumption of natural gas for electricity generation is also changing during this era (Figure 7), with government policy focusing on the installation of gas-fired electrical power plants to address the challenge of energy access. This policy direction was initially informed by the high natural gas reserves of Nigeria.

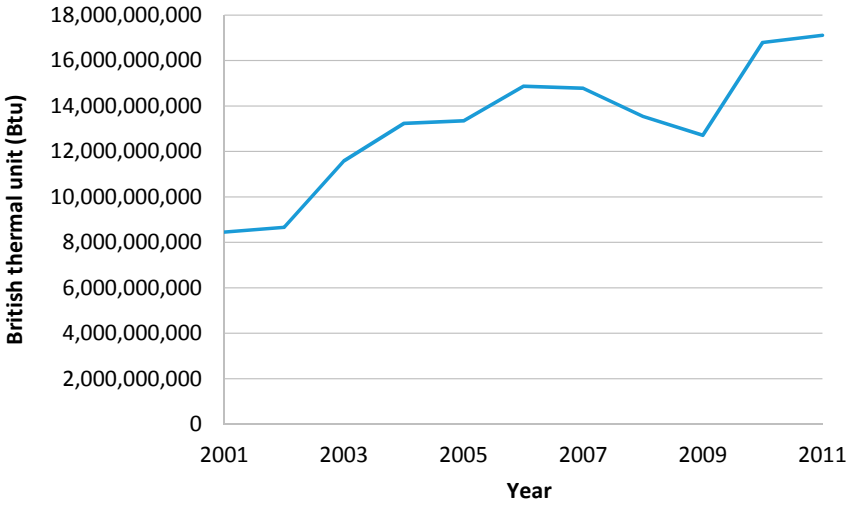

Figure 7. Natural gas used for electricity generation in Nigeria across 2001–2011 [32].

Influences of Decision-Making Institutions during the Information (Micro-Processor) Era

This era is characterized by democratic and civil institutions involved in the decision-making and policy process [34]. Key institutions include:

- Nigerian Electricity Regulatory Commission (NERC), which was established on 31 October 2007 as a regulatory body for the Nigerian power industry.
- The Power Holding Company of Nigeria (PHCN), which was established on 5 May 2005. It was established as a holding company, owning the various divisions responsible for generation, transmission, and distribution of electrical energy.

4. Discussion

Nigeria's energy transition has been influenced by a long history of trading relations, external interference in domestic decision-making, discovery of energy resources, and technology development.

Interestingly, Lagos has been the epicentre for the emergence and development of new energy supply infrastructure, which then tends to diffuse through to the rest of country via existing/developing transport routes, in addition to diffusing within the geographic constraints offered by new oil/gas discoveries. Population growth also influenced demand for energy. Improved infrastructural provision, such as roads, schools, health facilities, etc., made the Nigerian people—over time—appreciate the need and usefulness of energy. Thus, more health awareness, education, and the quest to improve comfort and well-being, were main contributors to increased demand for energy [37].

Importantly, institutions have played a vital role in the provision of energy infrastructure and in Nigeria's energy transition. The establishment of the various institutions within each energy era was geared towards providing the needed infrastructure to support industrialization, to improve and ease mobility, to improve trading activities through the development of ports and harbours, and to support economic development. Institutions established during the different energy eras provided a technical basis for decision-making, but it is important to remember that these institutions (and their technical bases) only came to exist because of the (deemed) societal needs of each specific era. Each era had its own socio-technical contexts, which brought the technical (infrastructure) and the social together in fairly distinct ways.

Indeed, these institutions were shaped both by energy needs and by significant external socio-political events which are unique to certain points of Nigeria's history. Such events certainly represent key moments of societal—and, consequently, infrastructural—change. For example, the First World War impacted on the sourcing of spare parts for the first set of electrical power plants. Some power plants needed to be cannibalized to keep others operational due to difficulty in getting spare parts during the war period. Moreover, during the Second World War, coal mining activities reduced, which led to the reduced use of coal for electricity generation during the war period.

Another key moment in the socio-technical evolution of Nigeria's energy infrastructure was Nigeria's independence on 1st October 1960, which also brought about changes in the institutional dimension of decision-making. Prior to 1960, there were more colonial institutions which started from the Public Works Department. There was the gradual hand-over of the various colonial institutions to Nigerian nationals for their operation and management in preparation for independence. After independence, the dynamics of decision-making changed and decisions were enacted through military decrees.

More recently, the potentially pivotal role of conflict and war was once again reiterated. Indeed, the Nigerian civil war (1967–1970) impacted on energy production. Whilst crude oil was discovered in commercial quantities in 1956, it was only after the Nigerian civil war that crude oil and natural gas production began in commercial quantities. By the early 2000s, the democratic process of decision-making, within many institutions, was gradually re-introduced.

5. Conclusions

The study of the Nigerian energy transitions, with respect to energy supply infrastructure reveals a complex connection between resources, trade, institutions, and political structures. The increased use of primary energy resources was influenced more by the fact that the natural resources were available within the country. A secondary reason was the rising demand for energy. This is obvious from the series of changes and transition in the use of different primary energy sources (from coal, to crude oil, to natural gas) to satisfy the growing demand for energy. This same transition was also supported by, and influenced the creation of, several decision-making institutions within each era, as well as the policy direction of the government.

Sustained public investment and leadership by public government institutions is still required to ensure that the provision of energy supply infrastructure is able to meet the changing needs of society, especially in the context of its development aspirations and future moments of change. We suggest that this can be, at least in part, enabled through more (effective) partnerships between public institutions, industry, and private investors, to improve access to energy and foster new clean energy technology

development and deployment. There is also a role for governments, through public institutions, need to provide economic incentives to increase energy infrastructure provision through promulgation of policies to aid private investment. Nevertheless, what this study implicitly makes clear is that whilst policymakers can prepare in all these sorts of ways (as part strategies to enable transitions in energy infrastructure), the most significant changes in the past have actually come from unforeseen socio-political changes that have had ripple effects into the provision of energy infrastructure.

As such, a key contribution of this Nigerian development case study is its empirical evidence that emphasizes how a better understanding of historic/future changes to energy infrastructure is actually enabled through studying the changing needs and wants of society.

Acknowledgments: Special thanks to the Nigerian Railway Corporation for allowing access to their archives. Also special thanks for permission to obtain some data as compiled by Francis Jackel containing the archival records on the history of the Nigerian railway. The authors would also like to thank the very useful suggestions from the four reviewers of this paper and the editors of the journal.

Author Contributions: Norbert Edomah conceived and designed the research study as part of his Ph.D. research. Chris Foulds and Aled Jones provided inputs during the analysis and writing up, in addition to also supervising the research. Norbert Edomah wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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