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Impact of Electricity on Industrial Output in Nigeria: A Systems Perspective

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This is to certify that the doctoral dissertation by

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2021

Abstract

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MBA, Abubakar Tafawa Balewa University Nigeria, 2001

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Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Philosophy

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Abstract

Lack of access to electricity, both in quantity and quality, has been a recurring problem in Nigeria. Scholars have investigated the relationship between electricity consumption and economic development with diverse outcomes, but they have not considered the subsystems that constitute the electricity delivery system. The purpose of this quantitative correlational study was to examine the relationship between monthly industrial output in Nigeria and available monthly power generation capacity, available monthly power transmission capacity, and monthly power distribution capability. Systems theory was the theoretical framework for this study. Data were collected on the monthly industrial output and operational data on electric utilities in Nigeria from 2015 to 2020 to constitute a population size of 72 months. The result indicated capacity incongruencies across the power supply value chain. Pearson's correlation analysis showed no statistically significant correlation between generation capacity and transmission capacity, and there was a negative but not statistically significant correlation between transmission capacity and distribution capability. The results of the multiple regression analysis indicate that the linear combination of the independent variables statistically significantly predicted industrial output in the regression model; however, only distribution capability had a statistically significant correlation with industrial output. The results of this study support policy development for improved electricity supply that will boost the competitiveness of local industries, leading to economic growth and reduced poverty due to more employment opportunities, thus contributing to positive social change.

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Dedication

I dedicate this to God Almighty, with whom all things are possible, and to my family for their support despite suffering the inconvenience of my absence on most weekends during the development of the study.

Acknowledgments

I want to acknowledge the support of my committee chair, Dr. Aridaman Jain, my second committee member, Dr. Marcia Steinhauer, and my URR, Dr. Bob Lavasseur, for their incisive and supportive reviews that made this possible. My special thanks go to Dr. Jain, who has been my mentor throughout my doctoral journey, for his steadfast support. This doctoral journey has been a journey in knowledge and self-discovery and has enabled me to understand what it means to be an agent of positive social change.

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Chapter 1: Introduction to the Study

The research on the relationship between electricity and economic development is vast, but there is no consensus on the direction or type of relationship. Various studies in Nigeria have yielded different results. Researchers have indicated that electricity consumption leads to economic development in Nigeria (Alley et al., 2016; Nwankwo & Njogo, 2013; Ubi & Effiom, 2013). Further, electricity and economic growth have a mutually reinforcing effect in Nigeria; economic development drives electricity consumption, and increased electricity consumption drives economic development further (Ogundipe & Apata, 2013; Ologundudu, 2015). Other researchers have discovered a unidirectional relationship that runs from economic development to electricity consumption in Nigeria (Ogundipe et al., 2016; Ugwoke et al., 2016). However, research has also shown no effects between electricity consumption and economic development in Nigeria (Ologundudu, 2015). These studies have policy implications, but the diverse research outcomes confuse rather than support policy development for electric power development and economic growth.

Most researchers in the literature I reviewed on the electricity economic development nexus treated electricity as a unitary system without consideration for the subsystems that constitute the power delivery system and how they could affect Nigeria's industrial output. A systems approach offers new perspectives on the relationship and interdependencies between available power generation capacity, available transmission capacity, distribution capability, and how they affect Nigeria's industrial output. It was difficult to locate published studies where researchers applied the systems approach in studying the interactions between the elements that make up the power delivery system and their effect on industrial output in Nigeria.

In this study, I evaluated the relationships, interdependencies, and the coordinated joint effort required between power generation capacity, transmission capacity, and distribution capability in delivering power and how these elements affect industrial output in Nigeria. Secondary data from the Nigeria Electricity System Operator (NESO) website that houses the operational data of electric utilities in Nigeria was used for the analysis. The outcome of this study could advance positive social change by providing new knowledge about the unique roles of various elements in the power delivery value chain in the relationship between electricity and economic development. This new knowledge may inform government policy to support economic development. The rest of this chapter consists of the background to the study, problem statement, purpose of the study, research questions and hypotheses, theoretical foundations for the study, nature of the research, assumptions, and delimitations, including limitations of the study.

Background of the Study

Since Nigeria gained independence from Britain, lack of access to electricity, both in quantity and quality, has been a recurring problem. In the 2017 state of electricity access report in the World Bank website (https://www.worldbank.org), Nigeria was ranked as the second country, behind India, with the largest electricity access gap, with an estimated 75 million people without access to electricity. In the World Bank 2021 energy progress report, Nigeria had topped the list of countries with the largest electricity access gap in 2019, with 90 million people without access to electricity. Research on the effect of electricity on economic development in sub-Saharan African (SSA) countries indicates that poor state of infrastructure and services negatively impact economic growth in the region (Azolibe & Okonkwo, 2020; Chakamera & Alagidede, 2018; Kodongo & Ojah, 2016; Owusu-Manu et al., 2019). Lack of electricity access impedes economic development, health care, and education (Zhang et al., 2019).

More than half of the world's population now lives in urban centers, with a projection that this figure could reach 75% by 2050, and SSA is mainly regarded as the region with the highest urbanization rate (Saghir & Santoro, 2018). It is difficult to transition from a low-income country to a medium or high-income country without urbanization (Saghir & Santoro, 2018). But economic growth in SSA countries may be challenged by poor electricity infrastructure and services. Urbanization usually puts pressure on existing electricity supply infrastructure leading to power supply shortages (Zhang et al., 2019). This situation is further compounded by diverse research outcomes on the region's electricity and economic development that do not support coherent policy development.

It was difficult to locate published studies where researchers used the systems approach to investigate the relationship between electricity and economic development. In this regard, it is rare to find researchers that have viewed electricity as a natural system to understand the interplay between the subsystems that constitute the electricity delivery systems and explore how these subsystems could impact economic development independently and collectively. There are about eight studies in Nigeria on the effect of electricity on economic development with growth hypothesis ($n = 3$), feedback hypothesis ($n = 2$), neutrality hypothesis ($n = 1$), and conservation hypothesis ($n = 2$). With this type of mixed or diverse research outcomes, it would be difficult for the government of Nigeria to develop a coherent policy to drive Nigeria's power sector and economic development.

To address gaps in research, in this study, I used a systems approach to investigate the interface relationships between power generation, transmission, and distribution, as elements of the power delivery system and how these variables affect industrial output in Nigeria. Von Bertalanffy (1968) noted the continuous relationship between elements of a system and the need to understand the interdependencies among these elements. Laszlo (1996) also identified the hypothetico-deductive method as an approach to promote understanding natural systems as being made up of systems in layers, superimposed on one another, to constitute a whole. Laszlo's hypothetico-deductive method allows for examining the interface relationships between systems and the joint effort required to maintain a dynamic equilibrium. The systems approach in the electricity and economic development literature can allow a deeper understanding of the power (electricity) supply dynamics and how electricity could affect economic development in different ways. This understanding will support a more informed and targeted policy development approach.

Problem Statement

The literature on the effect of energy resources on economic development indicates a correlation between electricity consumption and gross domestic product (GDP). Researchers have used the auto-regressive distributed lag (ARDL) cointegration test to establish the existence of a long-run correlation between electricity consumption per capita and real GDP per capita as well as a relationship between industrialization and economic development in Nigeria (Acaravci, 2010; Odeleye & Olunkwa, 2019). Electricity, through industrialization, has positive effects on economic development (Allley et al., 2016). But from 2015 onwards, Nigeria witnessed a steady decline in the production growth rate of most industrial sub-sectors (Odeleye & Olunkwa, 2019). In 2018, the International Monetary Fund and the World Bank ranked Nigeria 140 and 136 in the world, respectively, in terms of GDP per capita. Despite the identified relationship between electricity and industrialization and their impacts on economic development in Nigeria, it was difficult to locate studies that established how the elements or variables that constitute the electricity supply system affect industrialization or economic development. Researchers tend to view electricity as a unitary system, not considering the constitutive and interacting elements like power generation capacity, transmission capacity, and distribution capability that make up the electric power delivery chain and how they affect industrial output in Nigeria.

The general management problem is that there is a gap in the literature regarding the interrelatedness between the elements that constitute the power delivery value chain and industrial output in Nigeria. The specific management problem is the lack of understanding about the relationship between available monthly power generation capacity, available monthly transmission capacity, monthly distribution capability, and industrial output in Nigeria. Most research on the effects of electricity on industrial output points to correlations and causal linkages between electricity and industrialization, industrialization and economic development, and electricity and economic development, without explaining the relationship between various elements that constitute the electricity supply value chain and industrial output in Nigeria. Explaining the relationship between elements that make up the power supply value chain will serve to disaggregate all variables involved in the generation, transmission, and distribution of electricity and provide an understanding regarding how these variables interact to affect electricity supply and hence industrial output in Nigeria.

Purpose of the Study

The purpose of this quantitative correlational study was to examine the relationship between industrial output in Nigeria and available monthly power generation capacity, available monthly transmission capacity, and monthly distribution capability. In this study, I used secondary data on available monthly electric power generation capacity, available monthly power transmission capacity, monthly distribution capability, and industrial output in Nigeria to examine the relationships among these variables. Available monthly power generation capacity, available transmission wheeling capacity, and monthly power distribution capability constitute the independent variables, and industrial output in Nigeria was the dependent variable. The focus of multiple regression analysis was 6 years of monthly electricity sector operational data in Nigeria from 2015 to 2020. Examining the relationships between the power sector variables and industrial output can support the development of a conceptual model to explain how these variables individually and collectively contribute to the industrial output trajectory in Nigeria.

Research Question and Hypotheses

The primary aim of this study was to examine how the elements that make up the power delivery system affect industrial output in Nigeria. The elements that constitute the power delivery subsystems are (a) available monthly power generation capacity, (b) available monthly power transmission capacity, and (c) monthly power distribution capability. The research question and hypotheses that guided this study are as follows:

Research question: Is monthly industrial output in Nigeria related to available monthly power generation capacity, available monthly power transmission capacity, and monthly power distribution capability?

H_0: Monthly industrial output in Nigeria is not related to available monthly power generation capacity, available monthly power transmission capacity, and monthly power distribution capability.

H_a: Monthly industrial output in Nigeria is related to available monthly power generation capacity, available monthly power transmission capacity, and monthly power distribution capability

The independent variables are the available monthly power generation capacity, available monthly transmission capacity, and monthly power distribution capability, and the industrial output in Nigeria is the dependent variable. The level of measurement of all the variables is at the ratio scale.

Theoretical Foundation

Von Bertalanffy's (1968) systems theoretical perspective was the theoretical framework for this study. From the seminal works of von Bertalanffy (1968), Laszlo

(1996), Passmore (1988), and Oshry (2007), it is evident that to gain knowledge about the emergent nature of a system, there is a need to understand the interrelated and dynamic relationships that exist between elements of that system, including the effect of the environment on the system. The four propositions Laszlo used to investigate organizational invariances was used in this study to establish the Nigerian power supply value chain as a natural open system that is a whole with irreducible properties, how it maintains itself within a changing environment, responds to the self-creativity of other organizations or systems, and serves as a coordinating interface in the Nigerian super system or holarchy.

The electric power delivery value chain in Nigeria involves power generation, transmission, and distribution segments. Using a systems theoretical approach in this study enabled understanding how the different components that make up the power delivery value chain affect industrial output in Nigeria. The various components are the individual technological elements and heterogeneous technologies that comprise the power sector as a system and their impact on industrial output in Nigeria. Using this theoretical framework aided in understanding the interactions between these elements, their interdependencies, and the coordinated joint effect required at the interface points to achieve dynamic equilibrium, thus illuminating the complexities of multiple interactions resulting from the embedded connectedness of elements that make up the power supply system. The generation and distribution segments of the power delivery value chain in the Nigerian power sector are privatized, meaning they will face many risks, including technological, institutional, regulatory, political, and environmental risks. Adopting a systems view approach can provide details that support the development of practical and integrative models that may promote a more in-depth understanding of the relationship between power sector variables and industrial output in Nigeria.

Nature of the Study

The nature of the study is quantitative with a correlational design. Most studies on the effect of electricity on industrialization and economic development are mostly either correlational or causal, and the researchers treat electricity as a unitary system. In this study, I used a correlational design to examine relationships between the variables that make up the electric power supply value chain in Nigeria. Researchers use correlational design to measure the strength of association between variables (Gujarati & Porter, 2009).

Secondary data from government institutions that play critical roles in Nigeria's power sector was the source of data for the study. These institutions collect data, including available monthly power generation capacity, available monthly transmission capacity, and monthly distribution capability. Another source was secondary data published by the Nigerian Bureau of Statistics (NBS), which archives critical national economic statistical data. The Nigerian GDP was the source of data for industrial output, the independent variable in this study. The data points for this study were monthly operational data for 6 years from 2015 to 2020 for the three segments of the power delivery value chain and industrial output in Nigeria. I used Pearson's correlation to examine the correlation between power generation capacity, transmission capacity, and distribution capability to analyze the efficacy of the interface (ability) relationships between the variables. Multiple regression analysis was used to test the interaction effects between monthly industrial output, the dependent variable, and available monthly generation capacity, available monthly transmission capacity, and monthly distribution capability, the independent variables, and to estimate the extent to which each independent variable explains variations in the dependent variable.

Definitions

Available power generation capacity: The reported daily available Nigeria national power generation capacity from NESO website (https://nsong.org/). This figure is measured in megawatts (MW) and is usually different from the installed capacity of the power plants.

Available power transmission capacity: The reported daily available Nigeria power transmission capacity reported as transmission wheeling capacity from the website of NESO (https://nsong.org/). This capacity could vary from day to day and is measured in MW.

Power distribution capability: Total energy the distribution companies in Nigeria distribute, reported as daily energy utilized from the NESO website (https://nsong.org/). The energy the distribution companies distribute may vary from day to day.

Industrial output: GDP component of the industrial sectors as reported in the NBS website (https://www.nigerianstat.gov.ng/).

Growth hypothesis: A postulation that electricity consumption leads to economic development without feedback (Amin & Murshed, 2017). Under this hypothesis, there is a causal relationship between electricity consumption and economic development that runs from electricity consumption to economic growth. This hypothesis supports electricity expansion policies (Mawejje & Mawejje, 2016)

Conservation hypothesis: Under this hypothesis, improvements in economic development drive electricity consumption (Guan et al., 2015). There is a unidirectional relationship between economic development and electricity consumption, which is usually prevalent in energy-sufficient nations (Guan et al., 2015). Under this scenario, energy conservation policies would not hurt economic development (Mawejje & Mawejje, 2016)

Feedback hypothesis: A postulation that indicates a mutual and interdependent effect between energy consumption and economic development (Hasan et al., 2018). In this case, causation is bidirectional and reinforcing.

Neutrality hypothesis: Under this hypothesis, there is an absence of a causal relationship between electricity consumption and economic development (Mawejje & Mawejje, 2016). In this case, economic growth is independent of electricity consumption.

System thinking: System thinking is a broad knowledge approach to problem-solving that professionals in diverse domains use in analysis, synthesis, and inquiry regarding a problem of interest (Boardman et al., 2009). Thus, systems thinking represents a holistic approach to problem-solving that involves examining the bigger picture.

Assumptions

A major assumption in this study is that the population size would be adequate to avoid validity issues. I used G*Power software to determine 77 as the minimum sample size, but the available population size was 72 due to limiting data from 2015 to 2020. I assumed that the difference was not enough to affect the validity of the study. Second, because of the use of a systems approach in the study, the assumption was that examining the relationships between the independent variables would reveal interface issues within the power delivery system and expose possible infrastructural deficits that may further explain the relationship between the independent and dependent variables. Third, there was an assumption that the data for the study would satisfy all assumptions for multiple regression analysis to avoid issues of invalid inferences. Last, I used secondary data for this study, sourced from government agencies that hold the data; the assumption was that the data would be of high quality, minimizing issues of applicability, fit for purpose, availability, relevance, accuracy, and sufficiency.

Scope and Delimitations

In this study, I examined available generation capacity, available transmission capacity, and distribution capability to study the effect of power system variables on industrial output in Nigeria. Researchers in electricity and economic development literature have focused mainly on electricity consumption as the electricity variable. In this study, the focus was on the elements of the power delivery value chain and the potential to affect electricity consumption, especially in energy-challenged countries. This explanation goes beyond electricity consumption to include factors that affect electricity consumption and provides a path to convergence in the electricity and economic development literature.

A significant delimitation was the cut-off date for data collection. The government of Nigeria effectively privatized the Nigerian electricity market in 2015 through Order 136 of the Nigeria Electricity Regulatory Commission for commencement of the transitional electricity market, which represented a significant structural change in the electricity sector. Collecting data earlier than 2015 for this study could have introduced structural breaks in data analysis that may affect research validity (external validity).

Another delimitation was the choice of generation capacity, transmission capacity, and distribution capability as electricity delivery variables, including industrial output as the economic variable. The choice of the three power delivery variables was based on studies on the effect of poor infrastructure on economic development in SSA countries (Azolibe & Okonkwo, 2020; Chakamera & Alagidede, 2018; Kodongo & Ojah, 2016; Owusu-Manu et al., 2019). Studies on the effect of electricity on industrialization informed the choice of industrial output as the economic variable (Ologundudu, 2015; Zhang & Broadstock, 2016). Seventy-one percent of industries in Nigeria provide their electricity, further supporting the choice of industrial output as a dependent variable in the study (Osakwe, 2017).

From the literature on electricity and economic development, most scholars applied econometric theories and statistical methods to assess and analyze economic theories. The use of these theoretical models does not enable the investigation of electricity as a natural system. Von Bertalanffy’s (1968) general systems theory and Laszlo’s (1996) hypothetico-deductive systems method promote the understanding of electricity as a system, made up of layers, in a coordinated joint effort to deliver electricity for consumption. It was difficult to locate literature on electricity and economic development where researchers used the systems approach to the phenomenon.

Because this is a nonexperimental design study using secondary data, the threats to internal and external validity are minimal (see Drew et al., 2008). An external validity issue that may impact the generalizability of this study is the population size, which is somewhat less than the minimum sample size. The findings of this study could support the development of coherent energy and economic development policies through a better understanding of the dynamics between electricity and economic development in energy-challenged countries like Nigeria.

Limitations

The population size is a limitation in this study. The a priori power analysis at 80% power (1-β error probability) determined 77 as the minimum sample size; however, the available population size was 72. This limitation arose because 2015 was the data cut-off date, and monthly operational data of electric utilities and GDP data constitute the study population. During data analysis, the implementation of first differencing further reduced the sample size to 71. Small sample size issues introduce threats to statistical conclusion validity (SCV; Busk, 2010).

The second limitation is the omission of gas as a variable in the study. In 2015, thermal generation constituted up to 82% of the power generated in Nigeria (Osakwe, 2017). Natural gas, a fuel source for thermal generation in Nigeria, a covariate in this study, was not included as a variable in the study. Extraneous variables that could affect a study, other than the identified independent and dependent variables, could threaten internal validity (Drew et al., 2008). Excluding this variable could be a threat to internal validity as it could be interpreted as an omitted variable. The use of available generation capacity as an independent variable addresses this issue. The reason for this assertion is because gas availability could be one of the reasons for the level of available generation.

Another limitation of the study is the use of secondary data, which presents the issues of applicability and fit for purpose. In this regard, the issues of availability, relevance, accuracy, and sufficiency become veritable concerns. Though the Nigerian system's operator was the sole aggregator of operational data for the electricity industry in Nigeria, there was no means of cross-validating the data posted by this agency. In this regard, the issue of data quality remains a veritable concern. Given the geographically dispersed nature of the institutions that house data for the study, there may be issues of cost and time to travel to collect data.

Significance of the Study

Many scholars have studied the role electricity plays in industrialization and how industrialization leads to the economic development of countries. In these studies, the researchers identified electricity as a unitary system. In this study, I sought to present electricity as a natural open system that consists of available monthly power generation capacity, available monthly transmission capacity, and monthly power distribution capability as independent variables and industrial output as the dependent variable. Reducing this gap in the literature could afford a deeper understanding of the relationship between the power sector variables and how they individually and collectively impact industrial output in Nigeria.

Significance to Theory

In most of the articles reviewed in the electricity economic and development literature, researchers viewed electricity as a unitary system rather than acknowledging the interactive and interdependent nature of the constituent elements of the power delivery system. It was difficult locating studies in this field where researchers viewed electricity as a natural open system. By using von Bertalanffy’s (1968) general systems approach and Laszlo’s (1996) hypothetico-deductive method, it was possible to identify the elements that constitute the power delivery system and elucidate the interrelationships and interdependencies among them as well as the joint effort required to maintain a dynamic equilibrium. A systems approach enables an understanding of what happens at the interface points of these subsystems to offer a robust explanation of the effect of electricity on economic development and may explain the divergence in the literature. The various possible interface disconnect issues, especially in power deficit countries, include (a) available transmission capacity being lower than available generation capacity, (b) distribution capability being lower than available transmission capacity, and (c) available generation capacity being higher than distribution capability. Using generation, transmission, or power consumption (distribution capability) as an independent variable in the electricity and economic development research becomes problematic under any of these scenarios. A systems approach brings clarity to these issues and contributes to theory, especially in studying the effect of electricity on economic development in SSA and other power deficit countries.

Significance to Practice

Poor-quality power supply has negatively affected Nigeria's industrial output (Chete et al., 2014). Further, poor electricity access, low quality power supply, and high electricity cost were the three main reasons for low capacity utilization, lack of competitiveness, and lack of growth in Nigeria's industrial sector (Osakwe, 2017). In this study, I used a systems perspective to identify the power system variables and analyze the effect of electricity on industrial output in Nigeria, which can enable insights into the relationship between power sector variables and how they affect Nigeria's industrial output. Insights of this nature may support power sector practitioners in Nigeria to identify bottlenecks in the power delivery value chain. Identifying these bottlenecks could aid the development of practical and integrative models that support improved power supply to the industrial sector and lead to growth in industrial output in Nigeria. The diverse nature of research outcomes in the electricity and economic growth literature has made policy development difficult, especially for countries experiencing power supply shortages. The system thinking approach promotes a better understanding of the dynamics of the electricity supply subsystems, leading to convergence and a targeted approach to policy development.

Significance to Social Change

Because of the systems approach to this study, I used secondary data on available monthly generation capacity, available monthly transmission capacity, monthly distribution capability, and monthly industrial output in Nigeria to develop a predictive model that aids in the development of an integrated power sector policy to drive effective and efficient power delivery to the industrial sector. An integrated power sector policy may aid the development of infrastructural and institutional imperatives for improved production output in Nigeria. Because industrialization leads to economic growth and electricity has a positive impact on industrialization, the results of this study could lead to the development of effective policies that drive improvement in power supply to the industrial sector in countries where power supply has been identified to be deficient. Such improvements could catalyze enhanced production output that would lead to economic growth and eradication of poverty through increased economic activities that lead to gainful employment and positive social change.

Summary and Transition

The literature on electricity and economic development is diverse, with multiple studies in the same country yielding different results. Most researchers in electricity and economic development literature view electricity as a unitary system and use electricity consumption as a key independent variable in their studies. The purpose of this correlational study, anchored on a systems approach, was to examine the relationship between the power delivery subsystems and their effect on industrial output in Nigeria. In this chapter, I addressed delimitations, assumptions, limitations, and significance of the study, including social change implications and theoretical foundations of the study. Chapter 2 includes the theoretical foundation of the study and an examination of the literature related to key variables. Chapter 3 will include a description of the dependent and independent variables for the study, including a detailed explanation of the research design and methodology.

Chapter 2: Literature Review

There is a lack of research acknowledging the multiple elements of the electric power delivery chain such as power generation capacity, transmission capacity, and distribution capability despite documentation of the impact of electricity on industrialization and economic development (Acaravci, 2010; Alley et al., 2016; Odeleye & Olunkwa, 2019). The purpose of this quantitative correlational study was thus to examine the relationship between industrial output in Nigeria and available monthly power generation capacity, available monthly transmission capacity, and monthly distribution capability. In this chapter, I review relevant literature on the impact of electricity on industrialization and economic development. The focus of this literature review was Nigeria, though relevant studies in other countries were used to deepen understanding of the topic of the study. In this regard, there is a review of literature on electricity and industrial output, the relationship between electricity access and GDP, electricity and industrialization, and the impact of the quality of power on industrial output in Nigeria and other countries. This chapter also includes an exploration of the concept of systems theory, the foundational model in this study, and a description of the generation, transmission, and distribution of electricity as a natural open system.

Literature Search Strategy

I conducted literature searches using Thoreau Multi-Database Search, SAGE Journals database, and Google Scholar. Walden University Library served as an anchor for these searches. The key search terms and combinations were *electricity access and development, electricity consumption and development*, *energy utilization and* *development*, *quality of power and industrial output*, *quality of power and competitiveness, industrialization and GDP,* and *industrialization and development*. Because Nigeria is the focus of the study, these searches included the word "Nigeria." The searches were primarily limited to the last 5 years, from 2015 to 2020, but included some historical articles published more than 5 years due to their significance and relatedness to the study. The resources related to the theoretical framework were much older as they are seminal in nature and provided a foundational perspective. Of the more than 250 articles reviewed, I selected 100 for this study. I used Zotero to organize, store, and manage the references.

Theoretical Foundation

Most of the literature on systems theory contains references to the seminal works of Ludwig von Bertalanffy as the core proponent of general systems theory. I grounded this literature review on von Bertalanffy's (1968) foundations of general systems theory to provide a basic theoretical understanding of systems and support the conceptualization of electric power delivery as a system. Additionally, scholars like Laszlo (1996), Passmore (1988), and Oshry (2007) had approaches which hold elements that supported the elucidation of my research question and hypotheses. Laszlo presented the hypothetico-deductive method as a means of analyzing the organizational features of natural systems. This method involves hypothesizing about likely features of natural systems and using such a hypothesis as a guide to study phenomena to confirm or disconfirm them as systems. Oshry focused on real-life applications and likely implications of the concept of system theory. Oshry promoted the concept of seeing systems with the understanding that patterns of issues, either at the personal or organizational levels, experienced in human organizational settings, are systemic. Such patterns are mirrored in other organizations, making it a phenomenon that cannot be solved at the micro level (Oshry, 2007). Passmore (1988) described socio-technical research as the study of the interaction that exists between social and technical systems. Passmore noted a need first to understand how the interaction between humans and machines impacts organizational and environmental outcomes to understand the dynamic interaction and issues of emergence in organizations, including the impact of the environment on organizations.

The two systems viewpoints from Oshry (2007) and Passmore (1988) are relevant to this study because they support understanding of the interaction between the dependent and independent variables in this study. Von Bertalanffy (1968) and Laszlo (1996) presented systems from theoretical perspectives, but Passmore and Oshry presented real-life manifestations of systems in human organizations. Combining these works enabled insights into the emergent and complex nature of systems by providing an understanding of the dynamic nature of the interrelationships that exist between elements of a system, including the impact on the environment on systems. In this regard, the general systems theoretical foundations and systems thinking models provided direction for the analysis in this study.

Origins of General Systems Theory

Von Bertalanffy (1968) was the first to use the phrase *general systems theory* to describe system thinking approaches to phenomena in different fields in his book *General*

Systems Theory. The difficulties encountered using the logic of cause and effect to explain theoretical problems led to the development of the systems approach to explain phenomena, especially with a focus on factors related to the biosocial sciences and modern technology (von Bertalanffy, 1968). Shortcomings in the methods of the physical sciences gave rise to the systems approach to explaining phenomena.

Von Bertalanffy (1968) noted that the systems approach is not limited to studies within specific fields; rather, it involves consideration of several factors that generate systems, including the relationship between humans and machines. Von Bertalanffy noted that technology, for instance, does not refer to single machines working in isolation. Instead, technology should be viewed with consideration of various technologies, including the relationship between humans and machines and other intervening economic, political, and social factors that combine to give rise to the technology (von Bertalanffy, 1968).

According to von Bertalanffy (1968), there is a continuous relationship between parts or elements of a system, and these relationships are nonlinear. He further noted that this understanding facilitates the explanation of the issues of organization and order in terms of the dynamic interaction between parts of a system. In this regard, order and organization pertain to the differences in the behavior elements of a system exhibit when acting either as parts or wholes. Von Bertalanffy noted that the sum of the parts of a system is not equal to the whole. Further, the relationship between elements of a system and the nature of dynamic interaction between these elements in different fields tend to exhibit general trends; however, the causal factors that drive these relationships and interactions are different. Von Bertalanffy stated that there is a need for a theoretical framework to explain these trends to facilitate communication across disciplines. Core to these trends is the emergence and similarities or isomorphism of structures in different fields (von Bertalanffy, 1968). In von Bertalanffy's general systems theory, isomorphism is context-specific in terms of concrete and unique problems and their corresponding abstractions.

Closed and Open Systems

Von Bertalanffy (1968) described closed systems as those where the elements, under specific conditions, are isolated from their environment. Under this scenario, it is possible to measure the reaction rates between elements, including the attainment state of equilibrium. Living organisms represent open systems, as there is a constant exchange between the organisms and their environment arising from internal metabolism that leads to the generation and breakdown of energy. By interacting with the environment, living organisms attain a steady state, different from the state of equilibrium, as in thermodynamics laws that apply to closed systems.

Von Bertalanffy (1968) noted that in closed systems, the status of initial conditions impacts the final state; that is, a change in the initial condition tends to impact the final state. For open systems, the final state could arise from different initial conditions and processes. Von Bertalanffy referred to this phenomenon as *equifinality*. According to von Bertalanffy, these differences between open and closed systems, and hence the differences between physical and living systems, present difficulties in applying the general laws of physics to open systems.

Developments in System Theory

Von Bertalanffy's (1968) objective in promoting the general systems theory was to attain a unified language for analysis and conveyance of information/knowledge about a phenomenon across disciplines. But literature on systems research indicates a fragmentation in the field of systems research. This fragmentation is apparent in scholars' adaptation of system principles for their field of interest, thus presenting multiple views in systems research (Adams et al., 2014; Demetis & Lee, 2017; Rousseau, 2017; Stroh, 2015). The issue is a lack of cohesion or consensus in systems research. The trends and present-day reality of systems theory remain largely a work in progress as systems scholars are yet to achieve the unity of language that von Bertalanffy sought.

The different schools of thought within the systems field share the same fundamentals of the general systems theory; what differs is the methodology for analyzing systems and improving systems (Stroh, 2015). There is a multiplicity of definitions of systems theory in the systems research literature as a result of differences in the methods of inquiry in the different fields (Adams et al., 2014; Caws, 2015; Demetis & Lee, 2017; Rousseau, 2015, 2017; Stroh, 2015; Verhoeff et al., 2018). The failure of a standard definition for general systems theory may have arisen due to the inability of von Bertalanffy to provide a construct for theory or the lack of required axioms or prepositions (Adams et al., 2014). Others have pointed to the need for removing "general" from the original general systems theory given the yet-to-be explained trajectory of evolutionary processes of natural systems, including the unaccounted accidents of faith that happened in the process making it impossible to assume any form of generality (Caws, 2015). Though these generalization issues exist in systems research, the literature reviewed indicates the emergence of pluralism in systems approaches and methodologies.

The inherent diversity in the definition of systems theory is also present in systems thinking (Bonnema & Broenink, 2016; Cabrera et al., 2015; Chan, 2015; Clancy, 2018; Grohs et al., 2018; Monat & Gannon, 2015; Mononen, 2017; Whitehead et al., 2015). The disciplinary area impacts the view or definition of systems thinking given the propensity for system scholars to anchor system thinking on their guiding systems theory and corresponding method(s) of inquiry (Verhoeff et al., 2018). Researchers in the natural sciences view systems thinking from an objective/positivist approach that includes systematic processes that may consist of models (Verhoeff et al., 2018). System thinking is multidisciplinary, and theory is critical to applying system thinking (Monat & Gannon, 2015; Sibo-Ingrid et al., 2018; Verhoeff et al., 2018; Weissenberger-Eibl et al., 2019). The diverse definitions have made it difficult to achieve a common language for analyzing, understanding, and communicating research in system thinking across disciplines.

System Thinking Approaches

System thinking is both a worldview and a process used to solve complex system problems and develop and understand systems (Moldavska & Welo, 2016). Barry Richmond (as cited in Bonnema & Broenink, 2016) developed the term *system thinking* to press for the need to understand the complex ways systems behave to support decision making. The systems thinking approach means seeing systems within the context of their environment and that systems thinking enables the perception of complexity (Weissenberger-Eibl et al., 2019). Systems thinking can also be described as an approach for examining the relationships among elements or components, how they affect system outcomes, and their roles within their larger environment (Amissah et al, 2020). Systems thinking is also a collection of knowledge that assists system professionals in multiple or various domains to conduct analysis, synthesis, and inquiry regarding a phenomenon or system of interest (Boardman et al., 2009). When a problem is systemic, it means that it pervades all aspects of a system and therefore requires a holistic approach, rather than specific piecemeal efforts or solutions to deal with the issues; this is the bedrock of systems thinking (Boardman et al., 2009). Systems thinking involves seeing the bigger picture, both in terms of analyzing a problem and proffering a solution (Arnold & Wade, 2015).

Systems thinking is primarily a philosophy without a methodology; systems thinking is sometimes referred to as a multidisciplinary approach involving multiple perspectives (Sibo-Ingrid et al., 2018). The need to synthesize data from different sources into a single source remains an important underlying aspect of a systems approach (Sibo-Ingrid et al., 2018). Systems thinking introduces a problem recognition and analysis frame different from the more linear reductionist approaches that focus more on cause and effect type of relationships and analysis (Castelle & Jaradat, 2016). Systems thinking supports the understanding of wholes beyond the components that constitute it to include considerations for the connectedness of subsystems with the whole systems and the inter-relationships among the components that make up the systems and other systems

(Kordova et al., 2018). The reductionist approach poses the danger of working in silos that prevent the view of the full organizational context leading to limited potency in resolving complex problems (Vemuri & Bellinger, 2017). Though different approaches to systems thinking exist, there is no bad or good system thinking approach depending on the discipline (Castelle & Jaradat. 2016). This statement reinforces the need for pluralism in terms of the approaches used in systems research.

A review of systems literature reveals duplicity of efforts and lack of coherence in defining systems thinking and developing a standard methodology for applying systems theory to real-life/practical situations. Different authors have made attempts at attaining a unified definition or common language for system thinking (Boardman et al., 2009; Bonnema & Broenink, 2016; Cabrera et al., 2015; Clancy, 2018; Grohs et al., 2018; Harris & Caudle, 2019; Moldavska & Welo, 2016; Monat et al., 2020; Monat & Gannon, 2018; Mutingi et al., 2017; Serrano et al., 2018; Stroh, 2015; White, 2015; Whitehead et al., 2015; Zare et al., 2017). The most prominent of these approaches is system archetypes and *conceptagon* in the analysis of systems. Archetypes in systems thinking are a means of understanding the complex and dynamic relationships in organizations (Clancy, 2018; Moldavska & Welo, 2016; Zare et al., 2017). The conceptagon is a system thinking tool and a framework for applying system thinking in multiple domains of specialization (Boardman et al., 2009; Moldavska & Welo, 2016). The conceptagon is used to apply system thinking ideas such as emergence, relationships, interconnectedness, nonlinearity, feedback, delays, and system of systems in the analysis of systems (Moldavska & Welo, 2016). No matter the approach to systems thinking or methodology applied in the study of systems, the common denominator is the use of system thinking as a structured analytical process for understanding complex systems.

The systems research literature is dotted with multiple methods and approaches to system thinking and is mainly driven by ontological and epistemological differences. But literature is scarce about how to conduct system thinking (Bonnema & Broenink, 2016). The combination of different system thinking methodologies introduces a variety of worldviews that could enable, support, or facilitate the ability to analyze complex systems (Castelle & Jaradat, 2016). Further, the systems research literature is lacking on how electric power delivery system elements affect industrialization and economic development. In most literature reviewed for this study, researchers treat electricity as a unitary system.

System Thinking Approaches in the Energy Growth Nexus Literature

From the literature that was reviewed for this study, many scholars presented electricity as a unitary system. None of these studies presented or considered electricity as an open system. The systems theoretical perspective was used to explore electricity as an open system, consisting of multiple interdependent variables, and how these variables impact industrial output in Nigeria. I used von Bertalanffy's (1968) general systems theory as a foundational perspective on systems theorizing and the guiding framework for this study. Laszlo's (1996) hypothetico-deductive method was used to analyze the organizational features of natural systems. The electric power delivery value chain in Nigeria involves the power generation, power transmission, and power distribution segments. In this regard, Laszlo's four propositions were used to investigate organizational invariances to establish the Nigerian power supply value chain as a natural system with irreducible properties, how it maintains itself within a changing environment, responds to the self-creativity of other organizations (or systems), and serves as a coordinating interface in the Nigerian super system or holarchy. In this study, the elements that make up the Nigerian power delivery system are power generation, transmission, and distribution segments.

There are specialists in all disciplines; however, Laszlo (1996) noted that specialization leads to depth and not breadth of knowledge, which results in restricted perspectives. According to Laszlo, real-life scenarios manifest as varied and simultaneous influences of different factors or elements that interrelate in complex ways, including the biology of humans that present in multiple forms. Making sense of this complex, yet common, scenario can only be through a broad knowledge perspective that individual specialists in different fields may not be able to offer. Using such broad knowledge perspectives enables the understanding of the multiple factors and influences that interrelate as a complex whole rather than as single factors and influences.

Though elements that constitute a system may have unique characteristics, it is the type of relationships among them and the contingent interdependencies that bind them together that generate their characteristics as a system (Laszlo, 1996). Skyttner (as cited in Önday, 2018) stated that a system is where the behavior of two or more elements affects the whole in an interdependent manner and that though subgroups of elements may have an effect on the whole, these effects are not independent. In this regard, summing up the characteristics of the constituent units cannot characterize the whole without considering the mediating roles of the interdependencies and relationships among the constituent units. In this regard, the structure of the whole (system) informs the unique relationships between the constituent parts of the whole. Laszlo further stated that studying the organization of the structures of different systems by way of theorizing enables the understanding of the commonalities, and these commonalities represent the nonvarying aspects of organizations are known as organizational invariances.

Laszlo (1996) presented the hypothetico-deductive method as a means of using hypotheses to study phenomena to confirm or disconfirm them as systems. Laszlo developed four propositions, which represent four instances of organizational invariances with which to investigate and verify the existence of systems. Laszlo's four propositions state that natural systems: (a) are wholes with irreducible properties (p.25), (b) maintain themselves in a changing environment (p.30), (c) create themselves in response to the self-creativity of other organizations (p.39), (d) are coordinating interfaces in nature's holarchy (p.53).

Natural Systems are Wholes with Irreducible Parts

Wholes differ from heaps due to the relationships and interdependencies between elements that make up a whole system (Laszlo, 1996). The existence of a proper structure and interdependency between elements of wholes characterize the existence of wholes. The Nigerian electric power delivery system consists of generation, transmission, and distribution segments for supplying power to the people of Nigeria. It is difficult to reduce the properties of wholes to the sum of the elements that make up the whole. The reason for this assertion is that wholes exhibit properties based on the peculiar structure of the wholes and tend to retain these properties even with the gradual replacement of the elements that make up the wholes. Laszlo's assertion is based on the logic that it is the unique structure of wholes and the attendant specific interdependencies and relationships between the elements of the wholes that differentiate wholes. The expectation is that the Nigerian power sector, guided by its peculiar structure, will exhibit specific characteristics, and this is the object of this study.

Natural Systems in a Changing Environment

Open systems import energy from their environment to sustain operations and maintain a steady state (Laszlo, 1996). Natural systems are open systems because of their ability to maintain steady states. The main characteristic of open systems is the transport or exchange of energy and resources, including waste across systems boundaries. Another system characteristic is maintaining equilibrium under a changing external environment. Core to Laszlo's supposition is the embeddedness of subsystems within larger systems that may constitute an external environment. The generation subsector of the Nigerian power sector, an independent variable in this study, imports fuel from the external environment to generate power and hence possesses a core characteristic of systems.

Natural Systems Respond to the Self-Creativity of Other Organizations

A principal characteristic of natural systems is maintaining a steady-state or dynamic equilibrium by responding to environmental changes (Laszlo, 1996). Systems attain dynamic equilibrium in response to changes in the environment through self-creativity that involves creating structures and new functions. Differentiation is part of the reality of systems, given the existence of different structures, functions, and roles. In this regard, differentiation enables the joint action that systems require to attain a steady state and respond to emergent threats to survival. The interdependency between the generation sector, the transmission sector, and the Nigerian distribution sector represents a joint action needed to deliver power to consumers. The issues of increased demand for energy or changes in gas availability for power generation represent veritable changes in the environment and to continue to supply power, the power delivery system needs to respond to these changes. How the Nigerian electric power delivery system responds to these changes represents a critical component of this study. This assertion is in terms of how the independent variables in this study affect the dependent variable.

Natural Systems as Coordinating Interfaces

Laszlo (1996) presented natural systems are layered systems and these layers are made up of sub organic (physical sciences), organic (life sciences), and supra organic (social sciences). Simple structures occupy the lowest layers in this layered structure, the natural systems occupy the intermediate layers, and the more complex systems occupy the top layers. In this model, the natural systems coordinate interactions between the top and bottom layers. The constituent parts of each layer are wholes at that level and, at the same time, a part of the layer above them. This arrangement means that wholes at any layer or level serve as coordinating interfaces with other parts or wholes within the system and represent the joint efforts systems need to maintain dynamic equilibrium. Laszlo described holarchic duality as the way elements of a system interact as both parts and wholes in a coordinated joint effort to maintain systems. Holarchic systems respond to emergent environmental threats or changes dynamically as they continually interface with their environment. The cycle of interface and coordination between elements at the different layers of a system mirrors the structure and the attendant relationships and interdependencies between parts of a complex organization. The role of the generation segment in the Nigerian power delivery systems, both as sources of power generation and interconnection to the transmission system, represents a holarchic duality. The same argument holds for the interconnection between the power transmission and distribution segments, with both the distribution and generation segments in direct interaction with the external environment.

Literature Review

Research is scarce on the electricity and economic development nexus using a systems approach. Ordinarily, the constructs of interest regarding this study would be generation capacity and industrial output, transmission capacity and industrial output, and distribution capability and industrial output. Due to the limited availability of literature, I reviewed the literature on the impact of electricity on economic development, the impact of electricity on industrialization, and the impact of electricity access on economic development as related constructs of interest.

Electricity and Economic Development

Electricity consumption in developing countries tends to grow as the economy grows, hence the need to continuously study how electricity consumption rate affects economic development (Kunda & Chisimba, 2017). Four main hypotheses drive energy growth research: (a) the growth hypothesis, (b) the feedback hypothesis, (c) the neutrality hypothesis, and (d) the conservation hypothesis (Abokyi et al., 2018; Amin & Murshed, 2017; Guan et al., 2015; Hasan et al., 2018; Istaiteyeh, 2016; Mawejje & Mawejje, 2016; Ogundipe et al., 2016; Rashid & Yousaf, 2016; Samu et al., 2019; Sankaran et al., 2019; Sekantis & Motlokoa, 2015). The growth hypothesis points to a dependency of economies on energy consumption and how energy consumption positively impacts such economies' GDP (Sankaran et al., 2019). Under the growth hypothesis, there is a unidirectional causal relationship that runs from electricity consumption to economic growth such that an increase in electricity consumption would lead to a rise in economic development (Ogundipe et al., 2016). The feedback hypothesis is used to focus on situations where there is a bidirectional causal relationship between electricity consumption and economic development. Under the feedback hypothesis, energy use and economic growth are mutually reinforcing, such that a dip in energy consumption causes a drop in GDP and vice versa (Mawejje & Mawejje, 2016). The neutrality hypothesis indicates no relationship between electricity consumption and economic development and that policies aimed at energy conservation will not impact economic development (Ogundipe et al., 2016). The conservation hypothesis points to a unidirectional relationship that runs from economic growth to electricity consumption with the implication that economic growth drives electricity consumption (Mawejje & Mawejje, 2016). The divergence in research outcomes that drive these hypotheses implies that the literature on the role of electricity in economic growth remains varied.

From the literature reviewed (*n* = 100), the research results in the energy growth nexus fall under the four energy growth hypotheses with different policy implications for energy consumption and economic growth: growth hypotheses (*n* = 13), feedback hypothesis (*n* = 10), neutrality hypothesis (*n* = 5), and conservation hypothesis (n = 13). From Table 1, the studies conducted in Nigeria, Pakistan, Uganda, Bangladesh, and China showed conflicting results. For instance, out of the eight studies in Nigeria, three indicated growth hypothesis, two indicated feedback hypothesis, one showed neutrality hypothesis, and two indicated conservation hypotheses (see Table 2). These conflicts could be a result of differences in the methods, variables, and time frames for the studies.

Current Trends in the Electricity and Growth Literature

Most research in the electricity growth nexus is quantitative. Many researchers in the field used different instruments in their studies that tend to suggest methodological pluralism in energy and economic growth research. Most of the researchers in the literature I reviewed under the energy growth nexus utilized multiple regression methods with a diversity of statistical instruments. For studies in Nigeria, various authors implemented different statistical and econometric tools and different variables to arrive at different results. Table 1 showcases countries with conflicting results in the energy growth literature. Table 2 shows studies in Nigeria with different energy growth hypotheses, variables, and methods. As Table 1 shows, the country effect may not be the reason for the diversity in results obtained in the literature. A review of Table 2 indicates that authors using different variables and methods output different results for the same country. As shown in Table 2, when the variables and methods differ, the results may not support existing literature; instead, they create new perspectives.

Table 1

Countries with Conflicting Results in the Energy Growth Literature

Country	Hypothesis	Author
Bangladesh	Growth hypothesis	Amin & Murshed (2017)
	Conservation hypothesis	Hasan et al. (2018)
China	Growth hypothesis	Guan et al. (2015)
	Feedback hypothesis	Zhang & Broadstock (2016)
		Ha et al. (2018)
	Conservation hypothesis	Chol (2020)
Nigeria	Growth hypothesis	Alley et al. (2016)
		Nwankwo & Njogo (2013)
		Ubi & Effiom, 2013)
	Feedback hypothesis	Ogundipe & Apata, (2013)
		Ologundudu (2015)
	Neutrality hypothesis	Ologundudu (2015) [a]
	Conservation hypothesis	Ogundipe et al. (2016)
		Ugwoke et al. (2016)
OECD Countries	Growth hypothesis	Salahudin & Alam (2016)
	Feedback hypothesis	Baloch et al. (2019)
	Conservation hypothesis	Baloch et al. (2019) [b]
Pakistan	Growth hypothesis	Ali et al. (2020);
	Conservation hypothesis	Rashid & Yousaf (2016)
		Mawejje & Mawejje (2016)
	Feedback hypothesis	Sekantis & Motlokoa (2015)
	Conservation hypothesis	Sekantis & Motlokoa (2015) [c]

Note. [a] Neutrality hypothesis with respect to industrial output and not economic development; [b] Conservation hypothesis with respect to an indirect relationship through environmental pollution; [c] Conservation hypothesis with regard to short-run causality

Table 2

Variables and Methods Used in Studies in Nigeria

Hypothesis	Author	Variables	Methods
Growth hypothesis	Alley et al. (2016)	Labor, capital formation, industrial output, and GDP	Three-stage least squares (3SLS) estimation technique, Johansen cointegration tests, and
Growth hypothesis	Nwankwo & Njogo (2013)	Electricity, Gross fixed capital formation, industrial production, population variables, and RGDP Per capita.	Ordinary Least Square (OLS) regression analysis.
Growth hypothesis	Ubi & Effiom, (2013)	GDP, electricity supply, capital stock, and technology	OLS, the Johansen cointegration test, and ECM
Feedback hypothesis	Ogundipe & Apata, (2013)	Electricity consumption and economic development	The Johansen cointegration test, Juselius Maximum Likelihood approach, and Wald block endogeneity causality test.
Feedback hypothesis	Ologundudu (2015)	Electricity supply, industrialization, and economic development	Granger causality test and ARDL bounds test.
Neutrality hypothesis	Ologundudu (2015) [a]	electricity supply, industrialization, and economic development	Granger Causality test and ARDL bounds test.
Conservation hypothesis	Ogundipe et al. (2016)	GDP per capita, electricity consumption, stock of capital available in the economy, total labor force, government effectiveness, structure of Nigeria economy, state of technology, and measure of environmental degradation	The Johansen cointegration Test, Juselius maximum Likelihood approach, and Wald block endogeneity causality test.
Conservation hypothesis	Ugwoke et al. (2016)	Electricity supply and industrial output	Johansen cointegration and Augmented Dickey-Fuller test

Note. [a] Neutrality hypothesis with respect to industrial output and not Economic development

The question remains: how many views or perspectives will be enough to understand the relationship between electricity and economic growth? As indicated in Table 2, Nigeria represents a case in which the results of eight studies represent each of the four hypotheses in the energy growth nexus research. The same issues are observable in research in China (see Table 3).

Table 3

Variables and Methods Used in Studies in China

Hypothesis	Author	Variables	Methods
Growth hypothesis	Guan et al. (2015)	Energy consumption, urbanization, and economic development	ARDL; ECM.
Feedback hypothesis	Zhang & Broadstock (2016)	energy consumption, economic growth, industrialization, and urbanization	VAR; Directed Acyclic Graphs (DAG); Zivot and Andrews (ZA) test for structural breaks.
	Ha et al. (2018)	Energy consumption and economic development	Ð-wavelet analysis; Modified Wald test (MWALD) for linear causality test.
Conservation hypothesis	Chol (2020) [a]	Per capita national income, energy consumption, and environmental pollution	ARDL

Note. [a] Conservative hypothesis with respect to an indirect relationship through environmental pollution

Infrastructure and Economic Development

A review of literature reveals that new considerations, which represent gaps in the literature, introduce new variables that impact results, further increasing the diversity of research outcomes in the energy growth nexus. It was difficult to locate studies where researchers considered electricity as a system or introduced generation capacity, transmission capacity, and distribution capability as new variables in the energy growth research. Introducing these variables can offer possible clarifications or a path to convergence in the energy and economic growth research outcomes. In the literature reviewed, only Ali et al. (2020), Azolibe and Okonkwo (2020), Chakamera and Alagidede (2018), Kodongo and Ojah (2016), and Owusu-Manu et al. (2019) studied the effect of infrastructure on economic development with a focus on electricity infrastructure. By viewing the power sector (electricity supply chain) as a system, the objective was to include considerations for the effects of infrastructure deficits, especially related to the interface relationships between the independent variables (generation capacity, transmission capacity, and distribution capability).

Many scholars have identified poor infrastructure as one of the leading factors responsible for the lack of economic growth in SSA countries (Azolibe & Okonkwo, 2020; Kodongo & Ojah, 2016). In 43 SSA countries, improvements in infrastructure stock and quality drive economic growth (Chakamera & Alagidede, 2018). The researchers also determined that poor electricity services slow economic growth (Chakamera & Alagidede, 2018); these negative effects are only associated with the quality index of the infrastructure stock, which weights electricity high. Azolibe and Okonkwo (2020) tested the impact of infrastructure on industrial output in 17 SSA countries and noted that poor electricity infrastructure and services had a negative effect on industrial output, but in another study, Kodongo and Ojah (2016) found weak and indirect correlations between infrastructure development and economic development indices. By investigating the effects of generation capacity, transmission capacity, and distribution capability in this study, I sought to provide a new perspective, a systems perspective, on the impact of power delivery systems infrastructure on industrial output or economic development in Nigeria.

Electricity Access and Economic Development

A review of extant literature on the relationship between electricity access and economic development revealed some interesting dynamics. Zhang et al. (2019) implemented Bayesian model averaging (BMA) instead of the more common econometric models in energy growth literature that establish causality and long-run relationships between economic factors and electricity access. Zhang et al. discovered that urbanization did not significantly affect electricity access, in contrast with most results in the literature, and noted that lack of access to electricity limits economic development and modern services, including health care and education. The researchers focused on long-run relationships rather than causality factors and used BMA to identify significant predictor variables that impact electricity access in China. Though electricity access supports economic development, urbanization does not improve electricity access

Different Approaches and Their Strengths and Weaknesses

The literature on electricity consumption and economic development nexus is mixed. Different scholars have identified various reasons for the mixed results. Urbanization, industrialization, and improved electricity access are all drivers of energy consumption or demand and form significant considerations for electricity and economic growth research. A review of the energy growth nexus literature indicated that GDP and level of economic development tend to position countries into the different energy growth hypotheses. Most scholars in the energy growth literature did not factor in the effect of inadequate power (electricity) infrastructure in the electricity and economic development research. The conflicting outcomes notwithstanding, the different sociopolitical, sociocultural, socioeconomic, political, and geographic factors mean that each study will be unique and the issue will no longer be that of conflict; instead, it could be an issue of context (Akinwale & Muzindutsi, 2019; Kwakwa, 2017; Sankaran et al., 2019).

In a study of 10 nations, Sankaran et al. (2019) classified countries into the three broad categories of (a) developed, (b) developing, and (c) newly industrialized to account for the structural and socioeconomic differences among nations and to explain the differences in results in the energy growth nexus research, but the results were varied. The researchers noted the issues of differences in natural resources, population size, technology level, nature of labor market, the functioning of governments’ machinery, and the variety of industrial production as likely exogenous factors. Economic development and increased urbanization lead to increased electricity consumption in Malaysia (Ridzuan et al., 2020). Rashid and Yousaf (2016) studied the implication of economic development as a mediator on the energy growth nexus research and noted that increased urbanization amidst energy shortages leads to a negative correlation between electricity use and economic development. The inability to account for structural breaks could explain some of the diversity in the energy growth literature (Zhang & Broadstock, 2016).). Further, energy consumption patterns might have a bearing on the outcome of tests, especially high consumption by nonindustrial sectors (Ha et al., 2018). Overall, the differences in research outcomes remain varied, and the reasons for the variations are contentious.

Each researcher in the electricity growth literature claims to fill a gap in the literature. Scholars introducing new variables or considerations could be another source of diversity in the energy growth nexus literature. From the research I reviewed for this study, every new perspective contributes to the diversity in the results within the electricity and economic growth literature. The paucity of evidence, inadequacies in existing methodology, neglect of certain important variables in existing research, expansion of the scope of a study (variables), the introduction of new methodology or models, types of relationship between variables (linear vs. nonlinear), decomposition of scope into time frames, and types of data are some of the diverse perspectives that scholars bring to the energy growth nexus research.

Instances of the variations in the focus of study in the energy and growth literature abound. Ali et al. (2020) noted the focus of existing literature has been on the energy growth nexus instead of Pakistan's electricity consumption growth nexus and bifurcated electricity consumption into electricity generation and shortage as variables in their study and noted that these gaps could compromise the findings of previous studies. Amin and Murshed (2017) claimed that no prior research involved a multivariate method to investigate the relationship between electricity consumption and economic growth in Bangladesh to explain the disparities in previous studies. Baloch et al. (2019) found that most prior researchers investigated linear relationships between variables without considering the nonlinear relationships. Baloch et al. also pointed to the variations in the use of series and panel data in energy and growth research. All these approaches represent different perspectives and may account for the diversity in results.

Literature is scarce on the systems approach to the energy (electricity) growth nexus. Literature abounds on the use of econometric and multiple regression methods in the study of the electricity growth nexus. Ha et al. (2018) and Zhang and Broadstock (2016) implemented a time-varying framework to account for structural breaks that could cause data instability, leading to conflicting results. Ha et al. implemented the D-wavelet analysis to decompose time series data into time domains to account for possible structural breaks in the data. Zhang and Broadstock incorporated the vector autoregression into a time rolling framework to account for time variation in a system framework. At different times in the economic development of the United States, the relationship between energy use and economic development showed different trends (Hirsh & Koomey, 2015). From 2007 onwards, the United States recorded GDP growth with little or no net growth in electricity use, and since 1996, the United States had required less electricity to increase GDP (Hirsh & Koomey, 2015). Structural breaks are important considerations in the energy and economic growth literature and may account for some of the diversity in research outcomes.

From literature on the energy growth nexus, the relationship between electricity and economic development may vary in a nonlinear manner. Nazlioglu et al. (2014) implemented a nonlinear Granger causality test and found a bi-directional relationship between electricity consumption and economic growth in both the long run and short run in Turkey. Electricity consumption and economic growth nexus might vary in the short and long run within the same economy (Ali et al., 2020). In Thailand, there was a long run unidirectional relationship between GDP and electricity consumption, running from

GDP to electricity consumption, and a bidirectional relationship between the two variables in the short run (Jiranyakul, 2016). In a study of 17 industries in Taiwan, there was a bidirectional relationship between electricity consumption and GDP in both the long run and short run (Lu, 2017). These approaches emphasize considerations for correlational analysis, both in the short and long run, to understand relationships among variables in the electricity economic growth nexus.

A review of literature revealed that the issue of context is germane to energy growth nexus research. There is a need for new approaches in electricity and economic growth research to deal with issues of mixed or conflicting results (Ha et al., 2018). Owusu-Manu et al. (2019) studied quantum and quality of power sector infrastructure as key independent variables but did not incorporate the interface relationships between the various subsectors within the electric power delivery chain. By focusing on different subsystems that make up the power delivery chain and how they impact industrial output in this study, I introduced new approaches and considerations in the electricity and economic growth literature. Most researchers in the energy growth nexus used variables like electricity price, electricity consumption, national income, population, urbanization, foreign direct investments, industrialization, GDP, and inflation.

Rationale for Selection of the Variables

Many scholars have explored the complex interactions between economic variables in the electricity and economic growth literature. The purpose of this study was to explore the complex interactions between power sector variables and how they impact industrial output in Nigeria. The aim was to deepen understanding and present robust perspectives in the energy growth literature. Using the four propositions in Laszlo's (1996) hypothetico-deductive method can provide clarity on how failures in the interface relationships (infrastructure) between subsectors within the electricity delivery system could lead to conflicting results in the energy growth nexus research. Laszlo's (1996) hypothetico-deductive model focused on the unique characteristics of elements that make up a system, the interrelationship between the system's components, and the contingent interdependencies that bind them together. The sum of the constituent parts of a system's characteristics would not depict or describe the whole system without considerations for the mediating roles of the type of interdependencies and relationships among that system's elements (Laszlo, 1996). This logic holds for the different parts of the power delivery system that form the independent variables in the current study: power generation, power transmission, and power distribution systems.

The structure of the whole informs the type or unique relationships between the constituent parts of systems (wholes) (Laszlo, 1996). Studying the organization of different systems enables the understanding of the commonalities that exist and issues that characterize the systems. It is these commonalities that represent organizational invariances (Laszlo, 1996). Using Laszlo's systems concept to analyze the variables in the current study to answer the research question requires a correlational study of the power generation, transmission, and distribution data. This approach will promote an understanding of the unique relationship and interdependency between the subsystems and how these variables impact industrial output in Nigeria, both as a system and as independent variables.

Adopting Laszlo's hypothetico-deductive method implies that the generation, transmission, and distribution subsystems of the power delivery system require a joint coordinated effort at each subsystem's interface points for efficient power delivery. Still relying on the logic of the hypothetico-deductive method, a capacity mismatch at the various interface points of the power delivery systems could result in the inefficient transmission of power generated or inadequate distribution of power transmitted. In this regard, the risk could be that the electricity available for consumption may not truly reflect the capacity of the power delivery systems. Theoretically, these elements could impact industrial output differently when analyzed independently or as a unitary system.

Review, Synthesis, and Justification for Study and Variables

The independent variables in this study are generation capacity, transmission capacity, and distribution capability, while the dependent variable is the monthly industrial output in Nigeria. There was difficulty during literature search identifying studies where researchers had examined the relationship between the independent and dependent variables used in this study. The most closely related studies addressed the effects of electricity infrastructure and the quality of electricity services on industrialization and economic development. Other researchers investigated the impact of electricity on economic growth and treated electricity as a unitary system without considering the subsystems that constitute the electricity delivery system. Infrastructure plays a significant role in the development of SSA countries and the poor state of electricity infrastructure and electricity services impeded economic growth in these countries (Azolibe & Okonkwo, 2020; Chakamera & Alagidede, 2018; Kodongo &

Ojah, 2016). In these studies, the researchers assumed that the different subsystems (generation, transmission, and distribution) are in an equal state of disrepair and that poor services run across all the subsystems; what is yet to be studied is how the different power supply systems contribute to the infrastructure deficit and quality of service. In this study, I used a systems approach to investigate each power delivery subsystem, the interface relationships between the systems, the interdependencies that exist, and how they independently impact monthly industrial output in Nigeria. Results may provide broader perspectives that could explain some of the diversity in studies in Nigeria's electricity growth nexus.

Summary and Conclusions

There appears to be a lack of consensus or convergence in the electricity and economic growth literature on the energy and electricity growth nexus. The use of electricity offers more advantages over other energy sources as it enables more efficient utilization in the telecommunication and manufacturing industries, including lighting (Stern et al., 2019). In this regard, I focused on electricity and economic development in the literature review for this study. Different scholars have implemented different methodologies, levels of analysis, types of analysis, and variables to arrive at divergent results.

By adopting a systems approach to the electricity growth nexus research, this study filled a critical gap in the electricity and economic growth literature and provided a more robust perspective regarding the role electricity plays in the economic development of nations, especially in developing countries like Nigeria. Implementing a systems approach can enable the analysis of the interface relationships and interdependencies between the subsectors that compose the electricity delivery system. This type of analysis may shed light on the state of infrastructure at the different interface points in the electric power delivery system. Using Laszlo's (1996) hypothetico-deductive method will support the understanding of gaps in the coordinated joint effort required to sustain Nigeria's electricity delivery system.

Methodological differences may be responsible for the diversity in the electricity growth literature. Issues of the extent of sector analysis regarding the number of variables or factors under study may also account for the differences in the results. In this regard, the differences in bivariate, multivariate, linear, and nonlinear analysis of variables become prominent.

Chapter 3 contains an explanation of the data analysis plan for the study, including threats to validity (internal and external). Chapter 3 also contains a description of the dependent and independent variables for the study and a detailed explanation of the research design and methodology. In Chapter 4, there is a detailed explanation of the study implementation and data analysis to explore the relationship between power generation capacity, power transmission capacity, distribution capability, and industrial output in Nigeria.

Chapter 3: Research Method

The purpose of this quantitative correlational study was to examine the relationship between industrial output in Nigeria and available monthly power generation capacity, available monthly transmission capacity, and monthly distribution capability. Research on the impact of electricity on economic development is vast with varied outcomes, but none considered electricity as a system. I implemented a systems approach anchored on von Bertalanffy's (1968) and Laszlo's (1996) works to examine the interrelationships and interdependencies between the elements that make up the electricity delivery system and industrial output in Nigeria, which provided a better understanding of how electricity affects economic growth, especially in third world countries like Nigeria. This chapter contains a discussion of the research methodology and design for this study, including research questions, data collection, procedures for analysis, and threats to validity.

Research Design and Rationale

In quantitative methods, researchers use the quantitative properties of variables systematically and scientifically to investigate the relationships between specific variables (Edmonds & Kennedy, 2017). Measurement is a critical component of quantitative research as a means of understanding the relationship(s) between variables as numerical systems (Edmonds & Kennedy, 2017). I analyzed the relationship between independent and dependent variables to determine the relationship between electricity supply variables and industrial output, especially in third world countries like Nigeria. The independent variables in this study are the available monthly generation capacity, available monthly transmission capacity, and monthly distribution capability. The dependent variable is the monthly industrial output in Nigeria. Quantitative analysis goes beyond just a set of techniques applied to data; it represents a process of systematically analyzing research questions, research methodology, and observed patterns in data (Scherbaum & Schockley, 2015). Implementing quantitative analysis enables conceptual models that serve as invaluable resources in choosing appropriate analysis, research methodology, and research questions. This study involved numeric data and the analysis of relationships between variables, hence the use of quantitative methods in examining the research questions.

I implemented a quantitative method in this study with a correlational design. The use of multiple regression models enabled the evaluation of the relationships between the independent variables and the dependent variable (Gujarati & Porter, 2009; Wooldridge, 2013). A multiple regression model was utilized to answer the research questions. From systems thinking perspective, I implemented correlational analysis (pairwise correlation matrix) to study the relationship between available monthly generation capacity, available monthly transmission capacity, and monthly distribution capability as subsystems of the electricity supply system. This type of analysis deepened the understanding of the interrelatedness and interdependency between elements of the power supply delivery subsystems. The pairwise correlation coefficients enabled the analysis of the strength of the interface relationship between the subsystems.

Multiple regression analysis appears consistently in the energy (electricity) and economic growth literature. Multiple regression is important in analyzing nonexperimental data (Berry & Feldman, 1985). Multiple regression analysis enables the understanding of the correlation between independent variables and a single dependent variable (Frankfort-Nachmias & Leon-Guerrero, 2015; Reinard, 2011). Some of the advantages of multiple regression over simple correlation include testing the interaction effects between variables and estimating the extent to which a set of independent variables explain the variations in the dependent variable (Reinard, 2011). The use of multiple regression also enables the identification of the relative importance of each variable (Reinard, 2011) and was utilized in this study to test the relative relationship between each independent variable and the dependent variable in this study.

Multiple correlation analysis cannot infer causality; therefore, the result of a correlational study can only be used to gauge the extent of the association between variables and not causation (Asamoah, 2014). I utilized secondary data for this study, and it presents the issues of applicability and fit for purpose. In this regard, the problems of availability, relevance, accuracy, and sufficiency were veritable concerns.

Methodology

This section contains the work plan for this study by explaining the procedures and processes undertaken during this study. Research methodology comprises assumptions, postulates, and methods that enable a researcher to choose methods and render the study open to critique, analysis, replication, repetition, and adaptation (Given, 2008). In this regard, research methods are the tools that enable researchers to collect the data they need and to derive the broad assumptions and procedures that comprise the overall research methodology of the study.

Population

The population for this study consisted of 72 months during the period from 2015 to 2020. The privatization of the Nigerian electricity industry became effective in 2015 through Order 136 of the Nigeria Electricity Regulatory Commission for the commencement of the transitional electricity market. In this regard, the population size is 72.

Sampling and Sampling Procedures

There was no sampling. I worked with the whole population of 72 months. The focus of the study was the effects of some preselected operational power systems data on industrial output in Nigeria. The emphasis was on the sequential impact of variables based on time, which involved monthly operational data for the power delivery variables that represent the independent variables, and monthly data on industrial output in Nigeria that represents the dependent variable. The research question and the associated hypotheses testing constituted the inclusion criteria. The data sets selected from the power systems operational data were available monthly power generation capacity, available monthly transmission capacity, and monthly distribution capacity. Monthly industrial output was chosen as the national economic data to test the hypothesis and answer the research questions.

I used G*Power software to calculate the minimum sample size necessary to answer the research question using multiple linear regression with three predictor variables (Appendix). For medium effect size, an alpha level of 5%, and 80% power (1-β error probability), the minimum sample size was 77. A total population size of 72 for each group, three independent variables, and one dependent variable was used to address the research questions. The population size of 72 for each group was because monthly operational data from 2015 to 2020 was used to address the research questions. The effective privatization of the Nigerian electricity industry occurred in 2015 through Order 136 of the Nigeria Electricity Regulatory Commission for commencement of the transitional electricity market, and this represented a significant structural shift in the country; therefore, data before 2015 would not be used. In this regard, any data before 2015 could be unreliable for this study as it may introduce issues of structural breaks into the data with the potential to render the test results unreliable.

Secondary Data

This study consists of an examination of operational data of the electric utilities in Nigeria and the Nigerian industrial output as a component of the national GDP within the same period. The data for this study were mainly from the operational database of the NESO and NBS. The monthly data on generation capacity, reported as declared available generation capacity, was obtained from the NESO website (https://nsong.org/). The data for monthly transmission capacity and distribution capability reported as load delivered to the distribution companies was obtained from the database of NESO. The data on the industrial output, reported as part of the GDP statistics, was obtained from the NBS website (https://www.nigerianstat.gov.ng/). Because the NESO and the NBS compiled this data, I considered these data sets reliable.

Walden University requires that the Walden Institutional Review Board (IRB) approve study procedures, including data collection processes and procedures for any research. Most of the data for this study are electric utility operational data in third-party institutional databases. The Walden IRB approval ensures compliance regarding the ethical usage of third-party data in the approval process for a data request. Most of the data on industrial output is available on the NBS website, so permission was not required.

Data Analysis Plan

I used the IBM Statistical Package for Social Sciences (SPSS) and STATA statistical software packages to analyze data in this study. SPSS and STATA were used to implement multiple regression analyses to examine the relationship between the dependable variable and three independent variables. Multiple regression analysis enables the establishment of multiple regression coefficients that measure changes in the dependent variable per unit change in each of the independent variables while holding the other independent variables constant (Gujarati & Porter, 2009). The multiple regression coefficients were used to test the partial effects of generation capacity, transmission capacity, and distribution capability on industrial output.

There are some data requirements or assumptions connected with the use of multiple regression analysis. There are eight data assumptions associated with the implementation of multiple linear regression: (a) the measurement of the dependent variable should be on a continuous scale (interval or ratio); (b) the study should include two or more independent variables that should be measured on a continuous scale (interval or ratio); (c) there must be an independent observation of the variables; (d) there must be a linear relationship between the dependent variable and each of the independent variables, and between the dependent and the independent variables collectively; (e) there must be data homoscedasticity; (f) there should not be multicollinearity between the independent variables; (g) there should not be outliers in the data; and (h) the error term or residuals should be approximately normally distributed (Laerd Statistics, 2018). A violation of any of the assumptions could affect the validity of the results; nonetheless, SPSS and STATA provide mechanisms for normalizing the data when available data do not meet some of these assumptions (Laerd Statistics, 2018). Operational data of electric utilities and industrial output, a component of the national GDP data, were used for this study as independent and dependent variables, respectively.

The research question and study hypotheses formed the basis for exclusion and inclusion criteria to narrow down the data set. After narrowing down the data set, data screening was performed for missing data and likely data entry errors. Descriptive statistics were used to provide summary information about the independent and dependent variables in the study; the variables are continuous interval ratio.

The following are the research question and hypotheses for this study:

Research question: Is monthly industrial output in Nigeria related to available monthly power generation capacity, available monthly power transmission capacity, and monthly power distribution capability?

H_0: Monthly industrial output in Nigeria is not related to available monthly power generation capacity, available monthly power transmission capacity, and monthly power distribution capability.

H_a: Monthly industrial output in Nigeria is related to available monthly power generation capacity, available monthly power transmission capacity, and monthly power distribution capability.

As systems theory was the theoretical foundation for this study, there was a focus on the interface relationship between the power sector delivery systems and industrial output in Nigeria. Systems within a complex system serve as interfaces in coordination with other parts of the system in a joint effort to sustain the whole system (Laszlo, 1996). From a systems perspective, I used Pearson's correlation analysis to examine the correlation between power generation capacity, transmission capacity, and distribution capability to analyze the efficacy of the interface relationships between the variables. This type of analysis is necessary because a poor correlation between power generation capacity and transmission capacity may mean an inability to adequately or efficiently transmit the available generation. The same logic holds for the interface relationship between transmission and distribution sectors. Multiple regression correlation coefficients were used to examine the effects of each independent variable on the dependent variable in the study to answer the research questions by controlling for the effects of two independent variables each time. Multiple regression analysis enabled the examination of the combined correlation between all the independent variables and the dependent variable in the study to test the research hypothesis. The predetermined alpha value for this study was 0.05% (Type I error/false positive); that is, the premise for significance in this study is a *p*-value of less than or equal to 0.05 at a confidence interval of 95%.

Threats to Validity

External Validity

Research validity is the various ways factors a researcher has not accounted for in a study could result in an alternative outcome with the potential to impact the study in unanticipated ways (Greenstein, 2006). The danger in these scenarios is that the alternative outcomes can prevent the perception of the true or actual effects of the independent variables on the dependent variables (Greenstein, 2006). Drew et al. (2008) presented research validity from a technical viability perspective in terms of rigor and methodical value. Rigor and methodical value of a study are dependent on the researcher's ability to find the most valid information about a hypothesis regarding a phenomenon (Drew et al., (2008). Drew et al. described external validity in terms of ability or constraints to the generalizability of the findings from a study. Threats to external validity occur when researchers draw erroneous inferences from sample data (Creswell, 2009). In this regard, external validity is about methodological rigor and the researcher's ability to account for the effects of variables in a study.

Since this is nonexperimental design research, the effects of external validity are limited. In this study, the threat to external validity hinges on small sample size issues and the ability to draw generalizable inferences from such a sample. Because secondary data was used for the study, there is little room for remedial actions; however, the population size for this study is adequate, going by the sample size calculation using G*Power software.

Internal Validity

Since this is a nonexperimental study, internal validity issues would be limited to the problems of omitted variables. Drew et al. (2008) described internal validity in terms of the effects of extraneous factors (variables) other than the dependent and independent variables in the study. These issues become poignant when a study involves prediction and causal analysis as in experimental studies. Since this is primarily a correlational study, the problem of omitted variables is of limited effect.

Statistical Conclusion Validity

There are no constructs or instruments designed for this study's specific purposes; thus, construct validity is of little concern. Since secondary data was used in this study, applicability, fit for purpose, availability, relevance, accuracy, and sufficiency are more important validity issues. Literature on research methods indicates that a researcher's ability to make a valid conclusion from a study is a critical validity issue. The focus of SCV is on adequate analysis, the use of appropriate statistical methods, and the ability to draw correct inferences from the sample used to answer the research question(s) (García-Pérez, 2012). The need for SCV arose because conclusions drawn from insufficient data analysis sometimes could be at variance with those from appropriate data analysis (García-Pérez, 2012). In this regard, SCV is about how well researchers analyze data and the extent to which correct inferences are made from such research.

Multiple issues could lead to SCV violations. Low statistical power is one of the threats to SCV and manifests as type II error, which results from a small sample size (Busk, 2010). I used G*Power software with 80% statistical power to determine 77 as the minimum sample size to avoid SVC issues associated with low statistical power. The available population size for this study is 72; this difference was not considered significant enough to cause SCV issues. Further, The violation of an assumption or assumptions of test statistics might result in wrong inferences and lead to SCV issues (Busk, 2010). Another SCV issue is the unreliability of measurement instruments that could result in type II error. Secondary data was used for this study and was obtained from national institutions that keep both the electricity utility data (NESO) and national economic data (NBS). In this regard, there is a high tendency that the data will be of high integrity, and as such, the unreliability of measures will not affect SCV for this study.

Ethical Procedures

Consideration for research ethics is one of the protocols or processes for completing research at Walden University. The main task of the Walden Institutional Review Board (IRB) is to make sure that research performed in the university satisfies Walden university standards and complies with requirements of U.S. federal regulations. Intending researchers are expected to fill out Form A as a first step in obtaining the Walden IRB approval (Walden University, n.d.). Core to the Walden IRB approval is ethical concerns regarding the treatment of human participants, institutional permissions, recruitment of material and processes, data collection or intervention activities, and how the researcher seeks to mitigate or manage these issues and treat data. Other ethical issues of concern include how confidential data will be stored and managed to maintain confidentiality.

This research involves using secondary data and does not include the recruitment of human participants or intervention activities. The first step in ethical procedures for this study was completing Form A and all the associated processes as laid out in the Walden IRB process web page (https://academicguides.waldenu.edu/research-center). Since this study involves using secondary data in the form of operational data of electric utilities in Nigeria and the industrial output data, which is public domain data published by the NBS, most of the ethical issues involving humans were avoided. Notably, there were no interaction with humans, recruitment materials, and data concerning humans. Since this is not experimental design research, there was no intervention during the study, thus precluding ethical concerns.

Because of the nature of the data source for this study, institutional permits were not needed when such data were already in the public domain. The electric utilities' operational data was password protected and stored in a secure location, including a personal laptop and a secure cloud storage facility. This research is not within my work environment; thus, issues of conflict of interest and power differentials were avoided. Since humans are not involved, ethical concerns regarding the use of incentives did not arise.

Summary

The purpose of this multiple regression correlational study was to use a systems approach to study the effect of electricity on industrial output in Nigeria. In this regard, electricity is treated as a natural system to investigate the relationship between the power delivery system elements and industrial output. In this chapter, I examined and described the research design, methodology, and data analysis plan for the study. The issues of threats to validity and ethical considerations regarding the study were also investigated. Chapter 4 includes a description of the study execution and the data analysis approach used to explore the relationship between industrial output in Nigeria and available monthly power generation capacity, available monthly power transmission capacity, monthly distribution capability. Chapter 5 includes an interpretation of the results of data analysis from Chapter 4 and recommendations arising from the data analysis.

Chapter 4: Results

The purpose of this study was to establish whether monthly industrial output in Nigeria was related to available monthly power generation capacity, available monthly transmission capacity, and monthly distribution capability. Researchers have analyzed the relationship between electricity and economic development, mainly through the lens of electricity consumption. In this study, I used a system thinking approach to disaggregate electricity into subsystems that constitute electricity delivery system, other than electricity consumption, as predictor variables to broaden the understanding of the relationship between electricity and economic development. The research question and hypotheses that guided this research were:

RQ: Is monthly industrial output in Nigeria related to available monthly power generation capacity, available monthly power transmission capacity, and monthly power distribution capability?

H_0: Monthly industrial output in Nigeria is not related to available monthly power generation capacity, available monthly power transmission capacity, and monthly power distribution capability.

H_a: Monthly industrial output in Nigeria is related to available monthly power generation capacity, available monthly power transmission capacity, and monthly power distribution capability.

The independent variables are the available monthly power generation capacity, available monthly transmission capacity, and monthly power distribution capability. In this study, industrial output in Nigeria is the dependent variable and is measured in Naira, the Nigerian currency.

In this chapter, I discuss the data collection processes for this study. This chapter also includes the presentation of descriptive analysis of the study variables and the pairwise correlation analysis to examine the strength and direction of correlation between the independent variables and multiple regression analysis to reveal the effect of each independent variable on the dependent variable. The results of the analyses facilitated the answering of the research question.

Data Collection

Time Frame, Recruitment, and Response Rates

There were no issues of recruitment or response rates as secondary data were used for this study. The NESO website (https://nsong.org/) was the source of daily power generation, transmission, distribution data from 2015 to 2020. I aggregated these data into average monthly values for the study. The data on monthly industrial output in Nigeria were derived from the NBS website (https://www.nigerianstat.gov.ng/) for the same period.

Data Collection Discrepancies, Baseline, and Demographic Characteristics of Sample

There were no significant discrepancies in the data collection plan I presented in Chapter 3 and the actual processes and data collected for the study. Data collection for the study was only after the IRB approval (approval no. 07-21-21-0477044). The whole population was used for the analysis; hence, there was no sampling during data collection and collation.

The available monthly generation capacity represents the aggregated available generation capacity from all power generating plants in Nigeria measured in MW. The transmission capacity, measured in MW, represents the capacity of the entire power transmission network in Nigeria and is reported on the NESO website daily. Distribution capability represents the total daily energy the distribution companies in Nigeria distribute, reported as energy utilized from the NESO website. The industrial output, the dependent variable in the study, represents the GDP component of all the industrial sectors in Nigeria as reported in the NBS website.

Representative Sampling

I used G*Power 3.1 software to determine that the minimum sample size for the study was 77, but the available sample size was 72 and they were all used in the study analysis. There was no sampling since I used all the available population as my sample. The assumption was that the difference would not adversely affect the validity and generalizability of the study.

Study Results

Descriptive Statistics

The data for this study are GDP and operational data for the electricity industry in Nigeria and presents peculiar considerations regarding the nature of data and implications for operational performance. Though the average GDP for the period under study was 521,191 million Naira (*SD* = 22,654), the maximum and minimum values show a difference of about 100,000. Figure 1 shows that the difference in the minimum and maximum values was not due to economic improvement trends; rather, it indicated peaks and dips over the period. The mean generation capacity was 5,005 MW (*SD* = 863) with minimum and maximum values of 2,893 MW and 6,718 MW, respectively.

Figure 1

Industrial Output

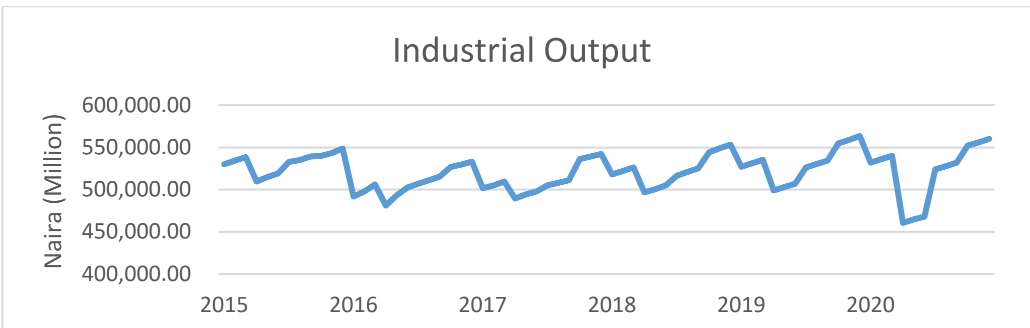
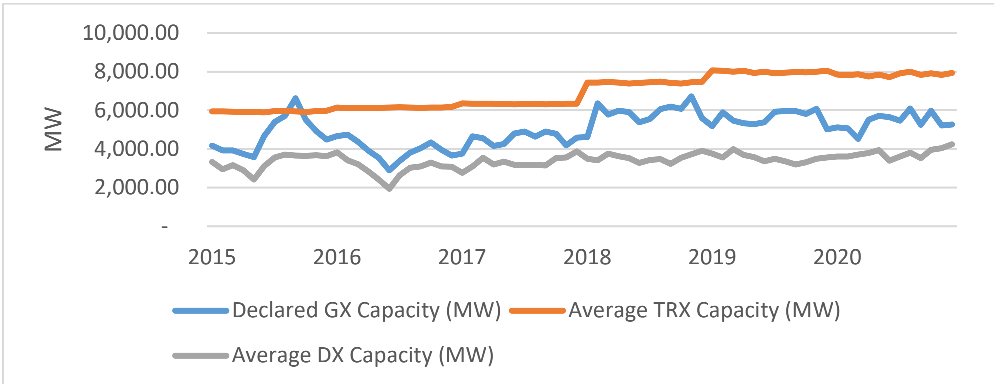


Figure 2 indicates that the disparity in generation capacity was not due to growth over the period. The transmission capacity recorded over the period ranged from 5,890 MW to 8,060 MW, with a mean value of 6,945 MW (*SD* = 844). Figure 2 shows an upward trend in transmission capacity and could be the reason for the difference between the minimum and maximum transmission capacity over the period. The average distribution capability during the period was 3,404 MW (*SD* = 397) with minimum and maximum values of 1940 MW and 4,240 MW, respectively. From Figure 2, it is likely that operational issues, rather than capacity growth, explain the high disparity between the minimum and maximum distribution capacity values. The assumption was that the data is of high quality.

Figure 2

Trend Analysis for Power Delivery Subsystems



Examining the descriptive statistics shown in Table 4 from systems thinking perspective reveals capacity mismatch across the power sector delivery value chain.

Table 4

Descriptive Statistics

		Industrial Output (Million Naira)	Generation Capacity (MW)	Transmission Capacity (MW)	Distribution Capability (MW)
N	Valid	72	72	72	72
	Missing	0	0	0	0
Mean	Statistic	521191	5005	6945	3404
	Std. Error	2669	101	99	46
Median		525650	5090	6866	3486
Std. Deviation		22654	863	844	397
Minimum		460578	2893	5890	1940
Maximum		563522	6718	8060	4240
Skewness	Statistics	-.447	-.227	.067	-1.01
	Std. Error	.283	.283	.283	.283
Kurtosis	Statistics	.03	-.716	-1.83	2.10
	Std. Error	.559	.559	.559	.559

Linear Correlation

I developed a correlation matrix using Pearson’s product-moment correlation to examine the relationship between the subsystems that constitute the electricity supply system in Nigeria, including available monthly generation capacity, available monthly transmission capacity, and monthly distribution capability. The essence was to use the strength and direction of correlation between the subsystems as a nexus for exploring the interface relationship and interrelatedness between the elements that constitute the power delivery value chain. The Pearson’s correlation was also used to evaluate the relationship between industrial output and subsystems that comprise the electricity supply system in Nigeria. There are five assumptions for the implementation of Pearson’s product-moment: (a) the variables should be continuous; (b) there should be an equal observation of the variables; (c) there should be a linear relationship among the variables; (d) no significant outliers; and (e) for inferential statistics, the variables should satisfy the test for bivariate normality (Laerd Statistics, 2018). As has been established earlier, the variables satisfy assumptions (a) and (b). A visual inspection of the SPSS scatterplot shows a linear relationship between the independent variables (see Figure 3, Figure 4, and Figure 5). The scatterplots also revealed no outliers in the data; hence four of the assumptions for correlational analysis were met.

Though Figure 3, Figure 4, and Figure 5 show some form of linearity or correlation between the elements of the power supply value chain (generation capacity, transmission capacity, and distribution capability), Figure 2 indicated otherwise. Figure 2 shows little or no symmetry in the trends of the elements of the power delivery system. For a value flow process like power generation, transmission, and distribution, the expectation is that the trends ought to be tightly coupled. The logic behind this assertion is that electricity generated needs to be transmitted, and electricity transmitted needs to be distributed to end users for consumption or utilization for residential, commercial, or industrial purposes. The lack of symmetry in trends portends little or weak or no correlation between the power delivery value chain elements. Figure 2 indicates that the data is time series in nature, and there is no independence of observations. Time series data are values or observations of a variable taken at defined time intervals over a period (Gujarati & Porter, 2009; Shrestha & Bhatta, 2017).

Overall, Figure 3 shows little or weak linearity between generation capacity and transmission capacity. Figure 4 shows a moderate linear relationship between generation capacity and distribution capability. This conclusion is also observable in Figure 2. Figure 5 shows a weak linear relationship between transmission capacity and distribution capability. Figure 2 indicates no relationship between transmission capacity and distribution capability.

Figure 3

Plot of Generation Capacity and Transmission Capacity

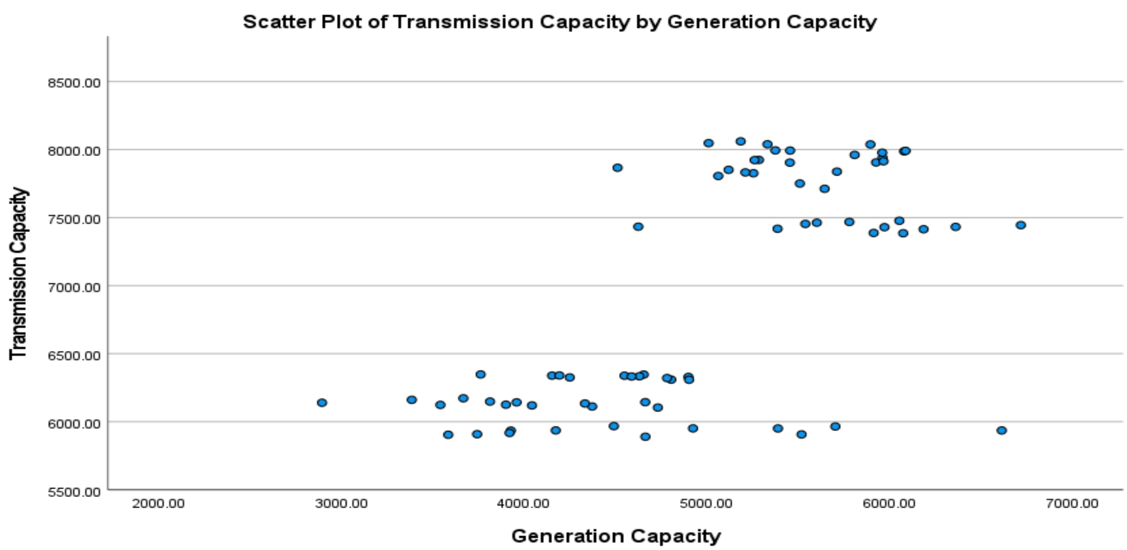


Figure 4

Plot of Generation Capacity and Distribution Capability

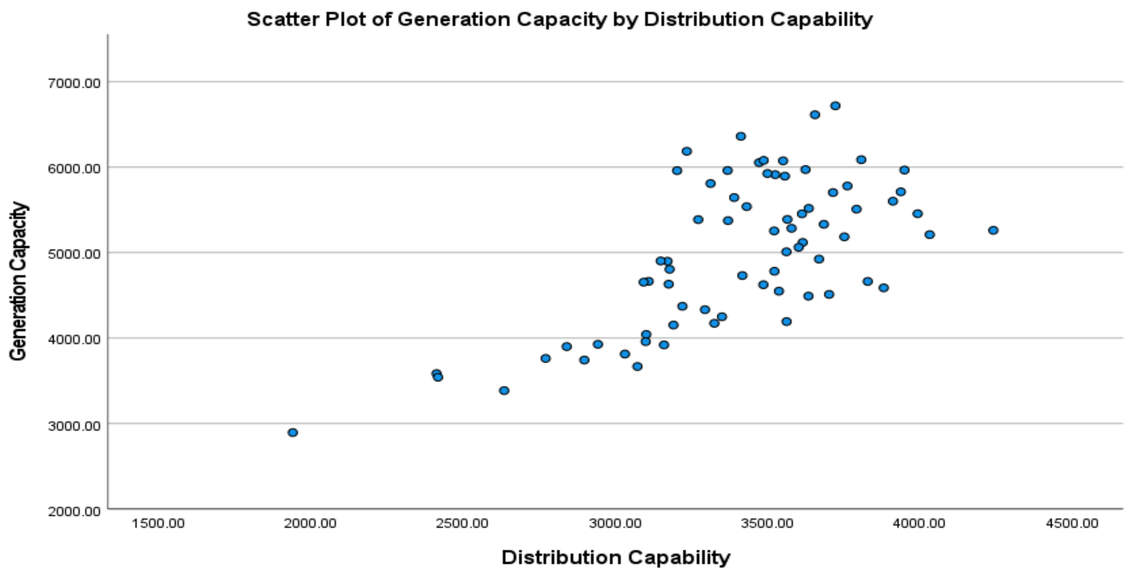
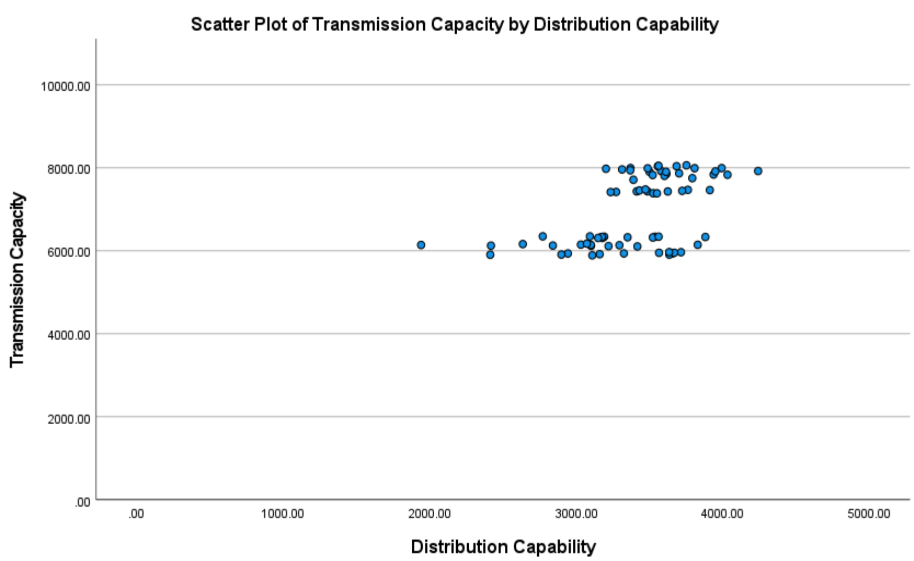


Figure 5

Plot of Transmission Capacity and Distribution Capability



Due to some unique qualities of time series, like a trend, most common analytical methods might not be applicable (Shrestha & Bhatta, 2018). Implementing the correct methodology in analyzing time series data is critical as the wrong approach (model) could lead to biased and unreliable estimates (Shrestha & Bhatta, 2018). A typical feature of time series data is that it is either stationary or nonstationary. A time series data is stationary if its trend values like mean and variance, remain constant or tend to revert to its original value after every change in time; that is, the data properties are not affected by time (Gujarati & Porter, 2009; Shrestha & Bhatta, 2017). Time series is nonstationary if the mean, variance, and covariance of the data change over time and thus contain a unit root (Gujarati & Porter, 2009; Shrestha & Bhatta, 2017). When time series data is nonstationary, it is impossible to generalize such data over different periods. In this regard, it is usual to transform nonstationary time series data to its stationary form to make it more amenable to most common data analytical methods (Gujarati & Porter, 2009).

I conducted unit root tests to determine the stationarity of the independent and dependent variables using the Augmented Dickey-Fuller (ADF) test. ADF and Phillips-Perrone unit root tests are the most widely used to test for stationarity of time series data (Gujarati & Porter, 2009; Shrestha & Bhatta, 2017). The ADF tests indicated that all the independent variables were nonstationary (see Table 5, Table 6, and Table 7. The ADF test indicated that industrial output, the dependent variable, was stationary (see Table 8). For all the independent variables, the absolute values of the test statistic were smaller than the critical values at 5%, indicating that the variables were nonstationary, but for the dependent variable, the absolute value of the test statistic was higher than the critical value at 5% indicating that it was stationary (Green, 2012).

Table 5

Generation Capacity Augmented Dickey-Fuller Test for Unit Root

	Test Statistic	Critical Value		
		1%	5%	10%
Z(t)	-2.546	-3.552	-2.914	-2.592

MacKinnon approximate *p*-value for *Z*(*t*) = 0.0632.

Table 6

Transmission Capacity Augmented Dickey-Fuller Test for Unit Root

	Test Statistic	Critical Value		
		1%	5%	10%
Z(t)	-2.088	-4.106	-3.480	-3.168

MacKinnon approximate *p*-value for *Z*(*t*) = 0.8112.

Table 7

Distribution Capability Augmented Dickey-Fuller Test for Unit Root

	Test Statistic	Critical Value		
		1%	5%	10%
Z(t)	-2.760	-3.552	-2.914	-2.592

MacKinnon approximate *p*-value for *Z*(*t*) = 0.0693

Table 8

Industrial Output Augmented Dickey-Fuller Test for Unit Root

	Test Statistic	Critical Value		
		1%	5%	10%
Z(t)	-3.570	-3.552	-2.914	-2.592

MacKinnon approximate *p*-value for *Z*(*t*) = 0.0064

I implemented the first difference method to transform the independent variables to stationary time series data, including the dependent variable. The transformation of the dependent variable was to ensure that all the variables were in the same level form during the correlation analysis. The ADF test was used to determine that the dependent variable remained stationary in the first difference form. First differencing is one of the data transformation methods for nonstationary time series data (Gujarati & Porter, 2009; Shrestha & Bhatta, 2018). First differencing will be discussed further in the next section. After first differencing, further tests using the ADF method indicated that all the independent variables became stationary. Table 9 shows the result of Pearson's correlation analysis conducted to assess the linear relationship between industrial output in Nigeria and available monthly generation capacity, available monthly transmission capacity, and monthly distribution capability. The population size reduced to 71 due to data transformation arising from the first differencing. The result from Table 9 is consistent with interpretations from Figure 2 for the independent variables. The Pearson's correlation analysis reveals that there is no statistically significant correlation between generation capacity and transmission capacity r (67) = .04, $p > .05$, and there is a negative but no statistically significant correlation between transmission capacity and distribution capability r (67) = - .10, $p > .05$. The results also indicate a statistically significant small correlation between industrial output and distribution capability r (67) = .25, $p < .05$, with distribution capability explaining 6% of the variation in industrial output. There was negative but not statically significant relationship between industrial output in Nigeria and generation capacity r (67) = -.07, $p > .05$, and transmission capacity r (67) = -.15, $p > .05$. The finding that only distribution capability has a statistically significant relationship with industrial output has an important implication for electricity delivery in Nigeria.

Table 9

Pearson's Correlations for the Dependent and Independent Variables

		Industrial Output	Generation Capacity	Transmission Capacity	Distribution Capability
Industrial Output	Pearson's Correlation	1	-.071	-.154	.247*
	Sig. (2-tailed)		.556	.199	.038
	N	71	71	71	71
Generation Capacity	Pearson's Correlation	-.071	1	-.035	.299*
	Sig. (2-tailed)	.556		.770	.011
	N	71	71	71	71
Transmission Capacity	Pearson's Correlation	-.154	-.035	1	-.103
	Sig. (2-tailed)	.199	.770		.394
	N	71	71	71	71
Distribution Capability	Pearson's Correlation	.247*	.299*	-.103	1
	Sig. (2-tailed)	.038	.011	.394	
	N	71	71	71	71

*. Correlation is significant at the 0.05 level (2-tailed).

Multiple Regression Analysis

In this study, I used multiple regression analysis, $\alpha = .05$ (two-tailed), to examine the relationship between monthly industrial output, the dependent variable, and available monthly generation capacity, available monthly transmission capacity, and monthly distribution capability, the independent variables, and to estimate the extent to which each independent variable explains variations in the dependent variable. Preliminary analysis was conducted to test the assumptions for multiple linear regression, including tests for linearity, level of measurement (scale or interval), number of variables (two or more), presence of autocorrelation, and multicollinearity, homoscedasticity, and normality.

Assumption Testing

From the correlation analysis, the assumptions for the number of variables and level of measurement were satisfied. The test for autocorrelation using the Durbin-Watson statistic (*d*) yielded a value of .710, see Table 10. Further, *d* ranges from 0 to 4 and a $d = 2$ indicates the absence of autocorrelation, values of *d* above 2 indicate negative autocorrelation, and values below 2 show the presence of positive autocorrelation (Laerd Statistics, 2018; Gujarati & Porter, 2009). In this regard, the model showed the presence of positive autocorrelation. This result was not unexpected given the time series nature of the data and unit roots in the independent variables as established during Pearson's correlation analysis. Autocorrelation indicates a correlation between data points or observations ordered in time (Laerd Statistics, 2018; Gujarati & Porter, 2009).

Table 10

Model Summary[b]

Model	*R*	R^2	Adjusted R^2	Std. Error of the Estimate	Durbin-Watson
1	.352[a]	.124	.085	21668.522	.710

a. Predictors: (Constant), Available Distribution Capacity, Available Transmission Capacity, Available Generation Capacity

b. Dependent Variable: Industrial Output

First differencing is one of the methods of correcting autocorrelation in a linear regression model (Gujarati & Porter, 2009). First differencing involves the subtraction of the lagged value of a variable from the preceding value in time. In this regard, first differencing will result in the loss of one observation as the first observation does not have a precedent (Gujarati & Porter, 2009). I implemented the 1st order differencing method to the data, and the *d* statistic improved to 2.01, see Table 11, indicating the near absence of autocorrelation and the presence of 1st order autocorrelation (Gujarati & Porter, 2009).

Table 11

Model Summary[b]

	Model	*R*	R^2	Std. Error of the Estimate	Durbin-Watson
1	.318[a]	.101	.061	17873.31286	2.015

a. Predictors: (Constant), DIFF(DistCap,1), DIFF(TransCap,1), DIFF(GenCap,1)

b. Dependent Variable: DIFF(IndPut,1)

The population linear regression model for this study is represented by:

$$InduPut_i = \beta_1 + \beta_2 GenCap_i + \beta_3 TrxCap_i + \beta_4 DxCap_i + u_i \quad (4.0)$$

Where InduPut is the dependent variable (industrial output), GenCap, TrxCap, and DxCap are generation capacity, transmission capacity, and distribution capability, respectively, *u* is the stochastic disturbance term or the error term, and i is the ith observation and can be replaced by t in a time series (Gujarati & Porter, 2009). In equation 4.0, β_1 is the intercept term, and β_2, β_3, and β_4 are the partial regression coefficients of the independent variables. The equation 4.0 can be rewritten as:

$$InduPut_{i-1} = \beta_1 + \beta_2 GenCap_{i-1} + \beta_3 TrxCap_{i-1} + \beta_4 DxCap_{i-1} + u_{i-1} \quad (4.1)$$

Where $InduPut_{i-1}$, $GenCap_{i-1}$, $TrxCap_{i-1}$, $DxCap_{i-1}$ are the lagged values of the dependent and independent variables respectively, and u_{i-1} is the lagged value of the error term. First differencing involves subtracting equation 4.1 from equation 4.0, which yields:

$$\Delta Induput_i = \beta_2 \Delta GenCap_i + \beta_3 \Delta TrxCap_i + \beta_4 \Delta DxCap_i + \Delta u_i \quad (4.2)$$

In equation 4.2, Δ is known as the difference operator and indicates the application of successive differences of the variables in the equation (Gujarati & Porter, 2009). That is, $\Delta Induput_i = (InduPut_i - InduPut_{i-1})$, $\Delta GenCap_i = (GenCap_i - GenCap_{i-1})$, $\Delta TrxCap_i = (TrxCap_i - TrxCap_{i-1})$, $\Delta DxCap_i = (DxCap_i - DxCap_{i-1})$, and $\Delta u_i = (u_i - u_{i-1})$.

Where $v_i = \Delta u_i = (u_i - u_{i-1})$.

In this regard, equation 4.2 can be written as:

$$\Delta Induput_i = \beta_2 \Delta GenCap_i + \beta_3 \Delta TrxCap_i + \beta_4 \Delta DxCap_i + v_i \qquad (4.3)$$

According to Gujarati and Porter 2009, equation 4.1 is the level form, and equation 4.2 is the first difference form of the regression model.

The scatter plot of the studentized residuals (SRE_1) against the unstandardized predicted values (PRE_1) was used to determine the existence of a collective linear relationship between the dependent and independent variables (Laerd Statistics, 2018), See Figure 6. Figure 6 shows some form of a collective linear relationship between the dependent and independent variables. Partial regression plots between each independent variable and the dependent variable were used to test the assumption for linearity. No significant violations for linearity were identified, see Figure 7, Figure 8, and Figure 9. To check for heteroscedasticity, the review of the scatter plot of the studentized residuals (SRE_1) against the unstandardized predicted values (PRE_1) showed some form of increasing funneling of the data points that may indicate heteroscedasticity (Laerd Statistics, 2012). The collinearity statistics were measured using the variance inflation factor (VIF) and showed that the highest VIF in the model was 2.37, indicating the absence of multicollinearity, see Table 12. Laerd Statistics (2018) noted that VIF values lower than 10 indicate the absence of multicollinearity. An inspection of the Cook's distance variable (COO_1) for the model showed that none of the cases had a value greater than 1. A COO_1 value greater than 1 should be investigated as it may indicate outlier(s) in the dataset (Laerd Statistics, 2018). In this regard, there was no violation of the assumption for outliers in the model. A review of the histogram with superimposed normal curve and the P-P plot for the regression model showed that there was no significant violation for the test for normality, though the OLS regression is still reliable, to some extent, in the presence of deviations from normality (Laerd Statistics, 2018), see Figure 10 and Figure 11.

Figure 6

Plot of Collective Linearity of the Dependent and Independent Variables

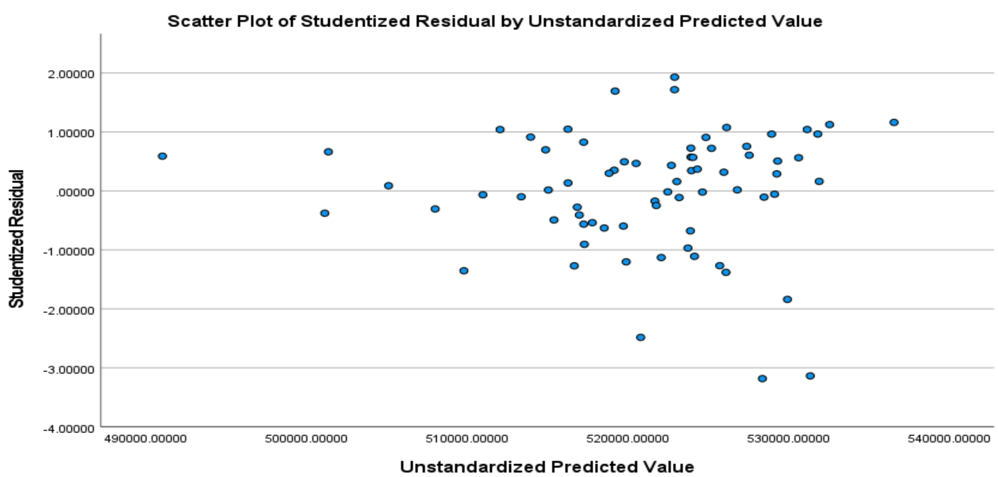


Figure 7

Plot of Linearity Between Industrial Output and Generation Capacity

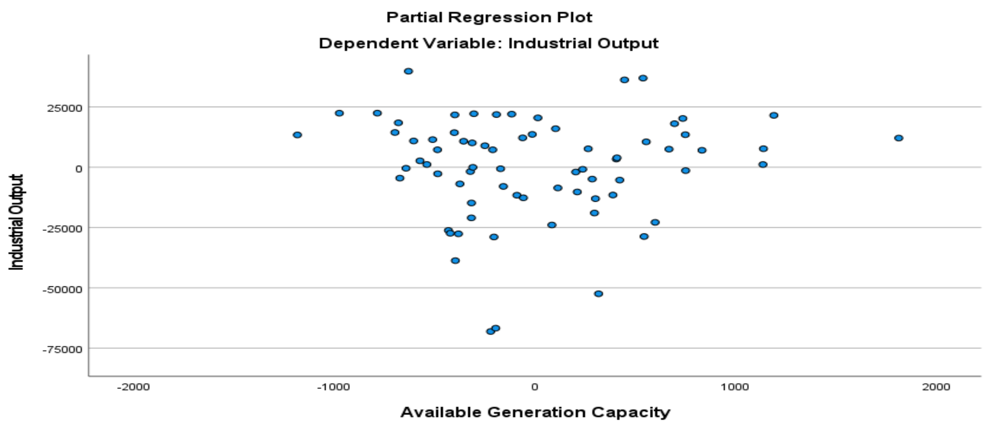


Figure 8

Plot of Linearity Between Industrial Output and Transmission Capacity

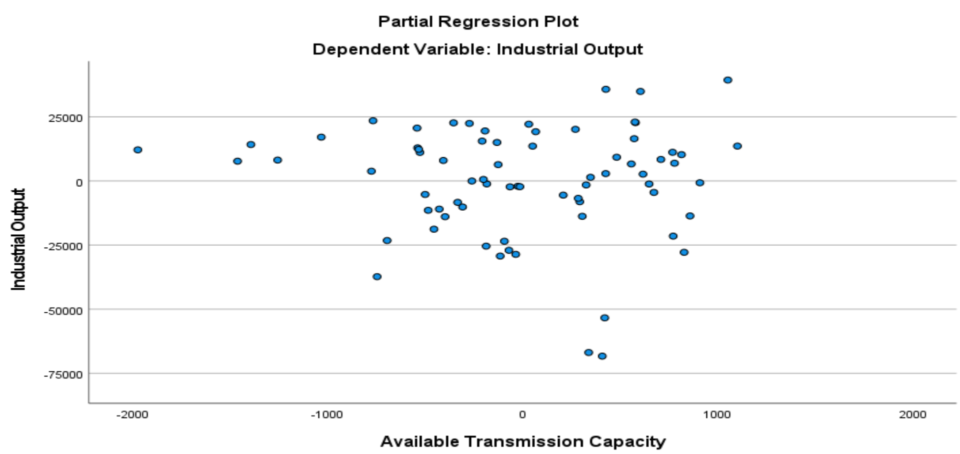


Figure 9

Plot of Linearity Between Industrial Output and Distribution Capability

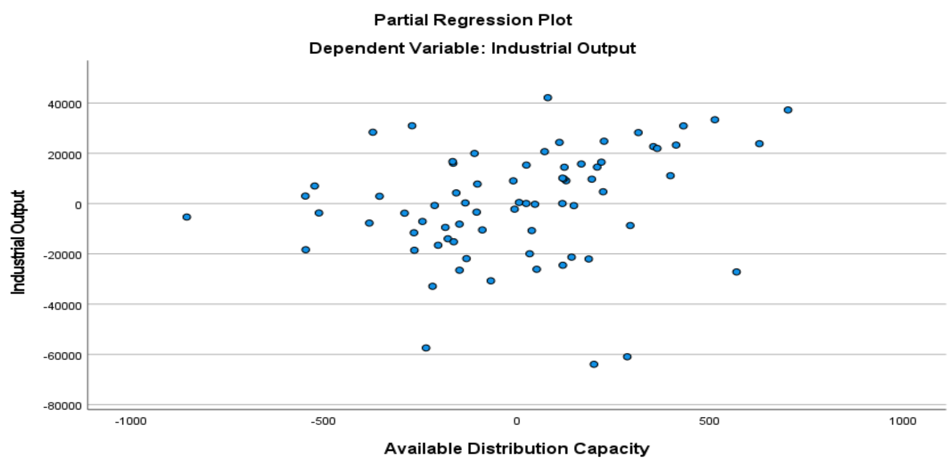


Table 12

Multicollinearity Statistics

	Tolerance	VIF
Generation Capacity	.423	2.366
Transmission Capacity	.552	1.810
Distribution Capability	.545	1.834

Figure 10

Histogram with Superimposed Normal Curve to Interpret Normality

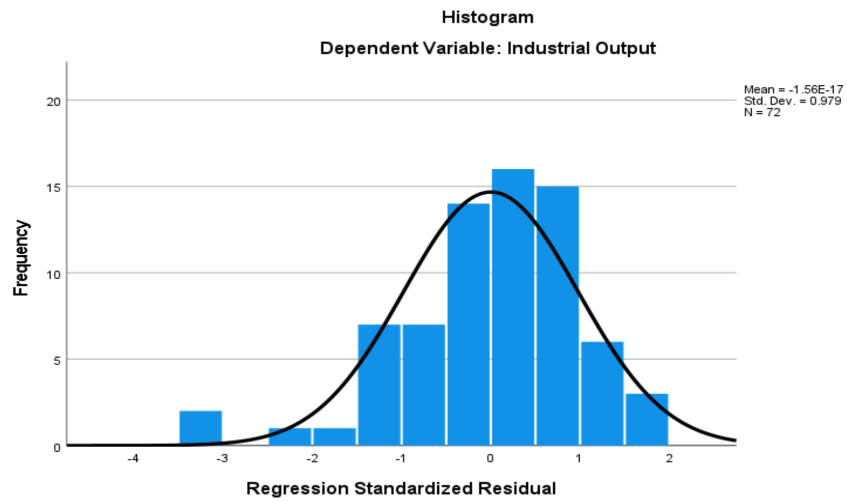
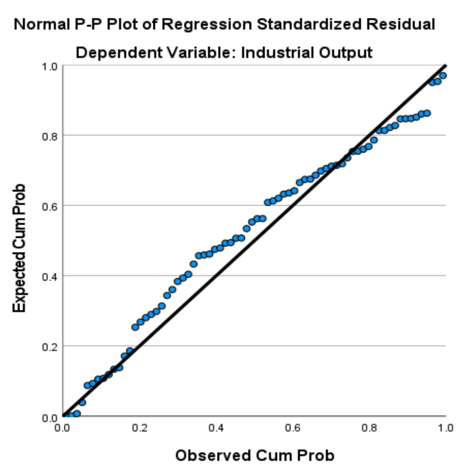


Figure 11

Normal P-P Plot to Check for Normality



Statistical Analysis Findings

Research question: Is monthly industrial output in Nigeria related to available monthly power generation capacity, available monthly power transmission capacity, and monthly power distribution capability?

H_0: Monthly industrial output in Nigeria is not related to available monthly power generation capacity, available monthly power transmission capacity, and monthly power distribution capability.

H_a: Monthly industrial output in Nigeria is related to available monthly power generation capacity, available monthly power transmission capacity, and monthly power distribution capability.

The tests for the assumptions for multiple linear regression indicated the likelihood of heteroscedasticity and autocorrelation in the dataset. All models are wrong to a certain degree and the best any researcher can achieve is to approximate the process of modeling and estimation of the outcome variable (Hayes and Cai, 2007). This observation is regarding the difficulty in strictly satisfying all the OLS assumptions and the subjective or qualitative nature of validating some assumptions, especially for heteroscedasticity and linearity using graphical plots (Gujarati & Porter, 2009). Using heteroscedasticity-consistent standard error estimators in estimating OLS parameters could reduce the effects of heteroscedasticity in OLS models without the requirements for the transformation of variables (Hayes and Cai, 2007). The Newey-West method of correcting OLS standard errors, known as the heteroscedasticity and autocorrelation-consistent standard errors or Newey-West standard errors, in addition to correcting for heteroscedasticity, also corrects for autocorrelation of errors (Gujarati & Porter, 2009). In this regard, the Newey-West standard errors method obviates the need for data transformations in the presence of heteroscedasticity and autocorrelation.

With likely heteroscedasticity and autocorrelation in the model, I ran an OLS regression with the Newey-West errors estimator using STATA to account for both autocorrelation of errors and heteroscedasticity and avoid the dangers of type I error that may arise due to either heteroscedasticity or autocorrelation, or both in the model. The reason for using STATA is because SPSS does not support the function for heteroscedasticity and autocorrelation-consistent standard errors analysis. The regression coefficients and standard errors are shown in Table 13. Only distribution capability (t = 2.17, $p < .05$) statistically significantly predicted industrial output in the model and is consistent with the findings from the Pearson's correlation analysis. In this regard, I rejected the null hypothesis that monthly industrial output in Nigeria is not related to available monthly power generation capacity, available monthly power transmission capacity, and monthly power distribution capability.

Table 13

Regression with Newey-West Standard Errors

Industrial Output	Coefficient	Newey-West std. err.	*t*	*P*>|*t*|	[95% conf. interval]	
Generation Capacity	1.282343	4.40031	0.29	0.772	-7.49834	10.06302
Transmission Capacity	-1.199524	3.639242	-0.33	0.743	-8.46152	6.06247
Distribution Capability	19.39199	8.954204	2.17	0.034	1.52415	37.25982
cons_	457077.8	22308.92	20.49	0.000	412561.1	501594.6

Number of observations = 72, Maximum lag = 1

The resulting multiple regression equation for the model is represented by:

$$\text{InduPut} = 457077 + 1.28\text{GenCap} - 1.2\text{TrxCap} + 19.4\text{DxCap} \qquad (4.4)$$

Where InduPut is the dependent variable (industrial output), the independent variables GenCap, TrxCap, and DxCap are available monthly generation capacity, available monthly transmission capacity, and monthly distribution capability, respectively. Given that distribution capability was the only independent variable that was statistically significant, equation 4.4 would not accurately represent the relationship between the dependent and independent variables in the study. In this regard, I refitted the regression model using a simple linear regression with monthly industrial output as the dependent variable and monthly distribution capability as the only independent variable. The results of the simple linear regression are shown in Table 14.

Table 14

Refitted Regression with Newey-West Standard Errors

Industrial Output	Coefficient	Newey-West std. err.	*t*	*P*>|*t*|	[95% conf. interval]	
Distribution Capability	19.91581	5.165661	3.86	0.000	9.613228	30.2184
cons_	453382.1	18065.99	25.10	0.000	417350.6	489413.6

Number of observations = 72, Maximum lag = 12

The multiple regression equation for the final model is represented by:

InduPut = 453382.1 + 19.2DxCap (4.5)

Where InduPut is the dependent variable (industrial output), the independent variable DxCap is monthly distribution capability. In the final model, distribution capability statistically significantly predicted industrial output ($t = 3.86$, $p < .000$), and distribution capability accounted for 12% of the variability in industrial output in Nigeria. The regression model indicates that a 1MW increase in distribution capability will result in a 19.2 Naira increase in industrial output in Nigeria. This result indicates that an increase in distribution capability will lead to a rise in industrial output, which could positively affect the overall GDP of the country. The final model also shows that when distribution capability is zero, industrial output will be 453382.1, where 453382.1 is the constant or intercept term. This scenario is plausible given Osakwe's (2017) finding that 71% of industries in Nigeria generate their power, suggesting that even without power supply from the distribution segment of the power supply value chain, there would still be a significant level of industrial production in Nigeria.

Summary

The purpose of this quantitative correlational study was to establish if monthly industrial output in Nigeria was related to available monthly power generation capacity, available monthly transmission capacity, and monthly distribution capability. Pearson's correlation analysis revealed no statistically significant correlation between generation capacity and transmission capacity. The correlation analysis also revealed that there was no statistically significant correlation between distribution capability and transmission capacity, and only distribution capability was statistically significantly related to industrial output in Nigeria. The results indicated a statistically significant small correlation between industrial output and distribution capability $r(67) = .25$, $p < .05$, with distribution capability explaining 6% of the variation in industrial output.

The multiple regression analysis enabled the examination of the extent to which generation capacity, transmission capacity, and distribution capacity predict industrial output in Nigeria. The OLS regression with the Newey-West errors estimator revealed that only distribution capability statistically significantly predicted industrial output (t = 3.86, $p < .000$), and distribution capability accounted for 12% of the variability in industrial output in Nigeria. The result is consistent with the outcome of the Pearson's correlation analysis. The interpretation of these findings is discussed in Chapter 5 with associated literature, limitation of the study, and recommendations for future studies.

Chapter 5: Discussion, Conclusions, and Recommendations

The purpose of this quantitative correlational study was to examine the relationship between monthly industrial output in Nigeria and available monthly power generation capacity, available monthly power transmission capacity, and monthly power distribution capability. Based on von Bertalanffy's (1968) and Laszlo's (1996) seminal works, I used the systems theoretical perspective to identify and examine how the power sector variables affect industrial output in Nigeria because little is known about how the elements that make up the electric power supply value chain impact industrial output in Nigeria.

In this study, I presented electricity as a natural open system consisting of available monthly power generation capacity, available monthly transmission capacity, and monthly power distribution capability as independent variables and sought to examine the interrelatedness between these variables. Pearson's correlation analysis was used to examine the correlation between the elements that constitute Nigeria's electricity supply value chain and the relationship between the dependent and independent variables. The results indicated no statistically significant correlation between available generation capacity and available transmission capacity $r\ (67) = .04$, $p > .05$, and there is a negative but no statistically significant correlation between transmission capacity and distribution capability $r\ (67) = -.10$, $p > .05$. The results also showed a statistically significant relationship between industrial output and distribution capability $r\ (67) = .25$, $p < .05$.

In addition to the Pearson's correlation analysis, I conducted a multiple linear regression analysis to examine the relationship between the industrial output, the dependent variable, and available monthly generation capacity, available monthly transmission capacity, and monthly distribution capability, the independent variables, and to estimate the extent to which each independent variable explains variations in the dependent variable. I ran an OLS regression with the Newey-West errors estimator to account for both autocorrelation of errors and heteroscedasticity. The final model indicated that only distribution capability ($t = 3.86$, $p < .000$) statistically significantly predicted industrial output.

Interpretation of Findings

Contribution to Literature

Most researchers in the electricity and economic development literature use electricity consumption as an independent variable in their analysis. The scholars who studied the electricity economic development nexus in Nigeria used either electricity supply or electricity consumption as an independent variable. The results of the study in SSA countries indicate that the poor state of electric infrastructure and services negatively impact economic development (2020; Azolibe & Okonkwo, 2020; Chakamera & Alagidede, 2018; Kodongo & Ojah, 2016; Owusu-Manu et al., 2019). A veritable interpretation of these findings is that the poor state of electricity infrastructure moderates the possible effects of electricity on economic development, thus making electricity consumption or supply a constrained variable.

The Pearson's correlation analysis results from this study indicated little or weak correlation between the elements of the power supply value chain (generation capacity, transmission capacity, and distribution capability). There was no statistically significant correlation between available generation capacity and available transmission capacity *r* (67) = .04, $p > .05$, and there was negative but no statistically significant correlation between transmission capacity and distribution capability *r* (67) = - .10, $p > .05$. The significant difference in means between generation capacity and distribution capability indicates the presence of possible constraints in distribution capability. These constraints could be due to poor power distribution infrastructure and services or constraints at the transmission and distribution interface points. This finding aligns with the study on the effects of poor electricity infrastructure and economic development in SSA countries.

Examining the difference in means in conjunction with the visual interpretation of Figure 2 and Pearson's correlation analysis indicates the possibility of stranded generation capacity during the period under study. This realization or possibility is a contradiction given the unenviable position Nigeria occupies in the league of nations regarding electricity access gap. Osakwe's (2017) finding that 71% of industries generate their power further reinforces the notion of stranded (idle) generation capacity amidst established scarcity, likely caused by constraints in the distribution capability or at the distribution and transmission interface points. The likelihood of unutilized generation amidst scarcity is a significant outcome of this study.

The prospect of constraints in distribution capability in Nigeria, arising from Pearson's correlation analysis results, has significant implications in the electricity and economic development literature, especially for energy-constrained nations like Nigeria. Constraints at the transmission/distribution interface points or distribution capability within the power supply value chain indicate that using electricity consumption as an independent variable in the electricity and economic development literature could lead to misleading or spurious conclusions.

The results of the multiple linear regression with the Newey-West errors estimator showed that only distribution capability in the regression model statistically significantly predicted industrial output. If distribution capability is constrained, either at the transmission and distribution interface points or within the distribution system, the conclusion that distribution capability significantly predicts industrial output could be misleading. This assertion is an important outcome of this study and a significant contribution to electricity and economic development literature. If there were no constraints, like in energy-sufficient countries, the results might be different.

From the Africa energy report for 2014, accessed from the website of the International Energy Agency (https://www.iea.org/), growth in household electricity consumption is about 70% in Nigeria. The multi-year tariff order, accessed from the website of the Nigerian electricity regulator (https://nerc.gov.ng/), indicated that commercial and industrial use of electricity account for 27% of total consumption, with the industrial sector accounting for only 7% of total consumption. Within the context of a high prevalence of self-generation within the industrial sector, these findings indicate that removing the perceived constraints could skew consumption more toward residential and commercial use than for industrial purposes. In this regard, removal of the perceived constraints in electricity distribution as indicated from this study could result in different outcomes regarding the results of the Pearson's correlation and multiple regression analyses, especially regarding the correlation between distribution capability and industrial output.

The capacity misalignment across the elements of the power delivery value chain in Nigeria, as adduced from the difference in means and Pearson's correlation analysis, confirms literature on the negative effects of poor electricity infrastructure on economic development in SSA countries. This study offers a deeper understanding of the relationship between electricity and economic development in electricity-challenged countries. In this regard, this study divides literature in electricity and economic development into literature for energy-sufficient and literature for energy-challenged countries, especially regarding support for policy development.

Theoretical Implication of Findings

Systems thinking was the theoretical framework for this study, anchored on the seminal works of von Bertalanffy (1968) and Laszlo (1996). The systems approach enabled understanding electricity supply or consumption as a system made up of interdependent subsystems. Laszlo presented the hypothetico-deductive method to examine the interface relationships between systems and the joint effort required to maintain a dynamic equilibrium. In this study, I used a systems approach to identify and investigate the interface relationships between power generation, transmission, and distribution, as elements of the power delivery system and how these variables affect industrial output in Nigeria.

Laszlo (1996) developed four propositions with which to investigate and verify the existence of systems. One of Laszlo's four propositions about natural systems is that they serve as coordinating interfaces in nature's holarchy. Holarchic duality represents the joint efforts systems need to maintain dynamic equilibrium (Laszlo, 1996).

The reason for Pearson's correlation analysis in this study was to test the holarchic duality properties of the Nigerian power supply value chain as a natural system. I used the correlation coefficient to test the extent or strength of relationship and interdependence between the elements of the power supply system (generation capacity, transmission, capacity, and distribution capability). As a natural system, the expectation was that the strength of correlation between the Nigerian power supply system elements would be strong or close to unity to confirm the holarchic duality property of a natural system. The Pearson's correlation analysis results indicate weak or no correlation between the Nigeria power supply system elements. There was no statistically significant correlation between generation capacity and transmission capacity, and there was a negative but no statistically significant correlation between transmission capacity and distribution capability. These findings indicate interface issues among the power delivery value flow elements or infrastructure deficits within the subsystems that constitute the power delivery system in Nigeria.

The value of the systems approach is in identifying misalignment of capacity in the Nigerian power supply value chain. This misalignment is with an attendant poor power supply amidst idle generation capacity. Using Laszlo's (1996) concept of holarchic duality, it is evident from Pearson's correlation analysis that the coordinated joint effort required for the attainment of dynamic equilibrium at the interface points for a natural system is lacking in the Nigerian power supply value chain. These findings exemplify how the use of theory could influence research and how outcomes of such research could support policy development and practice in terms of system planning and development

Limitations of the Study

There were a few limitations to the study with the potential to impact the validity, trustworthiness, generalizability, and reliability. The a priori power analysis at 80% power (1-β error probability), using the G*Power 3.1 software, determined 77 as the minimum sample size; however, the available population size was 72. Small sample size issues introduce threats to SCV (Busk, 2010). This issue was made worse by implementing the first difference data transformation methodology, which further reduced the sample size to 71.

Natural gas, a fuel source for thermal generation in Nigeria, a possible covariate in this study, was not included as a variable in the study. The NESO (https://nsong.org/) frequently reported lack of gas as a constraint to available generation capacity. In 2015, thermal generation constituted up to 82% of the power generated in Nigeria (Osakwe, 2017). Extraneous variables that could affect the study, other than the identified independent and dependent variables, could threaten internal validity (Drew at al., 2008). Excluding this variable could be a threat to internal validity as it could be interpreted as an omitted variable.

Another limitation of the study is the use of secondary data. The use of secondary data presents the issues of applicability and fit for purpose. In this regard, issues of availability, relevance, accuracy, and sufficiency become veritable concerns. Applicability and fit for purpose issues did not arise in this study. The Nigerian system's operator was the sole aggregator of operational data for the electricity industry in Nigeria, and there was no means of cross-validating the data posted by this agency. In this regard, the issue of data quality remains a veritable concern.

Recommendations

The Pearson's correlation analysis showed a statistically significant small correlation between industrial output and distribution capability r (67) = .25, $p < .05$, with distribution capability explaining 6% of the variation in industrial output. The regression analysis indicated that distribution capability statistically significantly predicted industrial output ($t = 3.86$, $p < .000$), and distribution capability accounted for 12% of the variability in industrial output in Nigeria. Both tests indicate that distribution capability is statistically significantly related to industrial output and is an important contribution to policy development for improved electricity delivery for enhanced industrial output in Nigeria.

Using a systems approach in this study provided invaluable insights into relationships and interdependencies between the elements of the power supply value chain in Nigeria. The study results indicate capacity misalignment that can be due to infrastructure deficits at the power transfer interface points within the power supply value chain or constraints within the electricity distribution systems due to either infrastructure deficits or poor services, or both. These capacity misalignments provide an opportunity for future studies to identify underlying factors that lead to the deficits and the type of relationship or correlation between these factors to support policy development.

The result of this study applies to Nigeria, but there is an opportunity for future studies to extend this type of study to countries within the subregion (West Africa) and the rest of SSA countries. The extension of this study to other countries like Nigeria will test the generalizability of the findings to other electricity-challenged countries in the world. Extending this study can potentially influence research approaches in the electricity and economic development literature, especially in electricity-challenged countries.

In the study, idle generation was identified as a fallout of capacity misalignment in the Nigerian power supply value chain. This finding is revealing in the context of the fact that Nigeria has the largest electricity gap in the world from the World Bank 2021 energy progress report. There is an opportunity arising from this study to examine the relationship between the rate of electricity access in Nigeria and available distribution capability and other sources of energy.

Seventy-one percent of Nigerian industries generate their power, further acknowledging the poor state electricity supply in Nigeria (Osakwe, 2017). In this regard, there is an opportunity for future research to examine the correlation or effect of self-generation on industrial output in Nigeria. Such a study will support policy development, especially regarding improving services and removing power distribution constraints to increase industrial output in Nigeria.

Gas was identified as a possible covariate in this study but was not one of the variables examined. There was no single aggregator for all sources of gas for power (private and government) in Nigeria. Given the high proportion of thermal power plants that require gas as fuel and the reported constraints to available power generation due to gas shortages, further studies may examine likely covariates that constrain gas supply for power in Nigeria. When gas supply shortages are factored in, this type of research can facilitate the determination of the extent of idle power generation capacity. A study of this nature could support policy development, especially policy for infrastructure development for power, gas supply, and improved services.

Implications for Social Change

The objective of this study was to present electricity supply as a system and provide a better understanding of the interrelatedness between the elements that make up the electricity supply value chain in Nigeria and how they impact industrial output. As an energy source, electricity is an important input in the industrial sector because of its ease of conversion (Stern et al., 2019). Poor-quality power supply adversely impacts Nigeria's industrial output, leading to high reliance on self-electricity generation and increased cost of production, which renders local industries less competitive with foreign products (Chete et al., 2014). Poor electricity access, low-quality power supply, and high electricity cost were the three main reasons for low capacity utilization, lack of competitiveness, and lack of growth in Nigeria's industrial sector (Osakwe, 2017).

The Pearson's correlation and regression analysis results indicate that distribution capability is statistically significantly related to industrial output and may provide support for a coordinated electricity power development policy in Nigeria. Improved electricity supply will positively impact the industrial sector by reducing or eliminating the high cost of self-generation that will boost the competitiveness of local industries. Such improvements can catalyze enhanced production output, which would lead to economic growth and eradication of poverty through increased economic activities that lead to gainful employment and positive social change. Improvements in electricity supply would facilitate electricity access growth in Nigeria, positively impacting the education and health sectors, including other public services. In this regard, it is conceivable that electricity affects people's lives in multiple ways. This study could provide the impetus for improvements in electricity supply in countries like Nigeria, leading to positive social change in many ways.

This study presented electricity supply as a system, which allowed the identification of the elements that make up the electricity supply value chain. The result of this study enabled the identification of capacity mismatch along the electricity supply value chain. This type of mismatch could be either due to infrastructure deficits or poor services or both and may be responsible for the poor state of electricity supply in Nigeria. This study enabled the identification of electricity consumption, a common independent variable in the electricity and economic development literature, as a constrained variable and consequently could invalidate or put to the test the validity of such studies, especially in electricity-challenged countries like Nigeria. By adopting systems theoretical perspective, future studies in the electricity and economic development literature would deepen understanding regarding the relationship between electricity and economic development and support coherent policy development.

Conclusions

The purpose of this correlational study, anchored on a systems approach, was to examine the relationship between the power delivery subsystems and their effect on industrial output in Nigeria. The literature on electricity and economic development is diverse. Multiple studies in the same country yielded different results that make developing a coherent policy for improved power supply and economic growth difficult. This study indicated that electricity consumption is a constrained variable and may invalidate studies where it has been used as an independent variable in electricity-constrained countries like Nigeria. This study also indicated the possibility of idle generation capacity amidst reports on the poor state of electricity supply in Nigeria.

Using the systems theoretical approach in this study contributes to the electricity and economic development literature by identifying and utilizing elements that make up the electricity delivery value chain as predictor variables to study the effects of electricity on industrial output in Nigeria. The result indicated capacity incongruencies across the power supply value chain. Pearson's correlation analysis showed no statistically significant correlation between generation capacity and transmission capacity, and there was a negative but no statistically significant correlation between transmission capacity and distribution capability. The capacity mismatch could be due to infrastructure deficits at the interface points across the supply value chain or due to poor services, or both.

The results of the multiple regression analysis indicated that only distribution capability statistically significantly predicted industrial output in the model. This study supports coherent policy development by bringing clarity to the workings of the electricity supply systems and how electricity impacts industrial growth in countries like Nigeria. Both Pearson's correlation and regression analysis indicate that distribution capability is statistically significantly related to industrial output and provides policy direction for improved electricity delivery. The three main outputs from this study are (a) the likelihood of the existence of idle generation even amidst scarcity, (b) that electricity consumption is a constrained variable and may invalidate studies where electricity has been used as an independent variable in electricity challenged countries like Nigeria, and (c) the existence of capacity incongruencies across the power supply value chain that indicate poor planning. All these findings have implications for literature and policy development.

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Appendix: Screen Shot of Sample Size A Priori Analysis