The effect of electricity losses on GDP in Benin

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THE EFFECTS OF ELECTRICITY LOSSES ON GDP IN BENIN

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Abstract

The current study has assessed the losses of GDP caused by electricity losses in Benin over the period 1980-2014. The technique used was the Autoregressive Distributive Lags (ARDL). Results showed that in the long run Benin loses 0.16% of its GDP on average because of electricity losses. Benin is a country which faces important losses of electricity. A financing mechanism of the cost associated with reduction of electricity losses has been proposed in the national policy framework for electricity. By investigating the gain in GDP resulting from a reduction in electricity losses, the current study has assessed the feasibility of such mechanism, and thus contributes to the advancement of energy efficiency policy in Benin.

Key words: electricity losses, GDP, financing mechanism, national policy framework, efficiency, Benin.

1 INTRODUCTION

According to Payne (2010) and Alam (2006), the availability and low costs of electricity will attract investments. Firms will not have to increase their fixed costs by purchasing a generator, as electricity is available and at low prices. Conversely, lack of access, high cost and shortages of electricity will negatively affect investments and the competitiveness of an economy. Firms will prefer to avoid investing in countries where access to electricity is very costly, as the purchase of a generator of electricity will be an additional fixed cost. The performance of the electricity sector has become one of the indicators of the ease of doing business in a country. Without electricity, several sectors of an economy, such as transport, industry, services and agribusiness, will cease to exist. Outages of electricity generate inefficiency in the economy as they increase costs for firms, delay production of goods and services, and harm labour force productivity. Without electricity the health and education system cannot function effectively, and these two sectors are essential in building human capital. As mentioned by the IMF (2015), electricity is an important driver of total factor productivity in an economy. High investments in electrical infrastructure, adequate regulation and good governance in the electricity sector will increase total factor productivity. Conversely, outages and low access to electricity will impede total factor productivity, economic growth and poverty alleviation. This indicates that investments in the electricity sectors should be a priority in all developing countries facing electricity shortages, especially in a country such as Benin where there were several electricity shortages in 1984, 1994, 1998, 2006, 2007, 2008, 2012 and 2013. Benin also faces huge amounts of electricity losses during distribution and transmissions and is ranked 20th in the world and 9th in Africa in terms of electricity losses in 2015 according to US EIA (2018). According to the World Development Indicators (2017), electricity losses include transmission losses which occur between sources of production and sources of distribution, and distribution losses which occur between sources of distribution and consumption's sites. Antmann (2009, p. 5) in a cross-country study defined losses of electricity as follows: "losses refer to the amounts of electricity injected into the transmission and distribution grids that are not paid for by users". In other words, losses of electricity are parts of the electricity supply that do not reach legal consumers. Illegal consumers can steal electricity from the national distribution lines. As reported by Republic of Benin (2008), stolen electricity from the national distribution lines is part of the non-technical electricity losses in Benin. Technical losses of electricity are related to the types of technology used for the transmission and distribution of electricity. Figure 1 shows the history of electricity supply and electricity consumption in Benin. The vertical axis shows electricity supply and electricity consumption expressed in billions of Kilowatt hour (kWh), and the horizontal axis shows years. The gap between electricity supply and electricity consumption represents electricity losses.

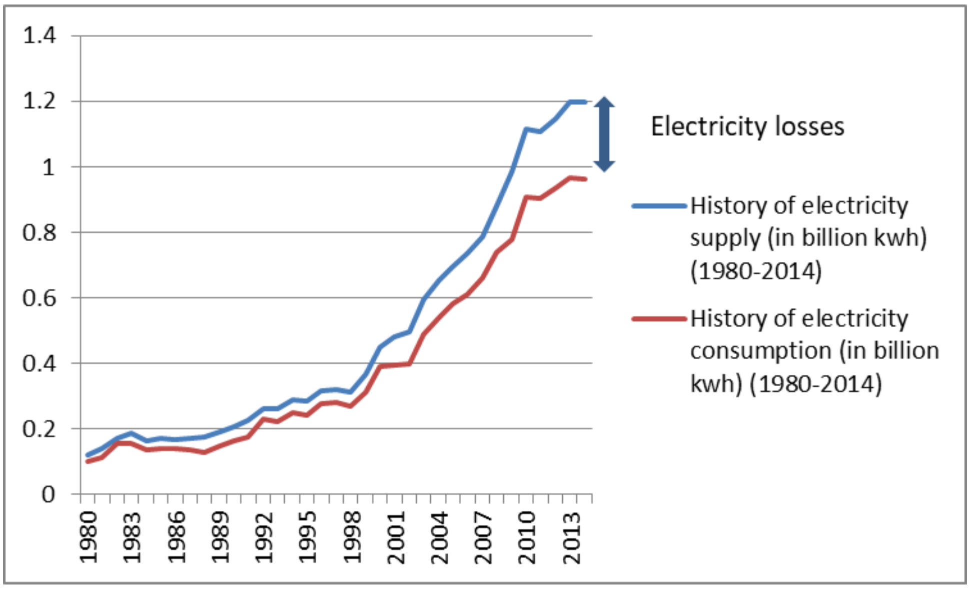

Figure 1: History of electricity supply and consumption (in billion kWh) (1980-2014)

Source: US EIA (2018)

In Benin, losses of electricity ranged between 9.35% and 25.14% of total electricity supply for the period 1980-2015; in 2015, the proportion was 19.358% of total electricity supply (US EIA, 2018), while ECA (2008) suggested that the international maximum target for electricity losses should not exceed 12% of total electricity supply. Total electricity supply in Benin is composed of total electricity generated domestically and imports of electricity. According to the World Development Indicators (2017), losses of electricity in Benin during the periods 1996-2000, 2006-2008 and the year 1994 (periods and year for which data is available on the World Development Indicators website at the time of analysis) have exceeded 50% of total electricity generated domestically. The proportions in 2006, 2007 and 2008 were respectively 81.81%, 56.81% and 61.13% of total electricity generated domestically (World Development Indicators, 2017). In order to improve electricity supply efficiency, the Beninese Ministry of Energy planned to reduce electricity losses by 18% from 2005 to 2010, and by 15% in 2015. However, the actual losses of electricity were far above the targets set by the Ministry for 2010 and 2015: they were respectively 18.56% and 19.35% (République du Bénin, 2008; US EIA, 2018). The cost of these losses of electricity can range between 0.5 and 1.2% of GDP in many countries of sub-Saharan Africa (Antmann, 2009). They constitute a burden for the Beninese economy. The promotion of electricity efficiency on both supply and demand sides is one of the pillars of the second objective of the national strategy for access to electricity. In alignment with such pillar, the Ministry of Energy has targeted a reduction of electricity losses by 14% in the period 2020-2025 in Benin (République du Bénin, 2008). In order to reduce technical losses of electricity, one of the goals of Benin's electricity efficiency policy is the modernization of the distribution lines with electricity-efficient technology. In order to reduce non-technical losses of electricity, Benin targets to implement an emergency plan aiming at fighting corruption and theft of electricity, and at improving the billing system for electricity supply and consumption in the country (see République du Bénin, 2008, pp. 54–55).

In alignment with Antmann (2009), the national policy framework for electricity acknowledged that electricity losses lead to losses of GDP. It then proposed a financing mechanism to be used to fund the cost of activities which will help to reduce electricity losses (see République du Bénin, 2008, p. 65). As reported by the Regulatory Indicators for Sustainable Energy (2018), Benin does not have a direct financing mechanism for the costs of activities which will help to reduce electricity losses. The mechanism proposed by the national policy framework for electricity is an indirect financing mechanism. As reported by the Republic of Benin (République du Bénin, 2008), the recommendation of such mechanism is twofold: first, to use donors or national budget funds to finance the cost of projects which will contribute to reduce electricity losses. Reduction of electricity losses will result in gains in GDP. For instance, an improvement of the billing system of electricity supply and consumption will lower commercial losses of electricity and government revenue generated through the sales of electricity by the SBEE and the CEB will increase. Reducing electricity losses will increase the quantity of electricity that reaches legal consumers, and such increase will lead to an equivalent decrease in importation of electricity. Hence, the cost of importation of electricity will be reduced by an amount equal to the monetary value of gain in electricity resulting from the reduction in electricity losses. Consequently, the government will save some of its revenues that was allocated to cover the costs of importation of electricity. These increases in government revenues constitute gains in terms of GDP as government revenues are included in the calculation of GDP. Second, the indirect financing mechanism described in the national policy framework for electricity proposed to use the gain in GDP resulting from reduction in electricity losses to reimburse the costs of projects aiming at reducing electricity losses. It therefore becomes important to evaluate the effect of electricity losses on GDP. To the best of the writers' knowledge, there is no empirical study on Benin which has investigated the effect of electricity losses on GDP. The current study conducts such an investigation. It will evaluate the effect of electricity losses on GDP; in other words, it will evaluate the gain in GDP resulting from reductions in electricity losses in the Beninese context. In so doing, the study will contribute to assess the feasibility of the indirect financing mechanism proposed by the national policy framework for electricity to fund the costs of reductions of electricity losses. The study will contribute to advancing electricity supply efficiency in Benin and will also add value to the existing literature on energy efficiency in general and electricity supply efficiency in particular. The approach adopted by the study to assess the effect of electricity losses on GDP is first to evaluate the effect of both electricity consumption and electricity supply on GDP. Electricity consumption in the Beninese context is equal to electricity supply minus electricity losses. Then, from this first evaluation, the study will derive the effect of electricity losses on GDP. Prior to all these assessments it is important to understand both theoretically and empirically the relationship between energy/electricity consumption and economic growth.

2 LITERATURE REVIEW

The goal of this study is to examine the effect of electricity losses on real GDP (economic growth). This will be done in a multivariate framework. As argued by Zachariadis (2007) multivariate analyses minimize bias of omitted variables encountered in bivariate analyses. Although control variables will be inserted in the model, the variables of interest remain electricity consumption/supply and real GDP. Electricity consumption can also be defined as electricity supply net of losses (electricity supply minus electricity losses). The theoretical foundation of the relationship between economic growth (real GDP) and energy consumption/supply will be examined first, as well as the theoretical foundation of the relationship between economic growth and its other determinants such as technological advancement, human and physical capital, which in this study represent control variables. Secondly, the empirical literature on the relationship between economic growth and electricity consumption/supply will be examined.

2.1 Theoretical foundation

2.1.1 Relationship between economic growth and energy

Early growth models such as Solow (1956) and Swan (1956) (also called Solow-Swan (1956)) in which technological advancement is exogenous, the endogenous growth model (for instance the

Schumpeterian model), Arrow's (1962) model (which denoted "learning by doing"), and Hicks's (1932) model (which denoted "induced innovation") did not consider energy as a factor of production. However, ecological economists such as Georgescu-Roegen (1971), Cleveland, Costanza, Hall and Kaufmann (1984), Ayres and Warr (2005, 2009), Costanza (1980), Hall, Cleveland and Kaufmann (1986), Hall, Lindenberger, Kümmel, Kroeger and Eichhorn (2001), Hall, Tharakan, Hallock, Cleveland and Jefferson (2003), and Murphy and Hall (2010) argued that energy plays a crucial role in the process of economic development. Following them, scholars in economic geography such as Smil (1994), and authors in economic history such as Allen (2009) and Wrigley (1988) argued that energy was one of the main determinants of the industrial revolution, and it was important to consider it as a factor of production, like capital and labour. According to Wrigley (1998), existing constraints on economic growth, energy supply and the production process were leveraged since new types of energy such as fossil fuels started to be used. He illustrated his statement by comparing the British economy to the Dutch economy. In the Dutch economy, the lack of an ongoing availability of energy was a constraint for capital, while in the British economy such constraint was lifted as the country has coal mines. Consequently, only the British economy experienced the industrial revolution while both economies could have experienced it. Following Wrigley (1998), Stern (2010) and Allen (2009) highlighted the crucial role of energy in the industrial revolution in the British economy. Theorists of ecological economy such as Hall et al. (2003, 1986) and Cleveland et al. (1984) considered that the use of energy has led to an increase in productivity, and consequently economic growth was only caused by an increase in the use of energy.

While Solow (1956) and endogenous growth theorists do not consider energy as one of the important determinants of economic growth, Stern (2010) stipulated that like capital and labour, energy is an important production factor for economic growth. However, Stern (2010) did not agree with the view of ecological economists who stated that energy was the only cause of economic growth: he highlighted the crucial role played by energy for economic growth but explained that capital and labour as well as energy are necessary production factors of an economy. Based on Stern (1997, 2010) and ecological economists' views, economic growth and energy/electricity are expected to have a positive relationship.

2.1.2 Relationship between economic growth, technology, and human and physical capital

The focus here is to explain the theoretical foundation of the relationship between economic growth and some of its main determinants such as technological advancement, physical capital and human capital. These determinants are considered in this study as control variables, as the main variables of interest are electricity consumption/supply and economic growth. According to Solow (1956) and Swan's (1956) neoclassical growth theory, also called the "exogenous growth model", advancement in technology drives economic growth in the long run, while physical capital accumulation drives growth in the short run. Endogenous growth theorists extended the “exogenous growth model” by including human capital stock (Islam, 1995; Mankiw, Romer and Weil, 1992), and productivity factors such as “technological knowledge” and “learning-by-doing” as variables which drive economic growth in addition to physical capital accumulation (Aghion and Howitt, 1992; Lucas, 1988; Romer, 1986, 1990). Throughout the theoretical literature, there is consensus that the stock of human capital, physical capital and productivity factors such as technological advancement constitute important macroeconomic variables which determine economic growth in most countries (Romer, 1986, 1990; Mankiw et al., 1992; Solow, 1956; Aghion and Howitt, 1991; Lucas, 1988; Frankel, 1962). However, throughout the empirical literature, there is no consensus on the sign of the correlation between economic growth and the stock of capital, either physical or human. The sign is not always positive as it depends on the country’s specific context. Some studies (Knight, Loayza, and Villanueva, 1993; Dollar, 1992; Barro, 1999, 2003; Hamilton and Monteagudo, 1998; Anaman, 2004; Fischer, 1992; Acikgoz and Mert, 2014; Anyanwu, 2014; Bayraktar, 2006; Checherita-Westphal and Rother, 2012; Bleaney, Gemmell and Kneller, 2001) established a significant and positive relationship between economic growth and physical capital, while other studies on developing countries (Chang and Mendy, 2012; Most and Vann de Berg, 1996, etc.) established that physical capital proxied by investment can have a significant and negative relationship with economic growth. Some studies (Knight et al., 1993; Anyanwu, 2014; Fischer, 1992; Freire-Seren, 2002; Easterly and Levine, 1997; Chen and Feng, 2000; Bayraktar, 2006) established a significant and positive relationship between human capital and economic growth, while other studies such as Hamilton and Monteagudo (1998) established a significant and negative relationship between economic growth and human capital. In a meta-analysis of the relationship between economic growth and human capital, Benos and Zotou (2014) established that this relationship is not homogenous, it varies according to several factors.

Based on the literature, a positive relationship between technological advancement and economic growth can be expected, while the relationship between economic growth and the stock of capital, either physical or human, can be either positive or negative: it will depend on the specific context of Benin, our country of analysis.

2.2 Empirical literature on the relationship between economic growth and electricity consumption/supply

As said previously, the goal of this paper is to investigate the effect of electricity losses on economic growth. In order to achieve this goal we investigate the relationship between economic growth and electricity consumption/supply. Hence, the focus here will be to review previous studies on the effect of electricity consumption/supply on economic growth. As explained previously, electricity consumption can be defined as electricity supply net of losses (electricity supply minus electricity losses).

2.2.1 Worldwide studies on the relationship between economic growth and electricity consumption/supply

There is extensive literature on the relationship between electricity consumption and economic growth (Acaravci and Ozturk, 2010; Niu, Ding, Niu, Li and Luo, 2011; Ozturk and Acaravci, 2011; Solarin and Shabaz, 2013; Shahbaz, Tang and Shahbaz Shabbir, 2011; Georgantopoulos, 2012; Akpan and Akpan, 2012; Bouoiyour and Selmi, 2013; Shahbaz and Feridun, 2012; Acaravci and Ozturk, 2012). This extensive literature can be divided into two groups: the first group comprises country-specific studies and the second group comprises multiple country studies.

Country-specific studies have established mixed results on the causal relationship between electricity consumption and economic growth. Some studies (Yang, 2000; Jumbe, 2004; Zachariadis, 2007; Tang, 2008, 2009; Odhiambo, 2009a; Lean and Smyth, 2010; Ouédraogo, 2010) established a bidirectional causal relationship between economic growth and electricity consumption. Other studies (Aqeel and Butt, 2001; Altinay and Karagol, 2005; Lee and Chang, 2005; Shiu and Lam, 2004; Yoo, 2005; Narayan and Singh, 2007; Yuan et al., 2007; Chandran, Sharma and Madhavan, 2010; Odhiambo, 2009b) established a unidirectional causal relationship running from electricity consumption to economic growth. Yet other studies (Ghosh, 2002; Narayan and Smyth, 2005; Yoo and Kim, 2006; Mozumder and Marathe, 2007; Jamil and Ahmad, 2010) established a unidirectional causal relationship running from economic growth to electricity consumption. Chandran et al. (2010) established a cointegration relationship between economic growth and electricity consumption for Malaysia. Shiu and Lam (2004) established a cointegration relationship between electricity consumption and economic growth for China.

Multiple countries studies have also established mixed results. For example, Yoo (2006) investigated the causal relationship between economic growth and electricity consumption for Singapore, Indonesia, Thailand, and Malaysia, and established a bidirectional causal relationship between economic growth and electricity consumption for Singapore and Malaysia. For Thailand and Indonesia, he established a unidirectional causal relationship running from economic growth to electricity consumption. Chen, Kuo and Chen (2007) investigated the causal relationship between economic growth and electricity consumption for 10 Asian economies (China, Indonesia, Korea, Taiwan, Thailand, India, Malaysia, the Philippines, Singapore and Hong Kong). They established a causal relationship between electricity consumption and economic growth for five of the countries studied, but found no causal relationship between economic growth and electricity consumption for Thailand, Indonesia, China, Taiwan and Korea. In the case of Malaysia, India, Singapore and the Philippines, they established a unidirectional causal relationship running from economic growth to electricity consumption; while for Hong Kong, they established a unidirectional causal relationship running from electricity consumption to economic growth. Squalli (2007) investigated the cointegration and causal relationship between economic growth and electricity consumption for OPEC countries (Iran, Libya, Algeria, Iraq, Indonesia, Nigeria, Saudi Arabia, Kuwait, Venezuela, United Arab Emirates (UAE), and Qatar). He established the existence of a long-run relationship between electricity consumption and economic growth for all these countries. He also established a unidirectional causal relationship for six of these countries (Libya, Iraq, Algeria, Kuwait, Indonesia and Venezuela), while in the case of Nigeria, Saudi Arabia, Iran, UAE and Qatar, there was a bidirectional causal relationship between electricity consumption and economic growth. Narayan and Prasad (2008) investigated the causal relationship between economic growth and electricity consumption in 30 OECD economies and established the absence of a causal relationship between economic growth and electricity consumption in 19 of these, and the existence of a causal relationship between economic growth and electricity consumption in the remaining 11 economies. Specifically, they established a unidirectional causal relationship running from economic growth to electricity consumption for Hungary, the Netherlands, and Finland. In the case of Italy, Portugal, Australia, the Slovak Republic and the Czech Republic, they established a unidirectional causal relationship running from electricity consumption to economic growth. For countries such as Korea, the United Kingdom and Iceland, they established a bidirectional causal relationship between economic growth and electricity consumption. Narayan and Smyth (2009) established that electricity consumption and exports had a positive effect on economic growth in six economies within the Middle East, while Narayan and Smyth (2005) established a cointegration relationship between electricity consumption, real income and employment in Australia. Yoo and Kwak (2010) analyzed the relationship between economic growth and electricity consumption for a group of seven South American economies, using Hsiao's (1981) approach to the Granger causality test. They established a unidirectional causal relationship running from electricity consumption to economic growth in Colombia, Brazil, Ecuador, Argentina and Chile. For Peru and Venezuela, they established the absence of a causal relationship and the evidence of a bidirectional causal relationship between economic growth and electricity consumption. They also established a cointegration relationship between economic growth and electricity consumption for Venezuela and Columbia. Ozturk and Acaravci (2010) investigated the causal relationship between economic growth and electricity consumption for some European countries, and established the absence of a causal relationship between economic growth and electricity consumption for Bulgaria, Albania and Romania, and a bidirectional causal relationship between economic growth and electricity consumption for Hungary. Acaravci and Ozturk (2010) investigated the long- and short-run relationship between electricity consumption and economic growth for 11 Middle East and North African economies. They established a cointegration relationship for four of these economies: Oman, Egypt, Saudi Arabia, and Israel. However, for Syria, Iran, and Morocco, there was no cointegration relationship. Using the Johansen and Fisher cointegration technique, Lean and

Smyth (2010) established a cointegration relationship between output, carbon dioxide emissions and electricity consumption for the Association of Southeast Asian Nations (ASEAN) countries. Wolde-Rufael (2006) on Tunisia, and Ciarreta and Zarraga (2010) on a panel data of 12 European countries established a negative unidirectional causal relationship running from electricity consumption to economic growth. While no explanation was provided for the negative causality result of Wolde-Rufael (2006), Ciarreta and Zarraga (2010) interpreted the negative causality as the result of the presence of several unproductive industries in this set of European countries. Acaravci, Erdogan and Akalin (2015) established both long- and short-run unidirectional causal relationships running from electricity consumption to economic growth in Turkey over the period 1974-2013. Wolde-Rufael (2006) in Egypt, Gabon and Morocco, and Yoo (2005) in Korea, established a bidirectional causal relationship between GDP and electricity consumption.

To sum up, there is no consensus on the direction of causality between electricity consumption and economic growth. Ozturk (2010), Chen et al. (2007) and Payne (2010) argue that the different results found in the empirical literature in regard to the direction of causality can be due to econometric techniques used, the countries' specific context, the database used, and the omitted variables bias. The different results found also highlight the complexity of channels though which economic growth and electricity consumption influence each other.

Four main hypotheses can be found in the empirical literature on the causal relationship between economic growth and energy consumption. The first is the "conservation" hypothesis, which stipulates that economic growth causes energy consumption. Hence, an energy conservation policy will not affect economic growth. The second is the "growth" hypothesis, which stipulates that energy consumption causes economic growth. The third is the "feedback" hypothesis which stipulates that energy consumption and economic growth cause each other and are interrelated. Any energy conservation policy in a context of the "growth" or "feedback" hypotheses will affect economic growth. The fourth is the "neutrality" hypothesis, which stipulates that no causal relationship exists between economic growth and energy consumption, hence any energy conservation policy will not affect economic growth (Apergis and Payne, 2009a, 2009b; Ozturk, 2010). Throughout the empirical literature of the causal relationship between economic growth and electricity consumption, these four hypotheses have also been noticed. Payne (2010), in a survey of the literature on the relationship between electricity consumption and economic growth, established that the neutrality hypothesis, the conservation hypothesis, the growth hypothesis and the feedback hypothesis are supported respectively by 31%, 28%, 23%, and 18% of the studies. Payne (2010, pp. 729) also established that 34.92% of studies surveyed used multivariate analyses, while 65.08% of them used bivariate analyses. One of the limitations of bivariate analyses is the omitted variable bias. Multivariate analyses allow the inclusion of different control variables in the model and therefore minimize the omitted variable bias. Zachariadis (2007) argued that multivariate analyses allow multiple causality frameworks.

While these studies have attempted to analyse the causal and cointegration relationship between electricity and economic growth, it is important to acknowledge their limitations. First, with the differing results provided by these studies, it becomes impossible to conclude the true direction of the causal relationship between electricity consumption and economic growth. Second, many of these studies are cross-country analyses, so they are very limited in terms of country-specific policy recommendations. As argued by Lindmark (2002), Stern, Common and Barbier (1996) and Ang (2008), cross-country analyses are too general and very limited for specific policy recommendations within countries.

In the literature on economic growth and energy, very few studies have focused on Benin. Because of this, the next section will present both studies on energy consumption and economic growth, and studies on electricity consumption and economic growth.

2.2.2 Specific studies on Benin and some African countries on the relationship between economic growth and energyelectricity consumption

There have been very few studies on Benin (Wolde-Rufael, 2009, 2005; Al-mulali and Binti Che Sab, 2012; Rault, Arouri, Youssef and M'Henni, 2014); Dogan, 2014; Menegaki and Tugcu, 2016; Fatai, 2014; Zerbo, 2017; Wolde-Rufael, 2006; Ouédraogo, 2013) that have analyzed the relationship between electricity/energy consumption and economic growth. Using a VAR model for a sample of 17 African countries, Wolde-Rufael (2009) established a causal relationship running from economic growth to energy consumption for three of these countries, including Benin. According to his study, the implementation of any energy conservation policy in these three countries will negatively affect economic growth. He argued that Benin has one of the lowest energy efficiency ratios and rates of access to electricity in the world: US$2.5 GDP per unit of energy use as the energy efficiency ratio and 22% as the rate of access to electricity in 2009. He explained that the Beninese average for these two indicators was below the sub-Saharan African averages, which in 2009 were respectively US$2.9 GDP per unit of energy use (energy efficiency ratio) and 25.9% (rate of access to electricity). He recommended that a country such as Benin must increase its use of energy use in order to achieve sustainable economic growth.

While Wolde Rufael (2009) established a causal relationship between economic growth and energy consumption, Wolde-Rufael (2005), using the bound testing approach and Toda Yamamoto approach to Granger causality in a bivariate analysis for 19 African countries, established for nine of these African countries, including Benin, that there is no causal relationship between economic growth and energy consumption. Lütkepohl (1982) and Wolde-Rufael (2009) relate such absence of causality to the omitted variables bias, which characterizes bivariate models.

A cross-country analysis of 30 African countries by Al-mulali and Binti Che Sab (2012), including Benin, established that energy consumption causes both economic growth and financial development, but with some environmental damage, such as CO_2 emissions, in these countries. Rault et al. (2014) studied 16 African countries, including Benin, using a VAR model, and established for Algeria a causal relationship running from economic growth to energy consumption. In the case of Ethiopia, they established a bidirectional causality between energy consumption and economic growth, and for seven of the countries (Tunisia, Egypt, Kenya, Senegal, Tanzania, DRC, Morocco) they established a positive causal relationship running from energy consumption to economic growth. For Cameroun, Zambia and South Africa they established a negative causality running from energy consumption to economic growth. In the case of Benin, no causality was found between economic growth and energy consumption.

Dogan (2014) established for Congo, Benin, and Zimbabwe that there is no causal relationship between economic growth and energy consumption. However, in the case of Kenya, he established a causal relationship running from energy consumption to economic growth. Menegaki and Tugcu (2016) established that there is no causal relationship between energy consumption and GDP for 42 African countries, including Benin. Ouédraogo (2013) found opposite results for countries of the Economic Community of West African States (ECOWAS), including Benin: he established a causal relationship running from energy consumption to GDP in the long run, and a causal relationship running from GDP to energy consumption in the short run. In a study of 18 sub-Sahara African countries Fatai (2014) established that there is no causal relationship between energy consumption and economic growth for countries of Western and Central Africa, including Benin. In the case of countries of Southern and Eastern Africa, he established the existence of a causal relationship running from energy consumption to economic growth. Zerbo (2017) studied 13 sub-Saharan African countries, including Benin, and established a long-run relationship between energy consumption and economic growth for all these countries. In the case of Togo, Côte d'Ivoire, Benin, Senegal, South Africa, Ghana and Congo, he established that there is no causal relationship between energy consumption and economic growth, but he established a causal relationship running from energy consumption to economic growth in the case of Nigeria, Kenya and Gabon. In the case of Cameroon, he established bidirectional causality between energy consumption and economic growth, while in the case of Sudan and Zambia, he established that causality runs from economic growth to energy consumption.

Among the few studies which have investigated the relationship between economic growth and energy consumption in Benin, very few have targeted electricity consumption (Ouédraogo, 2013; Wolde-Rufael, 2006). Using the bound testing and Toda Yamamoto approaches to Granger causality, Wolde-Rufael (2006) investigated the relationship between electricity consumption per capita and GDP per capita for 17 African countries using a bivariate framework where the dependent variable was electricity consumption per capita. For four of these countries, including Benin, he established a long-run relationship between GDP per capita and electricity consumption per capita. However, for three of these four countries, including Benin, the error correction term of his model was positive and not significant. For the Democratic Republic of Congo and Benin, he established a positive causal relationship running from electricity consumption per capita to GDP per capita, while for Tunisia he established a negative causal relationship running from electricity consumption to GDP per capita. In the case of Gabon, he established a bidirectional causality between electricity consumption and GDP per capita. However, the sign of the causal relationship was positive when the direction of causality was from GDP per capita to electricity consumption per capita, and the sign was negative when the direction of causality was from electricity consumption per capita to GDP per capita. As reported earlier, Ouédraogo (2013) investigated the causal relationship between energy consumption and economic growth for ECOWAS countries, including Benin. His study was not limited to the relationship between energy consumption and economic growth: he also examined the relationship between electricity consumption and economic growth, and established a causal relationship running from electricity consumption to economic growth in the long run for all these countries.

The main limitation of these studies is that many of them are cross-country studies, and hence, they are very limited in terms of policy recommendations for Benin. As mentioned by Lindmark (2002), Stern et al. (1996) and Ang (2008), cross-country studies are very general and limited in terms of policy recommendations for specific countries. Moreover, only a few of these studies have focused on electricity consumption. To the best of the writers' knowledge, no study on Benin has evaluated the losses of GDP resulting from electricity losses. Our study will fill these gaps by evaluating the losses of GDP due to electricity losses in the Beninese context. It will estimate both the effects of electricity supply and consumption on GDP, and then derive the net effect of electricity losses on GDP. It aligns with the objective of the national policy framework for electricity aiming at reducing electricity losses in Benin. It will thus contribute to advancing policies on electricity efficiency and electricity security aiming at reducing disruption risks to electricity supply caused by electricity losses. The study will also add value to the existing literature on electricity supply efficiency and electricity supply security.

2.3 Summary of the current study's contribution

Three main areas of contribution are possible in a study such as this: methodology, theory and application. Most of the contributions of this study are in the area of application. The main limitation of previous studies that this study has examined is the lack of evidence on the effect of electricity supply disruption (in the form of electricity losses) on GDP. Knowledge of the effect of electricity losses on GDP will be of great importance for policies on electricity efficiency and electricity supply security in Benin. As mentioned in the introduction, it will contribute to assessing the feasibility of the indirect financing mechanism proposed by the national policy framework for electricity to fund the costs of reductions of electricity. As explained previously, it will advance electricity efficiency policies aiming at reducing disruption risks to electricity supply such as electricity losses, and it will also add value to the existing literature on electricity supply security and electricity supply efficiency on Benin. To the best of the writers' knowledge, prior to this study there has been no empirical evaluation of the loss of GDP resulting from electricity losses in Benin.

3 METHODOLOGY

3.1 Empirical model specification

There is theoretical consensus on the positive correlation between electricity supply and growth. However, there is no empirical consensus on the direction of causality between these two variables. For Neoclassic economists, labour, capital and technology are the factors of production. According to the growth models of Harrod-Domar and Solow-Swan, energy is not to be considered as factors of production. However, authors such as Stern (1997) stipulated that energy can be considered as a factor of production or as a final product. Following Stern (1997), studies such as Pokrovski (2003) stipulated that equipment which involves the use of energy rather than the use of manual labour are to be considered as a production factor. After the oil crisis of the 1970s and the resulting shocks on many economies, many authors realized the importance of energy as a production factor. As a result, authors such as Thompson (2006), Beaudreau (2005), Ghali and El Sakka (2004), Alam (2006) and Stern (1993, 2000) argued that energy is one of the main variables of production, therefore it should be considered as a factor of production as are labour and capital. Following the work of Shahbaz (2015), Odularu and Okonkwo (2009) and Oh and Lee (2004a, 2004b), and Ghali and El Sakka (2004), we developed a growth model where energy is one of the independent variables. Our model is:

$$G_t = f(A, E_{j,t}, K_t, L_t) \tag{1}$$

where *A, E, L* and *K* are respectively technology, energy supply, labour and capital. *G* represents output (real GDP). Energy supply (*E*) is limited in this study to electricity supply; *j* represents either where the energy supply variable (*E*) in Equation 1 is electricity supply under the hypothesis of absence of losses (*ES*), or where the energy supply variable (*E*) in Equation 1 is electricity supply net of losses (in other words electricity consumption) (*EC*). The aim here is to investigate the effects of losses of electricity on aggregate output (real GDP). In other words, if there were no losses of electricity during the transmission and the distribution, what would be the gain in terms of increase in real GDP? In other words, what is the loss in terms of real GDP as a result of electricity losses? Therefore, there are two scenarios in Equation 1: in the first, *G* is a function of technology (*A*), labour (*L*), capital (*K*) and electricity supply (*ES*) under the hypothesis of absence of losses, and in the second, *G* is a function of technology (*A*), capital (*K*), labour (*L*) and electricity supply net of losses (also called electricity consumption (*EC*)). When assuming constant elasticities Equation 1 becomes:

$$G_t = AE_{j,t}^{\phi_j} K_t^{\rho_j} L_t^{\theta_j} \varepsilon_{j,t} \tag{2}$$

where θ, ϕ, and ρ, are the elasticities of output with respect to labour, electricity supply/consumption and capital, respectively, and where ε_t represents the residual term, *j* remains as described in Equation 1.

When taking the logarithm of Equation 2 we obtain:

$$. \ Ln(G_t) = Ln(A) + \phi_j Ln(E_{j,t}) + \rho_j Ln(K_t) + \theta_j Ln(L_t) + Ln(\varepsilon_{j,t}) \tag{3}$$

where ϕ, ρ and θ, respectively represent the output elasticities of electricity supply/consumption (*E*), capital (*K*), and labour (*L*); *j* remains as described in Equation 1. Equation 3 can be re-expressed as follows:

$$LnG_t = \beta + \phi_j Ln(E_{j,t}) + \rho_j Ln(K_t) + \theta_j Ln(L_t) + \omega_{j,t} \tag{4}$$

In Equation 4, β is a constant term and is equal to *Ln(A)* (see Equation 3), and ω_t represents the residual terms and is equal to $Ln(\varepsilon_t)$ (see Equation 3). From Equation 4, we can infer that growth in output is a function of growth in labour, electricity supply/consumption and capital. The study first analyzes the relationship between electricity supply (in the absence of losses) (*ES*) and aggregate output (real GDP), and the relationship between electricity consumption (electricity supply net of losses) (*EC*) and aggregate output (real GDP) using the framework of Equation 4. Second, the study compares the estimated coefficient of electricity supply net of losses (*EC*) to the estimated coefficient of electricity supply under the hypothesis of absence of losses (*ES*). This will allow us to estimate the loss in terms of real GDP as a result of electricity losses. Following Soytas and Sari (2006), Yuan, Kang, Zhao and Hu (2008), Sari and Soytas (2007), Lee and Chang (2008), we proxy the stock of capital (*K*) by Gross Capital formation (*GCF*). In alignment with Menyah and Wolde-Rufael (2010), Dogan (2015), Soytas and Sari (2009), Streimikienne and Kasperowicz (2016), and Soytas, Sari and Ewing (2007), we use labour force (population whose age is between 15 and 64) (*LF*) as a proxy for labour. The aim of this study is not to investigate the relationship between gross capital formation, labour force and economic growth: labour force and gross capital formation are not our variables of interest in this model, they represent control variables. Our variables of interest are electricity supply (*ES*) electricity consumption (*EC*) and real GDP.

3.2 Data

We gathered secondary data composed of annual series of real GDP (*RGDP*) at constant 2010 US$, real gross capital formation (*GCF*) at constant 2010 US$, labour force (LF) defined as the population whose age is between 15 and 64 years, electricity consumption (electricity supplied net of losses (*EC*)) in billions of kWh and total electricity supplied (electricity supplied under the hypothesis of absence of losses (*ES*)) in billions of kWh. The series on *RGDP* and *GCF* were collected from the World Development Indicators (2016) website, while the series on electricity consumption (*EC*) and total electricity supplied (*ES*) were collected from the US EIA (2016) website. The series on labour force (LF) were collected from the US Census Bureau (2016) website. All series were collected over the period 1980-2014. There were no missing values in the series. Following Shahbaz, Mallick, Mahalik and Sadorsky (2016) and Shahbaz, Hoang, Mahalik and Roubaud (2017), all series were converted into their logarithmic form in order to ensure proper distribution properties of the data.

3.3 Analytical framework

Akaike Information Criteria (AIC) was used to select the optimal lag in our models. It is crucial to check for the stationarity of our series in order to avoid supurious regressions. There are several different unit root tests (Elliott, Rothenberg, and Stock (1996) (DF-GLS), Augmented Dickey Fuller (ADF), Ng and Perron (2001), Phillip Perron (PP) test, Zivot Andrew test, Modified Augmented Dickey Fuller (MADF) test with breakpoint) which test the null hypothesis of evidence of unit root against the alternative hypothesis of no evidence of unit root. There are also some stationarity tests such as Kwiatkowski, Phillips, Schmidt and Shin (KPSS) which test the null hypothesis of stationarity against the alternative hypothesis of no stationarity. Perron (1989) argued that the use of the ADF test can lead to biased results when there is evidence of breaks in series. Leybourne, Mills and Newbold (1998) and Leybourne and Newbold (2000) argued that the rejection of the null hypothesis can be biased with the ADF test when there is evidence of a break in the beginning of the series. As a result, Perron and Vogelsang (1992), Perron (1997) and other studies developed different unit root tests which allow for one structural break. However, these tests omit the possibility of the existence of more than one structural break in the data, as the unit root test shows only the most significant break. Consequently, the results of these tests can be biased as the conclusions on stationarity of variables can be caused by an omitted break (Vogelsang, 1994). Consequently, Lee and Strazicich (2003), Narayan and Popp (2010), Lumsdaine and Papell (1997), Bai and Perron (1998, 2003) and Bai (1997) developed other unit root tests which allow for more than one structural break.

As mentioned previously, the Beninese economy has encountered several shocks: the devaluation of the CFA currency by 50% in 1994, the consecutive electricity crises in the 1980s, 1990s and 2000s, and the change in political and economic structure with the shift from a socialist regime to private ownership, democracy and a free market in 1990 (Constant, 2012; Hounkpatin, 2013; Schneider, 2000). Hence, it becomes necessary to apply to our series a unit root test which accounts for structural breaks. Because of the small size of our sample (35 observations), we did not account for more than one breakpoint in our series, hence the Narayan and Popp (2010), Lumsdaine and Papell (1997), Lee and Strazicich (2003), Bai and Perron (1998, 2003), and Bai (1997) unit root tests were not applied. Instead, we have used the MADF (which can be found in eviews 9.5 or 10), and the Zivot Andrew test (ZA), which determine one break date endogenously. We have also cross-checked the results of these unit roots with structural break with a stationarity test (KPSS). The next step was to investigate the existence of a cointegration relationship among variables of the models.

We used the autoregressive distributive lags (ARDL) bound testing approach developed by Pesaran and Shin (1999), Pesaran, Shin and Smith (2001) and Pesaran and Pesaran (2009) to investigate the existence of a cointegration relationship among the variables. There are several advantages related to the use of the ARDL. It simultaneously estimates both short- and long-run relationships, and it allows the use of both I(0) and I(1) variables. Pesaran and Shin (1999) and Pesaran (1997) mentioned that a sufficient increase of the order of the ARDL will correct simultaneously for serial correlation and endogeneity. Haug (2002) and Pesaran and Shin (1999) argued that the bound testing approach performs better on small sample sizes than other cointegration techniques such as Johansen and Juselius (1990), Engle and Granger (1987) and Philips and Hansen (1990). The sample size in this study was 35 observations. Using the Johansen test on small samples size may lead to inconsistent results.

Following Pesaran and Shin (1999) and Pesaran et al. (2001), the following dynamic unrestricted error correction models (UECM) were developed:

Model F(logRGDP\logEC, logGCF, logLF) with real GDP (logRGDP) as dependent variable:

$$\Delta\log RGDP_t = a_{10} + \sum_{i=1}^{q_1}\beta_{11,i}\Delta\log RGDP_{t-i} + \sum_{i=0}^{q_2}\beta_{12,j,i}\Delta\log E_{j,t-i} + \sum_{i=0}^{q_2}\beta_{13,i}\Delta\log GCF_{t-i}$$
$$+\sum_{i=0}^{q_2}\beta_{14,i}\Delta\log LF_{t-i} + \phi_{11}\log RGDP_{t-1} + \phi_{12,j}\log E_{j,t-1} + \phi_{13}\log GCF_{t-1} + \phi_{14}\log LF_{t-1} + \varepsilon_{1,t} \quad (5)$$

Model F(logE\logRGDP, logGCF, logLF) with electricity supply or consumption (logE) as dependent variable:

$$\Delta\log E_{j,t} = a_{20} + \sum_{i=1}^{q_1}\beta_{21,i}\Delta\log E_{j,t-i} + \sum_{i=0}^{q_2}\beta_{22,j,i}\Delta\log RGDP_{t-i} + \sum_{i=0}^{q_2}\beta_{23,i}\Delta\log GCF_{t-i}$$
$$+\sum_{i=0}^{q_2}\beta_{24,i}\Delta\log LF_{t-i} + \phi_{21}\log E_{j,t-1} + \phi_{22,j}\log RGDP_{t-1} + \phi_{23}\log GCF_{t-1} + \phi_{24}\log LF_{t-1} + \varepsilon_{2,t} \quad (6)$$

Model F(logGCF\logRGDP, logE, logLF) with gross capital formation (logGCF) as dependent variable:

$$\Delta \log GCF_t = a_{30} + \sum_{i=1}^{q_1} \beta_{31,i} \Delta \log GCF_{t-i} + \sum_{i=0}^{q_2} \beta_{32,j,i} \Delta \log E_{j,t-i} + \sum_{i=0}^{q_2} \beta_{33,i} \Delta \log RGDP_{t-i}$$

$$+ \sum_{i=0}^{q_2} \beta_{34,i} \Delta \log LF_{t-i} + \phi_{31} \log GCF_{t-1} + \phi_{32,j} \log E_{j,t-1} + \phi_{33} \log RGDP_{t-1} + \phi_{34} \log LF_{t-1} + \varepsilon_{3,t} \quad (7)$$

Model F(logLF\logRGDP, logE, logGCF) with labour force (logLF) as dependent variable:

$$\Delta \log LF_t = a_{40} + \sum_{i=1}^{q_1} \beta_{41,i} \Delta \log LF_{t-i} + \sum_{i=0}^{q_2} \beta_{42,j,i} \Delta \log E_{j,t-i} + \sum_{i=0}^{q_2} \beta_{43,i} \Delta \log GCF_{t-i}$$

$$+ \sum_{i=0}^{q_2} \beta_{44,i} \Delta \log RGDP_{t-i} + \phi_{41} \log LF_{t-1} + \phi_{42,j} \log E_{j,t-1} + \phi_{43} \log GCF_{t-1} + \phi_{44} \log RGDP_{t-1} + \varepsilon_{4,t} \quad (8)$$

Where all independent variables with a difference operator (Δ) represent short-run dynamics and all independent variables without a difference operator represent long-run dynamics. $\beta_{h,i}$ represents short-run coefficients, while $\phi_{h,i}$ represents long-run coefficients, for h = 1, 2, 3, 4 and i = 1, 2, 3, 4; $\varepsilon_{h,t}$ is a white noise, q_1 and q_2 represent the optimal lag for the dependent and independent variables respectively; j represents either the presence or the absence of electricity losses, E_j represents either electricity supply under the hypothesis of absence of electricity losses (*ES*) or electricity consumption (electricity supply net of losses) (*EC*). *RGDP*, *GCF* and *LF* represent real GDP, gross capital formation and labour force respectively. As said in previous sections, AIC was used for the optimal lag selection. Enders (2004) argued that the optimal lag for annual series should be 1, 2 or 3. While four UECMs are described in Equations 5 to 8, our main interest is the relationship between electricity supply/consumption and economic growth of Equation 5. UECMs of Equations 6, 7 and 8 represent the other possible cointegration vectors that could exist using linear combinations of electricity consumption (logEC), real GDP (logRGDP), gross capital formation (logGCF), and labour force (logLF), or linear combinations of electricity supply (logES), real GDP (logRGDP), gross capital formation (logGCF), and labour force (logLF). Using ARDL to estimate Equation 5 implies that we are assuming that the UECM in Equation 5 is the only viable cointegration vector and the UECMs of Equations 6, 7 and 8 are not viable. In order to verify such assumption we use the weak exogeneity test, which applies a Wald restriction on the error correction terms (*ECT*) of each of the models 5, 6, 7 and 8. If the p-value of the chi-square statistic is not significant then the corresponding UECM is not viable. In other words, the cointegration vector represented by such UECM does not exist. In addition to the weak exogeneity test, it is also important to check the sign and the significance of the coefficient of the error correction term (*ECT*) of each UECM of Equations 5, 6, 7 and 8. If the coefficient of the *ECT* (such coefficient is also called speed of adjustment to the long-run equilibrium) is not negative, or if it is not significant, then the corresponding UECM is not viable.

In Equation 5, both the UECMs F(logRGDP\logEC, logGCF, logLF) (model with electricity consumption or electricity supply net of losses) and F(logRGDP\logES, logGCF, logLF) (model with electricity supply under the hypothesis of absence of losses) are affected by heteroskedasticity and by the presence of unstable parameters at lags 1 and 3 (further details are provided in Table 2 and Figures 2 and 3 in Section 4.1 on descriptive statistics and optimal lag selection). Hence we have chosen 2 as the maximum lag during the lag selection procedure in both models and in other UECMs (F(logEC\logRGDP, logGCF, logLF), F(logGCF\logRGDP, logEC, logLF), F(logLF\logRGDP, logEC, logGCF), F(logES\logRGDP, logGCF, logLF), F(logGCF\logES, logRGDP, logLF) and F(logLF\logES, logGCF, logRGDP) in Equations 6, 7 and 8). The result of the lag selection criteria are discussed further (see Section 4.1 on descriptive statistics and optimal lag selection). As said previously, *j* represents either the absence or the presence of electricity losses.

The next step is cointegration analysis. The bounds test developed by Pesaran and Shin (1999) was used to investigate the existence of a cointegration relationship among the variables of Equations 5, 6, 7 and 8. The null hypothesis (H0) for each UECM stipulates that there is no cointegration relationship and is:

H0:

$$\forall (h,i) \in \{1,2,34\} \text{x} \{1,2,34\}, \phi_{h,i} = 0 \quad \textbf{(9)}$$

and the alternative hypothesis (HA) stipulates that there is a cointegration relationship which is:

HA:

$$\forall (h,i) \in \{1,2,3,4\} \text{x} \{1,2,3,4\},\ \exists \phi_{h,i} \in \mathbb{R},\ \phi_{h,i} \neq 0 \quad (10)$$

where $\phi_{h,i}$ represents the long-run coefficients of each of the UECMs of Equations 5, 6, 7 and 8. In other words:

For the UECM of Equation 5, the null hypothesis is:

$$H01: \phi_{11} = \phi_{12} = \phi_{13} = \phi_{14} = 0 \quad (11)$$

and the alternative hypothesis is:

$$HA1: \phi_{11} \neq 0;\ \text{or}\ \phi_{12} \neq 0;\ \text{or}\ \phi_{13} \neq 0;\ \text{or}\ \phi_{14} \neq 0 \quad (12)$$

For the UECM of Equation 6, the null hypothesis is:

$$H02: \phi_{21} = \phi_{22} = \phi_{23} = \phi_{24} = 0 \quad (13)$$

and the alternative hypothesis is:

$$HA2: \phi_{21} \neq 0; \text{ or } \phi_{22} \neq 0; \text{ or } \phi_{23} \neq 0; \text{ or } \phi_{24} \neq 0 \quad (14)$$

For the UECM of Equation 7, the null hypothesis is:

$$H03: \phi_{31} = \phi_{32} = \phi_{33} = \phi_{34} = 0 \quad (15)$$

and the alternative hypothesis is:

$$HA3: \phi_{31} \neq 0; \text{ or } \phi_{32} \neq 0; \text{ or } \phi_{33} \neq 0; \text{ or } \phi_{34} \neq 0 \quad (16)$$

For the UECM of Equation 8, the null hypothesis is:

$$H04: \phi_{41} = \phi_{42} = \phi_{43} = \phi_{44} = 0 \quad (17)$$

and the alternative hypothesis is:

$$HA3: \phi_{41} \neq 0; \text{ or } \phi_{42} \neq 0; \text{ or } \phi_{43} \neq 0; \text{ or } \phi_{44} \neq 0 \quad (18)$$

Ziramba (2008) stipulated that critical values of Pesaran et al. (2001) were computed on sample sizes that range from 500 to 1,000 and are not consistent with small sample sizes. Narayan (2004) established a new set of critical values for small samples that range between 30 and 80 observations. Because of the small size of our annual series (35 observations), we use the reformulated critical value of Narayan (2004) which is more consistent with small samples, instead of the critical value of Pesaran et al. (2001). Specifically, we use critical values' table on restricted intercept and no trend at 5% significance level. If the F statistic of the bounds test falls inside the bound's interval, then the result of the bounds test becomes inconclusive. If it is superior to the upper bound critical value of Narayan (2004), then there is evidence of a cointegration relationship between the variables. If the F statistic is inferior to the lower bound critical value of Narayan (2004), then there is no cointegration relationship between the variables. In case there is a cointegration relationship among the variables, and particularly if a cointegration relationship exists in the models of interest (F(logRGDP\logEC, logGCF, logLF) for the model with electricity consumption or electricity supply net of losses and F(logRGDP\logES, logGCF, logLF) for the model with electricity supply under the hypothesis of absence of losses), the next step will be to verify that the models of interest are the only cointegrating vectors and all other possible cointegrating vectors are not viable. As said before, this will be done using the weak exogeneity test, and by observing the sign and the significance of the coefficient associated to the error correction term of each cointegrating vector. If the only viable cointegrating vectors are our models of interest, then the next step will be to check the consistency of the models of interest of Equation 5 (F(logRGDP\logEC, logGCF, logLF) and F(logRGDP\logES, logGCF, logLF)) by conducting residuals and stability diagnostic tests (normality test, Breusch-Godfrey LM test for serial correlation, Breusch-Pagan-Godfrey test for heteroskedasticity, CUSUM and CUSUM of squares tests for parameter stability, Ramsey reset test). If the models of interest are consistent, in other words, if there is no serial correlation, no heteroskedasticity, if residuals are normal, if the model is well specified and if the parameters are stable, then the next step will be to estimate the long- and short-run effects of electricity supply/consumption (logE_j), gross capital formation (log*GCF*), and labour force (logLF) on real GDP (logRGDP) as follows:

Long-run model:

$$\log RGDP_t = b_0 + \sum_{i=1}^{k} b_{1,i} \log RGDP_{t-i} + \sum_{i=0}^{l} b_{2,j,i} \log E_{j,t-i} + \sum_{i=0}^{m} b_{3,i} \log GCF_{t-i} + \sum_{i=0}^{n} b_{4,i} \log LF_{t-i} + \mu_t \qquad (19)$$

Short-run model (restricted error correction model):

$$\Delta \log RGDP_t = c_0 + \sum_{i=1}^{k} c_{1,i} \Delta \log RGDP_{t-i} + \sum_{i=1}^{k} c_{2,j,i} \Delta \log E_{j,t-i} + \sum_{i=1}^{k} c_{3,i} \Delta \log GCF_{t-i} + \sum_{i=1}^{k} c_{4,i} \Delta \log LF_{t-i} + \lambda ect_{t-1} + \varepsilon_t \qquad (20)$$

where b_0, b_1, b_2, b_3, b_4 are long-run parameters and c_0, c_1, c_2, c_3,c_4 are short-run parameters, *j* represents either the presence or the absence of electricity losses. *RGDP* represents real GDP, *GCF* represents gross capital formation, *LF* represents labour force, and *Ej,* represents either electricity consumption (*EC*) or electricity supply in the absence of electricity losses (*ES*); *λ* represents the speed of adjustment to the long-run equilibrium and must be negative and significant before we can infer long-run causality, *k*, *l*, *m*, *n*, represent the optimal lag, *ect* is the error correction term, and *μ* and *ε* represent error terms. Based on the assumption that the stability diagnostic tests reveal that parameters of the model of interest are stable, it is not necessary to insert a dummy variable in the long- and short-run specifications of these models in order to account for structural breaks. In case such assumption will appear to be wrong, it will be necessary to ensure parameters' stability by inserting a dummy variable in the long- and short-run specification of these models in order to account for structural breaks.

Estimating the loss of GDP resulting from electricity losses:

The main purpose of this study is to compute the loss in terms of GDP resulting from losses of electricity in both the long and the short run. The long-run loss of GDP (*LR_LGDP*) resulting from electricity losses will be equal to the long-run coefficient on electricity supply in the absence of loss (*ES*) (*ES* is equal to E_j in the absence of electricity losses) minus the long-run coefficient of electricity consumption (*EC*) (*EC* is equal to E_j in the presence of electricity losses). The short-run loss of GDP (*SR_LGDP*) resulting from electricity losses will be equal to the short-run coefficient of electricity supply (*ES*) minus the short-run coefficient of electricity consumption (*EC*).

4 EMPIRICAL RESULTS

4.1 Descriptive statistics and optimal lag selection

Table 1 shows that all our variables have a normal distribution and that electricity consumption (logEC)/electricity supply (logES), gross capital formation (logGCF) and labour force (logLF) are positively correlated to with real GDP (logRGDP). This aligns with the a priori expectation explained previously (in Section 2.1 on theoretical foundation). Enders (2004) argued that the optimal lag for annual series should range between 1 and 3. At lags 1 and 3, our models of interest F(logRGDP\logEC, logGCF, logLF) and F(logRGDP\logES, logGCF, logLF) are affected by heteroskedasticity and instability of parameters (see Table 2 and Figures 2 and3 below)**.** Hence, we have chosen lag 2 as the maximal lag in the lag selection procedure for the annual series. In Table 3, all lag selection criteria revealed 2 as the optimal lag for the UECM F(logRGDP\logEC, logGCF, logLF) and 1 as optimal lag for the UECM F(logRGDP\logES, logGCF, logLF). Because of the nuisance due to heteroskedasticity and instability of parameters occurring at lag 1, we have chosen lag 2 when specifying the UECM F(logRGDP\logES, logGCF, logLF).

Descriptive statistics	**logRGDP**	**logEC**	**logES**	**logGCF**	**logLF**
Mean	9.6223	-0.5157	-0.4148	8.9974	6.4796
Median	9.6140	-0.5228	-0.4538	9.0033	6.4870
Maximum	9.9332	0.0094	0.1058	9.4371	6.7346
Minimum	9.3437	-1.0000	-0.9788	8.6180	6.2218
Std. Dev.	0.1772	0.3340	0.3108	0.1891	0.1573
Skewness	0.1193	-0.0404	0.1594	0.1996	-0.0518
Kurtosis	1.6895	1.8119	1.9094	2.8219	1.7623
Jarque-Bera	2.5873	2.0677	1.8826	0.2787	2.2495
Probability	0.2742	0.3556	0.3901	0.8699	0.3247
Correlation					
LogRGDP	1				
LogEC	0.9568	1			
LogES	0.9804	0.9558	1		
LogGCF	0.8362	0.8541	0.8182	1	
logLF	0.9944	0.9586	0.9725	0.8092	1
Observations: 35					

Table 1: Descriptive statistic of variables

Source: Authors' estimation

Models	Dependent variables in the model	Number of lags	Chi-square	P-values
F(logRGDP\logEC, logGCF, logLF)	logRGDP	1	14.33208	0.0063
F(logRGDP\logES, logGCF, logLF)	logRGDP	1	19.19069	0.0018

Table 2: Heteroskedasticity test (Breusch Pagan-Godfrey) at lag 1 for UECMs F(logRGDP\logEC, logGCF, logLF) and F(logRGDP\logES, logGCF, logLF)

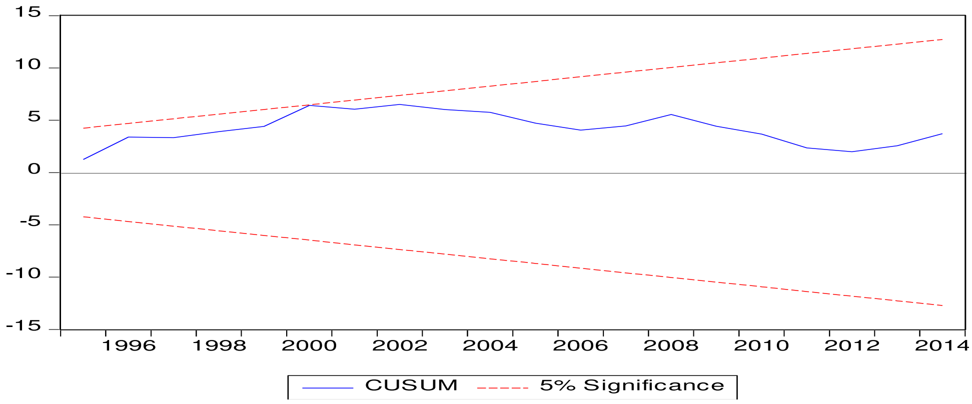

Figure 2: Stability test (CUSUM test) at lag 3 for the UECM F(logRGDP\logEC, logGCF, logLF)

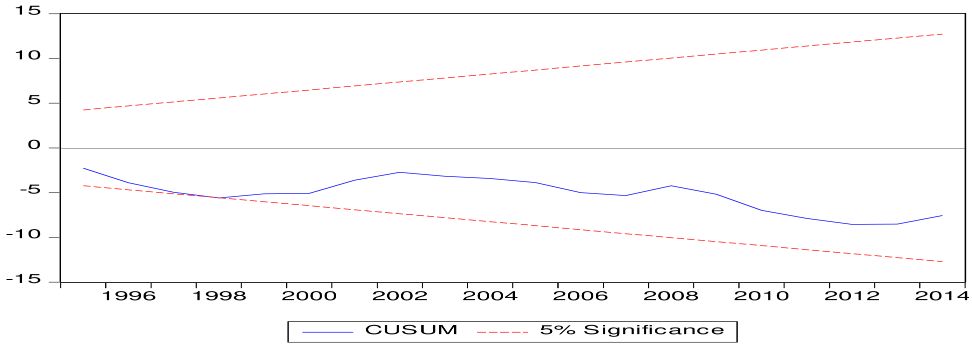

Figure 3: Stability test (CUSUM test) at lag 3 for the UECM F(logRGDP\logES, logGCF, logLF)

Table 3: Results of lag selection criteria

	Lag	LogL	LR	FPE	AIC	SC	HQ
F(logRGDP, logEC, logGCF, logLF)	0	170.8653	NA	4.77e-10	-10.1130	-9.9316	-10.0520
	1	343.7070	293.3071	3.58e-14	-19.6186	-18.7116*	-19.3134

	Lag	LogL	LR	FPE	AIC	SC	HQ
	2	367.8343	35.0943*	2.29e-14*	-20.1111*	-18.4786	-19.5618*
	Lag	**LogL**	**LR**	**FPE**	**AIC**	**SC**	**HQ**
F(logRGDP, logES, logGCF, logLF),	0	190.7814	NA	1.43e-10	-11.3200	-11.13869	-11.2590
	1	374.8220	312.3113*	5.43e-15*	-21.5043*	-20.59739*	-21.1991*
	2	390.0068	22.0870	5.98e-15	-21.4549	-19.8224	-20.9056

Table 3: Results of lag selection criteria

Notes: (*) indicates the optimal lag length selected by the criterion

LR: sequential modified LR statistic

AIC: Akaike information criterion

FPE: Final prediction error

SC: Schwarz information criterion

HQ: Hanan-Quinn information criterion

Source: Authors' estimation

4.2 Results of unit root and stationarity tests

We first observed graphs of our series and noticed that they all have a trend and an intercept (Figures 4, 5, 6, 7 and 8). Next, ZA unit root, the MADF test with breakpoint, and KPSS test were applied to each series at level with intercept and trend and at first difference with intercept and trend. The maximal lag used was 2. The tests revealed that the variables are either I(1) or I(0). Results are presented in Table 4 below. We then investigated the existence of a cointegration relationship among the variables, using the bounds testing approach to cointegration.

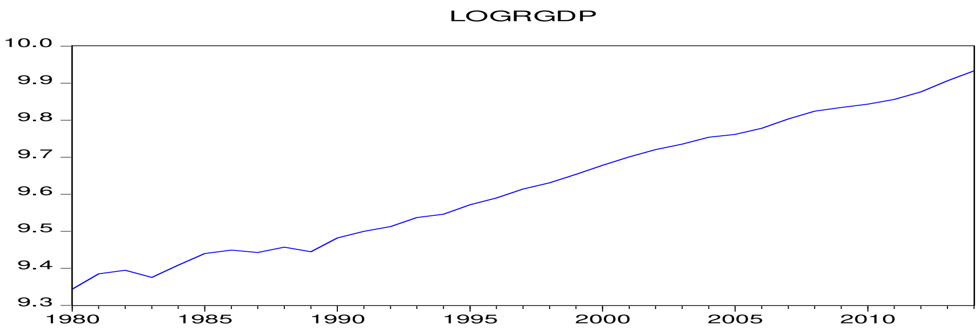

Figure 4: History of real GDP (logRGDP) (1980-2014)

Source: Authors' estimation based on data from World Development Indicators (2016)

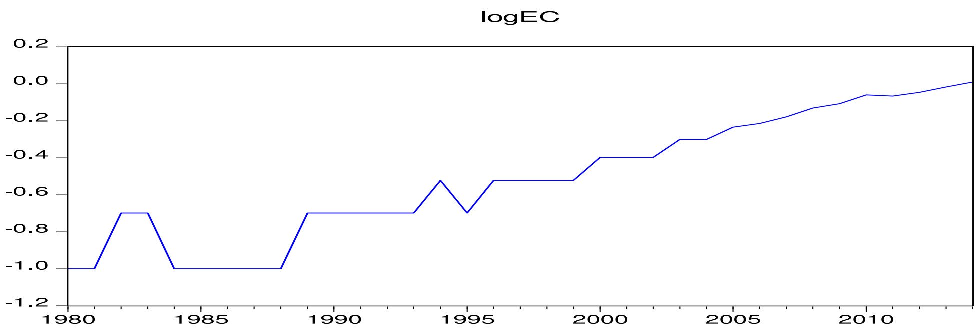

Figure 5: History of electricity consumption (logEC) (1980-2014)

Source: Authors' estimation based on data from US EIA (2016)

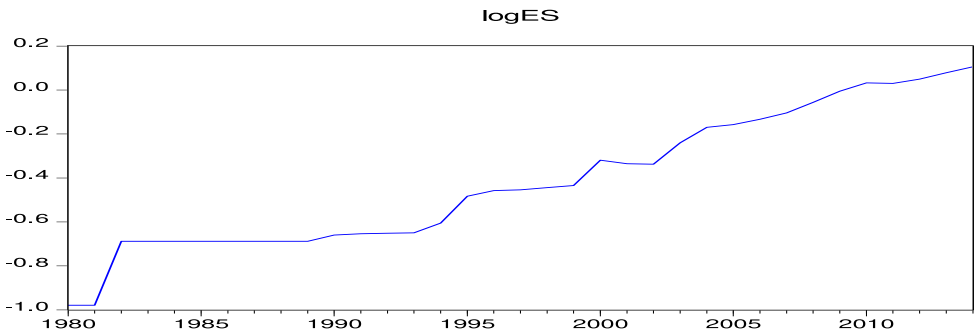

Figure 6: History of electricity supply (logES) (1980-2014)

Source: Authors' estimation based on data from US EIA (2016)

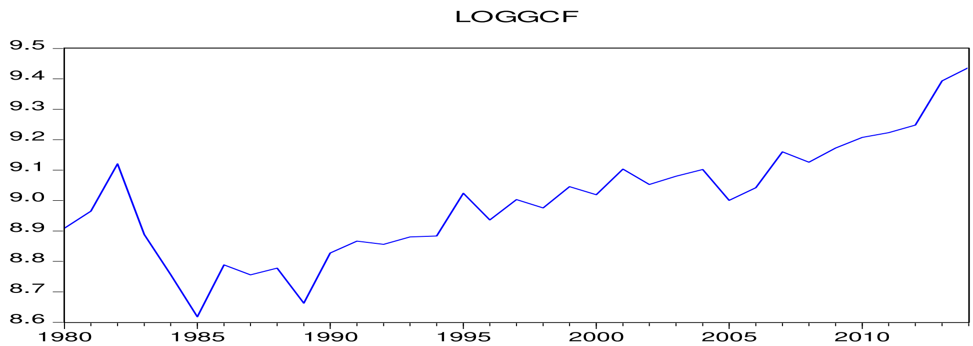

Figure 7: History of gross capital formation (logGCF) (1980-2014)

Source: Authors' estimation based on data from World Development Indicators (2016)

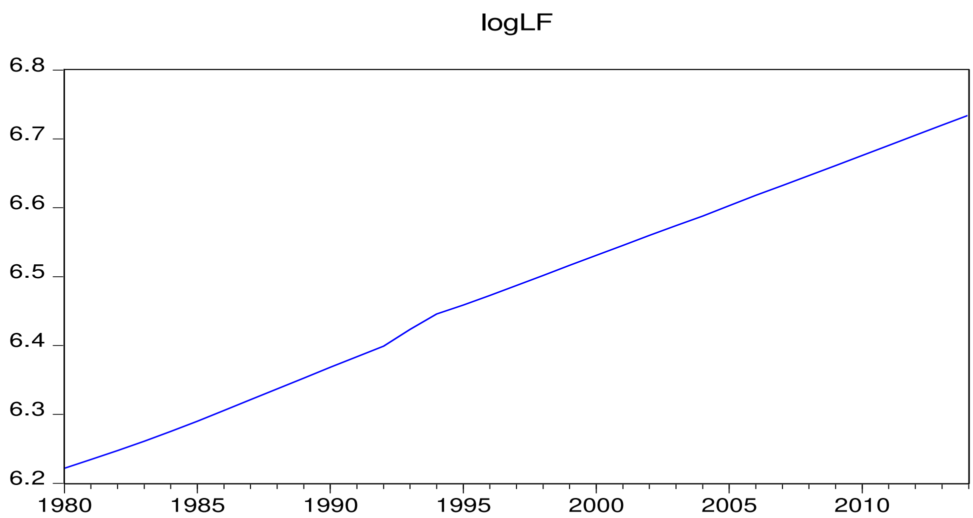

Figure 8: History of labour force (logLF) (1980-2014)

Source: Authors' estimation based on data from US Census Bureau (2016)

Table 4: Results of unit root tests

Unit root tests			**Variables**				
			logRGDP	**logEC**	**logES**	**logGCF**	**logLF**
KPSS	Level	Intercept and trend	0.144485	0.094474	0.135728	0.134771	0.151169**
	1st difference	Intercept and trend	---	---	---	---	0.121166
ZA	Level	Intercept and trend	-4.569203 (2) [1987]	-6.250517 (2)*** [1989]	-4.408400 (2) [1995]	-4.631197 (2) [1987]	-16.60632 (2)*** [1993]
	1st difference	Intercept and trend	-6.401279 (2)*** [1990]	---	-7.840395 (2)*** [2003]	-7.352964 (2)*** [1996]	---
MADF	Level	Intercept and trend	-4.4396 (2) [1986]	-8.4120 (2)*** [1988]	-10.5039 (2)*** [1994]	-4.5204 (2) [1987]	-16.2215 (2)*** [1992]
	1st difference	Intercept and trend	-6.9210 (2)*** [1987]	---	---	-7.1472 (2)*** [1991]	---

Table 4: Results of unit root tests

Notes: (***) and (**) indicate 1% and 5% significance levels respectively

The numbers in round brackets represent the maximum lag selected to run the unit root test.

The numbers in square brackets represent the break dates.

Source: Authors' estimation

4.3 Results of cointegration and diagnostic tests

Table 5 shows that for both model 1 F(logRGDP\logEC, logGCF, logLF) and model 2 F(logRGDP\logES, logGCF, logLF), the F statistic of the bounds test is superior to the upper bound critical value of Narayan's (2004) table (restricted intercept with no trend) at 5% and 1% respectively (model 1 and 2 are in bold in Table 5). This shows that there is evidence of a cointegration relationship among the variables of model 1 (real GDP (logRGDP), electricity consumption (logEC), gross capital formation (logGCF), labour force (LF)) and variables of model 2 (real GDP (logRGDP), electricity supply (logES), gross capital formation (logGCF), labour force (LF)).

	Models	F-statistic (Bounds test)	ARDL	DW test	Adj-R^2	R^2	F-statistic (cointegration test equation)	Probability F-statistic (cointegration test equation)
Model (with electricity consumption (EC))	**F(logRGDP\logEC, logGCF, logLF)**	5.5533**	ARDL (1,2,2,2)	1.9888	0.6415	0.7535	6.7266***	0.0001
	F(logEC\logRGDP, logGCF, logLF)	2.3584	ARDL (1,2,0,0)	1.5261	0.4991	0.5930	6.3148***	0.0003
	F(logGCF\logRGDP, logEC, logLF)	6.0597***	ARDL (1,2,2,0)	1.8667	0.5199	0.6399	5.3326***	0.0006
	F(logLF\logRGDP, logEC, logGCF)	2.6934	ARDL (2,0,0,0)	1.6753	0.1078	0.2472	1.7738	0.1520
Model (with electricity supply (ES))	**F(logRGDP\logES, logGCF, logLF)**	12.2598***	ARDL (2,0,2,2)	2.0470	0.5082	0.6465	4.6745***	0.0013
	F(logES\logRGDP, logGCF, logLF)	10.5689***	ARDL (1,2,1,0)	1.1504	0.6262	0.7079	8.6582***	0.00002
	F(logGCF\logES, logRGDP, logLF)	3.3518	ARDL (1,1,0,0)	2.1937	0.3499	0.4484	4.5537***	0.0036
	F(logLF\logES, logGCF, logRGDP)	2.5741	ARDL (2,0,0,0)	1.7620	0.0945	0.2360	1.6681	0.1763
Significance level of F-statistic from the bound test	Narayan critical value for lower bound I(0) (in the restricted intercept with no trend's table)	Narayan critical value for upper bound I(1) (in the restricted						

		intercept with no trend's table)
1%	4.578	5.864
5%	3.198	4.202
10%	2.644	3.548

Table 5: Cointegration results for all UECMs

Notes: (*), (**), (***) indicate significant at 10%, 5% and 1% respectively

The cells in bold represent our models of interest.

Source: Authors' estimation

The next step was to verify if the UECMs (F(logRGDP\logEC, logGCF, logLF) and F(logRGDP\logES, logGCF, logLF) are the only cointegrating vectors or if other UECMs ((F(logEC\logRGDP, logGCF, logLF), F(logGCF\logRGDP, logEC, logLF), F(logLF\logRGDP, logEC, logGCF), F(logES\logRGDP, logGCF, logLF), F(logGCF\logES, logRGDP, logLF) and F(logLF\logES, logGCF, logRGDP)) also constitute cointegrating vectors. This was done using the weak exogeneity test and by observing the sign and the significance of the coefficient on the error correction terms of each UECM. If the coefficient of the error correction term is not negative or not significant, the corresponding UECM is not viable. As said before, the weak exogeneity test applies a Wald restriction on the coefficient of the error correction term. If the Chi-square statistic is not significant, then, the corresponding UECM is not viable, in other words, such UECM is not a cointegrating vector. Tables 6 and 7 present the results of the weak exogeneity test.

Models	**Dependent variable**	**Coefficient of the error correction term (*ECT*)**	**P-value of *ECT***	**Chi-square (Wald test)**	**P-value of Chi-square**
F(logRGDP\logEC, logGCF, logLF)	∆logRGDP	-0.348799***	0.0003	17.74745***	0.0000
F(logEC\logRGDP, logGCF, logLF)	∆logEC	1.835386**[(a)]	0.0293	5.294696**	0.0214
F(logGCF\logRGDP, logEC, logLF)	∆logGCF	0.247019[(a)]	0.7528	0.101236	0.7504
F(logLF\logRGDP, logEC, logGCF)	∆logLF	0.005818[(a)]	0.7641	0.091864	0.7618

Table 6: Results of the weak exogeneity test (models with logEC as one of the variables)

Notes: (***) and (**) indicate 1% and 5% significance levels respectively.

The numbers in square brackets are the t-statistic.

(a) indicates that the coefficient of the error correction term is positive.

Source: Authors' estimation

Models	Dependent variable	Coefficient of the error correction term (ECT)	P-value of ECT	Chi-square (Wald test)	P-value of Chi-square
F(logRGDP\logES, logGCF, logLF)	ΔlogRGDP	-0.233617*	0.0585	3.903758**	0.0482
F(logES\logRGDP, logGCF, logLF)	ΔlogES	2.435854***(a)	0.0000	28.01633***	0.0000
F(logGCF\logRGDP, logES, logLF)	ΔlogGCF	0.444062(a)	0.6634	0.193588	0.6599
F(logLF\logRGDP, logES, logGCF)	ΔlogLF	0.001540(a)	0.9495	0.004090	0.9490

Table 7: Results of the weak exogeneity test (models with logES as one of the variables)

Notes: (***), (**), and (*) indicate 1%, 5%, and 10% significance levels respectively.

(a) indicates that the coefficient of the error correction term is positive.

Source: Authors' estimation

Tables 6 and 7 above show that only the coefficient of the error correction of our models of interest (models in bold in Tables 6 and 7) (F(logRGDP\logEC, logGCF, logLF) and F(logRGDP\logES, logGCF, logLF)) are significant at 1% and 10%. Tables 6 and 7 also show that only these coefficients are negative. Coefficients of the error correction term of other models are all positive. This indicates that only the cointegration vectors represented by the model of interest are viable. Cointegration vectors represented by other models are not viable.

Looking at the results of the Wald test, we can see that the chi-square statistic is significant in the case of the two models of interest (F(logRGDP\logEC, logGCF, logLF) and F(logRGDP\logES, logGCF, logLF)). In the other models, only the chi-square statistic of models F(logEC\logRGDP, logGCF, logLF) and F(logES\logRGDP, logGCF, logLF) are significant; however, as said previously, the coefficient of the error correction term for these models (F(logEC\logRGDP, logGCF, logLF) and F(logES\logRGDP, logGCF, logLF)) is positive. All these indicate that only the cointegrating vectors represented by the models of interest (F(logRGDP\logEC, logGCF, logLF) and F(logRGDP\logES, logGCF, logLF)) are viable. Cointegrating vectors represented by other models are not viable. These results confirm that the use of the ARDL model in this study was appropriate because the assumption stating that our model of interest should be the only cointegrating vector in an ARDL framework has been verified.

The next step was to check for the consistency of the models of interest by applying residuals and stability diagnostic tests. We established that the models of interest (model 1 for F(logRGDP\logEC, logGCF, logLF) and model 2 for F(logRGDP\logES, logGCF, logLF)) were stable, well-specified according to the Ramsey test, not affected by serial correlation and heteroskedasticity, and their residuals were normal (Table 8 below). The following step was to specify the short- and long-run dynamics of the models of interest (models 1 and 2) and to assess the GDP losses resulting from electricity losses. Because models 1 and 2 were stable, there was no need to ensure parameter stability by inserting a dummy variable which accounts for a structural break in the long and short run specifications of these models.

Models with electricity consumption (EC)	**Models**	**Normality (Jarque-Bera)**	**(LM test) Serial correlation**	**Hetero-skedasti-city test (Breusch Pagan-Godfrey)**	**Ramsey test**	**CUSUM**	**CUSUM of Sq**
	F(logRGDP\logEC, logGCF, logLF)	3.5607 (0.1685)	(0.5565)	(0.9610)	(0.9889)	stable	stable
Models with electricity supply (ES)	F(logRGDP\logES, logGCF, logLF)	1.0427 (0.5937)	(0.9262)	(0.5445)	(0.1033)	stable	stable

Table 8: Diagnostic test result for our model of interest

Note: Numbers in parentheses represent probability.

Source: Authors' estimation

4.4 Long- and short-run dynamics and losses of GDP

As said previously, our models of interest are F(logRGDP/logEC,logGCF,logLF) for model 1 and F(logRGDP/logES,logGCF,logLF) for model 2. The long-run estimates are presented in Table 9. It can be seen that a 1% increase in electricity consumption is associated with a 0.05% increase in real GDP in the long run. However, such increase in real GDP is not significant. Conversely, a 1% increase in electricity supply is associated with a significant 0.16% increase in real GDP in the long run. As the increase in real GDP associated with an increase in electricity consumption is not significant, it can be ignored. This indicates that in the long run, Benin loses on average 0.16% of its real GDP as a result of electricity losses. This represents a huge amount of inefficiency in the economy and has important policy implications.

In the short run, it can be seen (in Table 10) in the current period that the short-run effect of electricity supply on real GDP is positive (even though it is not significant), while the short-run effect of electricity consumption on real GDP is significant but negative due to the consecutive electricity shortages encountered by the country. In the past periods, the negative effect of electricity consumption on real GDP (due to the consecutive electricity shortages) would have been worse in the absence of electricity losses. In other words, in the past periods, if the losses of electricity are added to the shortages already occurring, the total negative effect on real GDP will be greater. This situation is illustrated by the greater coefficient of ES(-1) (-0.0793) in terms of absolute value than the coefficient of EC(-1) (.-0.0533). All this indicates that in the absence of electricity losses, in the short run, the country gains in terms of real GDP in the current period even though the gain is not significant (because the short-run coefficient on ES is positive but not significant), while in past periods the country loses 0.026% (the difference between the short-run coefficients of ES (-1) and EC(-1)) of its real GDP as a result of electricity losses and electricity shortages.

In both the short and long run (Tables 9 and 10), we observe a positive sign on the coefficient on gross capital formation and labour force in the current period. This aligns with our a priori expectation (see Barro, 1999 and 2003; Hamilton and Monteagudo, 1998; Anaman, 2004; Fischer, 1992; Acikgoz and Mert, 2014; Anyanwu, 2014; Bayraktar, 2006; Checherita-Westphal and Rother, 2012; Bleaney et al., 2001; Chang and Mendy, 2012; Most and Vann de Berg, 1996; Knight et al., 1993; Freire-Seren, 2002; Easterly and Levine, 1997; Chen and Feng, 2000; Benos and Zotou, 2014) which states that the correlations between real GDP and each of the independent variables (gross capital formation and labour force) depend on the country context: it can be positive or negative based on the country's economic context. We observe a negative sign on the coefficients on gross capital formation in the past period (GCF(-1)): this negative effect is related to the specific Beninese context where the economy has encountered consecutive energy crises (oil shortages, electricity shortages, etc.) which impeded productivity and growth.

Model 1: F(logRGDP/logEC,logGCF,logLF)	LogRGDP as dependent variable		
	Variables	**Coefficients**	**Probability**
	LogEC	0.0550	0.4803
	LogGCF	0.0715	0.2644
	LogLF	0.9754***	0.0000
	Constant	2.7788**	0.0301
Model 2: F(logRGDP/logES,logGCF,logLF)	**LogRGDP as dependent variable**		
	Variable	**Coefficients**	**Probability**
	LogES	0.1634***	0.0076
	LogGCF	0.0864*	0.0944
	LogLF	0.7576***	0.0000
	Constant	4.0149***	0.0001

Table 9: Long-run models

Note: (*), (**), (***) indicate significant at 10%, 5% and 1% respectively.

Source: Authors' estimation

Model 1: F(logRGDP/logEC,logGCF,logLF)	LogRGDP as dependent variable		
	Variables	**Coefficients**	**Probability**
	LogEC	-0.0318**	0.0245
	LogEC(-1)	-0.0533***	0.0003
	LogGCF	0.0694***	0.0001
	LogGCF(-1)	-0.0324**	0.0358
	LogLF	0.1894	0.7333
	LogLF(-1)	-1.2335**	0.0467
	ECTa1	-0.3691***	0.0000
Model 2: F(logRGDP/logES,logGCF,logLF)	LogRGDP as dependent variable		
	variable	**Coefficients**	**Probability**
	LogRGDP(-1)	0.2794*	0.0611
	LogES	0.0318	0.2880
	LogES(-1)	-0.0793**	0.0124
	LogGCF	0.0422**	0.0255
	LogGCF(-1)	-0.0517***	0.0096
	LogLF	0.0010*	0.0721
	ECTa2	-0.5607***	0.0001

Table 10: Short-run models

Note: (*), (**) and (***) indicate significant at 10%, 5% and 1% respectively.

Source: Authors' estimation

4.5 Discussion and policy recommendations

To the best of the writers' knowledge, previous studies on the electricity-growth nexus did not evaluate empirically the effect of electricity losses on GDP, comparing both long- and short-run estimated coefficients of electricity supply and consumption. A study by Obafemi and Ifere (2013) on the Calabar region of Cross River State in Nigeria identified the different types of non-technical electricity losses related to illegal human behaviour in the region. They did not go further to evaluate the effect of these electricity losses on the GDP of the region. Their study is a descriptive analysis using cross-sectional data. To the best of the writers' knowledge, the current study is the first to evaluate empirically the net effect of electricity losses on GDP in the Beninese context. Losses of electricity are one of the challenges of the Beninese electricity sector. Based on data from US EIA (2018), in 2015 Benin was ranked as the ninth country in Africa and the 20th in the world in terms of share of electricity losses in total supply of electricity. From the results of the current study, it is clear that in the absence of electricity losses, Benin would have gained in terms of real GDP in both the short and long run. Technical and non-technical losses generate inefficiency in the economy, as the country loses on average in the long run 0.16% of its GDP because of electricity losses. In 2014, for instance, Benin lost about US$ 13.7 million constant 2010 because of losses of electricity (Figure 9). Based on statistics from the World Development Indicators (2018), such loss represents 1.022% of total government expenditure 2014. These amounts converted into CFA, the currency used by Benin and other francophone countries in Africa, represent billions of CFA and a great waste of wealth for the country. Consequently, Benin's efforts to alleviate poverty and reduce income inequality are negatively affected by these losses of GDP resulting from electricity losses. If there were no electricity losses, these GDP losses would have been some economic gains for the country. As Figure 9 shows the annual GDP losses due to electricity losses have been increasing from 1980 to 2014.

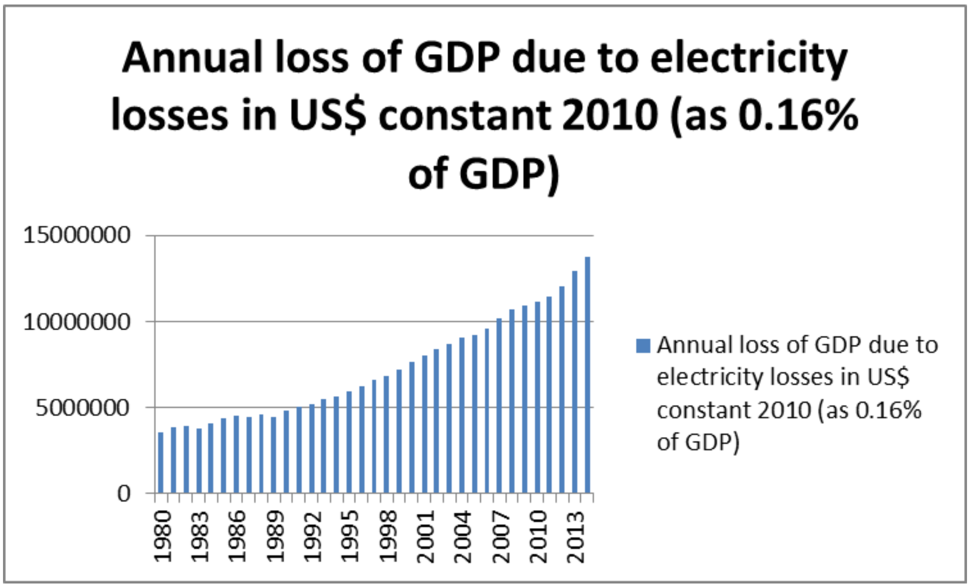

Figure 9: History of losses of GDP due to losses of electricity (in US$ constant 2010, and as 0.16% of GDP)

Source: Authors' estimation based on data from US EIA (2016) and the World Development Indicators (2016)

The current study has established that a 1% increase in electricity losses leads to a 0.16% increase in GDP losses. It has revealed that on average Benin loses 0.16% of GDP annually because of electricity losses. In other words, in the absence of electricity losses, the country would have gained on average 0.16% of its GDP annually. As said before, according to République du

Bénin (2008), one of the pillars of the second objective of the national strategy for access to electricity is to ensure electricity efficiency in Benin. In order to align with such pillar, the Beninese Ministry of Energy has planned to reduce electricity losses to 14% from 2020 to 2025 (République du Bénin, 2008). Based on the results on the effect of electricity losses on GDP established in this study, such 14% reduction of electricity losses would allow the country to gain in terms of GDP every year from 2020 to 2025. As explained previously, in order to achieve such goal the national policy framework for electricity has planned to modernize the distribution lines with equipment that is electricity-efficient in order to reduce technical losses of electricity. The country also has an emergency plan to fight against corruption and theft of electricity, and to improve the billing system of electricity supply and consumption in order to reduce non-technical losses of electricity (see République du Bénin, 2008, pp. 54–55). All these actions are costly and funding is required to finance them. As mentioned before, the Regulatory Indicators for Sustainable Energy (2018) reported that Benin does not have a direct financing mechanism of activities aiming at reducing electricity losses, and in this context the national policy framework for electricity proposed an indirect financing mechanism of activities aiming at reducing electricity losses. Such mechanism proposed to use funds from donors or the national budget to finance the costs of activities that will reduce electricity losses. Then, it suggested using the gain in GDP resulting from reductions in electricity losses to reimburse the donors or the national budget (see République du Bénin, 2008, p. 65). The current study has empirically established that a 1% reduction in electricity losses leads to a 0.16% increase in GDP. This indicates that the indirect financing mechanism proposed by the national policy framework for electricity is feasible, because there will be some gains in terms of GDP due to reduction in electricity losses. As explained previously, such gain could represent an increase in government revenues related to sales of electricity, because of reductions in commercial losses of electricity encountered by the SBEE and the CEB (which are state-owned electricity distribution companies). Commercial losses of electricity can be reduced by improving the billing system of electricity consumption and supply and by reducing thefts of electricity. For instance, the distribution companies can adopt the “prepaid” electricity approach instead of the “post-paid” approach which is in use currently. The “prepaid” approach means that consumers purchase electricity before consumption, in other words consumers pay electricity bills before consumption, while the post-paid approach means that consumers only pay the electricity bills after consumption. The post-paid approach has limitations because the distribution companies encounter a huge amount of default in electricity bill payments.

The gain in terms of GDP resulting from a reduction in electricity losses can also represent a reduction in the cost of imported electricity. If there is a reduction of electricity losses, the quantity of electricity supply that reaches consumers will increase by an amount corresponding to the reduction in electricity losses. For a country such as Benin, which aims to improve its self-sufficiency rate of electricity supply by limiting its dependency on importation of electricity, such increase will correspond to a reduction in electricity imports. Consequently, government will save some of its revenues allocated to importation of electricity. As said previously, government revenues are included in the calculation of GDP. Hence, increases in government revenues because of reductions in electricity losses constitute gains in terms of GDP. These gains can be used to reimburse the costs of activities aiming at reducing electricity losses as suggested by the financing mechanism proposed by the national policy framework for electricity.

By demonstrating that the indirect financing mechanism proposed in the national policy framework for electricity is feasible in Benin, the current study will contribute to the advancement of electricity efficiency policy and electricity security policy, which target to reduce disruptions to electricity supply caused by electricity losses.

5 CONCLUSION

This study has established that in the long run, Benin loses 0.16% of GDP as a result of electricity losses, which is a huge amount of resource for a low income country. Government should attempt to minimize electricity losses by improving the technology and the monitoring system related to the distribution of electricity. By demonstrating empirically that there will be some gains in terms of GDP if reductions of electricity losses occur, this study has proved that the indirect financing mechanism proposed by the national policy framework for electricity to fund the costs of reduction of electricity losses is feasible. The current study will therefore contribute to advance electricity efficiency and electricity security policy aiming at reducing disruption to the electricity supply caused by electricity losses. It will also add value to the existing literature on electricity efficiency and electricity security on Benin. Although losses of electricity constitute a major source of vulnerability of the Beninese electricity sector, they are just one challenge among many. As reported by the Republic of Benin (2008), the country has also encountered significant shortages of electricity due to sudden reductions of importation of electricity. These shortages of electricity constitute negative shocks on electricity consumption. The national policy framework for electricity (République du Bénin, 2008) has reported that these negative shocks to electricity consumption cause negative shocks to economic growth in Benin. However, to the best of the writers' knowlege, there is no empirical study on Benin which has verified if negative shocks to electricity consumption cause negative shocks to economic growth. As reported by the World Development Indicators (2017), the share of electricity consumption in total primary energy consumption is very low, and has remained less than 2.07% over 44 years (1971-2014). Because of this, it is possible that negative shocks to electricity consumption have no causal effect on negative shocks to economic growth. It therefore becomes important to verify empirically if negative shocks to electricity consumption cause negative shocks to economic growth. This constitutes the focus of another paper.

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