Energy Economics Letters
ISSN(e): 2308-2925
DOI: 10.55493/5049.v10i1.4732
Vol. 10, No. 1, 44-68.

URL: www.aessweb.com

Impact of rural and urban electricity access and economic growth in Ghana: Does line transmission losses matter?

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Article History
Received: 12 December 2022
Revised: 18 January 2023
Accepted: 31 January 2023
Published: 23 February 2023

Keywords
Dynamic ordinary least squares
Economic growth
Electricity transmission losses
Ghana
Political economy of rural and urban electricity access.

JEL Classification:
P18; Q4; Q40; Q43; Q48.

ABSTRACT

This paper aimed to estimate the impact of rural and urban electricity access on Ghana's economic growth between 1993 and 2018 by controlling for electricity transmission losses as a percentage of total electricity transmitted. The study used Stock-Watson Dynamic Ordinary Least Square (DOLS) to estimate the impact of electricity access and transmission losses on Ghana's economic growth. The Engle-Granger, Phillips-Ouliaris, Park's added variables and Hansen parameter instability cointegration methods were applied to test the long-run cointegration of the studied variables The results show that a 1% increase in electricity access was associated with a 0.073% decrease in economic growth. Additionally, a percentage increase in the rural electricity access rate was associated with a 0.527% increase in national income per capita. In contrast, urban population electricity access had no statistically significant association with economic growth in Ghana. The study suggests that improving population access to electricity infrastructure services while reducing power wastage through electricity transmission loss minimization is crucial to achieving the long-term impact of electric power on socio-economic development and environmental sustainability in Ghana, subject to other equally essential conditions.

Contribution/Originality: The study contributes to the literature on energy-development-nexus by examining the long-run impact of rural-urban population electricity access and the electric energy transmission losses on economic growth in Ghana. In this light, future research agenda considering the social, economic and environmental adverse effects of power wastage is proposed.

1. INTRODUCTION

The political economy of the recognition of electricity access as a tool for socio-economic transformation, holding other factors constant, is probably first evidenced in the words of the former Russian revolutionist, Vladimir Lenin led GOELRO[1] Plan in the former Soviet Union. In the words of Lenin, as re-echoed by Ryder (2020):

> *'Communism is government by the Soviets plus the electrification of the whole land [country]… Only when the economy has been electrified and modern heavy industry has become the technical basis of industry, agriculture and transportation, only then will we succeed at last.'. [Ch. 3].*

[1] The GOELRO Plan in Russian stands for 'Gosudarstvennaia komissia po elektrifikatsii Rossii' and is translated in English as 'State Commission for the Electrification of Russia" (Rindlisbacher, 2023). It was judged in the literature as the first Russian electricity integrated development plan under the leadership of Vladimir Lenin for industrialization and transforming rural agrarian communities in the 1920s (Sumburova & Zaelskaya, 2021).

Indeed, Vladimir emphasizes that 'his' country will remain 'small-peasant country', and that must be realized by the development planners Although Lenin's view represents a political ideology loaded with economic transformation agenda, one thing stands neutral: electricity access shapes modern social and economic transformation given its general technology characteristic for the reconstruction and economic development of the Soviet Union adopted in 1920 is one of the key tenets of the democratic governance system is to deliver basic commodities to all citizens as well as sharing the costs and benefits of the use of thereof in the course of the development process. Giving the general-purpose technology value of electricity (Allen, 2011) its services. Thus, reliable, affordable and environmentally benign access to electricity is understood contemporary as critical citizens' opportunities and improvement in subjective well-being, all things being equal. Access to modern energy services is a key component of the 2030 Global Sustainable Development Agenda (Filho, Azul, Brandli, Salvia, & Wall, 2021) and the Paris Agreement (Gupta & Dalei, 2019; van Soest et al., 2017).

Modern energy access (electricity and clean cooking fuel and technologies) is now considered a goal on its merit the Sustainable Development Goals (SDGs), as in with SDG 7, which clarified universal access to reliable, affordable, and ecologically friendly energy for all by 2030 as an expressive target to promote the right to development. The most recent estimates, including the COVID-19 pandemic and Russia-Ukraine crisscrossing crises scenario, estimated that about 774 million people representing a 20 million increase from 2021, maybe living without access to electricity by the end of 2022 (IEA, 2022). At the same time, approximately 75 million people globally are feared to have lost their ability to pay for electricity infrastructure services as a result of the COVID-19 pandemic-induced income losses and Russia-Ukraine propelled global energy crisis (Africa Energy Outlook 2022, 2022; IEA, 2022). In the context of Africa, about 600 million people, representing 43% of the Continent's total population, lacked access to 2021 (Africa Energy Outlook 2022, 2022) of which the majority of them are located in the rural regions of sub-Saharan Africa. The sciences of how the dynamics in the global energy systems before and during the global pandemic, war and energy crises interact to create social, economic, political, social-ecological systems threats and opportunities, in the face of existential uncertainties should be informed by our current empirical appreciation of the association correlation between energy access and social, economic and environmental outcomes. At least, if causation remains challenging to establish.

The empirical interface between electricity consumption and social and economic development has been widely explored in the Energy-Growth Nexus literature established (Afonso, Marques, & Fuinhas, 2019; Hajko, Sebri, Al-Saidi, & Balsalobre-Lorente, 2018; Hirsh & Koomey, 2015; Hızarcı & Zeren, 2020; Menegaki, 2021; Sarkodie & Adams, 2020a, 2020b). However, the question of how rural and urban electricity access heterogeneity affects economic growth, as measured in terms of per capita national income, appears under-researched, with unique reference to Ghana. Meanwhile, recent normative arguments in development studies have conceptualized the lack of electricity in low-income economies as 'energy poverty' (Aristondo & Onaindia, 2023; Hasheminasab, Streimikiene, & Pishahang, 2022). In addition, the growing evidence of energy resources scarcity in the face of demand expansions and environmental concerns means not only physical access to electricity infrastructure that should be policy thinking, but the efficiency of the transmission and distribution of power generated to various end-users must equally be part of sustainable electricity market reforms.

Ghana's renewable electricity source for rural, urban and peri-urban populations is mainly from HEP (hydroelectric power) generated largely from an artificial dam at Akosombo, which was built in 1965 (Boadi & Owusu, 2017) and other mini dams, including the Bui and Kpong dams. However, since the 1980s, Ghana's electricity supply systems have been facing intermittent shocks due to factors such as mismanagement and corruption (Jamil & Ahmad, 2019; Yakubu, Narendra Babu, & Adjei, 2018) climate change and variability (Boadi & Owusu, 2017; Hidalgo et al., 2020; Turner, Hejazi, Kim, Clarke, & Edmonds, 2017) and population growth and urbanization (Ackah, 2016; Asumadu-Sarkodie & Owusu, 2016). In particular, the periods 1983/4, 1997/98, 2003, 2006/7, 2013 to date, Ghana continues to suffer from serious electric load shedding mainly because of water shortage owing to droughts or changes in the patterns of precipitation befalling the tropical world largely, including the entire Sub-Saharan Africa regions. This climatological-induced electricity supply instability appears to reflect the projection that core sectors such as energy, water, agriculture, health, transport, and others will be severely hit (or already hit) by climate variability, especially in developing regions with weak and inequitable infrastructure systems (Parry, Canziani, Palutikof, Van der Linden, & Hanson, 2007).

As a result of the above (given other social, economic and political challenges), it was challenging to develop the economy in terms of critical infrastructure systems such as electricity expansion – a prerequisite for meaningful industrial take off, healthcare services delivery, agriculture mechanization, etc. that are needed for pragmatic structural transformations in the economy. Due to initial slow development of electricity infrastructure as an important social overhead capital countrywide, there is inevitably a growing gap between supply and demand, with the country almost failing to meet the growing demands, hence an intermittent acute load shedding over the past decades. These load shedding and intermittent power outages are estimated to have resulted in over USS$3 billion of economic activities, and thousands of jobs losses associated with the electricity supply crisis (Nduhuura, Garschagen, & Zerga, 2020). Meanwhile, the role of quality and affordable electricity is neatly correlated with multiple social-economic development indicators, including but not limited to human resource development (Hickey, 2017) poverty alleviation (Murshed & Ozturk, 2023) etc. It is within this context that the lack of access to electricity has been treated as a form of poverty or basic good deprivation (Lin & Okyere, 2020; Xiao, Wu, Wang, & Mei, 2021).

According to Ghana's official Multidimensional Poverty Index (MPI) Report published in 2020 by the Oxford Poverty and Human Development Initiative (OPHDI, 2020) approximately 20% of the Ghanaian population were deprived of electricity access between 2016 and 2017 based on the 2016/17 Ghana Household Living Standard Survey Seventh Round (GLSS 7). The report shows that sanitation and health insurance access, representing 86.8% and 64.4%, respectively, were the indicators in which most Ghanaians were deprived of, irrespective of their poverty status. Importantly, the observed geographical distributions, the rural-vs-urban and the North-vs-South dichotomies of poverty headcounts give ample reason to speculate how the nature of electricity infrastructure distributions continues to influence the level of socio-economic development between the urban and rural and North-South populations. Following the literature on the aforesaid, it appears that all the twelve indicators of MPI (with clean energy access in its own merits) in Ghana, including sanitation, health insurance, potable water access, etc. are directly or indirectly linked to the state of affordable, reliable, environmentally friendly access to electricity supply (Acheampong, Erdiaw-Kwasie, & Abunyewah, 2021; Chevalier & Ouédraogo, 2013; Khribich, Kacem, & Dakhlaoui, 2021; Raghutla & Chittedi, 2022; Wang, Bui, Zhang, Nawarathna, & Mombeuil, 2021).

However, until time of development thinking, the role of electricity access might have not influenced neoliberal policymakers generally, and specifically in Ghana, as compared with macroeconomic indicators – such as gross domestic product (GDP) growth, inflation, employment (unemployment), balance of trade, etc. in the mainstream economics and development models. For instance, in the preface to their book: 'Energy and the Wealth of Nations: An Introduction to Biophysical Economics', the authors mentioned: … *there are four books on our shelf that have the words, more or less, 'wealth of nations', … Curiously, none has the word 'energy' or 'oil' in their glossary (one trivial exception), and none even have the words 'natural resources* (Hall & Klitgaard, 2018).

However, recent decades have seen a growing normative-empirical convergence in the addressing the need to integrate energy infrastructure services as critical inputs into household and firm levels production functions (Hu & Hu, 2013a, 2013b; Willett & Naghshpour, 1987). The COVID-19 global pandemic has appeared to serve as a re-awaking call for researchers to investigate above relationship in high- and low-income economies (Barbier & Burgess, 2020; Carfora, Scandurra, & Thomas, 2021; Li, 2022; Mastropietro, 2022; Mastropietro, Rodilla, & Batlle, 2020). And, as the growth-development model remains dominant in both theoretical and empirical discourses, the role of electricity access, especially in low-income economies needs to be constantly interrogated to inform policies.

2. BRIEF LITERATURE REVIEW

2.1. Theoretical and Conceptual Lens

The general theoretical framework of this paper is modern energy access and economic growth. We defined energy from classical physical science perspective in the Dictionary of Energy as '*capacity to do work*' (Beck, 2014). Economic growth is defined from ecological economics as a 'quantitative increase in size or an increase in throughput'[2]. The choice of the definition of economic growth to draw the reader's attention to current on literature pertaining to sustainable development that emphasis the growing social-ecological systems and environmental degradation consequences of economic growth and energy use (Filho et al., 2021; Kurniawan, Sugiawan, & Managi, 2021). The literature posits that unlike the dominant neoclassical economics that placed emphasize on the role of labour, land, and capital as the key inputs into the production technology (Hackman, 2008) ecological economists, on the other hand, judged energy and material flows at the centre of growth and development discourses. For instance, an aspect of ecological economics that seeks to integrate the methods and principles of physics into economic analysis: econophysics (Hunter, 2016) strongly angled on the assumption of human-made and natural capital substitutability, including exosomatic energy which offers a limited role of attenuating resource scarcity. In addition, by integrating energy as an input into the mainstream growth frameworks offers ample understanding of some limitations of the long-held role of technical progress in economic growth literature (Hall, Lindenberger, Kümmel, Kroeger, & Eichhorn, 2001).

By a way of departure, however, scholars such as Stern and Kander (2012) remodelled the classical Solow growth model by building in energy as an input of production. These researchers argued that the influence of energy on economic growth is largely contingent upon its degree of scarcity. Given that the traditional Solow model theorizes economic growth, as a function of labour and capital, and long-run sustainability of growth as a function of technical progress, the energy augmented version of the thereof posits that energy (electricity for this paper) drives growth on the assumption that it is its scarcity is comparatively high (Best & Burke, 2018; Burke, Stern, & Bruns, 2018).

Consistent with the literature, the empirical results of recent energy-economic growth nexus can be theoretically put under the following sub-headings:

The growth hypothesis probably emerged from the empirical work of Kraft and Kraft (1978) which posits that there exists a positive relationship between economic growth and energy consumption. This implies that, there exists a unidirectional causality which runs from energy use to economic growth. The main argument here is that energy is a key variable in economic growth and development process, *ceteris paribus*. Therefore, lack or limited supply of energy has been judged as an underpinning factor responsible for slow economic growth and hence, underdevelopment, all things being equal. Based on this assumption, studies, e.g.; (Alfalih, 2022; Quacoe, Wen, & Quacoe, 2020) report a unidirectional causality running from energy use to economic growth.

The conservation hypothesis follows a line of argument that economic growth is independent of energy consumption. It elaborates, there is a unidirectional causality. That is, the causality runs from economic growth to energy consumption. Following this school of thought, the null hypothesis is that economic growth is independent of energy consumption. As a consequent, energy conservation and public policy can be executed by policymakers without attenuating the desired level of economic growth. Research findings by Hung-Pin (2014) confirmed this hypothesis empirically.

The feedback hypothesis, on the other hand, holds the view that there is a bidirectional relationship between energy consumption and economic growth. This hypothesis connects, at least, logically (may not be valid) well with the last stage of economic growth suggested by Rostow (1991) - the age of mass consumption in his Linear Growth Theory. Historical economic and energy data conservatively affirmed the above, as there is nearly a neat linear relationship

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[2] Throughput refers to the flow of raw materials, including energy from local, national, regional and global systems global ecosystem, through the economy, *and back to the global ecosystem as waste* (Daly & Farley, 2011).

between economic growth, energy consumption and a general increase in social metabolism. Following the direction of recent literature, it is fair to conclude that the feedback hypothesis cements the current debates on energy-growth nexus, energy-poverty nexus and the '*X-variable growth nexus*'.

The neutrality hypothesis suggests that there is no relationship between energy consumption and economic growth. This line of argument insists that even if there is any relationship, it is rather weak. Some empirical works confirm this hypothesis recently, including (Konuk, Zeren, Akpınar, & Yıldız, 2021; Pata & Aydin, 2020).

Notwithstanding the central role that theoretical scholarships continue to play in our renewed interest in appreciating multidimensional benefits of clean energy access, empirical studies recently on energy-economic growth nexus have also substantially added to the discourse on the various benefits associated with modern energy access such as electricity infrastructure services extensions. With regard to electricity, particularly in low-income economies, recent debates have focused on such issues as equity of access, reliability of supply, affordability, with line transmission losses scarcely discussed. The above issues are discussed in the next section.

2.2. Electricity Access and Growth Nexus

There is no single universally accepted definition for the concept of 'energy access'. However, the International Energy Agency (IEA, 2020) suggests that electricity access can be understood as.

> *… a household having initial access to sufficient electricity to power a basic bundle of energy services – at a minimum, several lightbulbs, phone charging, a radio and potentially a fan or television – with the level of service capable of growing over time.*

IEA (2020) position points economic theoretical reasoning that electricity access is not needed for its own right, but the services that electricity infrastructure can provide to meet human needs at micro, meso-and macro levels. Thus, electricity access, like other forms of energy fuels constitutes a derived demand (Bhattacharyya, 2019). A non-technical, and for that matter the political economy of the recognition of electricity infrastructure services as a bedrock of structural social and economic transformation is Lenin's illustrious observation that communism is '*electrification plus Soviets*' (Lenin Collected Works, 1920). Indeed, Lenin was emphatic that 'without a plan of electrification, we [the Soviet Union] cannot undertake any real constructive work' [probably meaning development projects] (Ibid.).

Although Lenin's proposition appears politically and ideologically loaded – given the time, his view on the role of electricity in promoting growth and development associates well in the world of now with the in which the international community is calling for universal access to electric energy to promote growth and development, particularly, in low-income economies such as those in the SDG 7. In this light, economists seem to acknowledging the nexus between generally, modern energy access and economic growth and multidimensional well-being over the past few decades. Thus, electricity access at micro, meso-and macro levels and economic growth nexus continues remains on top as a critical growth and development determinant, *ceteris paribus*. Using System Generalized Methods-of-Moment System (GMM), Lawal, Ozturk, Olanipekun, and Asaleye (2020) examine the empirical relationship between economic growth and electricity consumption in sub-Sahara African economies for the period 1971 and 2017. These researchers found positive and significant relationship between electricity consumption and growth. In addition, their findings confirmed the feedback hypothesis – that is, a bidirectional relationship between electricity consumption and economic growth in selected sub-Saharan Africa economies. By employing Probit and Instrumental Variable quantile regression models, Khandker, Barnes, and Samad (2012) assessed, '*the welfare impacts of household access to grid electricity*'. These researchers found that grid electrification has positive and significant impacts on household income, expenditure, and education. Their findings revealed that the household gain in total income because of electricity access was as high as 21%, with a 1.5% percentage point decrease in poverty annually. These empirical findings are supported by meso-and micro studies in other low-income and emerging economies which proved higher expected social-economic activities and incomes conditioned on electricity to access (Bensch, Kluve, & Peters, 2011; Khandker, Barnes, & Samad, 2013; Rao, 2013). Rao (2013) in particular, employed multivariate regressions model to the India Human Development and Survey. This research confirmed a prior analysis on economic benefits emanating from the expansion of electrification projects in underserved communities. In the case of Rwanda, Bensch et al. (2011) estimated the association between rural electricity access and multiple socio-economic development indicators. Their findings point to a robust positive relationship between electricity usage and such variables as household income, and children study hours at home. In Vietnam case, non-energized communities were reported marginally and on different socio-economic variables, including, income and education indicators and the effects on rural electrification terms as a result of expansions in the electrification of locations within catchment areas as the case of Vietnam (Khandker et al., 2013). These researchers' findings are interesting as they reported differential returns to electricity access on such indicators as farmers vs non-farmers; boys vs girls in the case of educational outcomes; poor vs rich households, etc. Last but not the least, in analyzing the impact of population electricity access, female education, and health expenditure on female health outcomes, Rahman and Alam (2021) find from ten South-East Asian economies that

> *Access to electricity, female education rate, public health expenditure, economic growth, and immunization rate, all have a positive effect on female life expectancy at birth, and a negative effect on the female adult mortality rate* (Rahman & Alam, 2021).

Holding other factors constant, these researchers approach to estimating the role of electricity on such qualitative macro health outcomes provides is practically superior to other analyses of population electricity access and quantitative outcomes, such as GDP per capita in this study. However, the direct relation between economic growth (quantitative reasoning) and economic development (qualitative reasoning) has been critically debated (unabated) by ecological economists, including the role of energy, such as in (Daly & Farley, 2010).

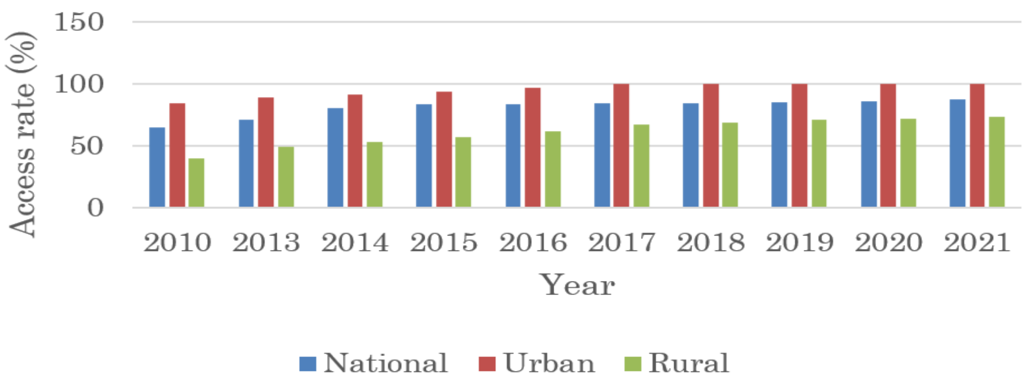

Figure 1. Proportion of population with access to electricity in Ghana (2010–2021).
Source: National Energy Statistics (2022a).

Though empirical discoveries from the reviewed literature indicate multidimensional benefits electricity across different economies, the questions of '*inequality*' and '*inequity*' in terms of the distribution the reported benefits remain [the] defining characteristics within and across nations, especially, in low-income economies (McCauley, Grant, & Mwathunga, 2022) (see Figure 1 for Ghana's case of inequality in electricity access rate). Economies in the sub-Saharan region faced with lack of quality electricity services, coupled with existential rising prices, are confronted with negative growth and, thus, making further expansion of reliable electricity, free from power outages is vital for the stability and economic development (Andersen & Dalgaard, 2013) giving other factors. For example, a view exists that '*reliable supply of electricity free from power outages is vital for the stability and economic development of any country*' (Letcher, 2019). A study conducted by Moyo (2013) in Tanzania, Uganda and Zambia at firms' levels concludes that surged in power outages were detrimental to productivity growth.

With specific reference to Ghana, research shows ailing social-economic impacts of prolonged and intermittent electricity power outages. For instance, Apenteng, Opoku, Ansong, Akowuah, and Afriyie-Gyawu (2018) reports a positive and significant relationship between the frequency of electricity power outages and 'infant mortality, with the risk for mortality estimated to increase by 43% for each day the power was out for over two hours' [p. 1]. The findings support Irwin, Hoxha, and Grépin (2020) who used social-ecological modified model and identified four main levels: individual; household; community and institutional in which unreliable electricity show high probabilities undesirable social-economic outcomes. Their findings support that poor electricity power reliability was negatively associated with an increasing morbidity and mortality; low quality of healthcare and reduced utilization of health services. Ghanaians have termed intermittent power outages and load shedding as '*Dumsor*'[3]. Energy analysts believed that between 2013 and 2016 alone, Ghana lost approximately US$3 billion in economic activities due to '*Dumsor*'. Poor quality of electricity in Ghana, and for that matter in many regions sub-Saharan Africa accounts such undesirable macroeconomic indicators outcomes such as high interest rate, high unemployment particularly in the industrial subsector (George, 2012) low productivity and less competitiveness (Ackah, Adjasi, & Turkson, 2014) low firm's sales (Cole, Elliott, Occhiali, & Strobl, 2018) and criminal activities that survive in darkness (Sarkodie & Adams, 2020b). In addition, evidence shows that charcoal fuel as solid biomass is largely used by households in Africa as a security for unreliable electricity supply (Sarkodie & Adams, 2020b). It is important to mention that mass unsustainable charcoal or firewood consumption is partly responsible for forest depletion and other forms of environmental degradation such as aboveground CO_2 emissions (Sedano et al., 2016; Sulaiman & Abdul-Rahim, 2022).

Recent discussions on energy and development nexus centred on households deprivation in multidimensional benefits from electricity infrastructure services in African, especially in the sub-Saharan regions, is worrying when we observe historical experiences of countries that have achieved substantial successes in social economic and technology via equitable and cheap electricity access, and sustained enhanced quality (Cook, 2012). A possible theoretical explanation is that electricity is a critical component of capital accumulation process – an important social and economic infrastructure system to augment future output and income (Todaro & Smith, 2020). Recent studies by the World Bank show that equitable access to electricity integrated with improved agricultural development in rural communities are cardinal levers in poverty reduction (Bank, 2017) giving other equally important factors. Beyond economic growth, Kumar (2018) finds that access to electricity was correlated with better education achievement (Kumar, 2018). Kumar's work ultimately shed further light on how '*pre-exiting sociocultural processes mediate development outcomes of energy access*' [p. 1]. In Ghana, the spatial distribution of poverty – between rural-urban, and north-south are neatly skewed with inequality of electricity network distributions and access (Amanfo, 2022). The urban-rural inequality in terms of households with access to electricity infrastructure services can be theoretically explained as 'urban bias' in development observed by Lipton (1977) in development policy decisions.

2.3. Electricity Consumption and Economic Growth

Accredited to the seminal work of Kraft and Kraft (1978) the analysis of energy-economic-growth nexus by employing energy consumption as a proxied variable marked the beginning of detailed analysis of how energy commodities (exosomatic energy) use as against merely how access to electricity augments economic growth. The underlying current of the debate here is that access to energy *may* not necessarily guarantee utilization. This is because, accessibility could be constrained by challenges such as reliability, affordability gap and quality of services, particularly in the context of developing economies. The extant literature, Kraft and Kraft (1978) opines that in the context of the United States of America, gross national product (GNP) contributed to energy consumption. Further analysis which proceeded Kraft and Kraft (1978) work indicated different results across time and space, probably due to fundamental production and consumption structural variations and different stages of development in the studied economies (Abbasinejad, Gudarzi Farahani, & Asghari Ghara, 2012; Sebri & Abid, 2012).

Polemis and Dagoumas (2013) found a bidirectional relationship between electricity consumption and economic growth in Greece by using the Vector Error Correction Model (VECM) and Johansen's cointegration. The study reported

[3] *Dumsor*" literally means "switching – of-and switching on in Twi dialect of Ghana.

that a 1% increase in national income was associated with an average of 1.6% increase in the consumption of electricity, holding other factors constant. On the other hand, Acheampong, Dzator, and Savage (2021) analyzed the causal relationship between electricity consumption, economic institutions, economic growth, carbon dioxide for the period 1960–2017 based on generalized method of moments-panel vector autoregression (GMM-PVAR) technique. Their results did not establish any relationship between electricity consumption and economic growth – confirming the neutrality hypothesis discussed previously. However, Acheampong, Erdiaw-Kwasie, et al. (2021) might have confirmed the earlier arguments in (Abbasinejad et al., 2012; Sebri & Abid, 2012) – that the directionality of economic growth and energy consumption varies across economies in the sub-Saharan regions.

Therefore, the growing debates pertaining to energy consumption-economic growth nexus vary spatially, and are also contingent on the periods of analysis and the kind of covariates applied. Notwithstanding, a few studies, however, have converged, in conclusion, that energy consumption (usually in aggregate terms) points to a positive association with economic growth. Whereas empirical debates on the exact relationship between economic growth and energy consumption appears unabated, the definition of economic growth, as provided by some ecological economists as '*a quantitative increase in energy-material throughput*' (Daly & Farley, 2010) descriptively points to the energy-economic growth nexus argument, and interactive degrading environmental pollution or energy-material-growth-entropy nexus based on the Second Law of Thermodynamics (Daly & Farley, 2010; Kümmel & Lindenberger, 2020). This view from ecological economists' perspective is not in both empirical and theoretical dispute, at least, among the energy-economic-nexus scholars.

2.4. Relationship between Electricity Transmission Losses and Economic Growth

Electricity transmission and distribution losses, otherwise known as *line losses* (Wu & Ni, 2015) is defined as '*all losses due to transport and distribution of electrical energy and heat*' (IEA, 2019), in a period of time. The importance of introducing line losses in this paper is to incorporate the effect of electricity infrastructure network quality and efficiency on economic growth. This is an important question, especially in low-income economies because quality, efficient and equitable infrastructure networks systems are (giving other equally important factors) key to addressing multidimensional poverty (Best & Burke, 2018).

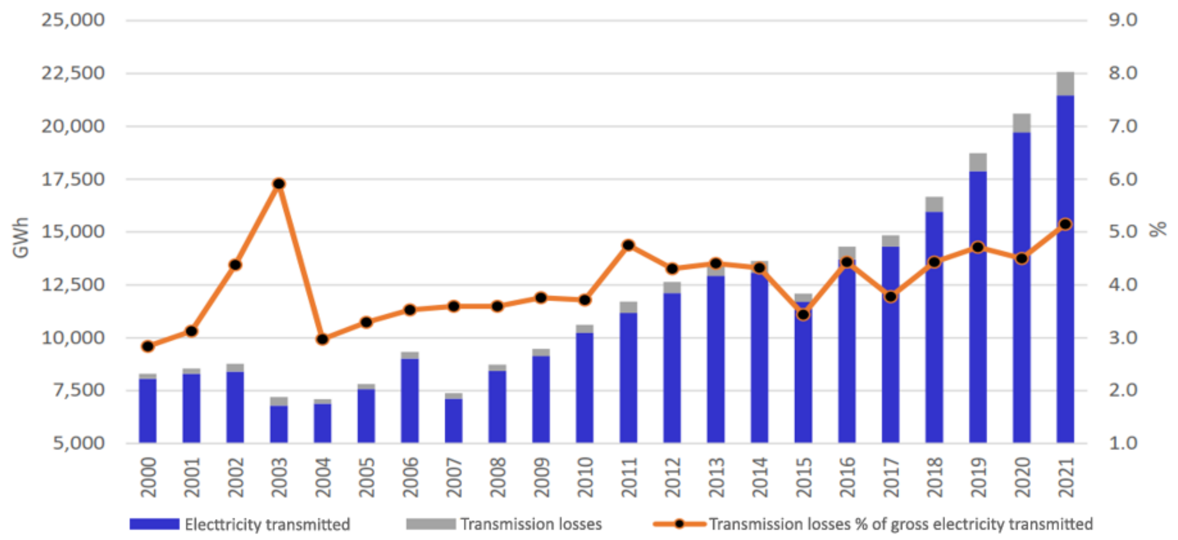

Figure 2. Electricity transmitted and transmission losses (2000–2021).
Source: Based on annual data from National Energy Statistics (2022b).

Blimpo and Cosgrove-Davies (2019) posit that whereas access to electricity is essential, issues of reliability is imperative for realizing higher impact of the access; as poor-quality results in notable economic losses in the African regions. It is held that line losses exemplify inefficiency in electricity infrastructure systems (Zhivov & Case, 2017).

And electricity transmission losses can be explained by multiple factors, including, but not limited to the type and age of equipment, the extent of periodic investments, corruption or poor governance, and the type of maintenance policy employed (Adams, Atsu, Klobodu, & Richmond, 2020). While the causes of line transmission losses are multifaceted, the phenomenon can negate growth and equitable share of benefits associated with electric power infrastructure services. In addition, electricity transmission losses are also detrimental to social-ecological systems' health as it can result in greenhouse gas (GHG) emissions (Zhivov & Case, 2017) especially carbon dioxide, the major contributor to anthropogenic induced climate change (Ibid.). Figure 1 shows electricity transmission losses as a percentage of total electricity transmitted from 2000 to 2021.

According to Energy Commission of Ghana report of 2022, the total electricity power transmitted grew from 8,067 GWh from 2000 to 21,466 GWh in 2021. This represents about 166% growth, while electricity transmission and distribution losses increased from 229 GWh in 2000 to 1,076 GWh in 2021, indicating approximately 368.9% increase. Between 2020 and 2021, the total system transmission losses increased by 21% (National Energy Statistics, 2022b) (see Figure 2).

Policy makers and major key stakeholders need to appreciate the existential interactive social, economic and environmental implications of the increasing phenomenon of electricity transmission and distribution losses to achieve equitable, resilient and sustainable infrastructure networks services as proposed in the SDG 9 (Nasrin, 2020). This is even more important as Ghana's economy during the time of writing this paper is either bankrupt or nearly so, facing unprecedented utility costs (including electricity) and undergoing domestic debt restructuring. Thus, policymaker should, in the very short-term, minimize 'electric power wastage', and such intervention should be integrated as a critical normative reasoning for the ongoing economic recovery policies in the country.

Empirically, a few researchers have tried to analyse the impact of electricity transmission losses on economic growth. By applying bounds testing approach to cointegration and Bai-Perron test in ordinary least squares method, Adams, Klobodu, and Lamptey (2017) find a long-run dynamic relationship between electricity transmission losses, while controlling for gross capital formation, inflation, trade openness and economic growth in Ghana for the period 1971 and 2012. They found that higher electricity transmission losses were negatively associated with GDP per capita growth in the country. Adams et al. (2020) applied autoregressive distributed lag (ARDL) technique to analyze the impact of electricity transmission and distribution losses (ETL) on the economic growth in South Africa for the period 1971–2014. Their findings show a long-run negative relationship between electricity transmission losses and economic growth in South Africa. Their results confirmed the earlier work of S. Adams et al. (2017). Therefore, there are both theoretical and empirical reasons to argue that whereas rural and urban electricity access may address the problem of equity and availability, the problem of efficiency and reliability of supply are also key to sustainable development. As the question of efficiency in the use of energy resources in general is key to addressing the global access gaps, affordability, and reduction in energy-related heat trapping gases (e.g. carbon dioxide) (Smart Edward AManfo, 2021) the electric power subsector considered under the SDG 7 framework needs continuous empirical investigations to provide information to influence energy policies. In particular, in an era in which the contribution of social-science research to the ongoing energy-society-economics-environmental nexus be a wake-up call for researchers (Davidson & Gross, 2018).

3. MATERIALS AND METHODS

3.1. Data Sources

The theoretical and conceptual framework of this paper is *Energy-Growth-Nexus* (EGN), also conceived as '*Energy-Economy Nexus*' (EEN) (Hajko et al., 2018; Menegaki, 2021; Shahbaz, Sarwar, Chen, & Malik, 2017). Against this background this paper estimates the parameters of rural and urban electricity access; and electricity transmission losses (as a percentage of total electricity transmitted) on economic growth in Ghana (proxied by per capita national income) spanning the time 1993 to 2020. Due to the lack of sufficient national time series data, the relevant data for the study were sourced from various sources, including, the World Bank's World Development Indicators and Energy Commission of Ghana's National Energy Statistics. Table 1 shows the variables, data description and sources used in the study.

Table 1. Variables descriptions and sources of data.

Variable	Description and measurements	Source of data
Real GDPC	Real domestic product per capita (In 2011 US$ constant)	Maddison project database Bolt and Van Zanden (2020)
Rurea	Rural electricity access rate (%)	WDI (2022)
Urbea	Urban electricity access rate (%)	WDI (2022)
ETL	Electricity transmission losses (%)	WDI (2022)

The variables employed in this study are gross domestic product per capita (millions in $2011 constant); rural population access to electricity (% of total); urban population access to electricity (% of total) and electricity transmission losses (as % of electricity transmitted).

3.2. Empirical Model Specification

To estimate the long-run and short-run relationship between rural and urban population electricity access (as a % of total transmitted) and transmission losses (% of total electricity transmitted) and their impact on economic growth in Ghana, this study adopted the following popular neoclassical growth model as:

$$GDPC_t = f(Rurea_t,\ \mathrm{Urbea}_t,\ \mathrm{ELT}_t) \qquad (1)$$

Where the subscript t is time identifier $GDPC$ (a proxy for economic growth) is estimated as a function of the rural and urban population access to electricity (as % of the total access) and line transmission losses (as % of total electricity transmitted and distributed). Following Ozatac, Taspinar, El Rifai, and Eren (2018) and Esteve and Requena (2007) the variables in Equation 1 were transformed into the log-log linear form to capture the long-run effect of the regressors and the response variable (economic growth) in Equation 2 as follows :

$$LnGDPC_t = \beta_0 + \beta_1 LnRurea_t + \beta_2 LnUrbea_t + \beta_3 LnELT_t + \varepsilon_t \qquad (2)$$

Where $LnRurea_t$, $LnUrbea_t$, and $LnETL_t$ are respectively, the natural logarithm of GDP per capita (economic growth proxy variable), rural population electricity access (% of total), urban population electricity access (% of total population) and transmission losses (% of total electricity transmitted) ε_t denotes the stochastic (error) term. In empirical economics perspective, parameter(s) estimated from a log-log-linear model is usually interpreted as partial '*elasticity*' (Dimitrios & Hall, 2021). Thus, β_1, β_2 and β_3 are interpreted as a measure of a percentage change in economic growth in Ghana associated with a 1% increase in line losses, rural or urban electricity rate, *other things held constant*. Equation 2 can be estimated using the Ordinary Least Squares (OLS), as applied in some studies (Sulaiman & Abdul-Rahim, 2017). However, Stock and Watson (1993) argue that in general, the estimation based on the OLS results in a 'non-normal distribution'. As such, the results may be misleading. Therefore, the Dynamic Ordinary Least Squares (DOLS) have been suggested to address the weaknesses in the OLS estimator (Ibid.). The study thus applied the DOLS advanced by Stock and Watson (1993); Stock and Watson (2020) based on the estimator's ability to address the drawbacks in the OLS can contain relatively small sample size (as characteristic of time series data in low-income economies) and dealing with potential dynamic biased sources. Furthermore, the DOLS was applied to correct for any possible endogeneity problem associated with the regressors in the model by including the first difference of the leads and lags of the endogenous independent variables. It is worth mentioning that the DOLS estimator has been recently emphasized in energy-economic-growth literature (Menegaki, 2021). Accordingly, the equation establishing the DOLS is specified in Equation 3 as follows:

$$LnGDPC_t = \beta_0 + \Psi X_t + \sum_{i=-\eta}^{i=\eta} \phi_i Ln\Delta Rurea_{t-i} + \sum_{i=-\lambda}^{i=\lambda} \varphi_i Ln\Delta Urbea_{t-i} + \sum_{i=-\theta}^{i=\theta} \tau_i Ln\Delta ELT_{t-i} + \varepsilon_t \text{ ....(3)}$$

Where $\Psi = (\beta_1,\ \beta_2 \text{ and } \beta_3)$, $X = (Rurea,\ Urbea \text{ and } ETL)$, while η, λ and θ are the estimated lengths of the futures (leads) and lags (past values) of the regressors in our models $\Delta Urbea_{t-i}$, $\Delta Urbea_{t-i}$ and ΔELT_{t-i} are respectively, the difference operators of rural, urban population access to electricity rates as a percentage of the total population electricity access and electricity transmission and distribution losses as a percentage of the total electricity transmitted and distributed during the study period. Again, ϕ_i, φ_i and τ_i represent the coefficients of futures (lead values) and lags (past values) of $Rurea$, $Urbea$ and ELT, and ε denotes the error metric. By relying on Equation 3 the Engel-Granger test was applied to verify if the series are cointegrated or multi-cointegrated in nature or otherwise (Mhaka, Runganga, Nyagweta, Kaseke, & Mishi, 2020). All econometric analyses and outputs in this study were carried out using EVIEWS 12 package

3.3. Important Pre-Estimation and Post-Estimation Tests

One standard requirement in statistical time series analysis is that time series variable(s) should exhibit covariance stationarity characteristics. As suggested by Wayne, Bivin, and Robertson (2022) a time series X_t is said to possess a *covariate stationarity* if these three conditions are met:

$$\mu_{x_t} = \mu (\text{i.e., constant mean } (\mu)\ \forall X \in t);$$

$$\sigma^2_{x_t} = \sigma^2 < \infty \text{ (i.e., a constant finite, and constant variance, } \forall X \in t\text{)}, \text{ and}$$

$\gamma_{x_{t1}x_{t2}}$ and $\rho_{x_1x_2}$ being a function of only $t_2 - t_1$ (i.e. the *autocovariance* ($\gamma_{x_{t1}x_{t2}}$) and *autocorrelation* ($\gamma_{x_{t1}x_{t2}}$) between data points, say, X_{t1} and X_{t2} depends solely on the extent to which they t_1 and t_2 are far apart, not where they t_1 and t_2 are in a given time (Wayne et al., 2022). The test of whether a time series X_t meets the above three statistical conditions are commonly performed through unit root tests.

Several unit root tests are available in the literature. However, the Augmented Dickey-Fuller (ADF) unit root test (Dickey & Fuller, 1979) is applied frequently in statistical time series analysis in various fields, including energy-growth nexus in the recent decades. One critical theoretical assumption behind the ADF unit root test is to verify the extent to which a time-series data is determined by a trend (Doloc, 2020; Macro, 2022). The ADF relies on an autoregressive model and optimizes an IC (Information Criterion) over multiple lags. The ADF unit root is often preferred because it can tolerate some form of serial correlation. Therefore, the ADF unit root test can moderate some higher order autoregressive process in the error term (Greene, 2019). If statistical prove of non-stationarity process in the time series is identified, a series of data transformations, such as '*differencing*' ought to be applied, following the literature. In addition, the Engle and Granger (1987); Park's Added Variables (Park, 1992) the Phillips-Ouliaris (Phillips & Ouliaris, 1990) and Hansen Parameter Instability (Hansen, 1992) were used to test the cointegration between the variables for Ghana (see Table 4). The above tests of cointegration have been applied in studies (Chen, Lee, Lin, & Shrestha, 2022; Hasanov, Aliyev, Tashkin, & Suleymanov, 2022; Hundie & Daksa, 2019; Miyan & Miah, 2022) for instance.

4. ECONOMETRIC RESULTS AND DISCUSSIONS

4.1. Unit Root Tests

Econometric and probability theory of unit root require that an important characteristic need to be verified (Berlinger et al., 2015) before running the time series regressions. The unit root diagnostics are needed to evade false specious regressions, therefore getting meaningless outcomes. The null posits the series has a unit root, or is non-stationary. In theory, each of the variable of a time series should exhibit stationarity attributes 'before involving in the model' (Al-Bajjali & Shamayleh, 2018; Patterson, 2011).

Table 2. Augmented Dickey Fuller & Phillips Perron tests results.

Variables and assumptions	ADF t-statistic		PP t-statistic	
At level	**Intercept**	**Intercept with trends**	**Intercept**	**Intercept with trends**
LnGDPC	0.659 (0.988)	1.757 (0.694)	1.276 (0.998)	1.707 (0.718)
LnRurea	2.939 (0.057)	2.926 (0.176)	7.484 (0.000)***	4.294 (0.012)***
LnUrbea	0.834 (0.792)	3.868 (0.024)**	0.834 (0.792)	3.968 (0.024)**
LnELT	1.811 (0.792)	1.328 (0.857)	1.811 (0.367)	1.328 (0.857)
At first difference				
LnGDPC	3.174 (0.034)**	3.319 (0.087)	3.174 (0.034)	3.317 (0.087)*
LnRurea	4.775 (0.000)***	3.312 (0.090)*	4.484 (0.000)***	7.075 (0.000)**
LnUrbea	7.533 (0.003)***	7.740 (0.003)***	12.024 (0.000)***	14.719 (0.000)***
LnELT	5.230 (0.000)***	5.227 (0.003)***	5.413 (0.000)***	5.092 (0.000)***

Note: The asterisks: ***, ** and * represent 1% and 5% and 10% level of significant of rejecting the null hypothesis respectively. The numbers in parentheses () are p-values. Stationarity tests for the series are based on E-Views 12 outputs.
PP stand for Phillips-Perron unit root test.

The ADF test Dickey and Fuller (1979) are employed to diagnose stationarity and provide evidence of the unit root in the series variables. For a counterfactual analysis, the PP unit root test (Peter & Perron, 1988) was used to double-check the ADF results. Unit root diagnosis results are presented in Table 2. The classical ADF unit root test was employed to check if the series are stationary or otherwise, and our pre-test results are presented in Table 2. The 'I(1)-ness' (Stigum, 2015) for all the four variables is confirmed after the ADF and PP unit root tests following the first-differencing of the variables Table 2. $LnELT$ and $LnUrea$ can be interpreted as being stationary in first difference at α = 1% (0.001) using intercept and intercept and trend characteristic in both ADF and PP tests outcomes $LnRurea$ is stationary at α = 10% when intercept and intercept with trends are considered in the ADF test. However, $LnRurea$ it is stationary in first difference at α = 1% (0.001) using intercept and intercept with trend components based on PP test outcomes. Moreover, $LnDGP$ the variables are stationary in first difference at α= 5% and 10% respectively using intercept and constant with the trend for PP test. Finally, the '$I(0)-ness$' of two variables: $LnRurea$ and $LnUrea$ were verified at acceptable statistically significant level. In particular, $LnRurea$ it is in order $I(0)$ at α = 10% with constant using ADF, while in order $I(0)$ at α = 5% and 10% respectively, using intercept and intercept with trends characteristics. Finally, the variable: $LnRurea$ is stationary at level with intercept at α = 10% for ADF test, while stationary at α = 1% and 5% respectively for intercept and intercept with trend characteristics in the case of PP test. The variable $LnUrea$ shows '$I(0)-ness$' at α = 5% with intercept and intercept and trend using both ADF and PP test methods as shown in Table 2. Our pre-tests show nearly the same results. The PP method reasonably supported that of the ADF for all the four variables under study. However, following the literature, we cannot reject the null hypothesis of the ADF stationarity, which is a dataset has *no unit root*, since the *p-values* greater are 0.05 (5%). Therefore, the null should be accepted as an existence of unit root in two of the variables, namely $LnGDPC$ and $LnELT$ at levels. However, the alternative hypothesis for a non-existence of unit root was accepted for the first-difference variables at 1% (0.001) and 5% (0.005) significance levels, following the literature.

Based on the unit root tests results obtained from the pre-estimation, and consistent with the literature, the study applied the DOLS multivariate times regression to estimate long-run equilibrating behaviour of economic growth proxied by GDP per capita; and three regressors: rural and urban electricity access (% of total population) and electricity transmission losses (% of total electricity transmitted). In time series multivariate regression analysis, stationarity of the series is presumed at levels; that is, the series variables are not considered as being zero order integrated (i.e. $(I(0))$. If some of the variables are stationary at levels, using the traditional OLS (Ordinary Least Squares) to estimate the parameters may result in an estimated coefficient(s) that are statistically and empirically appealing, whereas in reality, there is no short- or long-run co-integration between the regressors and regressand as the variables may deviate from an equilibrating state (Huang & Petukhina, 2022; Marcus-Burnett, 2022). Accordingly, applying the traditional OLS may be highly susceptible to a spurious-misleading results (Jalil & Rao, 2019; Washington, Karlaftis, Mannering, & Anastasopoulos, 2020). Theoretically, a series with a unit root means it is unstable (unpredictable) and thus, may not be efficient for univariate and multivariate time series models.

Set against the above, a commonplace is to apply data transformations, including differencing the series data to undo spurious regression outcomes due to cointegration[4]. Since our pre-tests demonstrate that some of the variables are in $I(1)$ order, we have at least a theoretical reason to refrain from the use of the traditional OLS. This is because the $I(1)$ order variables are less likely to meet a constant behaviour assumption strongly held by the OLS estimator.

Table 3. DOLS results.

Variable	Coefficient	Std. error	T-statistic	Prob.
LnRurea	0.527	0.118	4.457	0.001***
LnUrbea	0.206	1.012	0204	0.843
LnETL	-0.073	0.038	-1.937	0.082*
C	5.215	4.208	1.239	0.244
R-squared	0.975	Mean dependent var.		7.879
Adjusted R-squared	0.945	SD dependent var.		0.260
S. E. of regression	0.061	Sum square residual		0.037
Long-run variance	0.004			

Note: * and *** indicate 10% and 1% significance, respectively.
SD and S. E. respectively, denote standard deviation and standard error of regression.

Moreover, the results of the unit root pre-tests are imperative to the empirical model estimations, and because some of the series are in $I(1)$ order, there might be a long-run nexus between the regressand and regressors notwithstanding the fact that the series can deviate from one another in the short-run analysis (Afees, 2017). The DOLS are presented in Table 3. The results show that, save the variable $LnETL$, rural and urban electricity access rates, $LnRurea$ and $LnUrbea$ respectively, are positively correlated with economic growth in Ghana for the period 1993 to 2018. However, there is no statistical evidence to reject the null that the coefficient of $LnUrbea$ is not different from zero. In particular, the results show that a 1% increase in the rate of urban population electricity is associated with about 0.21% of GDP growth, holding other variables constant, but the associated $p-value$ >0.1. Although this result is not statistically significant, it is consistent with the findings of Rehman, Deyuan, Chandio, and Hussain (2018).

who applied autoregressive dynamic lag model to Pakistan's data from 1990 to 2016 and find that urban population access to electricity promote economic growth in terms of the direction of association. In addition, in the case of China, Milin, Mungiu, Rehman, Chirtoc, and Ecobici (2022) find a long-run positive and statistically significant impact of total population access to electricity, urban population access to electricity and energy consumption on economic growth.

[4] Interesting reader may read detailed information from "MathWorks Econometrics Toolbox™ User's Guide", 2022, p. 62

However, Mhaka et al. (2020) obtained a contrary result from the DOLS estimator model in which urban the population electricity access rate was found to be negatively associated with economic growth in the case of Zimbabwe. Some meta-analysis on this subject matter is needed to clarify possible sources of mixed results. Interestingly, however, the variable $Lnurea$ has a significant association with economic growth in Ghana, *holding other factors constant*. Specifically, a 1% increase in rural electrification rate is associated with about 0.52% increase in economic growth in Ghana from 1993 to 2018, *ceteris paribus*. Once again, this result is consistent with the empirical work of Rehman et al. (2018) . The findings suggest empirically that rural population electricity access plays a critical role in economic growth relative to urban access rate in Ghana. This finding appears confirming the work of Lewis and Severnini (2020) claim that

> *in the short run, rural electrification led to increases in agricultural employment, rural-farm population …for the long run, rural counties that gained early access to electricity experienced increased economic growth that persisted for decades after the country was fully electrified.* [Emphasis added].

Again, the findings reveal that the variable $LnETL$ has an inverse relationship with GDP per capita in the period of study, as efficiency theory suggests. A 1% increase in the electricity transmission losses as a percentage of the total electricity transmitted was associated with a decrease in GDP per capita by 0.074%, *holding other variables constant*. The result is statistically significant at 10% level. This result is consistent with Adams et al. (2020) using data from South Africa, and find that after controlling for foreign direct investment, gross capital formation and financial development, a 1% increase in the electricity transmission losses was collated with a 0.66% and 3.79% decline in GDP in the short-run and long-run respectively Lewis and Severnini (2020). Adams, Klobodu, and Lamptey (2017) by employing the ADRL cointegration method to estimate the short-run dynamic relationship between electricity transmission losses in Ghana for the period 1971–2012 confirmed that a 1% increase in the electricity transmission losses is associated 'an increasing negative effect on GDP per capita' (Adams et al., 2017). Furthermore, Adams et al. (2020) also find that a 1% increase in electricity transmission losses was associated with a decrease in economic growth from 3.8% to 2.2%, *holding other factors constant*.

According to Aburn and Hough (2015) electricity transmission losses, akin to '*powe*r wastage' in the grid power sector is hardly mentioned in the global efforts to cut down energy-related CO_2 emissions. Whereas available empirical literature appears focusing on the economic costs (monetary costs) of electricity losses, an interesting recent scientific understanding is that the phenomenon is also associated with increasing greenhouse gas emissions, especially, CO_2 (Surana & Jordaan, 2019) and also, might have been detrimental to energy efficiency programmes. In addition, electricity line losses are, technically, a function of the extent of the electricity infrastructure network systems' efficiency and resilient Adams et al. (2020). Thus, a rise in the thereof, is a presumption of a weak and inefficient electricity infrastructure network system. A practical possible implication of these findings is that policymakers will maximize both social and ecological systems benefit in Ghana by optimizing each component of the electricity transmission and distribution processes through such activities as research and development and learning from the best practices from peer countries. Again, by reasoning from complex thinking perspective, it is reasonable to appreciate that increasing line losses amount to increasing entropy, and could lead to increasing aggregate ill-fare. Thus, beyond socio-technical reasons, there is a moral reason to minimize inefficiencies in the transmission and distribution of the electric power in Ghana, as the same, may maximize societal welfare at micro, meso-and macro levels. All things being equal.

Further, the results of four long-run co-integration relationships between the variables: the Engle and Granger (1987); Park (1992) Added Variables, the Phillips and Ouliaris (1990) and the Hansen Parameter Instability cointegration tests are presented in Table 4. The null hypothesis for the Engle and Granger (1987) and Phillips and Ouliaris (1990) is that the series are not cointegrated in the long-run. The $p-values$ for both the $Tau-stat$ and $Z-stat$ with respect to these tests are greater than the conventional acceptable 5% and 10%

significant levels, meaning we have no evidence to reject the null of none existence of cointegration between the variables in our estimated model. The Park's Added Variables Test of cointegration rejected the null hypothesis of long-run cointegration between the studied variables, as the result $p-value$ is reasonably below 1% (0.01) significant level. Finally, the Hansen Instability Test result accepted the null hypothesis of long-run cointegration between the variables $p-value > 0.05$. Among the four tests of long-run cointegration between rural and urban electricity access, electricity transmission and distribution losses, and economic growth, only one (Hansen's Instability Test). Using a simple 'majoritarian rule', the researcher concludes that there is no long-run cointegration relationship between the studied variables. Accordingly, the study suggests that, notwithstanding the identification of $I(0)$ in some of the variables, and $I(1)$ for others, we find no empirical reason to claim a possible long-run equilibrium connection between the studied variables in Ghana's context.

Table 4. Results of four cointegration tests.

Test	Engle-Granger	Phillips-Ouliaris	Park's added variable test	Hansen parameter instability
$Tau-stat$	-2.604 (0.664)	-2.708 (0.595)		
$Z-stat$	-8.343 (0.821)	-9.251 (0.764)		
$Chi-square$			15.891 (0.000)	
$LC-Stat$				0.064 (0.200)

Note: 1. Tau and Z – statistic = Engle and Granger (1987) and Phillips and Ouliaris (1990) cointegration tests.
2. Chi-square L_c cointegration tests represent Park's added variables and Hansen parameter instability, respectively.
P-values are presented in the parentheses.

The post-estimation tests show that the regression residual terms, based on the Jarque-Bera test (J-B test), are normally distributed. The J-B test shows the histogram and descriptive statistics the regression residual terms. A common rule is that if the residuals are normally distributed and thus, meets the goodness-of-fit assumption, then J-B statistic should not be significant (Jarque, 2011). The J-B test reported 0.115, with probability 0.944. Since the $p-value$ related to the J-B test statistic is greater than 0.05 (5%) significant levels, it means the null hypothesis of residual terms being normality should be accepted. The normality graph is excluded in the text to save. However, interesting readers who want to visualize the normality graph may request directly from the author,

5. CONCLUSIONS AND POLICY IMPLICATIONS

This paper estimated the effect of rural and urban electricity access on economic growth in Ghana for the period 1993–2018. We pre-tested the stationarity and co-integration features of the series variables to identify long-run relationship between rural and urban electricity access rates, and electricity transmission and distribution losses, as a percentage of the total electricity transmitted from 1993 to 2018. To address possible endogeneity and serial correlation issues in the time series, the Dynamic Ordinary Least Squares (DOLS) was employed to investigate the dynamics of a long-run relationship among the variables studied. Findings from the full model estimated show that rural and urban electricity access, and electricity transmission losses (line losses) have empirical association with economic growth in Ghana using data from 1993 to 2018.

The results suggest that increasing both rural and urban electricity access was positively associated with increasing GDP per capita, *ceteris paribus.* Surprisingly, however, the elasticity of urban electricity access to GDP per capita was not statistically significance in comparison to rural electricity access. The reason for this result is not clear theoretically. However, if future studies further confirm this relationship, then policies and strategies to promote electricity access in urban areas in Ghana should concentrate on promoting 'electricity for productive use' to drive sustainable development, given other relevant conditions. A more detailed analysis would have accounted for a number of other variables and in analyzing the long-run relationship between rural and urban electricity access and economic growth and not only to concentrate on electricity infrastructure expansion. But also, on issues such as the quality of electricity services and addressing matters of affordability gap (Mitra & Buluswar, 2015).

Again, the results show that electricity transmission losses were found to be detrimental to economic growth in Ghana as increasing line losses were found to decrease economic growth after controlling for other variables. From a physical science perspective, line losses happen at every stage of transmission and distribution of electricity. Moreover, electricity transmission losses do not only impose social and economic cost to society. But also a major source of anthropogenic greenhouse gas emissions, especially, carbon dioxide which is emitted through electricity transmission losses. Based on the results of our analysis and the relevant literature supporting the study, three policy implications are suggested.

Ultimately, policymakers and stakeholders in energy and development planning must provide comprehensive norms and frameworks that set a material ground to assess the complexity of electricity transmission and distribution losses on both national output and ecological systems in Ghana. It is not in contention that strategic investment in socio-economic infrastructure, e.g., roads, rail, water supply, information and communication, education, markets, hospitals, legal systems, etc.; which cumulatively constitutes capital stocks in the long-run are all function of reliable, viable, efficient and equitable electricity supply, all things being equal.

Currently, it appears lines losses quantified and embedded in monthly electricity bills paid by various end users, including, households, industries, and transport sector. If line losses are viewed from the perspective of inefficiency and entropy theories, then, there are social, economic and environmental reasons for policy interventions to reduce the annual observed inefficiencies in the electric power sector in Ghana. Also, in a contemporary world with almost zero marginal cost in obtaining data and information regarding the performance of energy sectors globally, any evidence of (in)efficiency of the electricity subsector is an important *signalling* variable to industry players both domestically and abroad.

As our analysis reported, industry players who are aware of the negative impact of electricity transmission losses (*power wastage*) might have lost investment confidence in the economy with high incidence inefficient power supply. Country risks analysts are likely to interpret such information might be interpreted as having a negative correlation with economic/firm levels of performance (Brem, Nylund, & Viardot, 2020) *all things being equal.* With the current meltdown of the Ghanaian economy, coupled with increasing energy prices and inflation more than 50% as the time of writing this paper, the call to ensure efficiency and decarbonization of the energy sector in line with the 2015 Paris Agreement, the Government of Ghana must bring reforms to incentivize the three main electricity energy sub-sectors: the generation subsector (Volta River Authority), the distribution subsector (Electricity Company of Ghana and the Northern Electricity Distribution Company (NEDCo), and the transmission subsector, maned by Ghana Grid Company (GRIDCo)), to provide a framework of estimating social, economic and environmental costs connected with electricity distribution and transmission losses for the short-medium-long-term policy energy sustainability policy programming.

Secondly, it is imperative for policymakers and development partners to continue prioritizing financial flows and investments, in line with the SDG 7.a[5] and 7.b[6] in the energy sector considering the country's population hitting about 30.8 million compared to the current 33.3 million people, and the expansion of the urban, rural and peri-urban economic activities. Against this background, both domestic and international financial resource investments should

[5] SDG 7. states that: "By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology".

[6] According to SDG 7. b, "By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, least developed countries, small island developing States and landlocked developing countries, in accordance with their respective programmes of support", (Huck, 2021).

be dedicated to renovating existing weak infrastructure network systems, including, but not limited to distribution and transmission lines. For example, under the SDG 7.a (1) which provides a framework for international public financial flows in support of clean energy and technologies development in low-income economies, the Government of Ghana has received USD million (in 2019PP), USD922 million (in 2019PP), and USD3 million (in 2019 Purchasing Power Parity (PPP –) in 2000, 2007 and 2019, respectively. as can be observed in the statistics of international public financial flows, predating the global COVID-19 pandemic and Ukraine-Russian conflicts, there appears fluctuations in terms of annual flows, mostly from advanced economies. With the world economies in unprecedented recession, international financial flows are likely to be tumbled (UN, 2021). This provides even further grounds for the Government of Ghana and Independent Power Producers (IPPs) to ensure efficiency and minimize line losses in the electricity sub-sector, in tandem with meeting the egalitarian vision of electricity access.

The Energy Profiles of Districts in Ghana, prepared by the Energy Commission of Ghana, has a comprehensive data on regional and districts distribution of energy resources, including renewables (Energy Profiles of Districts in Ghaana, 2019). The report provides vital information to support diversification of energy resources and production, such as renewables. Diversification of the energy sector is an essential component of energy democracy and decentralization of energy systems, which can provide both social, economic and environmental sustainability for the economy in the long-run energy will immensely benefit the entire nation (Ghana). For instance, in relation to the above proposal, Cook and Elliott (2020) mention that in spite of political, cultural and economic differences among countries in Africa,a single thing that is not in dispute is:

> *Africa has a very large renewable energy potential, which, if properly developed, can help mitigate some of the major social, environmental and economic problems it faces, including rising energy demand and climate change, poor energy access and environmental pollution, while creating sustainable employment* (p. 239).

The above quote provides a comprehensive, at least, at a normative level of public policy thinking, why the issue of electricity line losses should be framed as a national economic, social, political and environmental concerns. And, as further empirical evidence becomes available, such as reported in this study, the Government of Ghana, Independent Power Producers (IPPs) and all stakeholders should aim at addressing closing the electric energy infrastructure services access gaps in tandem with deliberate efforts to minimizing 'power wastages', as both energy poverty and line losses are both detrimental to social-ecological systems. In addition to above, a number of reports, including, International Renewable Energy (IRENA) reports suggest multiple benefits of renewable energy development including healthcare delivery, jobs and environmental protection (IRENA, 2022a, 2022b). Thus, as demand for energy, especially electricity due to urbanization, population growth, industrialization, and rising average temperature which is inducing thermal comfort products, such as air-conditioning in emerging economies (Pavanello et al., 2021) developing and deploying renewable energy technologies are imperative to achieving sustainable growth, ensuring energy systems decentralization democratization, and reducing lines losses due to long-distance transmission and distribution grid systems.

Finally, in the face of post-COVID-19 global pandemic uncertainties, geopolitical instability in major energy producing nations (Russia and Ukraine), rising energy prices globally, it is important that recent perceived and real reports about increasing corruption in the electricity sub-sector should be brought to a halt, or at least, minimized. Some analysts have mentioned that the energy sector, including electricity, is among fertile grounds for corruption incidence, especially in low-income economies (Jiang & Martek, 2021; Junxia, 2019; Sovacool, 2021). Recent econometric analysis in a panel of 47 sub-Saharan economies, including Ghana, between 2002 and 2013, concludes that corruption can substantially reduce technical efficiency, electricity access and income of the electricity industry. A case in point is the World Bank decision to cancel a $190 million grant meant for upgrading the distribution and transmission subsector of the country's electric energy sector due to alleged corruption risks involving the state officials.

In the nutshell, the study recommends that policymakers should fast track decentralization of electricity supply network systems by matching local demand and supply, which consequently, reduces electricity transmission and distribution distances, as long transmission and distribution distances have been cited as a contributing factor to line losses (Jain, Mital, & Gupta, 2021). As a matter of urgency, reforms in the Ghanaian educational systems, especially technical and engineering programmes must be geared purposefully toward the creation of a human resource base to manage the country's energy resources and related infrastructure stocks. Given both normative and empirical evidence is required to close what Romer (1993) has described as 'Idea Gasps' and Object Gaps', in low-income economies giving other equally important factors.

Funding: This study received no specific financial support.
Competing Interests: The author declares that there are no conflicts of interests regarding the publication of this paper.

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