MODELLING THE EFFECT OF DISRUPTION TO ELECTRICITY SUPPLY ON ECONOMIC GROWTH IN BENIN

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Dissertation presented for the degree of

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Declaration

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AGD Dakpogan December 2019

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Dedication

In memory of my beloved son, Joseph Essenam Arnaud Dakpogan. My dearest son, this PhD journey has taken so much of our time together. I was not able to see your face, carry you in my arms as your father, and welcome you in this world. I long to hug you one day in Heaven. I love you, my dearest son. From your earthly father.

In memory of my beloved aunt, Marguerite Tchanhoun. Maman, I will always be grateful to God for using you that night to save the lives of both my mother and I from a tragedy. Your generosity and compassion will never be forgotten. I love you my dearest aunt and long to hug you one day in Heaven. From the son that you have adopted as your own.

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Abstract

Infrastructure is an important factor that contributes to economic growth. Energy, telecommunications, roads, rails, sea ports, airports, and drinkable water are important elements which determine the ease of doing business in a country. Among these various types of infrastructure, energy is essential, as it contributes to the development of other infrastructure. Energy is important for the construction of roads, telecommunication lines, sea ports, airports, and even the transportation of potable water. Among the different types of energy, electricity is essential as it plays a vital role in the functioning of all sectors of the economy. Electricity is used in industry, the health sector, at schools, in the transport sector, in the agroindustry, in the construction sector, in banks, in public administration, and in houses, amongst other things. Because of this, electricity is an important factor that contributes to economic growth and the improvement in the standard of living.

However, the situation of sub-Saharan Africa regarding access to and consumption of electricity is very alarming. Sub-Saharan Africa has the lowest access to and consumption of electricity in the world. Benin is one of the countries with low access to and consumption of electricity in sub-Saharan Africa. In addition, the Beninese electricity sector faces three major challenges: a high level of dependency on the importation of electricity, high losses of electricity, and high reliance on oil for domestic electricity production. Benin is the only sub-Saharan African country which figures simultaneously among the top 10 countries for heavy dependence on importation of electricity in 2015, for the high proportion of electricity losses in 2015, and for the heavy reliance on oil for the domestic electricity generation in 2014 (most recent year for which data was available at the time of analysis). Other countries in sub-Saharan Africa figure in either one or two of these lists of top 10 countries. This indicates that in sub-Saharan Africa, the Beninese electricity sector is one of the most vulnerable. This was among the main reasons that the focus of this study is on the Beninese electricity sector.

First, the country imports more than 70% of its electricity supply from neighbouring countries such as Ghana and Nigeria. Hence, it is very vulnerable to any electricity shortages occurring in these neighbouring countries. Such import dependency has resulted in electricity crises, which occurred in the 1980s, 1990s and 2000s in Benin due to shortages of electricity in Ghana. This is therefore one of the causes of disruption to the electricity supply in Benin. Second, the Beninese electricity sector encounters significant amounts of electricity loss during transmission and distribution. Such losses exceed the international target of electricity losses defined by ECA (2008). These electricity losses reduce the quantity of electricity supplied to consumers and are therefore sources of disruption to the electricity supply. Third, Benin relies heavily on oil to produce its electricity domestically, while the country is a net importer of oil. More than 90% of the domestic electricity production is based on oil. Hence, the Beninese electricity sector is exposed to fluctuation in oil

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prices. Increases in oil prices limit the country’s domestic capacity of electricity production, and therefore are a source of disruption to the electricity supply.

The World Bank (2016) has reported that these disruptions to electricity supply have resulted in losses of sales by firms in Benin. The national policy framework for electricity (République du Bénin, 2008) also reported that these disruptions to electricity supply have negatively affected economic growth. However, there is no empirical evidence which has verified that disruptions to electricity supply have caused reductions in economic growth. In addition, the World Development Indicators (2018) reported that the share of electricity consumption in total primary energy consumption is very low, and has never exceeded 2.07% over 44 years (1971-2014). It is thus possible that disruptions to the electricity supply do not cause any reduction of economic growth. It is therefore important to investigate empirically the effect of disruptions to the electricity supply on economic growth. This was the main objective of the current study. Such an objective has been decomposed into three specific objectives. The first is to construct a composite index of disruption risk to the electricity supply in order to measure the performance of the Beninese electricity sector concerning the disruption of electricity. One of the goals of the national policy framework for electricity is the definition and improvement of performance indicators for the electricity sector and the national distribution company. Constructing a composite index of disruption risk to the electricity supply to measure the performance of the electricity sector, aligns with this goal. A composite index of disruption risk to electricity will be a useful tool for the monitoring of Benin in regard to electricity supply security.

The second specific objective is to assess the effect of electricity losses on GDP. Such an objective aligns with another goal of the national policy framework for electricity, which is to use an indirect financing mechanism to fund the costs associated with the reduction of electricity losses. Such a mechanism suggests using funds from donors or the national budget to finance the costs associated with the reduction of electricity losses. It then proposes using the gain in GDP resulting from the reduction in electricity losses to reimburse the donors or the national budget. It is therefore important to understand the effect of electricity losses on GDP. Understanding the effect of electricity losses on GDP will help to assess the gain of GDP resulting from a reduction in electricity losses. It will therefore contribute to assessing the feasibility of the indirect financing mechanism proposed by the national policy framework for electricity. It will also contribute to advancing policy on electricity supply efficiency in Benin.

The third specific objective is to assess the causal effect of negative shocks to electricity supply on negative shocks to GDP as is the general belief. As said previously, the national policy framework for electricity reported that disruptions to electricity supply have caused a reduction in economic

growth, while there is no empirical evidence showing that negative shocks to electricity supply have caused negative shocks to GDP. It is therefore important to investigate empirically the causal effect of negative shocks to electricity supply on negative shocks to GDP. Such an investigation will contribute to verifying the conclusions of the national policy framework for electricity. It will also contribute to advancing the formulation of policy on electricity supply security in Benin. Two different approaches have been used to conduct these investigations and assessments: a symmetric and an asymmetric approach.

The objectives of the study have been organized into three different empirical papers. The first paper constructed a composite index of disruption risks to electricity supply. Depending on the level of disruption risk, the values of such an index fall in the following ranges: [0.5, 1[(low level of disruption risk), [1, 1.5[(medium level of disruption risk), [1.5, 2[(high level of disruption risk), [2, 2.5[(very high level of disruption risk), 2.5 and above (extremely high level of disruption risk). The paper established that Benin's performance concerning its effort to avoid disruptions to electricity supply is very low. Benin is among the countries of the world that have a very high level of disruption to electricity supply. The average values of the composite index of disruption risks to electricity supply for Benin over the periods 2002-2005, 2006-2010 and 2011-2015 are 2.157, 2.036 and 2.132 respectively. Benin was ranked fourth in the world with a very high level of disruption to electricity supply over the periods 2002-2005 and 2006-2010. Over the period 2011-2015, the country was ranked third in the world with a very high level of disruption to electricity supply.

The second paper has established that on average Benin loses 0.16% of its GDP because of electricity losses. In other words, on average, Benin would have gained 0.16% of its GDP for a 1% reduction in electricity losses. This loss of GDP constitutes an inefficiency in the economy. This result confirms that the indirect financing mechanism proposed by the national policy framework for electricity is feasible.

The third paper established that negative shocks of electricity supply cause negative shocks to GDP, while positive shocks of electricity supply have no causal effect on positive shocks to GDP. This result ascertains the conclusion of the national policy framework stating that shortages of electricity supply have caused reductions in economic growth. It also indicates that electricity supply is still low in Benin, and has not yet reached the threshold at which it will start having a positive effect on economic growth.

Based on the results of these three empirical papers, it is recommended first that Benin must improve its electricity efficiency policy by for instance leaving the postpaid system and adopting the prepaid system. In the postpaid system, consumers have the option of not paying their electricity bills, resulting in a loss of revenue for the national distribution company and therefore for the government. Losses of government revenues constitute losses of GDP, because government

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revenues are included in the calculation of GDP. In the prepaid system, consumers purchase the amount of electricity they will consume and there is no option for them but to pay for their electricity, which makes the prepaid system more efficient than the postpaid system. Second, in order to reduce losses of electricity, it is strongly recommended that the country implement the indirect financing mechanism proposed in the national policy framework for electricity. Such a mechanism aims to finance the costs of activities that will promote the reduction of electricity losses.

Third, it is recommended that Benin must try to avoid disruptions of electricity, because they have a negative impact on economic growth. Disruptions of electricity are caused by several factors including dependency on the importation of electricity and heavy reliance on oil for the domestic production of electricity. Benin must reduce both its dependency on importation of electricity and its heavy reliance on oil to produce electricity domestically. Fluctuations in oil prices have a negative impact on Benin’s capacity to produce electricity domestically. In many cases, shortages of electricity occur in the country because of sudden reductions of the available quantity of electricity to be exported by Ghana toward Benin. One way for Benin to reduce its heavy reliance on oil for the domestic production of electricity is to increase the share of electricity produced based on renewable sources in the total domestic production of electricity. Therefore, the production of electricity using renewable energy, such as solar and wind energy, must be explored. The country should increase access to electricity via the off-grid system with solar electricity. Other factors which cause a disruption of electricity are the low quality of the governance system and rapid urbanization. Poor governance has a negative impact on the delivery of electricity. The insufficient control of corruption and the weak rule of law have led to thefts of electricity on the transmission and distribution lines in Benin. Therefore, Benin must improve its government effectiveness, the rule of law, the quality of its regulatory system, and the control of corruption. When the growth rate of urbanization evolves more rapidly than the growth rate of urban access to electricity, there is a supply gap of electricity in urban areas because the urban demand of electricity exceeds the urban supply. Such a supply gap is a source of disruption of electricity. This is the case in Benin. In order to slow down massive migration from rural to urban areas, the country must provide rural areas with social and economic infrastructure such as schools, hospitals, paved roads, and so on, which will create an incentive for the rural population to continue residing in rural areas and not migrate to urban areas on a large scale.

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Acronyms and Abbreviations

ABERME	Agence Béninoise d'Electrification Rurale et de Maîtrise d'Energie (Beninese Agency for Rural Electricity Distribution and Regulation)
ADB	Asian Development Bank
ADF	Augmented Dickey-Fuller
AfDB	African Development Bank
AIC	Akaike Information Criterion
AIDI	Africa Infrastructure Development Index
ANADER	Agence Nationale pour le Développement des Énergies Renouvelables et de l'efficacité énergétique (National Agency for Renewable Energy Development and Energy Efficiency)
APERC	Asia Pacific Energy Research Centre
ARCH	Autoregressive Conditional Heteroskedasticity
ARDL	Autoregressive Distributive Lags
ASEAN	Association of Southeast Asian Nations
BOD	Benefit of the Doubt Approach
CEB	Communauté Électrique du Benin (Beninese Electrical Community)
CFA	Communauté Financière Africaine (Financial Community of Africa, official currency of Benin and other francophone countries in Africa)
DEA	Data Envelopment Analysis
DECC	Department of Energy and Climate Change
DF-GLS	Dickey-Fuller Generalized Least Squares
DGE	Direction Génerale de l'Énergie (Directorate General of Energy)
EC	Electricity Consumption
ED	Domestic Electricity Production
ECA	Economic Commission for Africa
ECT	Error Correction Terms
ECOWAS	Economic Community of West African States
EI	Education Index

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EIA	Energy Information Administration
EL	Losses of Electricity
ENL	Electricity Not Lost
ES	Electricity Supply
ESE	Rate of Electricity Supply Efficiency
ESRI	Electricity Supply Disruption Risk
ESS	Rate of Electricity Supply Self-sufficiency
EXE	Exports of Electricity
FA	Factor Analysis
FPE	Final Prediction Error
GCF	Gross Capital Formation
GI	Governance Index
GDP	Gross Domestic Product
HDI	Human Development Index
HQ	Hannan-Quinn Information Criterion
IADB	Inter- American Development Bank
ICZ	Inter-tropical Convergence Zone
IE	Imports of Electricity
IEA	International Energy Agency
II	Income Index
IMF	International Monetary Fund
IT	Information Technology
KPSS	Kwiatkowski–Phillips–Schmidt–Shin
LEI	Life Expectancy Index
LF	Labour Force
LR	Likelihood Ratio
MADF	Modified Augmented Dickey Fuller
MCA	Millennium Challenge Account

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MESRI	Modified Electricity Supply Disruption Risk Index
MVP	Mean Variance Portfolio
NIE	Net Imports of Electricity
OECD	Organisation for Economic Co-operation and Development
PCA	Principal Component Analysis
PP	Phillip-Perron
RACE	Rate of Access to Electricity
RGDP	Real GDP
RGDPcW	Normalized Real GDP Per Capita
RNEEX	Share of Real GDP Not Dedicated to Cover the Cost of Electricity Supply
RRE	Rate of Renewable Electricity
RUB	Ratio of the Growth of Urban Access to Electricity to the Growth of Urbanisation Rate
SBEE	Société Béninoise d'Energie Electrique (Beninese Electrical Energy Company)
SC	Schwarz Information Criterion
TES	Total Supply of Electricity
UCM	Unobserved Component Models
UC-PDER	Unité Chargée de la Politique de Développement des Energies Renouvelables (Unit in Charge of Policy for the Development of Renewable Energy)
UECM	Unrestricted Error Correction Models
UK	United Kingdom
UNDP	United Nations Development Program
US	United States
USEIA	United States Energy Information Administration
USGS	United States Geological Survey
VAR	Vector Autoregressive
WEL	West Coast Energy Limited
ZA	Zivot-Andrews

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CHAPTER 1[1]

INTRODUCTION

1.1 MOTIVATION AND BACKGROUND

1.1.1 Importance of infrastructure for economic development

The availability and access to infrastructure such as energy/electricity, water sanitation, rails, roads, and telephone lines, in a country stimulates economic growth by improving the productivity of the economy, while enhancing the standard of living and the quality of life for residents (Ajakaiye and Ncube, 2010; Egert, Kozluk and Sutherland, 2009; Sanchez-Robles, 1998). According to Mbaku (2013), public infrastructure improves trade and many other commercial activities within countries and between countries. It also contributes significantly to the alleviation of poverty and inequality (World Bank, 2006; Ndulu, 2006).

Three main schools of thought emerge in the theoretical literature on the link between infrastructure development and economic growth. The first considers infrastructure to be included in the physical stock of capital of any given country and is, therefore, a factor of production (Gramlich, 1994; Aschauer, 1993). It argues that change in the available stock of infrastructure will directly influence economic growth. The second considers infrastructure as a complement to other factors of production. It argues that infrastructure development may lower input costs, and expand the production frontier for different remunerative ventures (Barro, 1990). The third considers infrastructure to be an economic variable causing an accumulation of production factors. It argues that infrastructure development influences economic growth indirectly by stimulating the productivity and accumulation of production factors. Access to roads and affordable electricity, health and education facilities contributes to building skilled labour and improving labour productivity (Fedderke and Garlick, 2008).

When examining the relationship between infrastructure and economic growth different infrastructure indicators can be used: energy supply or consumption, kilometres of telephone lines, and so forth. Alternatively, a composite index of infrastructure development such as the AIDI (Africa Infrastructure Development Index), developed by the African Development Bank (2013) for African countries, can also be used. In a cross-country analysis of sub-Saharan Africa, Kodongo and Ojah (2016) established that countries which have a high level of infrastructure also have a high level of income, and countries which have a low level of infrastructure also have a low level of income. Specifically, they established a positive and high correlation (0.66 for the correlation

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[1] An article based on this chapter, titled “*The vulnerability of the electricity sector in sub-Saharan Africa: who is the most vulnerable*”, has been presented at the First International Conference on Energy, Finance, and the Macroeconomy (ICEFM), held in November 22, 2017, at Montpelier Business School, in France.

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coefficient) between income and energy consumption, and a positive and low correlation (0.37 for the correlation coefficient) between income and kilometres of telephone lines. Their results illustrate the existence of a positive relationship between infrastructure development and economic growth, and an especially strong positive relationship between energy consumption and economic growth in Africa. Energy remains essential for the development of other types of infrastructure such as school and health facilities, roads, seaports, airports, telecommunication capacity, railways, water and sanitation. In other words, without energy it will be difficult to develop other types of infrastructure. This makes energy an important infrastructure necessary for economic development.

1.1.2 Importance of energy and electricity for economic development in the world and Africa

Energy/electricity is essential for technical progress and the productivity of an economy. According to Templet (1999) and Ebohon (1996), energy plays a key role in complementing capital and labour for production. A lack of energy is a limiting factor for economic growth and progress in science and technology. Energy/electricity is necessary for factory production in the industrial and agricultural sectors, and is vital for the daily performance of the tertiary sector (public administration, banks, schools, hospitals).

The IEA (2002) compared the effects of access to different forms of energy (coal, gas, oil, biomass, electricity, and so forth.) on the welfare of the poor and concluded that access to electricity has the greatest effects on those living in poverty. Ferguson, Wilkinson and Hill (2000) argue that the correlation between electricity consumption and wealth creation is stronger than that of other forms of energy consumption (such as coal, oil, gas, biomass). This indicates that amongst all forms of energy, electricity plays a crucial role in economic growth and the improvement of welfare within countries. As argued by Ebohon (1996) and Rosenberg (1998), electricity is a driver of economic productivity and is the main source of energy used in new sectors such as the digital industry. Without electricity, such industry cannot exist. In addition, the IEA (2002) argued that the economic and social development of countries cannot be achieved in the absence of different types of energy, particularly in the absence of electricity. It went further and stipulated that a strong correlation exists between the consumption of electricity and wealth; and additionally, between a lack of access to electricity and poverty (as a percentage of the population living with less than 2 US Dollars per day). All these studies demonstrated the important role of energy in economic development and poverty reduction, and particularly highlighted access to electricity as having a great positive effect.

No country has ever moved from a state of poverty with a developing economy to a state of wealth and a developed economy without access to energy (World Bank, n.d.). In alignment with such a statement, Toman and Jemelkova (2003) argued that improvements in the quality of energy

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services will contribute to increased economic productivity. Further, Toman and Jemelkova (2003) and Burney (1995) argued that for any country, the interrelations between energy and other production factors evolve according to the level of economic development. Low development stages correspond to a low level of energy usage, while high development stages require a high level of energy usage. They also highlighted the increasing role of fossil fuels and electricity in a country as it moves to higher stages of economic development. Ferguson et al. (2000) illustrated this using the example of developed countries. They argued that increases in wealth in developed countries are highly correlated to increases in energy consumption. In alignment with them, Rosenberg (1998) stipulated that in developed countries, the supply of electricity has been an important determinant of both industrial development and an improved standard of living. In the case of developing countries, the Economic Comission for Africa (ECA) (2004) argued that export diversification is highly correlated with per capita electricity consumption and access to electricity. This indicates that countries where access to electricity is high, also have lower energy costs and more diversified exports; conversely, countries where electricity consumption per capita is low, also have high energy costs. This implies that sufficient investments in energy infrastructure are necessary for export diversification and for a strong and sustainable economic growth and poverty reduction. Theoretically, there is consensus on the important role of energy or electricity consumption to achieve economic growth and poverty reduction, and there are many diverse channels through which energy or electricity contributes to promoting economic growth and poverty reduction.

Stern (2011) argued that in the pre-industrial era, people used human physical strength, then animal traction, for production, and in the industrial era, people started using energy from water, wind, hydrocarbon and lastly, electricity. This indicates that energy/electricity, when combined with the appropriate technology, increases human capacity to produce. In the post-industrial era, all sectors of the economy continue using energy/electricity to function. Government, households and firms buy energy or electricity on energy markets where producers are composed of energy companies (in liberalized energy markets) or public monopolies (in non-liberalized energy markets). Government uses energy or electricity to produce public goods and services such as roads, bridges, public schools and hospitals, national security (police digital checking at airports and seaports, digital identity) aiming to improve the common welfare of society.

Households use energy or electricity for lighting, air conditioning, cooking, and for the functioning of different electrical appliances such as televisions, computers, cell phones, and so forth. According to Slutsky (1915), Allen (1934), Houthakker (1961), Chipman, Hurwicz, Richter and Sonnenschein (1971) and Samuelson (1974), commodities purchased in the market influence the consumer's welfare. Energy or electricity is also among commodities purchased by households. Dubin (1985) and Flaig (1990) have argued that the purchased electricity is combined with a stock of electrical appliances to produce an electric composite good, which then influences the households' welfare. Without electricity, students at home cannot easily review their daily courses at night. With electricity, households save time in using electricity for cooking rather than using biomass, which can be harmful for their health and for the natural environment. Moreover, with electricity at home, households can safely conserve food by refrigeration. Electricity significantly contributes to the improvement of welfare and the standard of living within households.

Firms use energy or electricity as an input for production. According to Stern (2010), energy or electricity is a production factor in the same way as are labour and capital. The industrial sector uses these production factors as inputs to produce manufactured goods purchased by households, government and the rest of the world. The industrial sector also uses electricity for air conditioning and lighting. The transportation sector (sea, rail, air, road transportation), and the IT (information technology) and telecommunication sectors, rely heavily on energy or electricity. Accessible and affordable energy or electricity reduces production costs for firms.

While energy, including electricity, has been one of the main drivers of technological progress, economic development and improvements in the standard of living in developed countries, it is still not very accessible in many developing regions of the world. According to the World Development Indicators (2016), sub-Saharan Africa is the region of the world where the lack of access to energy, including electricity, is most observed. Between 1990 and 2014, the consumption of electricity per capita has remained stagnant in sub-Saharan Africa compared to other regions of the world (see Figure 1.1).

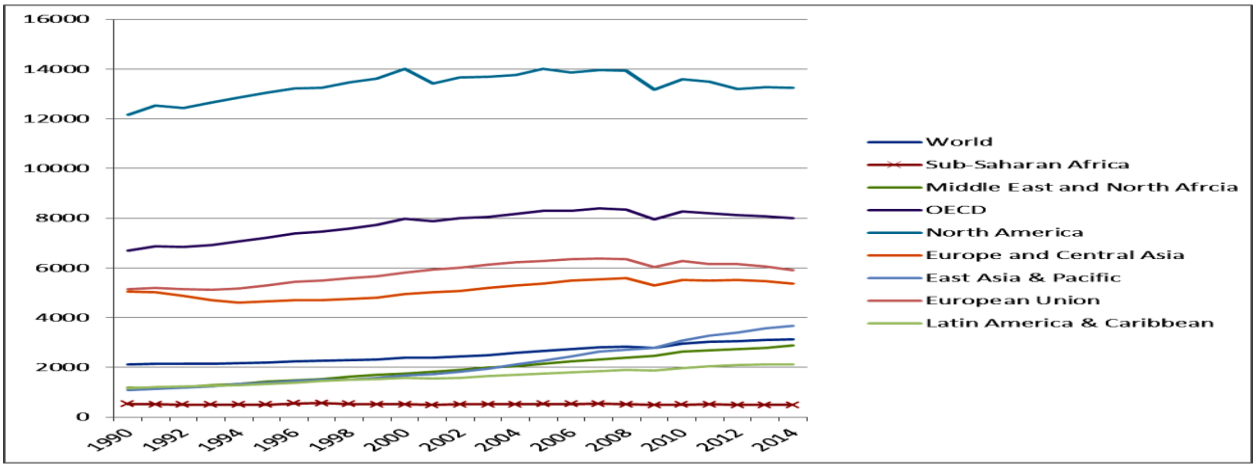

Figure 1.1: History of electricity consumption per capita in some main regions of the world (1990-2014)

Source: World Development Indicators (2016)

The Economic Commission for Africa (ECA) (2004) and Karekezi and Kimani (2002) argued that the consumption of energy, including electricity, is very low in sub-Saharan Africa. According to the IEA (2002), electricity consumption per capita in 2000 in sub-Saharan Africa (excluding South

Africa) was only 112.8 kWh and represented only 5% of the total consumption of the world, and access to electricity in that same year was very low: only 23% of the population of sub-Saharan Africa used electricity in 2000. According to the World Development Indicators (2016), on average, access to electricity in sub-Saharan Africa was only 33.33%, while the total access for the world was around 83.08% for the period 2005-2014 (Figure 1.2). Compared to other regions of the world, sub-Saharan Africa had the lowest average rate of access to electricity in the period 2005-2014. In North America and the European Union, access to electricity is 100%. Energy consumption per capita in sub-Saharan Africa is, by contrast, the lowest in the world in the period 2005-2014 (Figure 1.3).

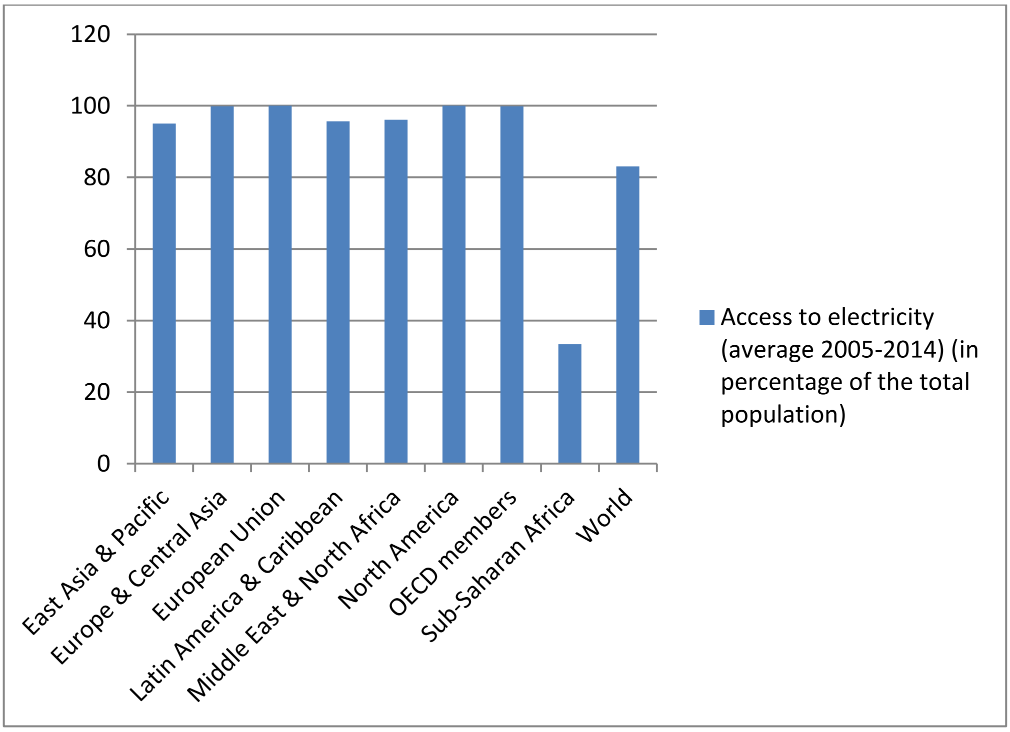

Figure 1.2: Access to electricity in sub-Saharan Africa and the world (average 2005-2014; in percentage of the total population)

Source: World Development Indicators (2016)

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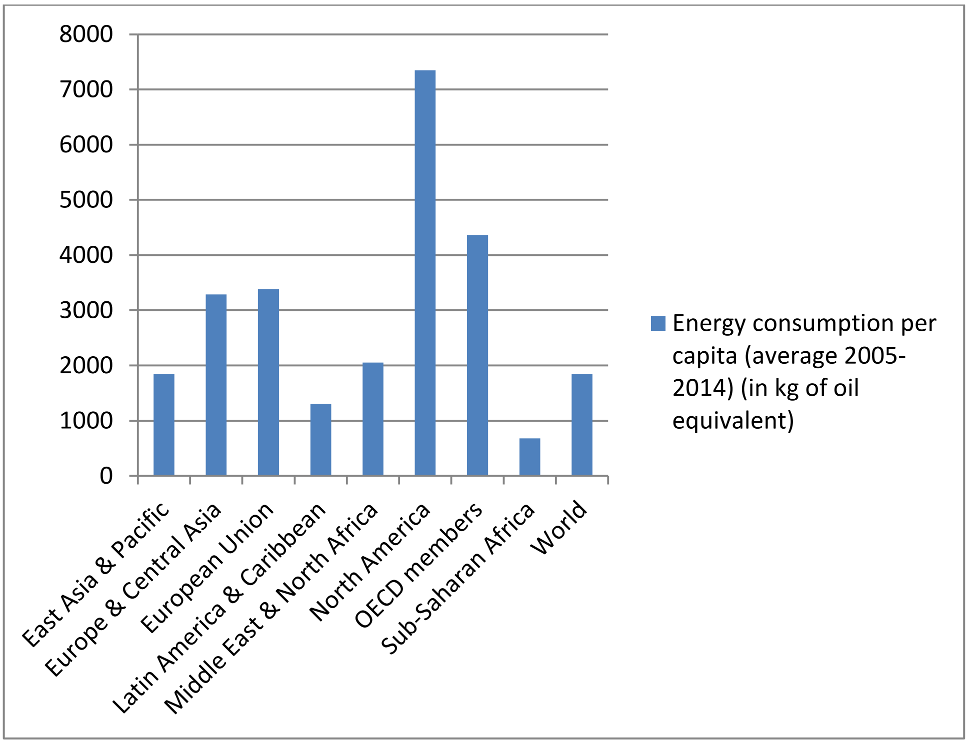

Figure 1.3: Energy consumption per capita in sub-Saharan Africa and the world (average 2005-2014; in kg of oil equivalent)

Source: World Development Indicators (2016)

There is a huge disparity between urban and rural access to electricity in Africa compared to other regions (Figures 1.4 and 1.5). Of the 33.33% of total population who had access to electricity in the period 2005-2014, only 16.22% of the rural population had access to electricity, while 68.85% of the urban population had access to electricity. Over the period 2005-2014, sub-Saharan Africa still had the lowest electricity consumption per capita compared to other regions of the world (Figure 1.6).

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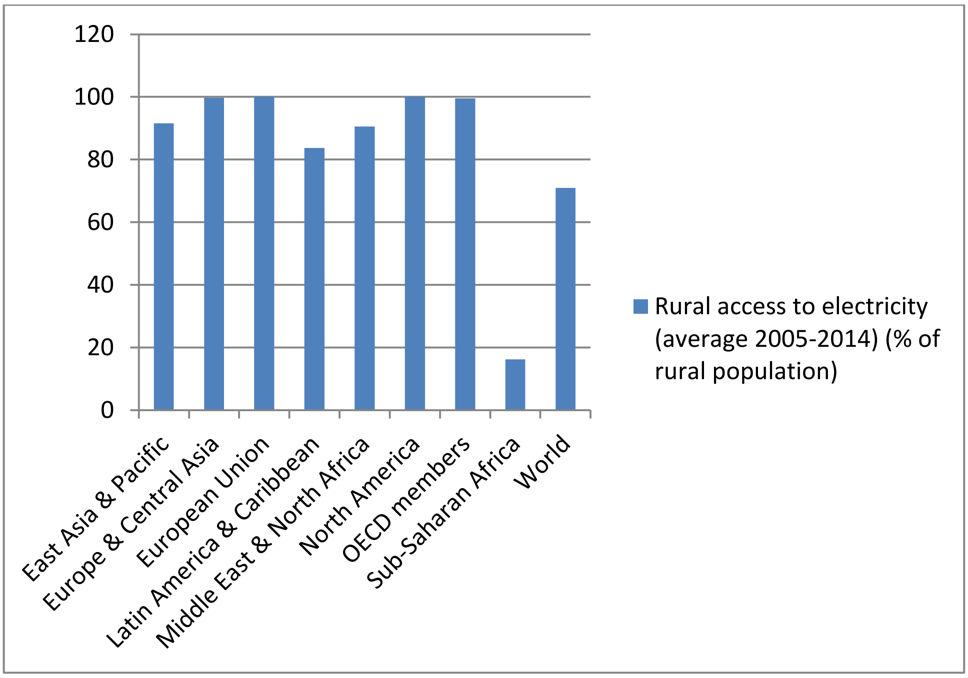

Figure 1.4: Rural access to electricity in sub-Saharan Africa and the world (average 2005-2014; in percentage of the rural population)

Source: World Development Indicators (2016)

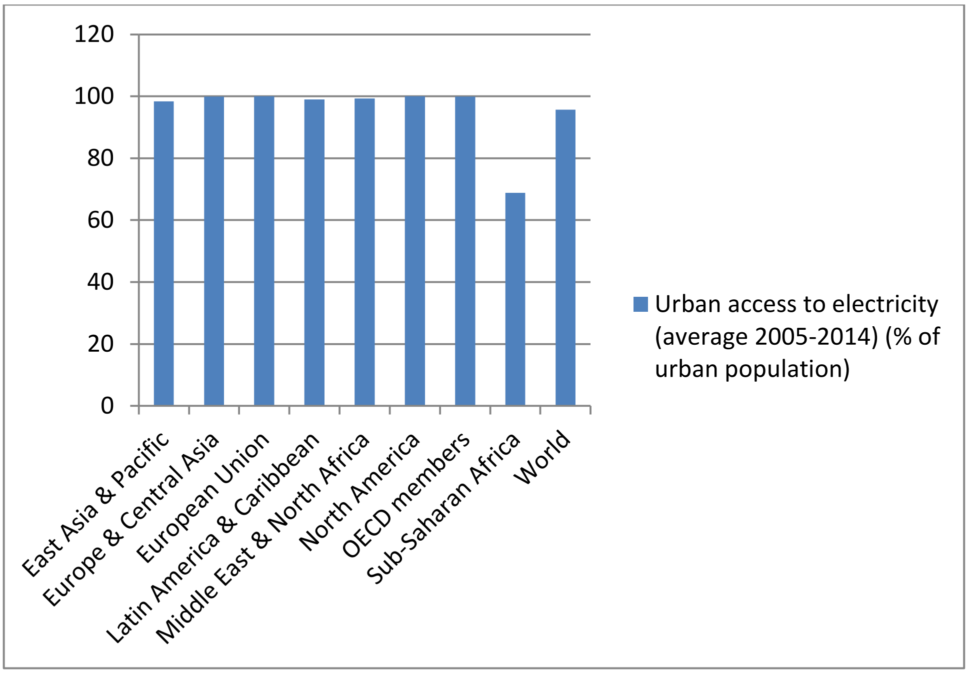

Figure 1.5: Urban access to electricity in sub-Saharan Africa and the world (average 2005-2014; in percentage of the urban population)

Source: World Development Indicators (2016)

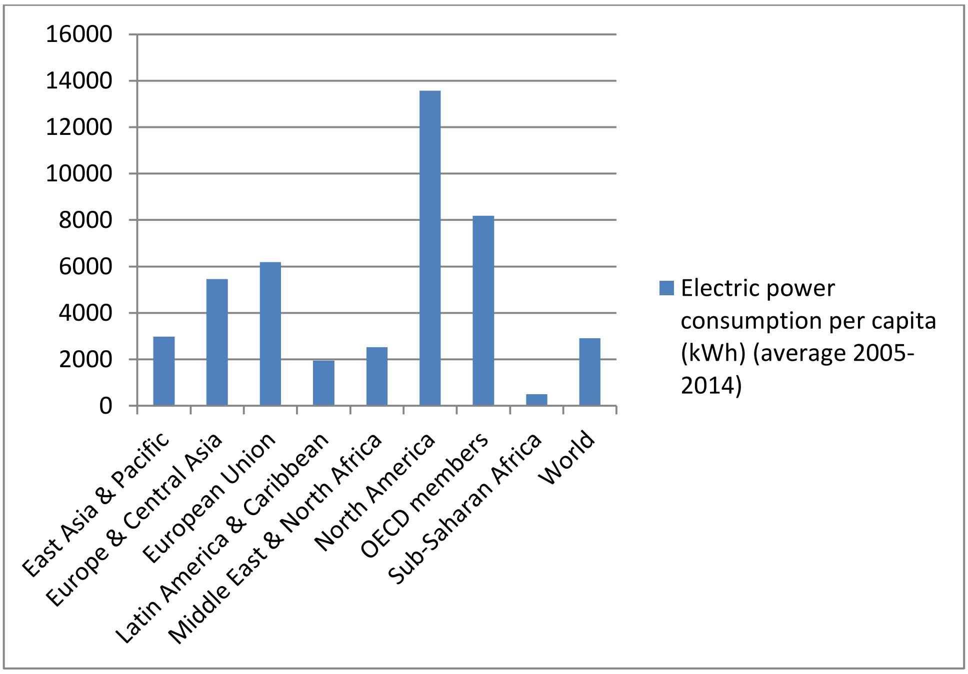

Figure 1.6: Electricity consumption per capita in sub-Saharan Africa and the world (average 2005-2014; in kWh)

Source: World Development Indicators (2016)

In summary, sub-Saharan Africa has both the lowest access to, and consumption of, energy or electricity compared to other regions of the world. Davidson and Sokona (2002) argued that the energy used by the average sub-Saharan African was lower than the energy used by the average person in England a century ago. According to the IEA (2002), Africa will remain by 2030 the continent where most of the population does not have access to electricity, and it will take almost 80 years for Africa to make electricity accessible to its entire population; while in Asia achieving this will take only half the time. This is the main reason why this research is focused on a case study of energy consumption within the African context.

While there is a huge deficit in electricity supply in Africa, studies have shown that, for the economic and social development of the continent, access to electricity is fundamental. The ECA (2004) argued that export diversification is highly correlated to both electricity production per worker and electricity consumption per capita on the African continent. It further suggested that adequate and reliable energy infrastructure would enable export diversification and lead to sustained economic growth in Africa. However, the continent’s supply capacity for energy, including electricity, is very limited and constitutes one of the constraints on its export diversification.

In addition to a very limited supply capacity for electricity, sub-Saharan Africa is among the regions facing huge technical and non-technical electricity losses (Figure 1.7). Electricity losses occur mainly during the transformation, the transmission, and the distribution phases. Because of a lack

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of data, this study does not focus on transformation losses: rather the focus is on transmission and distribution losses. 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 sites. Losses of electricity are measured as a percentage of total electricity generated or total output. According to the World Development Indicators (2016), in the period 2005-2014, losses of electricity in sub-Saharan Africa were on average around 11.38%, far above averages of the world (8.41%), OECD (6.38%), North America (6.38%), Europe and Central Asia (8.15%), East Asia and Pacific (5.82%), the European Union (6.46%), and below the average of the Middle East and North Africa (13.18%). According to Camos, Bacon, Estache, and Hamid (2017), the huge losses of electricity observed in the Middle East and North Africa are the results of inefficiencies observed in their power sectors, due to, for example, inefficiencies in terms of electricity bills' collection. Not the total electricity consumed is billed to consumers because of a poor management of the billing system. This poor management of the billing system leads to important commercial losses of electricity, which adds to the existing technical losses of electricity.

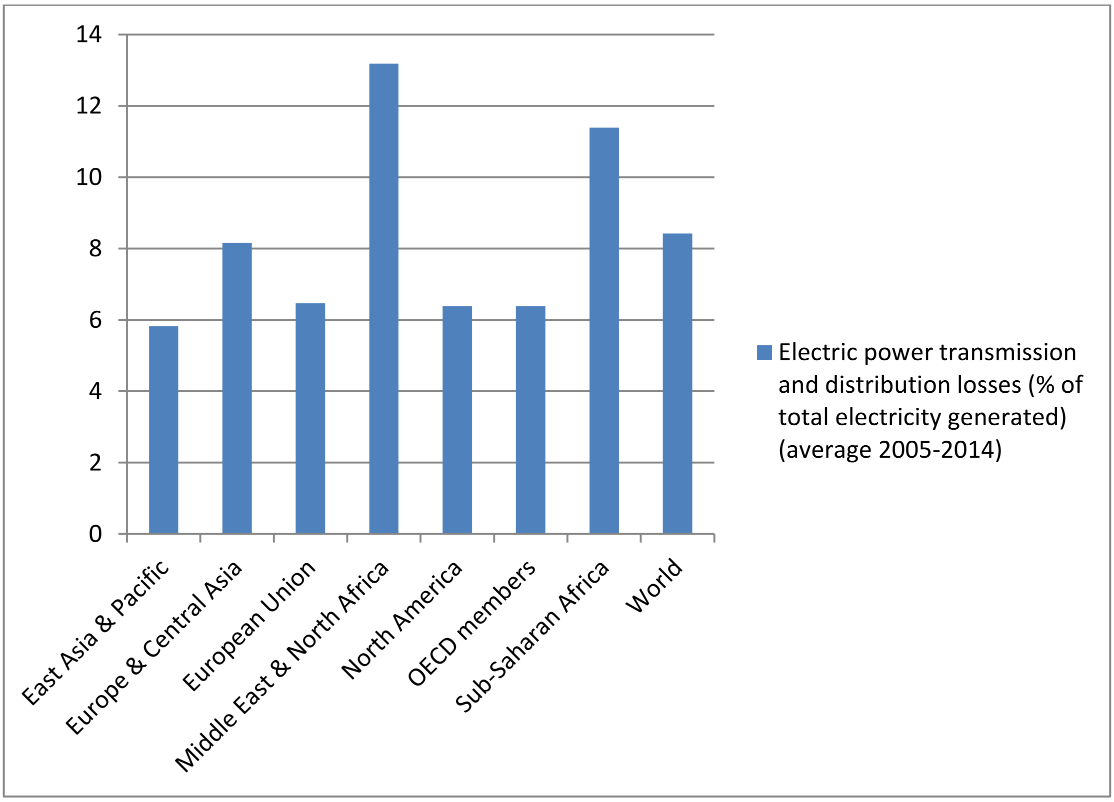

Figure 1.7: Electric power transmission and distribution losses of different regions of the world (as percentage of total electricity generated) (average 2005-2014)

Source: World Development Indicators (2016)

Technical losses occur because of the technology used during the distribution and transmission, while non-technical losses occur because of human behaviour such as the theft of electricity,

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default in electricity bill payments, and so forth. Developed nations have strong institutions which can enforce laws in order to avoid non-technical losses. Moreover, they are finding ways of saving energy by using energy-efficient technology during transmission and distribution. In Africa, the rule of law still has a long way to go in many countries. Due to political instability, ethnic conflict and corruption, the quality and the capacity of many institutions remain weak. In addition, the technology used for transmission and redistribution of electricity is not always energy-efficient. All this results in a higher proportion of losses of electricity compared to many regions of the world. While the economic and social development of the African continent is already constrained by its limited supply of and access to electricity; energy is one of the inputs for production, and losses in electricity represent losses in significant production factors and GDP.

According to Turkson and Wohlgemuth (2001), if sustainable economic growth and poverty reduction is to be achieved in sub-Saharan Africa, access to reliable and efficient electricity supplies within African countries is a requirement. The IEA (2002) argued that total access to electricity is vital in sub-Saharan Africa, in order to reduce the consumption of biomass that generates deforestation, desertification and health disorders due to the use of charcoal: 89% of the population use biomass as their primary source of energy. The IEA (2017) reported that 90% of the world’s population cooking with biomass live in 25 countries and 20 of these countries are located in sub-Saharan Africa.

According to the World Development Indicators (2016), only 37.38% of the population of sub-Saharan Africa had access to electricity in 2014. This indicates that in 2014, more than 60% of the population of sub-Saharan Africa were still using biomass (charcoal, animal waste, wood) as their primary source of energy for cooking and were thus exposed to lung diseases as they breathed in the toxic smoke coming from burnt charcoal or wood. The IEA (2017) also reported that globally 2.8 million people, mostly women and children, die from these lung diseases every year. Every day 1.4 hours are dedicated by households (mostly women) to collect firewood and cook using biomass as the sole energy source, and many more hours are dedicated by them for cooking with inefficient ovens (IEA, 2017). In addition, statistics from the World Development Indicators (2016) and the World Health Organization (2016) indicate that there is a negative correlation between access to electricity and the consumption of biomass or waste (Figure 1.8), and a negative correlation between electricity consumption per capita and deaths attributable to household air pollution (Figure 1.9). On average, countries which have a high rate of access to electricity have a low consumption of biomass or waste, and countries which have a low rate of access to electricity have a high consumption of biomass or waste. In the same way, countries which have a high consumption of electricity per capita, have a low number of deaths attributable to household air pollution on average, and countries which have low electricity consumption per capita, have a high number of deaths attributable to household air pollution on average. Access to electricity therefore constitutes a precondition for the sustainable development of sub-Saharan Africa. All these constitute important reasons why this study specifically focuses on electricity among energy types in Africa.

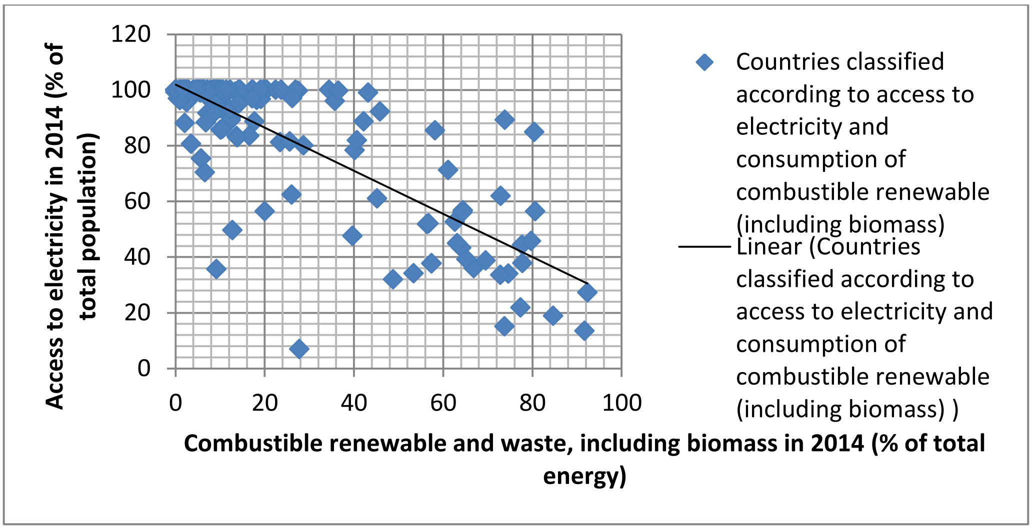

Figure 1.8: Classification of countries based on access to electricity and consumption of combustibles renewable and waste, including biomass in 2014

Source: World Development Indicators (2016)

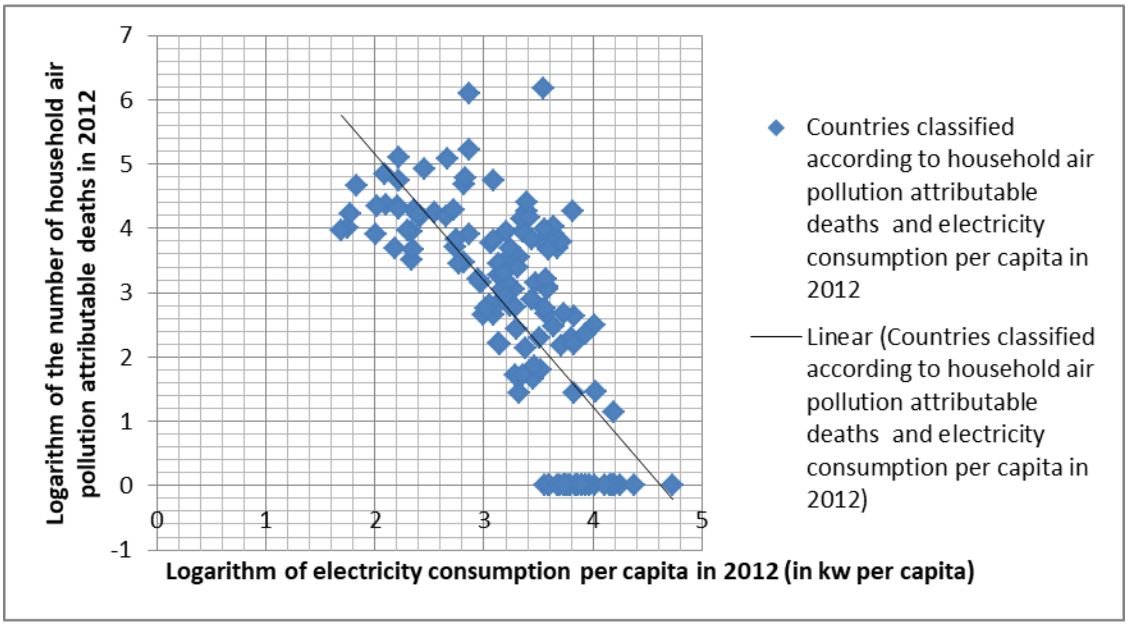

Figure 1.9: Classification of countries based on electricity consumption per capita and deaths attributable to household air pollution in 2012

Source: World Health Organization (2016) and World Development Indicators (2016)

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While access to electricity in sub-Saharan Africa is the lowest in the world, there are some disparities in terms of electricity supply and consumption per capita from one country to another.

1.1.3 Cross-country stylized facts on the electricity sector within sub-Saharan Africa

In 2014, South Africa's electricity consumption per capita was above the sub-Saharan African and the world's average electricity consumption per capita and remains the highest in the region (Figure 1.10), followed by Mauritius, Botswana, Namibia, Gabon and Zambia where electricity consumption per capita was far below the world average, but above the sub-Saharan average. Benin, Democratic Republic of Congo, Ethiopia, Niger, South Sudan and Tanzania, had the lowest electricity consumption per capita in the region (Figure 1.10).

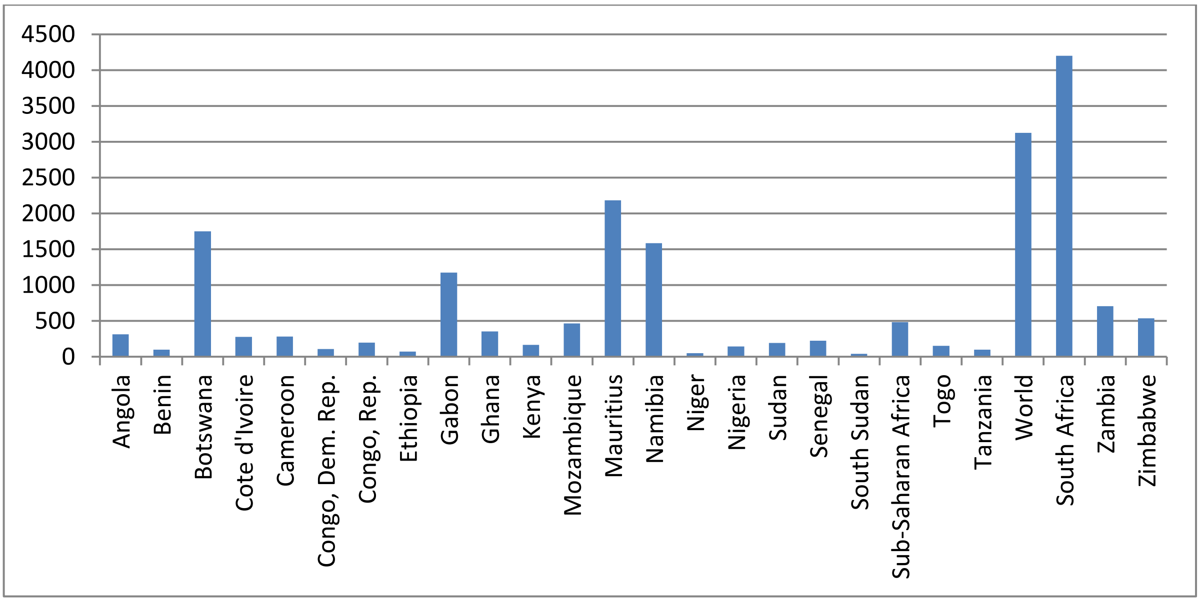

Figure 1.10: Electricity consumption (in kWh) per capita in sub-Saharan African countries in 2014

Source: World Development Indicators (2016)

There are three major causes of the vulnerability of the electricity sector across countries in sub-Saharan Africa. First, some countries are heavily dependent on imports of electricity in order to fill their supply gap (Table 1.1). Imported electricity can be defined as the proportion of electricity that is purchased from abroad. It is added to the domestically generated electricity to constitute the total electricity generated. Net imported electricity is defined as imported electricity minus exported electricity. If the value of net imported electricity is positive, it indicates that the country has a deficit of electricity supply; if it is negative, this indicates that the country has a surplus of electricity supply. Benin and Togo imported 77.575% and 94.034% (net import) of their electricity supply respectively in 2015. According to the world ranking in 2015, Togo and Benin were respectively the first and the fifth net importer of electricity, and in sub-Saharan Africa, they were respectively the first and the second net importer of electricity in 2015 (Table 1.1). Other countries such as Ghana

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and Zambia generate domestically the main proportion of their electricity supply. Their proportions of electricity imported (net import) were respectively -2.907% and -2.779% in 2015. This indicates that these two countries had a surplus of electricity and are able to export it. According to the world ranking, Ghana and Zambia were respectively the 193rd and the 192nd net importers of electricity in 2015. In sub-Saharan Africa, they were respectively the 50th and the 49th net importers of electricity in 2015 (Table 1.1). Figure 1.11 depicts the share of net imports of electricity in the total supply of electricity for African countries over the period 2006-2015 (most recent past 10 years for which data was available at the time of analysis). The vertical axis shows averages of net imports of electricity (as a percentage of total supply of electricity) over the period 2006-2015. The abscissa line shows the countries. According to the figure, Benin and Togo are among the top net importers of electricity on the African continent with a high positive net import of electricity every year, while countries such as Ethiopia, Mozambique are among the rare exporters (negative net import) of electricity.

Table 1.1: Ranking of African countries as net importers of electricity in 2015

Countries	Net imports of electricity in 2015 (as a percentage of total electricity supply)	World ranking in 2015	Africa ranking in 2015
Togo	94.034	1	1
Benin	77.575	5	2
Swaziland	71.476	6	3
Namibia	61.203	9	4
Niger	61.028	10	5
Botswana	34.484	14	6
Burkina Faso	31.939	16	7
Burundi	28.125	19	8
Lesotho	25.466	21	9
Cameroon	17.622	26	10
Morocco	15.027	30	11
Gabon	14.146	32	12
Rwanda	12.464	37	13
Tanzania	1.165	56	14
Libya	0.248	62	15
Kenya	0.228	63	16
Angola	0.000	68	17
Cape Verde	0.000	68	18
Central African Republic	0.000	68	19
Chad	0.000	68	20
Comoros	0.000	68	21
Djibouti	0.000	68	22
Equatorial Guinea	0.000	68	23
Eritrea	0.000	68	24
Gambia, The	0.000	68	25

Guinea	0.000	68	26
Guinea-Bissau	0.000	68	27
Liberia	0.000	68	28
Madagascar	0.000	68	29
Malawi	0.000	68	30
Mali	0.000	68	31
Mauritania	0.000	68	32
Mauritius	0.000	68	33
Nigeria	0.000	68	34
São Tomé and Principe	0.000	68	35
Senegal	0.000	68	36
Seychelles	0.000	68	37
Sierra Leone	0.000	68	38
Somalia	0.000	68	39
Sudan	0.000	68	40
Algeria	-0.047	167	41
Congo (Brazzaville)	-0.236	173	42
Tunisia	-0.518	174	43
South Africa	-0.636	176	44
Egypt	-0.649	177	45
Zimbabwe	-0.950	181	46
Ethiopia	-1.605	188	47
Uganda	-2.224	190	48
Zambia	-2.779	192	49
Ghana	-2.907	193	50
Congo (Kinshasa)	-4.531	195	51
Mozambique	-7.731	198	52
Côte d’Ivoire (Ivory Coast)	-10.248	205	53

Source: US Energy Information Administration (2018)

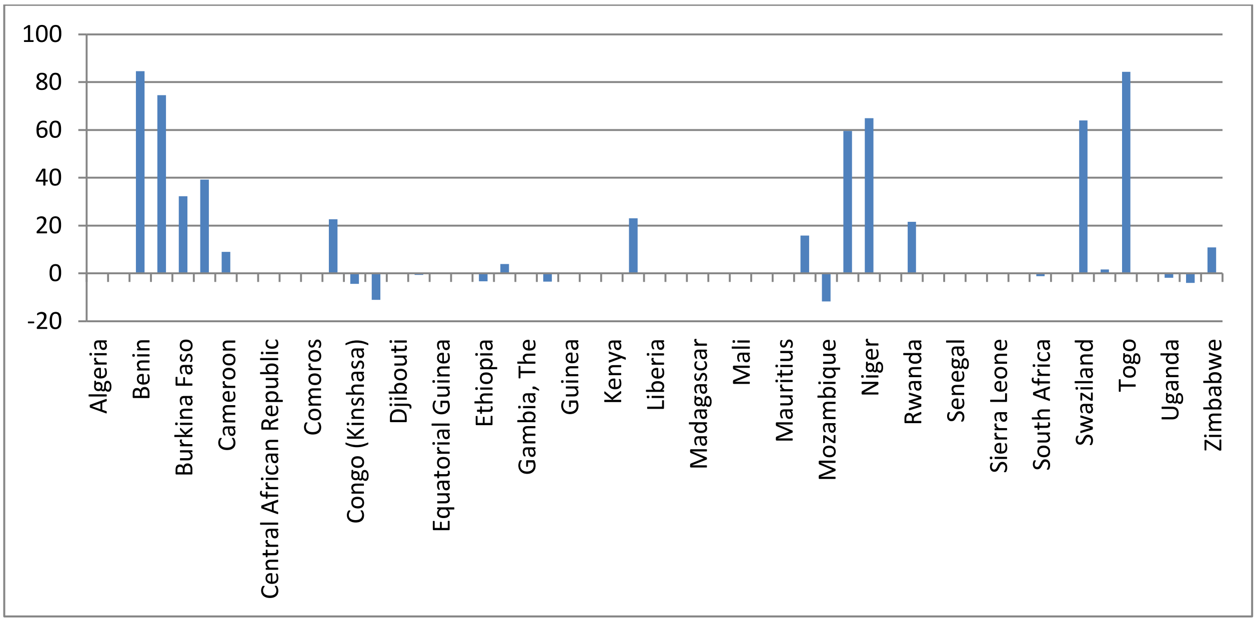

Figure 1.11: Net imports of electricity (as a percentage of total supply of electricity) for African countries (average 2006-2015)

Source: USEIA (2018)

A heavy reliance on imports of electricity puts countries at risk whenever energy or electricity crises occur in exporter countries, especially within the African context, where even countries that export electricity are also facing a growing demand for electricity. This has been the case with Benin and Togo, which import electricity from Ghana, Nigeria and Côte d'Ivoire. Benin and Togo have been facing consecutive electricity crises, because the countries from which they import electricity, have been facing a growing demand, and have had to reduce the amount of electricity they export in order to increase their domestic supply. Benin, for instance, has encountered several electricity shortages due to sudden cuts in the quantity of electricity available to import from Ghana and Côte d'Ivoire. These cuts resulted in severe electricity shortages in 1984, 1994, 1998, 2006, 2007, 2008, 2012 and 2013. The Beninese and Togolese electricity sectors are thus very vulnerable to external shocks, which can at any time lead to electricity shortages in these two countries and thus slow economic production.

Second, some countries are particularly inefficient in their supply of electricity due to a high amount of electricity losses. As can be seen in Table 1.2, Congo (Brazzaville), Cameroon, Côte d'Ivoire, Ghana, Gabon, Kenya, Mozambique, Benin, Sudan and Tanzania are the sub-Saharan African countries with the highest losses of electricity during the transmission and distribution phases in 2015. Congo (Brazzaville) is the most electricity-inefficient country in sub-Saharan Africa, the second most electricity-inefficient country in Africa, and the fourth most electricity-inefficient country in the world, totalling a 46.160% loss of its total supply in 2015. Benin is the 20th most electricity-inefficient country, totalling 19.358% loss of its total supply in 2015. The most electricity-

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efficient countries in Africa are Swaziland, Burkina Faso and Burundi (Table 1.2). Swaziland for instance, totals only 1.997% loss of its total supply, is the 212th most electricity-inefficient country in the world and the 54th most electricity-inefficient country in Africa, in 2015. Figure 1.12 represents the averages of electricity losses in African countries over the period 2006-2015 (the most recent 10 years for which data was available at the time of analysis). The vertical axis shows averages of electricity losses (as a percentage of the total supply of electricity) over the period 2006-2015, and the abscissa shows the countries. The figure shows that over the period 2006-2015, Benin and many other African countries experienced electricity losses in excess of 12%, while the ECA (2008) stipulated that the international target for maximal energy losses should range between 10% and 12%.

Table 1.2: Ranking of African countries with respect to percentages of electricity losses in 2015

Countries	Losses (as a percentage of total electricity supply in 2015)	World ranking in 2015	Africa ranking in 2015
Libya	77.120	1	1
Congo (Brazzaville)	46.160	4	2
Cameroon	28.938	8	3
Côte d’Ivoire (Ivory Coast)	23.527	12	4
Ghana	22.182	13	5
Gabon	19.939	16	6
Kenya	19.855	17	7
Mozambique	19.635	19	8
Benin	19.358	20	9
Sudan	19.093	21	10
Tanzania	18.372	24	11
Senegal	17.943	26	12
Zimbabwe	17.816	27	13
Nigeria	17.627	28	14
Ethiopia	17.415	29	15
Tunisia	17.366	30	16
Algeria	17.317	31	17
Morocco	16.742	35	18
Niger	16.311	38	19
Congo (Kinshasa)	14.911	47	20
Eritrea	14.071	54	21
Botswana	12.567	62	22
Egypt	11.944	66	23
Angola	11.655	70	24
Zambia	9.881	86	25
South Africa	8.686	93	26
Togo	8.177	97	27
Uganda	7.162	108	28
Cape Verde	7.106	109	29

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Central African Republic	7.000	112	30
Djibouti	7.000	112	31
Guinea	7.000	112	32
Guinea-Bissau	7.000	112	33
Madagascar	7.000	112	34
Mali	7.000	112	35
Seychelles	7.000	112	36
Chad	7.000	112	37
Comoros	7.000	112	38
Equatorial Guinea	7.000	112	39
Gambia, The	7.000	112	40
Liberia	7.000	112	41
Malawi	7.000	112	42
São Tomé and Principe	7.000	112	43
Sierra Leone	7.000	112	44
Namibia	6.981	161	45
Somalia	6.980	162	46
Mauritania	6.503	171	47
Mauritius	6.195	178	48
South Sudan	6.123	180	49
Rwanda	6.122	181	50
Lesotho	5.217	188	51
Burundi	5.031	191	52
Burkina Faso	4.764	195	53
Swaziland	1.997	212	54

Source: US Energy Information Administration (2018)

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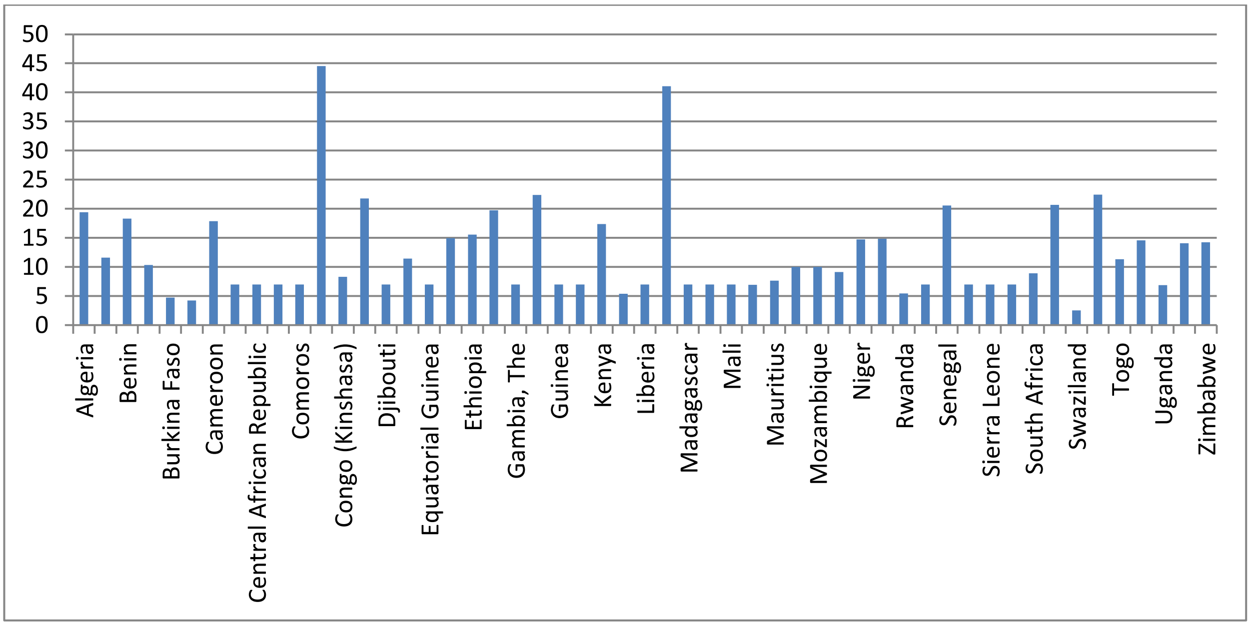

Figure 1.12: History of electricity losses (as a percentage of total supply of electricity) for African countries (average 2006-2015)

Source: USEIA (2018)

As mentioned in previous sections, losses of electricity can be technical or non-technical. Non-technical losses, due to theft and defaults in electricity bill payments, are very common in sub-Saharan African countries because of the weak institutions and the ineffective law enforcement system. In a country such as Benin, theft of electricity is common, especially in the suburbs. Default in electricity bill payments is also an important issue: the main distribution company (SBEE) has been bankrupt several times. One of the reasons for this bankruptcy was related to defaults in electricity bill payments. In order to minimize these defaults the SBEE and the regulatory authority (Ministry of Energy) are considering substituting the current system with that of a prepaid electricity system, where customers must purchase the quantity of electricity they want to use prior to consumption. As long as sub-Saharan African countries do not improve the quality of their institutions, reduce corruption and enforce laws, non-technical losses of electricity will remain a challenge and will add to the vulnerability of their electricity sectors. As mentioned earlier, technical losses also contribute to overall electricity loss. These are due to the technology used for the transmission and distribution of electricity. Improving the technology used requires important investment in energy-efficient infrastructure, but most sub-Saharan African countries are unable to finance such investments due to a lack of resources.

Third, some countries are highly dependent on oil for their domestic generation of electricity. As can be seen in Table 1.3, South Sudan, Eritrea and Benin were respectively the second, third and fourth countries in the world and first, second and third in sub-Saharan Africa, in terms of oil dependency for domestic electricity generation in 2014. South Sudan relied on oil to generate

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99.590% of its electricity internally, while Eritrea and Benin relied on oil to generate 99.459% and 99.457% respectively of their electricity internally in 2014. Other countries such as South Africa and the Democratic Republic of Congo (also called Congo (Kinshasa)) have the least reliance on oil for their domestic electricity generation. Figure 1.13 represents African countries' reliance on oil for domestic electricity production over the period 2005-2014 (most recent past 10 years for which data was available at the time of analysis). The vertical axis shows the proportion of domestic electricity generated based on oil (average 2005-2014) as a percentage of the total domestic electricity generated. The abscissa shows the countries. The figure shows that on average, countries such as Benin and Eritrea had the highest reliance on oil (close to 100% of total domestic electricity generation) for their domestic electricity generation over the period 2005-2014. A heavy dependency on oil for domestic electricity generation exposes countries' electricity supply to external shocks related to fluctuations in oil prices.

Table 1.3: Ranking of sub-Saharan African countries with respect to the share of electricity production from oil sources in 2014 (most recent year for which data was available at the time of analysis) (as a percentage of total domestic production of electricity)

Country	Share of electricity production from oil sources in 2014 (as a percentage of total domestic production of electricity)	World rank in 2014	Africa rank in 2014
South Sudan	99.590	2	1
Eritrea	99.459	3	2
Benin	99.457	4	3
Senegal	83.588	12	4
Angola	46.825	20	5
Niger	27.826	31	6
Gabon	26.996	32	7
Sudan	21.651	35	8
Kenya	18.514	36	9
Ghana	17.072	37	10
Tanzania	15.485	38	11
Cameroon	12.800	44	12
Togo	11.972	46	13
Côte d'Ivoire	6.131	56	14
Botswana	4.190	62	15
Zambia	2.837	65	16
Namibia	0.868	91	17
Zimbabwe	0.509	97	18
Ethiopia	0.094	119	19
South Africa	0.076	120	20
Congo (Kinshasa).	0.045	122	21

Source: World Development Indicators (2017)

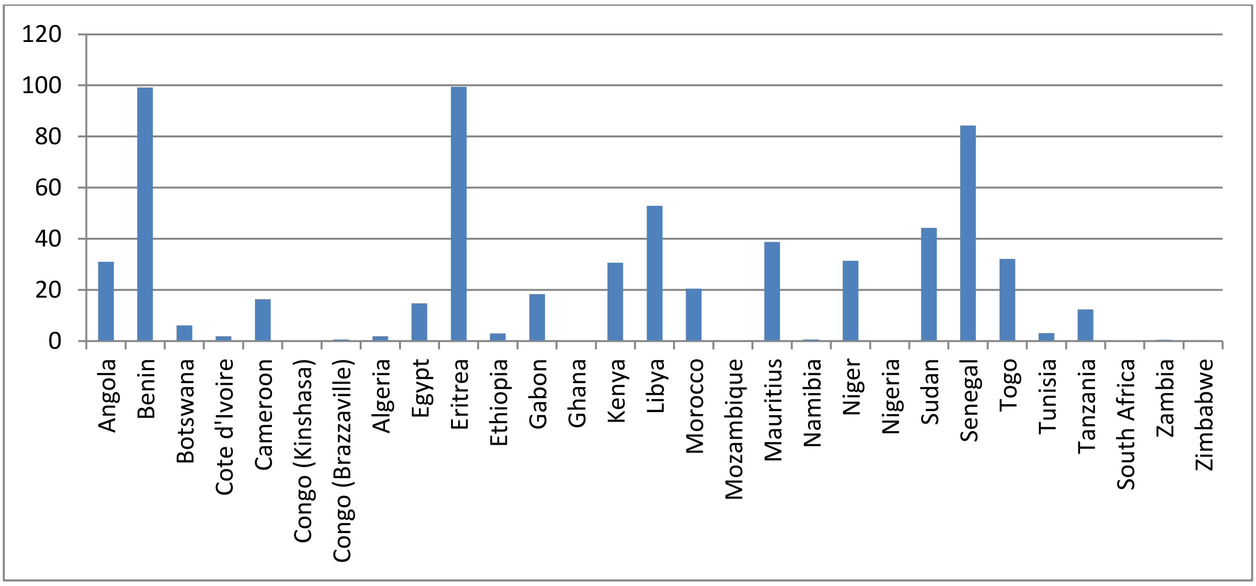

Figure 1.13: Share of electricity produced based on oil (as a percentage of total domestic production of electricity) in African countries (average 2005-2014)

Source: World Development Indicators (2018)

Among sub-Saharan African countries, Benin is the only one, which figures simultaneously in the list of the top 10 countries for heavy dependence on importation of electricity in 2015, for the high proportion of electricity losses in 2015, and for heavy reliance on oil for domestic electricity generation in 2014 (Tables 1.1, 1.2 and 1.3 above). Other sub-Saharan African countries figure in either one or two of these lists of top 10 countries. According to Tables 1.1, 1.2 and 1.3 above, some countries such as Togo rely heavily on the importation of electricity but very little on oil for their domestic electricity production. Other countries, such as Congo (Brazzaville), encounter huge losses of electricity but rely less on the importation of electricity. South Sudan and Eritrea rely heavily on oil for their domestic electricity generation, but encounter lower quantities of electricity losses compared to Benin. All this indicates that the Beninese electricity sector is one of the most vulnerable in sub-Saharan Africa. It is simultaneously vulnerable to three types of uncertainty or risk which have a negative effect on its supply of electricity: fluctuation in the quantity of electricity available to import from neighbouring countries, fluctuation in oil prices, and losses of electricity. These risks have caused significant disruption to the electricity supply in the country. These are among the main reasons that this study focuses specifically on the Beninese electricity sector.

1.1.4 An overview of electricity sector challenges in Benin

Benin is among the sub-Saharan African countries which had the lowest electricity consumption per capita in 2014, as shown previously in Figure 1.10 (previous section). The average electricity consumption per capita is around 100.23 kWh per capita and is far below the sub-Saharan average of 483.12 kWh per capita (Figure 1.14) and the world average of 3,128.40 kWh per capita in 2014. The rate of access to electricity is also very low: 34.1% (Figure 1.15) when compared to the sub-Saharan average of 37.38% (Figure 1.16) and the world average of 85.34% in 2014. As shown in Figure 1.15, access to electricity has been growing in Benin since 1990; however, from 2012 to 2013 and 2014, access to electricity has decreased because of the severe electricity crises of 2012 and 2013. As explained by Hounkpatin (2013), such crises have significantly reduced rural electrification and slow down the connection to the national grid of several remote districts of Benin's municipalities. This situation has led to a reduction of access to electricity in 2013 and 2014 when compared to 2012. Even among those countries identified by the UN as the least developed in the world, electricity consumption per capita remains higher than that of Benin (Figure 1.14). The consumption for the least developed countries was 182.07 kWh per capita, 195.39 kWh per capita, and 205.66 kWh per capita in 2012, 2013, and 2014 respectively compared to 93.12 kWh per capita, 96.76 kWh per capita, and 100.23 kWh per capita respectively for Benin in these same years (Figure 1.14). There is a huge gap between urban and rural access to electricity: only 16% of the rural population had access to electricity in 2014, while around 57.6% of the urban population had access to electricity in the same year (Figure 1.17). The transmission and distribution lines are also short, offering only 5,620 km for domestic lines and 618 km for trans-national lines (World Development Indicators, 2016).

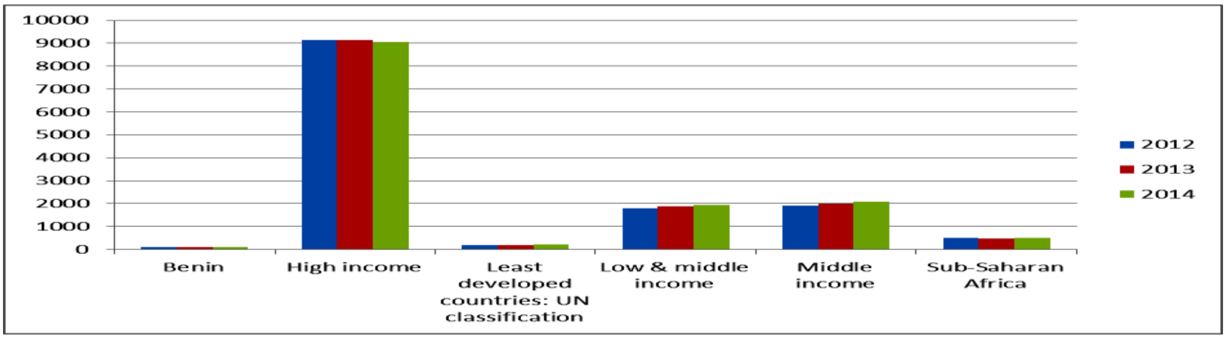

Figure 1.14: Electric power consumption (kWh per capita) in Benin and some regions of the world over the period 2012-2014

Source: World Development Indicators (2016)

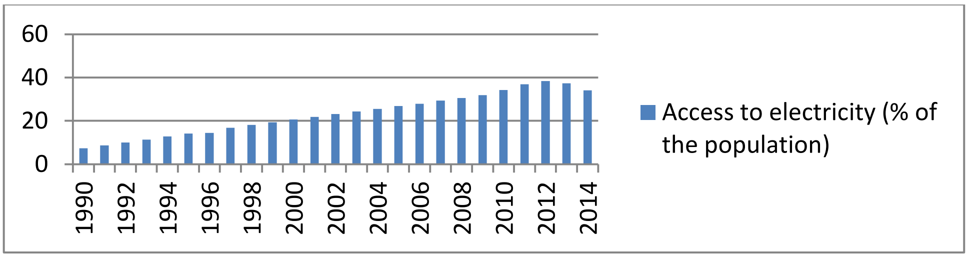

Figure 1.15: Access to electricity in Benin (% of population), 1990-2014

Source: World Development Indicators, (2016)

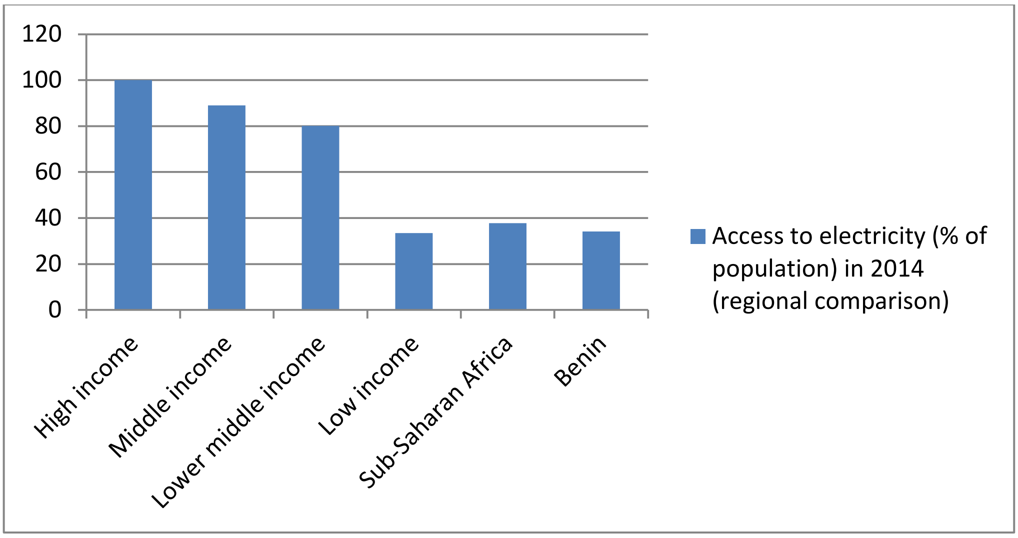

Figure 1.16: Access to electricity in Benin in 2014 compared to other regions of the world (% of population)

Source: World Development Indicators (2016)

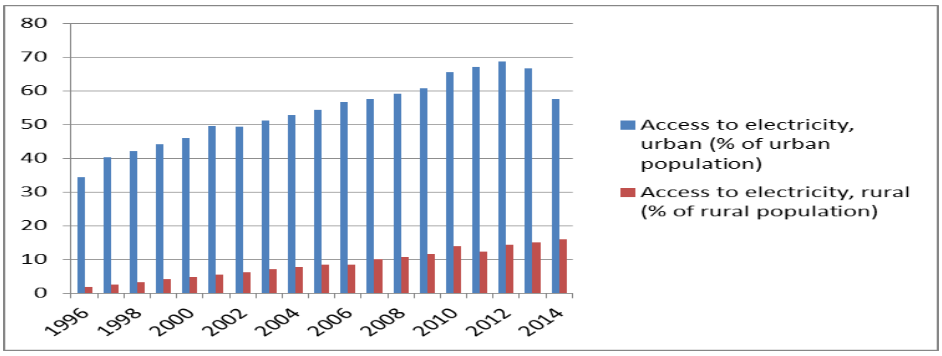

Figure 1.17: Urban and rural access to electricity in Benin, (1996-2014)

Source: World Development Indicators (2016)

In Benin, the transmission and distribution of electricity are state monopolies. Four government institutions are in charge of the electricity generation, transmission, distribution and policy: the Beninese Electrical Community (CEB) (Communauté Électrique du Benin), the Beninese Electrical Energy Company (SBEE) (Société Béninoise d’Énergie Électrique), the Beninese Agency for Rural Electricity Distribution and Regulation (ABERME) (Agence Béninoise d'Electrification Rurale et de Maîtrise d'Energie), the Directorate General of Energy (DGE) (Direction Génerale de l’Énergie), and the Ministry of Energy. The CEB supplies the distribution companies in Benin and Togo. The SBEE is the main distributor of electricity throughout Benin and also ensures the transmission of electricity. ABERME is in charge of managing electricity access in rural areas, while the DGE and the Ministry of Energy are in charge of the energy sector policy, regulations and reforms. Two main

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pieces of legislation regulate the Beninese electricity sector. The first is an agreement between Benin and Togo, the Beninese-Togolese Act for Electricity ("Code Bénino-Togolais de l'Électricité"), which explicitly states the conditions by which electricity may be imported (from Ghana) and transported between the two countries. This act was established on July 27th 1968 and gave a monopoly on the importation and transportation of electricity to the CEB (République du Bénin, 2008). However, on April 13th, 2018, the Beninese parliament amended this act by liberalizing the importation and transportation of electricity. The amended act is called "The bill authorizing the ratification of the international agreement on the amended Beninese-Togolese Act for Electricity" ("projet de loi portant autorisation de ratification de l'accord international sur le Code bénino-togolais de l'électricité amendé"). It denies the monopoly of importation and transportation of electricity to the CEB and opens the electricity market to private firms, allowing competition among them within the electricity sector. Such an amendment might be expected to improve Benin's capacity to import and transport electricity. However, it is a very recent legislation and has, as yet, had no effect on the sector (République du Bénin, 2018).

The second is the Beninese Act for Electricity ("Loi portant Code de l'Electricité au Bénin") and regulates the generation, transmission and distribution of electricity in the country. This act also regulates the application of international norms in terms of electricity efficiency for both producers and consumers (République du Bénin, 2008). Yet, despite these various institutional and legal capacities, Benin is unable to meet the national demand for electricity and remains dependent on other nations for its electricity supply (République du Bénin, 2008).

Figure 1.18 summarizes the history of net electricity consumption and generation in Benin. It can be seen that from 1980 there has been a growing consumption of electricity in the country. Between the years 2005-2010, the need for electricity has greatly increased due to service sector and industrial development, as well as greater access to electricity in many rural and urban areas. There is also a strong overall growth in net electricity generation since 1980. However, a huge gap remains between the consumption and generation of electricity due to the growing electricity demand from the residential, industrial and service sectors. To fill this gap, the country has to rely on imported electricity. Figure 1.19 summarizes the history of imported electricity compared to consumption and generation. There has been a growing dependence on imported electricity since 1980. As of 2015, Benin imports about 77.575% of its electricity supply from neighbouring countries such as Ghana, Ivory Coast and Nigeria (USEIA, 2018).

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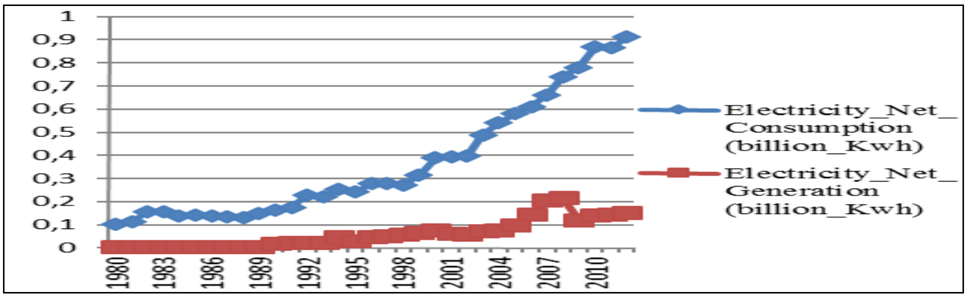

Figure 1.18: Benin net electricity consumption and net electricity generation (1980-2012)

Source: USEIA (2016)

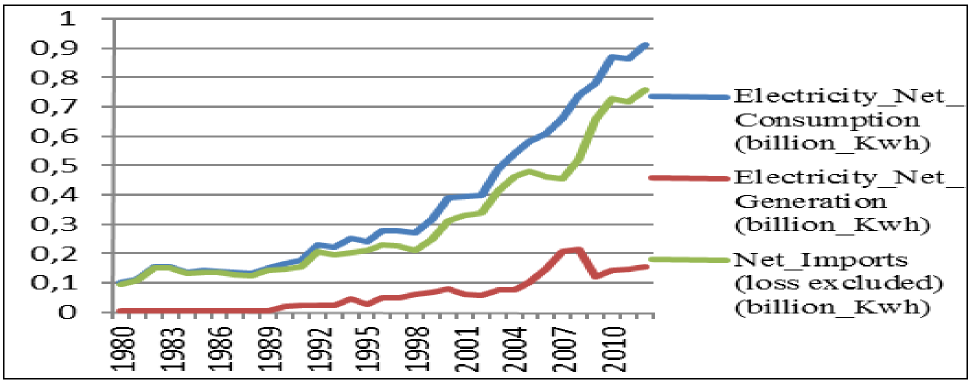

Figure 1.19: History of electricity imports compared to consumption and generation in Benin (1980-2012)

Source: USEIA (2016)

Although Benin has imported electricity from neighbouring countries for many years, this has not averted several energy crises occurring in 1984, 1994, 1998, 2006, 2007, 2008, 2012 and 2013. These crises were due to repeated electricity shortages from its two suppliers, Ghana and Ivory Coast, which were both facing a growing demand. Other contributing factors to these crises included the weakened capacity of the SBEE to distribute electricity, and the droughts faced by Ghana in 1983, 1994 and 1998. One of the main risk factors with importing electricity from Ghana is drought, which can reduce the volume of water in the Akosombo hydroelectric dam. As a result, the quantity of electricity produced by the dam decreases, and Ghana's domestic supply and export of electricity also decrease, hence the quantity of electricity imported from Ghana by Benin is reduced significantly. This has been the cause of severe electricity shortages in Benin. This was the case with the Ghanaian drought of 1983, which caused the country to reduce its exports of electricity to Benin and Togo by 50%. A similar situation occurred in 1994 and caused Ghana to limit its exports of electricity to Benin and Togo to 40 Mw that year, while the initial agreement stipulated an expected export of 50 Mw of electricity. A similar situation occurred in 1998 but the impact was far worse than during previous droughts because the volume of water in both Akosombo and Nangbeto dams was reduced. The Nangbeto hydroelectric dam is owned by Benin and Togo and produces a limited quantity of electricity for these two countries. The production of electricity by the Nangbeto dam contributes to the domestic production of electricity for Benin and Togo. Hence, the situation in 1998 was extreme due to the simultaneous reduction of imported electricity from Ghana as well as a reduction in the domestic production from the Nangbeto dam. The resulting energy shortage was severe: the initial quantity of electricity supplied to Benin and Togo by the CEB dropped from 40 Mw to 16 Mw in February and to 4 Mw in April 1998. Between 2004 and 2007, another drought occurred, limiting Ghana's capacity to export electricity to Benin. Again, this resulted in Benin experiencing severe shortages in 2006 and 2007 (République du Bénin, 2008; Hounkpatin, 2013). The electricity shortages faced by Benin in the 1980s, 1990s and 2000s, illustrate the fact that a high level of dependence on imported electricity creates a significant electricity supply disruption risk in the Beninese context.

The resulting reduction in the consumption of electricity during these periods of supply shortage negatively affected trade: according to the World Development Indicators (2016), Benin lost 6.2% and 9.4% of sales value in 2009 and 2016 respectively because of electricity outages. However, whether the resulting decrease in the consumption of electricity (the negative shocks to electricity consumption) caused negative shocks to economic growth during the period 1971-2014 (period for which data was available for both electricity consumption and economic growth at the time of analysis) is still a question to be investigated, as electricity constitutes only a very small share of total primary energy in Benin. Figure 1.20 represents the history of the share of electricity consumption, biomass consumption (biofuel and waste), and fossil fuel consumption in the total energy consumption for Benin over the period 1971-2014. It is important to observe that although the share of electricity consumption in the total energy consumption has been growing slowly since the 1990s, it is still very low, and has remained below 2.07% over the entire period. At the same time, it can be seen that the shares of biomass (biofuel and waste) and fossil fuel consumption are very high: 53.41% in 2016 for biomass consumption (the lowest value over the period 1971-2014), and 44.38% in 2016 for fossil fuel consumption (the highest value over the period 1971-2014). It can also be seen that there is a trade-off between the consumption of biomass and the consumption of fossil fuel (their graphs follow almost the same patterns but move in opposite directions). In the 1970s and 1980s, biomass consumption has an upward trend, while fossil fuel consumption has a downward trend. In the mid-1990s and in the 2000s, biomass consumption has a downward trend, while fossil fuel consumption has an upward trend. All this indicates that Benin has been making efforts to lower its consumption of biomass and replace it by the consumption of another type of energy, which does not involve the use of vegetation products and deforestation.

Unfortunately, such a substitute to biomass is not electricity, rather it is fossil fuel, which also has environmental consequences.

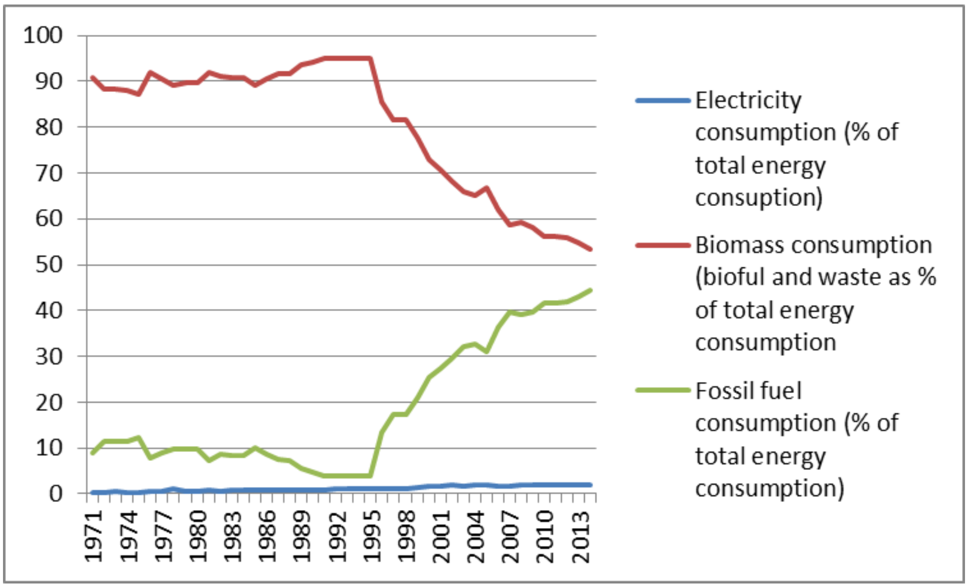

Figure 1.20: Energy balance comprising the share of electricity consumption, biomass consumption and fossil fuel consumption in total energy consumption in Benin over the period 1971-2014

Source: World Development Indicators (2017)

According to the IEA Statistics (2018), electricity supply (electricity consumption added to electricity losses in the case of Benin) constituted only 2.04% of the total share of primary supply of energy (energy consumption added to energy losses) in 2015, while biomass supply (biofuels and waste), oil supply, and coal supply constituted respectively 60.8%, 38.6%, and 0.6% of the share of total primary energy supply in 2015. According to the World Development Indicators (2018), access to electricity and to clean cooking (including electricity) has been growing, but is still very low: they remained respectively below 42% and 6.5% over the period 2000-2016 (period for which data was available for both access to electricity and access to clean cooking at the time of analysis; see Figure 1.21 below).

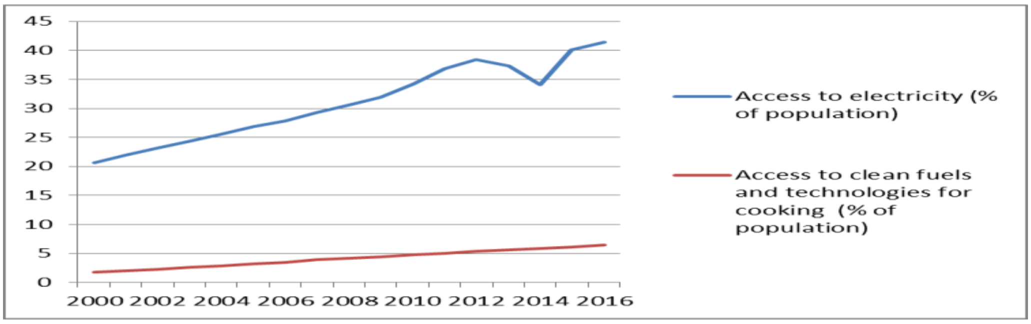

Figure 1.21: History of access to electricity and clean cooking in Benin over the period 2000-2016

Source: World Development Indicators (2018)

All this indicates that the use of electricity is very low in Benin compared to the use of other types of energy such as biomass and fossil fuel. Even though the national policy framework for the electricity sector (République du Bénin, 2008) emphasized that electricity supply disruptions related to outages have impeded economic growth in Benin, there is no empirical evidence which demonstrates that negative shocks to electricity supply have caused negative shocks to economic growth over the period 1971-2014 (period for which data was available for both electricity supply and GDP at the time of analysis). It is, therefore, important to investigate empirically if negative shocks to electricity supply have caused negative shocks to economic growth. In addition, with the very low use of electricity in Benin, it is not obvious that a causal relationship can exist between electricity supply and economic growth. Hence, an empirical investigation of the causal relationship between these variables is necessary in order to verify the conclusion of the national policy framework for the electricity sector.

The total electricity generated domestically and through imports does not reach consumers in Benin. Although the Beninese Act for Electricity requires a high level of efficiency during the transmission and the distribution of electricity as well as the use of energy efficient materials for the construction of public and private buildings, electricity losses remain high. These electricity losses can be technical or non-technical. As indicated in previous sections, the technical losses are mostly due to the technology used during the distribution and the non-technical losses are due to theft, default in payments, and so forth. On average 10 to 22% of the electricity supply in Benin is lost during distribution (République du Bénin, 2008). Antmann (2009) reported that losses of electricity can cost between 0.5% and 1.2% of GDP in many sub-Saharan countries. These losses of electricity greatly increase the burden on the Beninese economy, which already has to cope with consecutive electricity outages due to shortage in supply. Total losses of electricity have been increasing since 1980; such an increase has become huge from 2001 (Figure 1.22). This situation is due to an important increase in both the imports and the domestic production of electricity in the

2000s compared to the 1980s and the 1990s (see USEIA (2016)), while the distribution system of electricity has remained ineffective (see République du Bénin (2008 & 2014)).

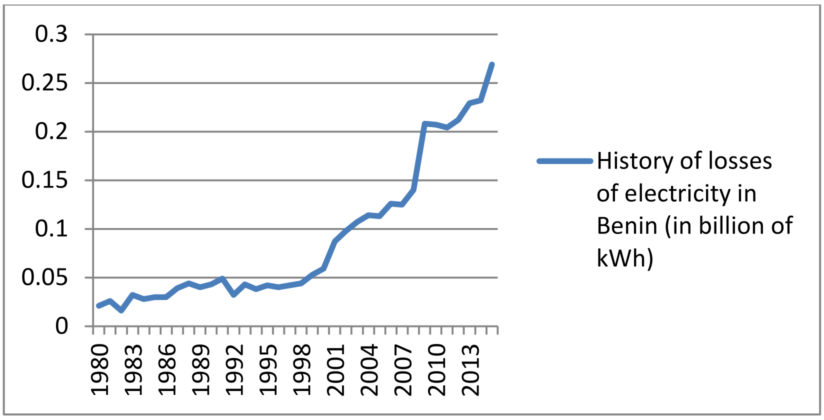

Figure 1.22: History of electricity losses in Benin (1980-2015; in billion of kWh)

Source: USEIA (2018)

According to the World Development Indicators (2017), losses of electricity in Benin have remained above 50% of total domestic generation (electricity produced exclusively in Benin, not imported electricity) in the periods 1996-2000, 2006-2008 and 1994 (periods for which data was available on the World Development Indicators website at the time of analysis). These electricity losses are far above the international maximal target of 12% for energy losses suggested by ECA (2008). Benin also has a huge proportion of electricity losses (as a percentage of total domestic generation) compared to other regions of the world in 2006, 2007 and 2008 (Figure 1.23 below). According to the World Development Indicators (2017), electricity losses as a percentage of electricity generated domestically for these years were respectively 81.81%, 56.81% and 61.13%. Figure 1.24 below represents the history of the share of electricity losses in the total electricity supply (total electricity supply is equal to domestic electricity plus imported electricity, or electricity consumption added to electricity losses). It can be seen that the value of electricity losses (as a percentage of total electricity supply) has ranged from 9.35% to 25.14% over the period 1980-2015. The percentage in 2015 was 19.35%, far above the international target of 12% maximum energy losses. In order to reduce non-technical losses of electricity due to default in payment of electricity bills, distribution companies are currently focusing on replacing the current billing system with a prepaid system.

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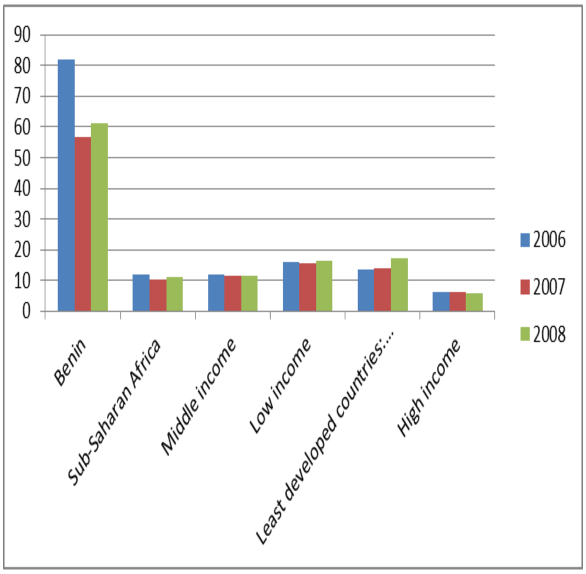

Figure 1.23: Comparison of electric power transmission and distribution losses in Benin and other regions of the world (% of total domestic electricity production)

Source: World Development Indicators (2017)

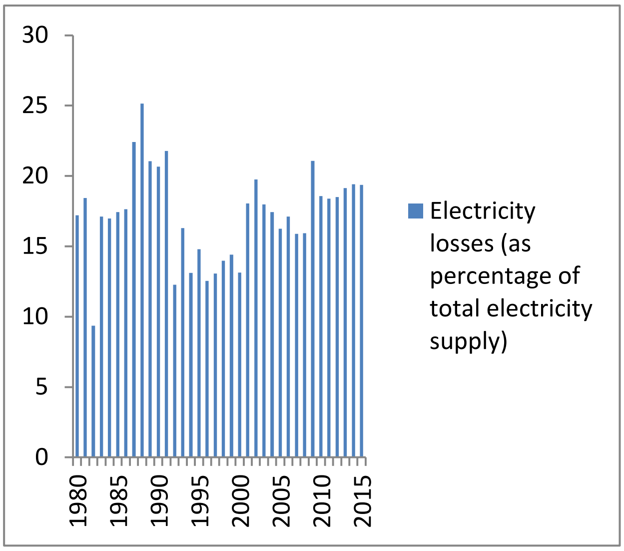

Figure 1.24: Electricity losses in Benin over several years (% of total electricity supply (domestic production and imports); 1980-2015)

Source: USEIA (2018)

Figure 1.25 below describes the history of electricity consumption intensity compared to that of electricity losses intensity. The vertical axis shows the measurement of electricity intensity (both electricity intensity and electricity losses intensity) in Kw/US$, and on the horizontal axis shows the years (from 1980 to 2014). Electricity consumption intensity (in Kw/US$) is an expression of the amount of electricity consumed in order to produce US$1 (of GDP), and electricity losses intensity (in Kw/US$) is an expression of the amount of electricity lost when producing US$1 (of GDP). It can be seen in Figure 1.25 that both electricity consumption intensity and electricity losses intensity have been increasing on average since 1980 (as shown by their overall upward linear trends). As electricity consumption is essential to increase total factor productivity, these electricity losses could represent total factor productivity losses and as a result losses in terms of economic growth. However, as mentioned previously, empirical evidence is necessary in order to ascertain such an assumption.

According to Antmann (2009), electricity losses represent the amount of grid electricity which transits through the transmission and distribution system, and for which consumers (both legal and illegal consumers) do not pay. Therefore, electricity consumption is the amount of grid electricity that transits through the transmission and distribution system and for which consumers pay. As indicated in previous sections, electricity losses include technical losses and non-technical losses:

stolen electricity is a non-technical loss that occurs during the transmission and distribution of electricity, and therefore is not included in the calculation of electricity consumption. Increases in losses of electricity reduce the quantity of electricity supply that reaches consumers. Therefore, losses of electricity create an additional electricity supply disruption risk.

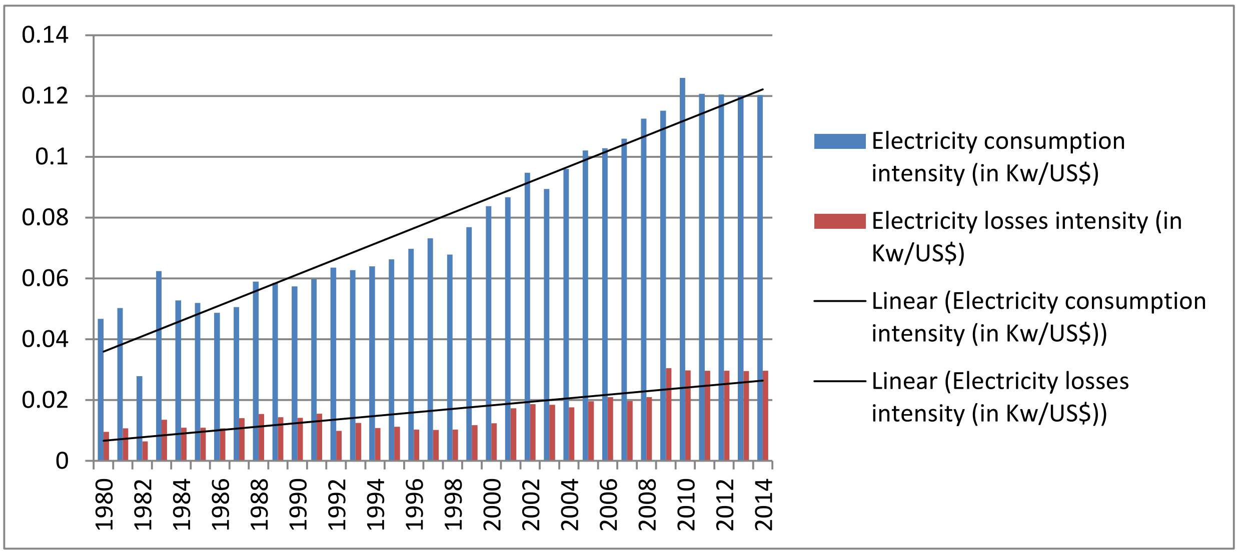

Figure 1.25: History of electricity consumption intensity and electricity losses intensity in Benin (1980-2014)

Source: USEIA (2017); World Development Indicators (2016)

These losses of electricity undermine one of the pillars of the second objective defined in the national strategy for access to electricity: the promotion of electricity efficiency on both the supply and demand side. Supply side policies aim to reduce transmission and distribution losses. In an effort to reduce technical losses, the focus is to modernize the distribution lines and networks by replacing old equipment with new, more energy-efficient equipment that aligns with international norms. This should be done in the form of a five year project. Regarding the reduction of non-technical losses, an emergency plan has been established to fight corruption and electricity theft, and to verify and improve the electricity billing system. The plan is expected to be implemented over a period of two to three years maximum (République du Bénin, 2008).

The national policy framework for the electricity sector acknowledged that electricity losses constitute loss of GDP and are a burden to the Beninese economy. It also emphasized that a reduction in electricity losses will allow the economy to gain in terms of GDP. One of the financial mechanisms of the development of the electricity distribution network, stated in the national strategy for access to electricity, is described in two steps (see République du Bénin, 2008: page 65). The first step is to reduce electricity losses by 1.5% every year, over the period of five years. The second step is to use the gain in GDP that has resulted from a reduction in electricity losses, as a contribution to reimburse the cost related to improvements made in the electricity distribution network. However, to date there has been no empirical assessment of the gain in GDP resulting from a reduction in electricity losses. It therefore becomes important for policy reasons to empirically assess the gain in GDP resulting from the reduction in electricity losses, or in other words the losses of GDP resulting from electricity losses.

As mentioned previously, apart from challenges such as electricity losses and dependence on imported electricity, Benin also bears the burden of a high dependency on oil for its domestic electricity generation. Figure 1.26 below compares the share of domestic electricity produced based on oil in Benin to that of the rest of the world over the period 2005-2014. The vertical axis shows the averages of the share of domestic electricity produced based on oil as a percentage of total electricity produced domestically, over the period 2005-2014. The abscissa shows the regions of the world (including Benin). It can be seen that, compared to other regions of the world, Benin depends mainly on oil for its domestic electricity production.

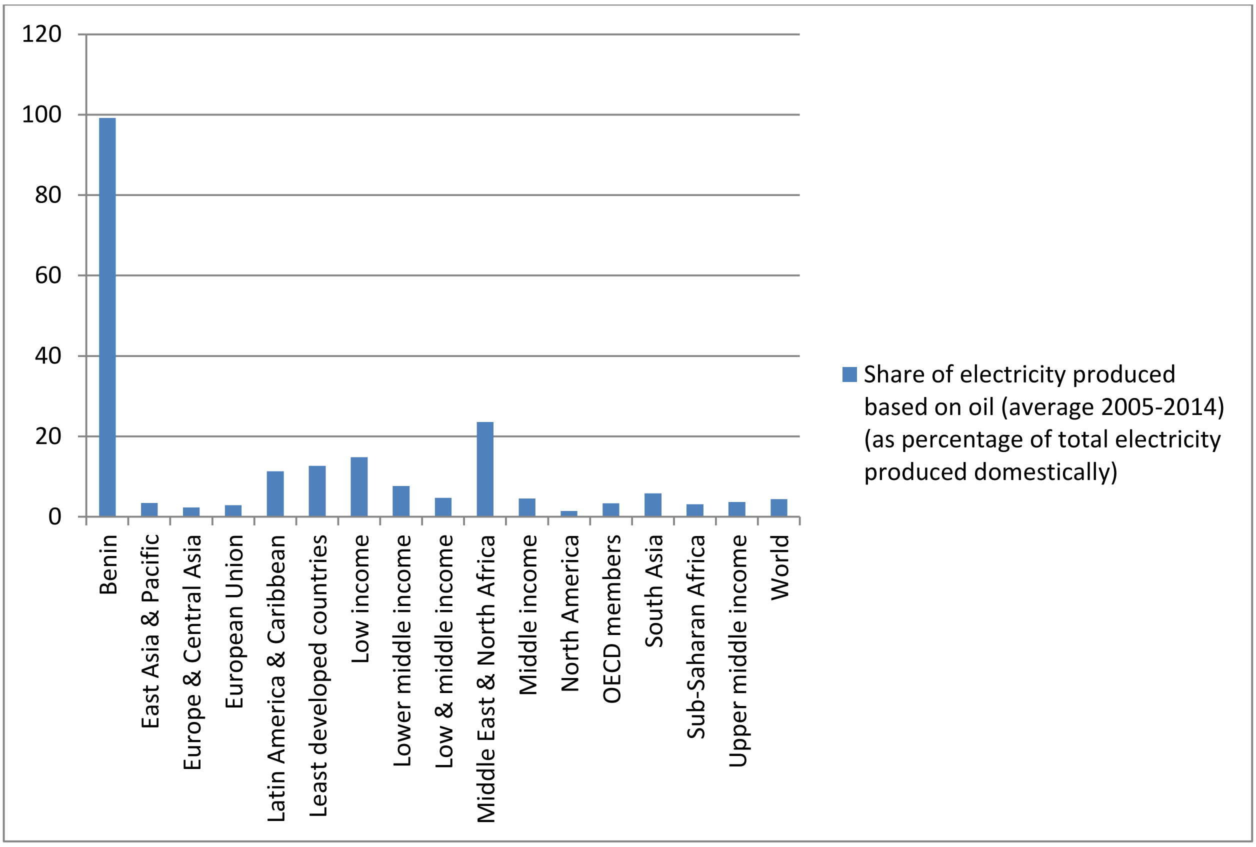

Figure 1.26: Comparison of the share of electricity produced based on oil (as a percentage of total electricity produced domestically) in Benin to that of the rest of the world (average 2005-2014)

Source: World Development Indicators (2018)

Figure 1.27 describes the history of the dependency on oil for domestic generation of electricity in Benin. It can be seen that up to 1994 the dependency on oil for domestic electricity generation was 100%. After 1997, the rate of dependency went below 100% as the country could also rely on other sources of domestic electricity generation such as the hydroelectric dam of Nangbeto. However, as of 2014, the rate of dependency on oil for the domestic generation of electricity was still high: around 99.46%.

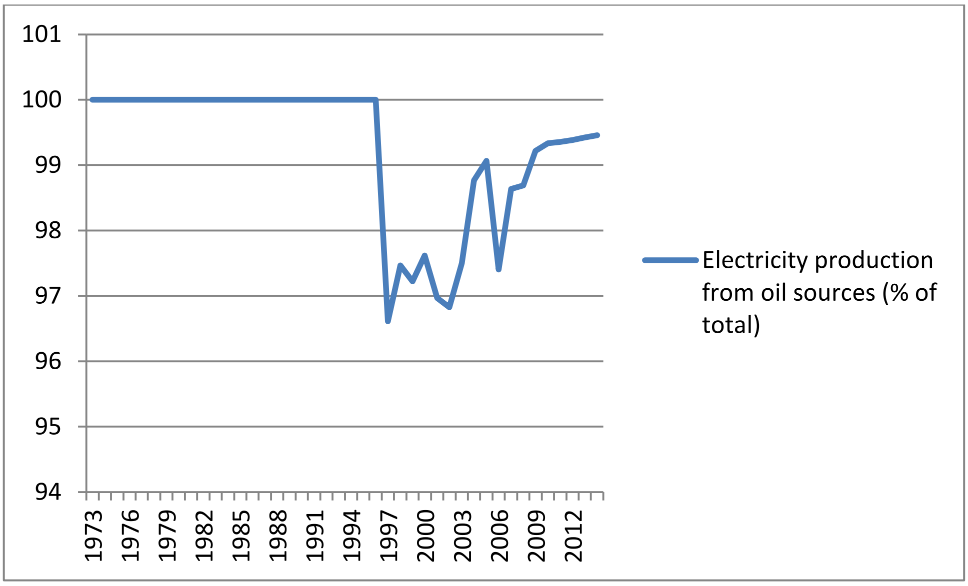

Figure 1.27: Electricity production from oil sources (as a percentage of total electricity produced domestically) in Benin over the period (1973-2014)

Source: World Development Indicators (2017)

This dependency situation is also confirmed in Figure 1.28 where the history of domestic electricity generation by source is represented over the period 1973-2014. The vertical axis shows electricity generated by sources: electricity production based on oil sources ('oil' here represents petroleum products and crude oil, see IEA statistics (2014)), electricity production based on hydroelectric sources, electricity production based on other renewable sources (sources such as solar, wind, geothermal, biofuels, tides, and biomass) this excludes hydroelectric sources (see IEA statistics (2014)). Electricity generated based on different sources is expressed as a percentage of total domestic production of electricity on the vertical axis. The horizontal axis shows years. It is clear that the share of electricity produced from oil sources is very high compared to the share of electricity produced from other sources. This indicates that the production sources for electricity are not well diversified. There is a huge dependency on oil to produce domestic electricity. This high dependency on oil is caused by the limited capacity of Nangbeto's hydroelectric dam, and the very weak use of other renewable energy such as solar electricity. A high dependency on oil indicates that any increase in oil prices will generate additional costs for domestic electricity generation. As stipulated in the national policy framework for electricity (République du Bénin, 2008, pp. 21-22), increases in oil prices have limited the capacity of Benin to promote rural access to electricity using electric generators, which consume oil. This situation has slowed rural access to electricity, as the use of other alternative sources of electricity generation (renewable sources such as solar energy, wind energy, etc.) is still very weak. Increased oil prices result in budget constraints, which can limit the quantity of domestic electricity generated. This, in turn, reduces the overall electricity supply in the country. Therefore, it is demonstrated that a heavy dependence on oil for the production of domestic electricity results in additional electricity supply disruption risks.

The reduction in overall supply of electricity can impede economic growth. As stipulated in the national policy framework for electricity, supply disruption can negatively affect economic growth. However, there has not been any empirical evidence to demonstrate that negative shocks to electricity supply can cause negative shocks to economic growth. It becomes therefore important to empirically verify whether or not negative shocks to electricity supply do, in fact, cause negative shocks to economic growth.

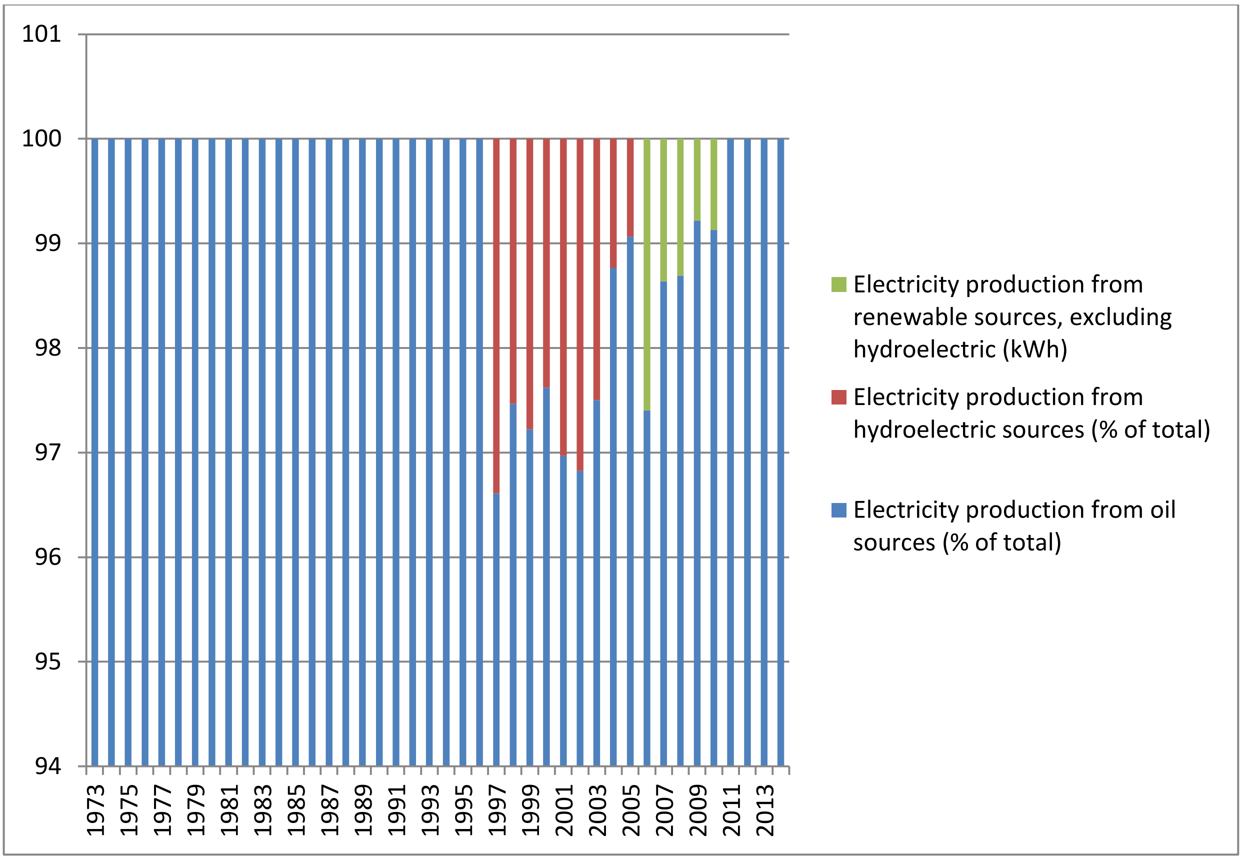

Figure 1.28: Domestic electricity production by sources (as a percentage of total electricity produced domestically) in Benin over the period (1973-2014)

Source: World Development Indicators (2017); IEA statistics (2014)

With all the uncertainties faced by the Beninese electricity sector, the capacity for electricity consumption/supply to play its role in sustainable economic growth and poverty reduction becomes questionable. Electricity shortages, losses of electricity, dependency on imported electricity, and increases in oil prices, all constitute significant electricity supply security risks related to supply

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disruption in Benin. They have economic costs and influence the performance of the electricity sector in the country. The national policy framework for electricity (République du Bénin, 2008, pp. 68-69) stated different sub-objectives which will contribute to the achievement of its fourth strategic goal: the "Development of institutional and legal capacities and the building of human resource capacity in the electricity sector". Several of these sub-objectives aim to define and improve performance indicators for the electricity sector and the national distribution company.

The current state of the electricity sector in Benin, as described in the national policy framework for electricity, revealed that high dependency on imported electricity, increases in electricity losses, increases in oil prices and lack of diversification of sources of electricity production, all introduce major supply disruption risks, however, there is currently no index or framework which can be used to assess the performance of the electricity sector taking these risks into account. Therefore it becomes important to construct a composite index which will measure these electricity supply security risks and thus contribute to the assessment of the performance of the Beninese electricity sector. Before assessing the performance of the electricity sector in Benin, it is important to have a retrospective view on the different policies which have been implemented in the electricity sector, their success, and their failures.

1.1.5 Overview of past and present electricity policies in Benin

Prior to March 2004, no national policy framework for the Beninese energy sector had been designed. The existing documentation on energy and electricity policies in Benin were Benin's energy strategy (République du Bénin, 1996), the SBEE's master plan for production, transportation, and distribution of electricity (SBEE, 1992), and the CEB's action plan for investment over the period 1988-2003. The CEB operates for both Benin and Togo based on a mutual cooperation between these two countries. Each of these countries has some geographic advantages that are beneficial to the other. Togo is located at the western frontier of Benin. Both countries import electricity from Ghana and Nigeria. Benin uses the Togolese territory and electrical lines to import electricity from Ghana, which is located at the western frontier of Togo. Togo uses the Beninese territory and electrical lines to import electricity from Nigeria, which is located at the eastern frontier of Benin. The CEB is in charge of managing these importations and distribution of electricity for both Benin and Togo, and thus plan for both countries. Both the CEB's action plan and the SBEE's master plan have focused on supply side policies. Their final goal was to enable Benin and Togo to increase their capacity of electricity supply. The lack of a national policy framework for the Beninese energy sector translated into the absence of national objectives for the electricity sector before March 2004. The electricity sector was regulated and managed based on the action plans of the CEB and the master plan of the SBEE before that date. Because there were no predefined objectives at the national level before that period, it has been impossible

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to accurately evaluate the effectiveness of the electricity sector. Evaluations that have been done were based on the existing documents of the CEB and the SBEE (République du Bénin, 2008).

The first objective of the CEB's action plan for investment over the period 1988-2003, was to see both Benin and Togo achieve an electricity supply self-sufficiency rate of 70% by 2003. In other words, by 2003, Benin and Togo would ideally import only 30% of their electricity supply. Such an objective was established based on the potential future increase of Benin's domestic capacity of electricity production: the construction and commissioning of the hydroelectric dams of Adjarala and Ketou. The Adjarala dam was expected to operate by 1995. The second objective was to increase the transmission and distribution lines and ensure total access to electricity in the capitals of all administrative regions of both Benin and Togo (République du Bénin, 2008).

The third objective was to build an electrical interconnection with neighbouring countries such as Nigeria, in order to facilitate easier electricity trade between countries. The evaluation of the CEB's action plan for investment revealed that most objectives were not achieved. Particularly, the plan for the construction of hydroelectric dams to increase domestic electricity production was not executed. The goal of a 70% self-sufficiency rate in electricity supply was not achieved. The capacity of production has only been increased by 20 Megawatt (Mgw) with the construction of two gas turbines. This was far below the objectives. In addition, the electrical interconnection with Nigeria, which was planned for 2002, was delayed for five years because of a lack of funding, and only started in 2007. Moreover, the objective to ensure total access to electricity in the capitals of all administrative regions for both Benin and Togo was delayed. This goal was only achieved in 2008 when an electrical interconnection was established between North Benin and North Togo (République du Bénin, 2008).

Apart from its action plan for investment over the period 1988-2003, the CEB also undertook other initiatives aimed at increasing the production of electricity in Benin and Togo using thermal power plants. Two companies were appointed for the production of electricity from thermal sources. The first was West Coast Energy Limited (WEL), which was appointed for the construction of a thermal power plant at Krake in Benin, and was to supply the CEB with an annual quantity of electricity of 570 Gigawatt GW) beginning no later than April 15th 2004. The second was the Electrotogo Company, which was appointed to repair and use the thermal power plant of Lome in Togo, and to supply the CEB by January 1st 2005 with an annual quantity of electricity of 350 GW. Neither of these initiatives were successful. The failure of these initiatives can be attributed to the inability of the two companies to fulfil the requirements of their appointment. In summary, the CEB did undertake different interventions to increase the capacity of electricity supply in Benin and Togo; however, lack of financial resources was a major cause of the failure of these interventions (République du Bénin, 2008).

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The SBEE’s master plan for production, transportation and distribution of electricity was to develop several thermal power plants in order to complement the quantity of electricity supplied by the CEB, which fluctuates due to the amount of electricity it imports. In addition to its domestic production, the CEB imports electricity from neighbouring countries, which themselves have been facing a growing demand for electricity. Whenever these countries decide to reduce their exports due to this internal demand, the quantity of electricity supplied by the CEB is reduced. The goal of the SBEE’s master plan for production, transportation and distribution of electricity was to enable Benin to fill the electricity gap caused by sudden reductions in the quantity of electricity supplied by the CEB, in order to avoid electricity shortages in the country. However, because of the growing demand for electricity in Benin, both the supplies of electricity of the SBEE and the CEB were not able to fill the electricity supply gap of the country (République du Bénin, 2008).

Many other reasons explain the electricity deficit or electricity supply gap observed in Benin. First, compliance to international norms in terms of distribution line extension is very costly for the SBEE. This has limited its efforts to extend the distribution lines in rural areas, and resulted in a high proportion of the rural population being left without electricity. In addition to this situation, there were very few initiatives related to rural access to electricity using an off-grid system based on renewable energy. Moreover, projects for rural access to electricity were not profitable because of the low purchasing power of the rural population and a dispersed rural habitat. While there is a need to extend distribution lines across the rural habitat, the expense related to this extension is very high due to the distance between rural homes and villages; this expense is not offset by the purchase of electricity in rural areas because purchasing power in the these areas is very low. This situation has been one of the constraints which hinders the nation’s ability to reduce its electricity supply gap (République du Bénin 2008).

The combination of reduction in electricity imports and the existing gap between consumption and domestic production of electricity has accentuated the electricity deficit and outages observed in Benin. The national strategy for the development of the electricity sector, as stated in the national policy framework for electricity, is based on several principles. The first principle is to make the Beninese economy very competitive. The second principle provides the necessary tools required to achieve the goal. The second principle was established to ensure the availability of production factors, including electricity, at an affordable cost in order to see the Beninese economy become more competitive. As mentioned in the national policy framework for electricity, outages or supply gaps of electricity have affected the Beninese economy (République du Bénin, 2008). However, as stated previously, to the best of the writer’s knowledge, there is (prior to this study) no empirical evidence on Benin that has ascertained that negative shocks to electricity supply caused negative shocks to GDP. As the electricity consumption has never exceeded 2.07% of total primary energy consumption in Benin for over 44 years (1971-2014) (World Development Indicators, 2017), it is possible that negative shocks to electricity supply (electricity consumption added to electricity losses; see IEA statistics (2018)) have no causal effect on GDP. Hence, empirical evidence is necessary to verify if negative shocks to electricity supply have caused negative shocks to GDP in Benin. As explained previously, the current study aims to provide such empirical evidence by investigating if negative shocks to electricity supply cause negative shocks to GDP in Benin. This information will contribute to the understanding of electricity supply security risks and policy in Benin.

While the extension of transmission and distribution lines requires additional cost in rural areas compared to urban areas, an assessment revealed that in major urban cities, the distribution lines built are insufficient compared to the need for extension of transmission and distribution. This situation has resulted in illegal extension of distribution lines by a proportion of the population, who though living in urban areas remain without access to electricity. The result has been a saturation of distribution lines and low electrical voltage. Such illegal distribution lines have increased the non-technical losses of electricity. The Beninese Ministry of Energy had planned to reduce electricity losses by 18% from 2005 to 2010, by 15% in 2015, then by 14% from 2020 to 2025 (see Table 1.4 below) (République du Bénin, 2008). However, the losses of electricity encountered in Benin during the years 2010 and 2015 were above the targets (see Table 1.4 below).

Table 1.4: Targeted electricity loss reduction for the period 2005-2025 and actual electricity losses in Benin during the period 2005-2015

Years	**2005**	**2010**	**2015**	**2020**	**2025**
Targeted electricity losses (as a percentage of total supply)	18	18	15	14	14
Actual electricity losses (as a percentage of total supply)	16.24	18.56	19.35		

Source: République du Bénin/Ministry of Energy (2008), USEIA (2018)

As mentioned previously, modernizing distribution lines to be more electricity-efficient is part of Benin's electricity efficiency target aimed at reducing technical losses. Benin has an emergency plan to fight electricity theft and corruption, and to improve the electricity billing system, in order to reduce non-technical losses. The national policy framework for electricity acknowledged that reductions in electricity losses would lead to gains in terms of GDP. It also emphasized that one of the strategies for reimbursing part of the cost to modernise distribution lines is to capture the gain in GDP resulting from a reduction in electricity losses (République du Bénin, 2008). It is therefore relevant to assess the effect of electricity losses on GDP. Benin has also attempted to meet its electricity efficiency target by making changes to demand side policies. Firstly, these policies encourage the use of electricity-efficient equipment in the construction and usage of public

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buildings, and in the installation of public lampposts. In addition, they encourage the use of electricity-efficient appliances (lamps, air conditioners, refrigerators) and devices using solar electricity within households. The implementation of an electricity-efficient policy in public buildings has helped the public sector reduce its electricity consumption costs by 402 million CFA in 2007 (currently, approximately equivalent to US$ 687336.33; according to the exchange rate of April 30th, 2019) (République du Bénin, 2008).

The most recent assessment of the energy efficiency policy in Benin revealed that the country has a national action plan for energy efficiency called “Feasibility study document for the operationalization of the National Agency of Renewable Energy Development and Energy Efficiency (ANADER)” (“Étude de faisabilité pour l’opérationalisation de l’Agence Nationale pour le Développement des Énergies Renouvelables et de l'efficacité énergétique (ANADER)”) (République du Bénin, 2014). This action plan includes targets for electricity efficiency already specified in the national policy framework for electricity. The national plan contains energy efficiency targets to reduce energy intensity, including electricity intensity, by 4% every year. Its objective is to reduce energy consumption, including electricity consumption by 20% in 2025. However, there are no sectoral targets in terms of energy and electricity efficiency at the residential, commercial and industrial level. One of the strategies for electricity efficiency is to diversify the sources of electricity generation by increasing the share of renewable electricity that contributes to the total electricity supply, and to limit electricity losses. The national target for such a strategy is to increase the share of renewable electricity in the total electricity produced to at least 25% by 2025, while reducing electricity losses in transmission and distribution networks (Regulatory Indicators for Sustainable Energy, 2018).

The DGE is in charge of defining the energy/electricity efficiency strategy for the country, while the ANADER regulates energy/electricity efficiency for suppliers and consumers of energy/electricity. It also certifies compliance with energy/electricity standards in Benin. Recently, a law called Decree Number 2018-050 of February 15th, 2018 (“DÉCRET No 2018- 050 du 15 Février 2018 portant création et mise en place de l'Unité Chargée de la Politique de Développement des Energies Renouvelables (UC/PDER)”; see République du Bénin, 2019) was issued by the council of government ministers in Benin to establish the Unit in Charge of Policy for the Development of Renewable Energy (UC-PDER), in replacement of ANADER. Although Benin has established these institutions (DGE, ANADER, and UC-PDER) to implement its energy efficiency policy, and demand side policy has made progress in saving electricity through more efficient construction of public buildings, there is still a legislative gap to be filled in terms of creating a binding obligation for electricity/energy efficiency in public buildings (Regulatory Indicators for Sustainable Energy, 2018). Although the implementation of electricity-efficient policies in public buildings by the Ministry of Energy has helped the public sector to significantly reduce its electricity consumption costs

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(République du Bénin, 2008), there is still no binding electricity/energy saving obligation for public buildings. There is, however, a public procurement guideline for energy/electricity efficiency, and a public budgeting regulation for energy/electricity efficiency. However, there is neither a public recognition of electricity/energy efficiency performance for large scale users of electricity/energy, nor are there tax incentives or financial incentives for large consumers to invest in electricity/energy efficiency. Electricity/energy efficiency targets and electricity/energy efficiency audits are not required for large consumers. In addition, there are no penalties in place for the violation of electricity/energy efficiency regulatory obligations by large consumers (Regulatory Indicators for Sustainable Energy, 2018).

Figure 1.29 represents a measurement of the energy efficiency policy framework in Benin according to a set of 12 indicators (indicator 1: national energy efficiency planning; indicator 2: energy efficiency entities; indicator 3: information provided to consumers about electricity usage; indicator 4: energy efficiency incentives from electricity rate structures; indicator 5: incentives and mandates: large consumers; indicator 6: incentives and mandates: public sector; indicator 7: incentives and mandates: utilities; indicator 8: financing mechanisms for energy efficiency; indicator 9: minimum energy efficiency performance standards; indicator 10: energy labelling systems; indicator 11: building energy codes, and indicator 12: carbon pricing). On the vertical axis are the indicators' scores measured on a scale of 0 to 100, and on the abscissa line are the indicators. The scoring system uses a set of questions to collect some information about each indicator. Each response to these questions receives a score based on its importance. The score of an indicator is the sum of the scores allocated to the responses to questions related to such indicator. All the indicators are equally weighted, and the overall score of the Beninese energy efficiency policy framework is the arithmetic mean of the indicators' scores (Regulatory Indicators for Sustainable Energy, 2018).

It is clear that Benin's energy sector performs well concerning indicators 1, 2 and 4, while its score for indicators 3 and 6 are below the average of 50. This indicates that Benin has an energy efficiency plan in place. This plan is described in the "Feasibility study document for the operationalization of the National Agency of Renewable Energy Development and Energy Efficiency (ANADER)". Benin also has legal institutions in charge of its energy efficiency policy such as the Ministry of Energy, the DGE and ANADER (currently replaced by the UC-PDER). The country does have some energy efficiency incentives built into electricity rate structures for residential and industrial consumers (Regulatory Indicators for Sustainable Energy, 2018).

At the same time, the scores for indicator 5 (incentives and mandates: large consumers), indicator 7 (incentives and mandates: utilities), indicator 8 (financing mechanisms for energy efficiency), indicator 9 (minimum energy efficiency performance standards), indicator 10 (energy labelling systems), indicator 11 (building energy codes) and indicator 12 (carbon pricing) are zero. This indicates that there are no incentives or mandates for large consumers or utilities to invest in energy-efficient goods (tax reduction or other financial incentives for large consumers to invest in energy-efficient equipment, no penalties to utilities for non-compliance to energy efficiency standards in terms of equipment, etc.). There are no minimum energy efficiency performance standards and there is no labelling system for energy-efficient appliances or machinery (energy efficiency standard and energy labelling system for refrigerators, lighting equipment, air conditioners, industrial electric machinery, etc). Although there is an energy efficiency bill which describes energy efficiency standards related to public buildings, there are no building codes requiring that residential and commercial buildings are constructed in an electricity-efficient manner. In addition, there is no incentive for energy efficiency in the construction and usage of residential and commercial buildings. Benin does not have a carbon pricing mechanism (carbon tax, etc.). This can be explained by the fact the country still has a low consumption of energy per capita and the level of greenhouse gas emissions is still low. Finally, there is no direct financing mechanism for energy efficiency in Benin, and the overall score of the Beninese energy efficiency policy framework is low (23.51) (Regulatory Indicators for Sustainable Energy, 2018).

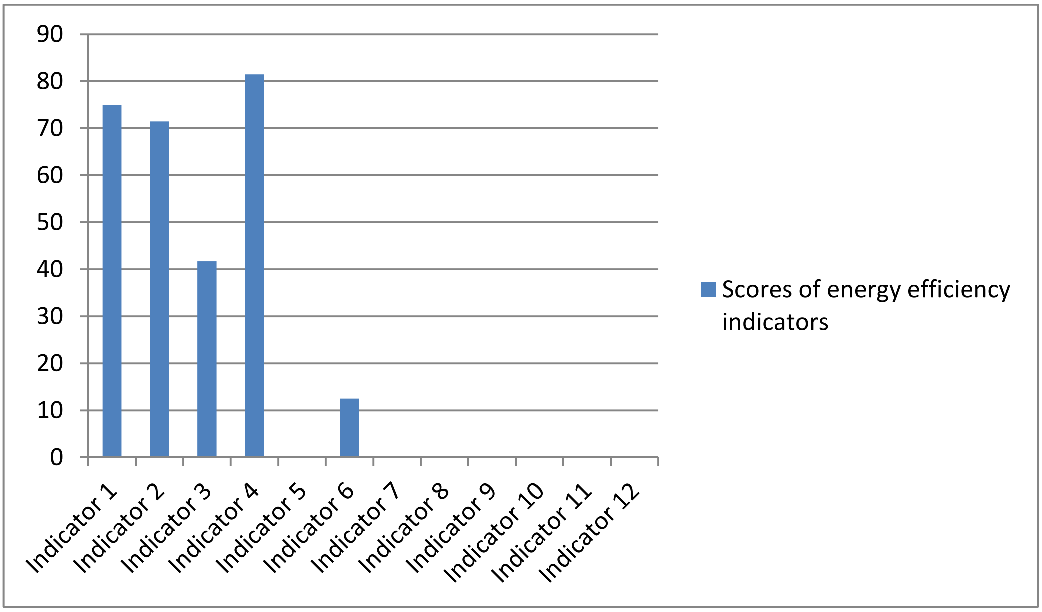

Figure 1.29: Measurement of Benin's energy efficiency policy framework according to a set of indicators

Source: Regulatory Indicators for Sustainable Energy (2018)

The indicators respectively refer to:

Indicator 1: national energy efficiency planning;

Indicator 2: energy efficiency entities;

Indicator 3: information provided to consumers about electricity usage;

Indicator 4: energy efficiency incentives from electricity rate structures;

Indicator 5: incentives and mandates: large consumers;

Indicator 6: incentives and mandates: public sector;

Indicator 7: incentives and mandates: utilities;

Indicator 8: financing mechanisms for energy efficiency;

Indicator 9: minimum energy efficiency performance standards;

Indicator 10: energy labelling systems;

Indicator 11: building energy codes, and

Indicator 12: carbon pricing

The absence of a direct financing mechanism for energy efficiency in Benin calls into question the ability of the country to implement its electricity efficiency policy. The implementation of an electricity efficiency policy is costly, the reduction of technical and non-technical losses in particular is expensive to rectify. As mentioned previously, reductions in technical losses of electricity require Benin to purchase electricity-efficient equipment, while reductions in non-technical losses of electricity require some monitoring costs (monitoring of billing systems, monitoring of the legal distribution network, etc.). According to the Regulatory Indicators for Sustainable Energy (2018), there is no direct financing mechanism in Benin to fund these costs. To solve this situation, the national policy framework for electricity proposed an indirect financing mechanism, which consists of borrowing funds from donors or the national budget to finance the costs related to the reduction of electricity losses, and reimbursing the donors or national budget with the anticipated gains in GDP that will result from the reduction in electricity losses. Assessing the actual effect of electricity losses on GDP is therefore necessary, and will contribute to advance electricity efficiency policy implementation in Benin. It will help to forecast the gain in GDP resulting from electricity losses, and it will also help to assess the feasibility of the indirect financing mechanism proposed in the national policy framework for electricity.

As stated previously, losses of electricity and electricity shortages limit the available supply of electricity to consumers. Therefore, they constitute electricity supply security risks or, more precisely, electricity supply disruption risks, and affect the performance of the Beninese electricity sector. As also explained previously, there is currently no indicator or index measuring the performance of the Beninese electricity sector in terms of the risk of non-occurrence or disruption of the electricity supply. The national policy framework for electricity (République du Bénin, 2008, pp. 68-69) has defined several sub-objectives aiming to contribute to the accomplishment of its fourth strategic goal: the “Development of institutional and legal capacities and the building of human resource capacity in the electricity sector”. As mentioned before, the definition and improvement of performance indicators for the Beninese electricity sector and the national distribution company (SBEE), are among these sub-objectives. The African Development Bank (2013) has established an infrastructure index ("Africa Infrastructure Development Index") for African countries, including Benin, which includes an "electricity composite index". However, this electricity index focuses only on net generation of electricity and does not capture risk as it relates to the disruption of electricity supply, which is one of the major issues faced by the electricity sector in most African countries. The current study aims to fill that gap by constructing a composite index which will measure risk as it relates to disruptions in the electricity supply.

1.2 PROBLEM STATEMENT

Compared to types of energies such as fossil fuel, biomass and coal, electrical energy is clean and easy to use in many different applications such as telecommunications, refrigeration, lighting, heating, cooking and transportation. A sufficient and accessible quantity of electricity in a country is an indicator of a high standard of living and economic development, as the presence of electricity improves the ease of doing business, the standard of living of households, and the productivity of all sectors of the economy (Hounkpatin, 2013). Ferguson et al. (2000) argued that wealth is more strongly correlated with electricity consumption than it is with total energy consumption. The IEA (2002) argued that an electricity service is the most effective way of improving the welfare of the poor. Hence, the supply of electricity is a requirement for the social and economic development of Africa. According to Turkson and Wohlgemuth (2001), there is consensus on the fundamental role of access to electricity for sustainable economic growth and poverty reduction in African countries. Hounkpatin (2013) stipulated that investment in electricity supply capacity should be Benin's first priority if this country aims to pursue sustainable economic growth and reduce its poverty rate.

However, in Benin, the electricity sector is vulnerable because of three main uncertainties. First, there is a huge gap between supply and consumption. Hence, the country has to rely on importing electricity from neighbouring countries such as Ghana, Nigeria, and Côte d'Ivoire for 77.57% as of 2015. The resulting consequences for Benin have been severe electricity shortages in 1984, 1994, 1998, 2006, 2007, 2008, 2012 and 2013, because Ghana, Nigeria and Côte d'Ivoire have also been facing a growing demand and a limited generation capacity due to droughts. Second, Benin encounters significant losses of electricity during transmission and distribution, and as of 2015, these losses of electricity were 19.35% of the total supply. Such losses reduce the available quantity of electricity supplied to consumers, and therefore constitute a disruption risk for the electricity supply. Thirdly, the country is highly dependent on oil for its domestic generation of electricity (Hounkpatin, 2013; World Development Indicators, 2017; USEIA, 2018). Whenever oil prices rise, there will be additional costs in the process of generating domestic electricity. This constitutes a factor of risk and can limit the domestic capacity of electricity generation. According to

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République du Bénin (2008), the disruptions to electricity supply had a negative impact on the Beninese economy.

Many studies have investigated the relationship between electricity consumption and economic growth: Niu, Ding, Niu, Li and Luo (2011), Ozturk and Acaravci (2011), Solarin (2011), Shahbaz, Tang and Shahbaz Shabbir (2011), Mozumder and Marathe (2007), Jamil and Ahmad (2010), Hsiao (1981), Acaravci, Erdogan and Akalin (2015), Apergis and Payne (2009a&b); Ozturk (2010), Payne (2010), Shiu and Lam (2004), Chen, Kuo and Chen (2007), Narayan and Prasad (2008), Yoo and Kwak (2010), Tang (2008 & 2009), Chandran, Sharma and Madhavan (2010), Yoo and Kim (2006), Ho and Siu (2007), Georgantopoulos (2012), Akpan and Akpan (2012), Bouoiyour and Selmi (2013), Shahbaz and Feridun (2012), Acaravci and Ozturk (2012) Narayan and Smyth (2005 & 2009), Narayan, Smyth and Prasad (2007), Narayan and Singh (2007), Jumbe (2004), Wolde-Rufael (2006), Squalli (2007), Kebede, Kagochi and Jolly (2010), Ekpo, Chuku and Effiong (2011), Zamani (2007), Acaravci and Ozturk (2010), Altinay and Karagol (2005), Ghosh (2002), Yoo (2005), Yuan, Zhao, Yu and Hu (2007), Ciarreta and Zarraga (2010), Khobai, Abel and Le Roux (2016). Depending on the methodology, the data used, and the countries' specific context, authors have established different results.Very few studies have focused on the Beninese context. Most of them are in the form of a cross-country analysis. The most comprehensive of them is the work of Wolde-Rufael (2006) on Benin and other sub-Saharan African countries. Such a study is very limited in terms of country-specific policy recommendations. In addition, it was done in 2006, and the context of Benin has evolved considerably since then.

To date, no empirical study on Benin has investigated the effects of disruption to electricity supply on economic growth. This study will fill that gap by investigating the effects of disruption to electricity supply on economic growth. First, this study will contribute to the definition and improvement of performance indicators in the Beninese electricity sector by constructing a composite index of risks that disrupt the electricity supply. Risk in the context of this study, is defined as any factor that can cause disruptions to electricity supply. As mentioned previously, in order to implement its fourth strategic goal (the "Development of institutional and legal capacities and the building of human resource capacity in the electricity sector"), one of the sub-objectives defined by the national policy framework for electricity (République du Bénin, 2008) is the definition and improvement of performance indicators for the Beninese electricity sector and the national distribution company (SBEE). A composite index of risks that disrupt electricity supply constitutes a performance indicator for the electricity sector.

With the construction of such a composite index, the current study will contribute to the achievement of one of the sub-objectives (mentioned earlier) defined by the national policy framework for electricity, and will advance the formulation, monitoring and measurement of electricity policy in Benin, especially policies related to the security of the electricity supply. It will also contribute to the body of knowledge as no study in the world (to the best of the writer's knowledge) has established a composite index related to risks that can disrupt the electricity supply, which takes into account all the following dimensions of the security of energy supply: affordability, acceptability, accessibility and availability of energy. As stated previously, the electricity composite index developed by the African Development Bank (2013) does not capture risks that can disrupt electricity supply, which are the major cause of electricity crises in Benin, Africa and many other developing countries. In addition, it focuses mostly on net generation of electricity. The electricity index developed by the World Bank (2018a) is built upon a survey where respondents are asked to rank the reliability (absence of voltage fluctuations or lack of disruption) of electricity supply based on scores ranging from 1 to 7. Respondents' allocation of the score can be subjective as it is not necessarily based on a quantitative assessment of shortages of electricity supply. In addition, such an index only focuses on the availability of electricity supply. Aspects related to the use of renewable electricity to ensure the sustainability of electricity supply, and issues related to the affordability of electricity are not considered. Affordability of electricity can become an issue for many reasons. For instance, increases in oil price can lead to high production costs of electricity in countries which depend on oil to generate domestic electricity. High production costs of electricity can lead to high prices of electricity both domestically and internationally. Hence, importing electricity can become more costly. Disruption to electricity supply can occur in poor economies as they may no more afford to import the total quantity of electricity that will fill their supply gap.

Second, the current study will contribute to advancing the electricity efficiency policy in Benin by evaluating the effect of electricity losses on GDP. As noted previously, one of the pillars of the second objective of the national strategy for access to electricity is the promotion of electricity efficiency on both supply and demand sides. In alignment with that pillar, the Beninese Ministry of Energy has planned to reduce electricity losses by 14% from 2020 to 2025 (République du Bénin, 2008). As also mentioned previously, the national policy framework for electricity recognized that electricity losses result in loss of GDP, and suggested a financing mechanism to fund the cost of activities aimed at reducing electricity losses. As mentioned by the Regulatory Indicators for Sustainable Energy (2018), there is no direct financing mechanism to fund the costs of activities aimed at reducing electricity losses. The mechanism described in the national policy framework for electricity is an indirect financing mechanism. The policy suggested that donors or a portion of the national budget can be used to finance the cost of creating a reduction in electricity losses; in turn, the resulting gains in GDP once losses are reduced can be used to reimburse the donor or national budget. Therefore, it becomes important to assess the effect of electricity losses on GDP. No empirical study on Benin thus far has carried out such an assessment. This study aims to fill that gap by investigating the effect of electricity losses on GDP. It will help to evaluate the possible gains in GDP resulting from reductions in electricity losses, and contribute to assessing the

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feasibility of the indirect financing mechanism proposed in the national policy framework. It will also add to the existing literature on energy efficiency in Benin.

Third, the current study will contribute to the understanding and formulation of an electricity security policy in Benin by investigating if negative shocks to electricity supply cause negative shocks to GDP. As already mentioned, the first principle of the national strategy of the development of the electricity sector, described in the national policy framework for electricity, is to promote the competitiveness of the Beninese economy. In order for the economy to be competitive, it needs access to affordable production factors, including electricity. The second principle is therefore to ensure the availability and affordability of production factors, including electricity. As stated previously, there have been several outages of electricity in Benin due mainly to a sudden reduction in electricity imports. The World Development Indicators (2016) reported that firms have lost some of their sales values in that country because of electricity outages. The World Bank (2016) also reported that 95.6% of firms established in Benin have experienced electricity outages. Based on these reports it is possible that outages of electricity have negatively affected the Beninese economy. However, the share of electricity consumption in the total primary energy consumption is very low in the country. This suggests that it is also possible that outages of electricity have no causal effect on GDP. All these justify the necessity to empirically verify if, in fact, outages of electricity have caused reductions in GDP. No empirical evidence on Benin thus far has demonstrated that outages of electricity have caused reductions in GDP. This study will fill that gap by verifying if negative shocks to electricity supply cause negative shocks to GDP in Benin. As mentioned previously this study will contribute to the policy dialogue on electricity security in Benin, and will also add to the existing literature on energy security.

Therefore the problem investigated is: the effect of disruption risk to electricity supply on economic growth in Benin.

1.3 RESEARCH QUESTIONS

In alignment with the previously stated focus of this study, the general research question is the following: What is the effect of disruption in electricity supply on economic growth in Benin? The specific research questions are as follows:

Q1. How does Benin perform in terms of offsetting the risk of disruption to electricity supply?

Q2. What is the effect of electricity losses on GDP in Benin? In order to calculate the effect of electricity losses on GDP, it is necessary to know the effect of both electricity supply net of losses and electricity supply under the hypothesis of absence of losses, on GDP. The effect of electricity supply under the hypothesis of absence of losses minus the effect of electricity supply net of losses is the net effect of electricity losses on GDP. Therefore, this question is divided into three sub-questions:

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Q2.1. What is the effect of electricity supply net of losses on real GDP in Benin? In the context of Benin, electricity supply net of losses should be understood as the total electricity generated minus electricity losses. It can also be defined as electricity consumption, in other words the amount of electricity that is distributed to consumers after exclusion of electricity losses. It is measured in kilowatt hours (kWh).

Q2.2. What is the effect of the electricity supply under the hypothesis of absence of electricity losses, on real GDP in Benin? In the context of Benin, electricity supply is defined as the sum of electricity consumption (electricity supply net of losses) and electricity losses. In other words, it is the electricity supply under the hypothesis of the absence of losses, or in a situation where it is assumed that transmission and distribution losses are equal to zero. It can also be called total electricity generated, which is composed of electricity generated domestically and imported electricity. It is measured in kilowatt hours (kWh).

Q2.3. What is the net effect of losses of electricity on real GDP in Benin?

Q.3. Do negative shocks to electricity supply (electricity supply net of losses) cause negative shocks to GDP?

1.4 RESEARCH OBJECTIVES

In alignment with the focus of the research questions, the general objective of the study is to investigate the effect of disruption to electricity supply on economic growth in Benin.

Specifically, the aims are:

O1. To measure Benin's performance in terms of electricity supply disruption risks. This will be done by constructing an electricity supply disruption index: this composite index will assess the country's overall performance in terms of disruption to electricity supply.

O2. To evaluate the loss of real GDP resulting from electricity losses. This requires first an investigation of the relationship between electricity supply net of losses (electricity consumption) and real GDP. Second, the relationship between electricity supply (under the hypothesis of absence of electricity losses) and economic growth must also be investigated. As electricity supply (under the hypothesis of absence of electricity losses) is the sum of electricity supply net of losses (electricity consumption) and electricity losses, the net effect of electricity losses on real GDP will be equal to the effect of electricity supply (under the hypothesis of absence of electricity losses) on real GDP, minus the effect of electricity supply net of losses (electricity consumption) on real GDP. Therefore, this objective is composed of three sub-objectives:

O2.1. To investigate the effect of electricity supply net of losses (electricity consumption) on real GDP.

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O2.2. To investigate the effect of electricity supply under the hypothesis of absence of electricity losses, on real GDP.

O2.3. To assess the net effect of electricity losses on real GDP.

O3. To verify if negative shocks to electricity supply (electricity supply net of losses) cause negative shocks to real GDP.

1.5 JUSTIFICATION, SIGNIFICANCE AND CONTRIBUTION OF THE STUDY

This study aligns with the formulation and implementation of electricity policy in Benin in three different ways. First, as mentioned previously, it will contribute to defining and measuring performance indicators within the Beninese electricity sector by constructing an electricity supply disruption index, which will assess Benin’s overall performance related to managing risk to disruption in electricity supply. In doing so, the study will align itself with one of the sub-objectives set out by the national policy framework for electricity: this sub-objective is necessary for the implementation of the policy’s fourth strategic goal. This sub-objective seeks to define and improve performance indicators for the Beninese electricity sector and the national distribution company. Constructing an electricity supply disruption index will advance the monitoring and evaluation of the electricity security policy in Benin. Such an index will also be a contribution to the body of knowledge, as there is currently no composite index in the world to measure overall performance as it relates to managing risks to disruption in electricity supply, while accounting for dimensions of energy supply security such as the availability, acceptability, accessibility, and affordability of energy.

Second, as said before, the current study will advance electricity efficiency policy in Benin by assessing the effect of electricity losses on GDP. In doing so, it aligns with one of the pillars of the second objective set out in the national strategy for access to electricity, which is the promotion of electricity efficiency on both demand and supply sides in Benin. As stipulated by the Republic of Benin (République du Bénin, 2008), the target of the Beninese Ministry of Energy is to lower electricity losses by 14% from 2020 to 2025. As explained previously, the national policy framework for electricity suggested an indirect financing mechanism aiming to fund the costs associated with the reduction of electricity losses. It has been suggested that such a mechanism first use funds from donors or national budget to finance the costs and then, use the gain in GDP resulting from reductions in electricity losses to reimburse these funds. Assessing the effect of electricity losses on GDP will therefore contribute to assessing the feasibility of this indirect financing mechanism as set out in the national policy framework for electricity. Apart from its contribution to policy, this study will also add to the existing literature on electricity efficiency in Benin.

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Third, as explained previously, this study will contribute to advancing electricity security policy in Benin by verifying if negative shocks to electricity supply caused negative shocks to GDP. As explained previously, the second principle of the national strategy of the development of the electricity sector aims to ensure the affordability and availability of production factors, including electricity, in order for the Beninese economy to become more competitive. However, over the years, there have been many shortages of electricity in Benin, and according to the national policy framework for electricity, these electricity shortages have had a negative effect on the economy. The current study aims to verify such conclusions by investigating if negative shocks to electricity supply caused negative shocks to GDP. Such verification is important as there currently exists no empirical evidence demonstrating that negative shocks to electricity supply have caused negative shocks to GDP in Benin. Apart from its contribution to policy, this study will also add to the existing literature on electricity security.

1.6 ORGANIZATION OF THE DISSERTATION

The rest of the study is organised as follows: Chapter 2 measures Benin’s overall performance related to managing risk to disruption in electricity supply with the creation of an electricity supply disruption index (electricity supply security index). Chapter 3 evaluates the effect of electricity losses on real GDP. Chapter 4 verifies if negative shocks to electricity supply (electricity supply net of losses) cause negative shocks to real GDP. Chapter 5 concludes the study and summarizes the policy recommendations. As it is expected in a dissertation based on articles, each of the chapters of this study (except the chapters 1 and 5) is a paper that has its own introduction, literature review, methodology, empirical results, and conclusion. Because of this requirement, it is possible that some aspects of the study are repeated from one chapter to another, as each chapter constitutes a publishable paper.

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CHAPTER 2
MEASURING ELECTRICITY SECURITY RISK

2.1 INTRODUCTION

Over the last several decades, the concept of energy security has become the focus in different fields, government, industries, and has also been considered in many countries as a national security issue (Vivoda, 2010; Ang, Choong and Ng, 2015). Many factors have justified such attention: volatility in oil prices, political instability in energy exporting countries, increasing dependency of industrialized countries on energy, military conflicts in energy exporting areas, limited oil reserves, climate change issues, competition in access and supply of energy, important disruptions in the supply of energy within importing countries, etc. (Vivoda, 2010; Bielecki, 2002; Jonsson, Johansson, Månsson, Nilsson, Nilsson and Sonnsjö, 2015; Kaare Koppel and Leppiman, 2013; Kunz, 2012; Asif and Muneer, 2007; Haghighi, 2007; Aparicio, Pinilla and Serrano, 2006; Kim, 2014; Bang, 2010; Constantini and Gracceva, 2004). Both developed and developing countries have been working to identify ways of minimizing the vulnerability of their energy sector to internal and external risks. For many countries energy security has become an important pillar among their national policy targets because a continuous supply of energy is necessary for the functioning of the economy. Hence, there have been many attempts to conceptualize, define and quantify energy security. However, it is impossible to provide a universal definition of energy security, as each definition depends on the people and countries, the types of threats to energy security, the social and economic response of countries, the time period (Alhajji, 2007), and the type of energy. Hence there is no consensus on the definition of energy security (Ang et al., 2015).

The focus of the current study is on electricity security. However, because there is a lack of literature which provides a clear definition of electricity security, this study will provide different definitions of energy security as an attempt to understand electricity security, and will finally provide a general definition of electricity security, and a definition of electricity security that is specific to the Beninese context. Although the definitions of energy security provided concerns total energy, they also apply to specific types of energy such as electricity.

Some studies focused exclusively of the security of energy supply in importing countries (Andrews-Speed, 2004; Bahgat, 2007, amongst others), highlighting the importance of availability and prices of energy (Spanjer, 2008; Jamasb and Pollitt, 2008), while other studies included aspects such as the effects on social and economic welfare of energy security risks (Vivoda, 2010). Very few studies, such as Platts (2012) and Marcel (2006), focused on the security of energy demand from the perspective of the exporting countries. Security of demand is a concern for exporting countries, as a reduction in energy demand significantly affects revenues from energy exports, as is the case with oil exporting countries such as Saudi Arabia and Russia. Security of domestic energy supply has also become a concern in several energy exporting countries. As they are facing a growing domestic energy demand, one of their focuses is to ensure the availability of domestic supply in order to meet the domestic growing demand, before any energy exportation. This has been the case in the African electricity market with exporting countries such as Ghana. Again, few studies, such as Yafimava (2011), focused on the security of the transportation and transit of energy to some countries. Transit countries are used by several exporting and importing countries when transporting energy. The absence of violence and terrorism in these countries as well as their political stability matter for the safe transportation and transit of energy supply.

Energy security in this study will be mostly analysed from the supply side perspective because of lack of data on energy/electricity demand in Benin and many developing countries. There have been some surveys on energy/electricity demand at different time periods, but in Benin and many developing countries, these surveys have been conducted randomly over time; hence, they are not useful for studies that requires times series data. In addition, because these surveys are not conducted at the same period of time for all countries, it is impossible to make use of them when comparing annually the state of energy/electricity security in Benin to that of other countries.

Throughout the literature, most studies which attempt to define the security of energy supply can generally be classified in three main groups. The first group comprises studies which consider security as an uninterrupted supply of energy commodities. One of the advocates of such a definition is the United Kingdom (UK)'s Department of Energy and Climate Change (DECC). According to the DECC (2009, p. 19): “Secure energy means that the risks of interruption to energy supply, are low”. Other advocates of such definition of energy security include studies such as Ölz, Sims and Kirchner (2007), Scheepers, Seebregts, de Jong and Maters (2007), Wright (2005), Hoogeveen and Perlot (2007), and Lieb-Dóczy, Börner and MacKerron (2003).

A few studies (Billinton and Allan, 1996); Makarov and Moharari, 1999) among the first group introduced the notion of “reliability” to explain the concept of “low interruption risks” stated in the DECC's (2009) definition of energy security. According to these studies, the “reliability” of an energy system implies two sub-concepts: “security” and “adequacy”. An energy system is considered to be secured if it is able to remain unaffected by risks, and it is considered to be adequate if it is able to ensure consumers' energy needs at any time. Unlike DECC (2009), Billinton and Allan (1996) and Makarov and Moharari (1999), in their framework on “reliability” do not define energy security as a state of “low interruption risks”, rather, they define energy security as the ability of an energy system to resist risks or adapt to change. While there are slight differences in the definition of energy security among studies of the first group, their common view is that a rise in the shortage of energy can be interpreted as energy insecurity.

The second group of studies differentiates between secure and insecure levels of uninterrupted energy supply when defining energy security. Small outages or discontinuities in the supply of

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energy are not necessarily a risk for energy security. The most known definitions of energy security among this group of studies are those of the International Energy Agency (IEA) and the United Nations Development Program (UNDP). According to the IEA (2001, p. 76), “Energy security is defined in terms of the physical availability of supplies to satisfy demand at a given price”. The IEA (2007, p. 160) defines energy security as: “adequate, affordable and reliable supplies of energy”, and for the IEA (2014, p.13) energy security is the “uninterrupted availability of energy sources at an affordable price”. The UNDP (2000, p. 112) argued that energy security is “the continuous availability of energy in varied forms, in sufficient quantities and at affordable prices”. According to the World Energy Council (2008, p. 1), energy security is “an uninterruptible supply of energy, in terms of quantities required to meet demand at affordable prices”. Such definitions imply that in addition to interruptions of the energy supply, increases in energy prices above a certain threshold are also considered as energy security risks. However, increases in energy prices below such thresholds are not considered as energy security risks. A significant number of studies align with the IEA’s definitions, such as Andrews (2005), Vicini, Gracceva, Markandya and Costantini (2005), Yergin (1988), Luciani (2004), Jun, Kim and Chang (2009), Le Coq and Paltseva (2009), Fondazione Eni Enrico Mattei (FEEM) (2008).

Another definition of energy security among this group is that of Mabro (2008, p. 3) who stated the following: “Security is impaired when supplies are reduced or interrupted in some places to an extent that causes a sudden, significant and sustained increase in prevailing prices”. His definition implies that interruptions of energy supply can be considered as an energy security risk only if increases in energy prices are beyond a certain threshold. Other studies in the second group included in their definition the occurrence of a predictable or unexpected event which can determine energy security. Significant among these are McCarthy, Ogden and Sperling (2007), Rutherford Scharpf and Carrington (2007) and Spanjer (2007). While most studies of the second group agree on the differentiation between secure and insecure levels of energy supply, they diverge in their identification of a common secured quantity energy supply because secure and insecure levels of energy supply vary from one country to another. A secure level of energy supply in one country can be considered insecure in another country.

Within the third group of studies, first, some studies extended the definition of energy security to the impact on the ability to provide energy services. Their definition of energy security is focused on the potential impact of energy disruption on the availability of energy services. Significant among them are Patterson (2008), Findlater and Noel (2010), and Li (2005). Findlater and Noel (2010, p. 2) on gas supply security stated the following: “security of gas supply (or gas supply security) refers to the ability of a country’s energy supply system to meet final contracted energy demand in the event of a gas supply disruption”. Their statement implies that disruption of gas supply may or may not necessarily affect the continuity of gas services such as heating, cooking, and so forth.

Other studies within the third group extended the definition of energy security to the impact on the economy of a country. Significant among these are Bohi, Toman and Walls (1996), Joode, Kingma, Lijesen and Shestalova (2004), Grubb, Butler and Twomey (2006) and Lefèvre (2010). The most comprehensive is Bohi et al. (1996) who defined energy insecurity as reductions in welfare that may arise because of variation in the availability or the price of energy. This definition implies that changes in the price or availability of energy may or may not necessarily affect the economy; in addition, the economic impact of energy disruptions varies from one type of energy to another.

Finally, a number of studies within the third group extended the definition of energy security to the impact on the environment. Significant among these are Verrastro and Ladislaw (2007), the study of the Asia Pacific Energy Research Centre (APERC) (2007), the European Commission (2000), and Kruyt, van Vuuren, de Vries and Groenenberg (2009). APERC (2007, p. 6) define energy security as: “the ability of an economy to guarantee the availability of energy resource supply in a sustainable and timely manner with the energy price being at a level that will not adversely affect the economic performance of the economy”.

The differentiation between secure and insecure levels of energy supply and the inclusion of impacts on energy services, the economy and the environment, make the definition of energy security very inclusive. However, such inclusiveness is also a disadvantage as it makes the concept of energy security difficult to measure. Although there is no consensus on a unique definition of energy security, all definitions reflect the idea that energy security implies avoiding risks which can lead to an interruption of the supply of energy services, and leave the demand unmet. Such interruption of energy supply varies according to the country, the risk context and the energy type. Hence, it is worth indicating that each country has its own energy security risks and energy security risks vary according to the type of energy (electricity, oil, coal, etc). This study will specifically focus on the sustainable security of electricity supply in the Beninese context.

Based on the idea that energy security implies avoiding risks which can lead to an interruption of the supply of energy services, and leave the demand unmet, it is worth defining electricity security as an uninterrupted supply of electricity services which satisfies the demand. In Benin, electricity supply security risk is mainly related to the inability to cope with sudden disruptions of electricity supply. First, the country has a high dependency on the importation of electricity: according to the USEIA (2017), in 2015 around 77.575% of its electricity was imported from neighbouring countries. Hence, the Beninese electricity sector is affected by any outages of electricity supply which occur in its neighbouring countries (exporting countries).

Second, the country relies heavily on oil for its domestic electricity generation: according to the World Development Indicators (2017), in 2014 Benin relied on oil to generate 99.45% of its

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domestic electricity, while the country is not an oil exporter. This high dependency on oil exposes the electricity sector to fluctuations in oil prices. High oil prices constitute a limitation to the country's capacity to generate electricity domestically because they increase electricity production costs. In addition, oil, as any other fossil fuel energy, is a limited and non-renewable resource. In the perspective of long-run and sustainable energy security, countries should include in their energy mix an important share of sustainable energy resources such as renewable energy. Increases of the share of renewable electricity in the total domestic generation of electricity will therefore contribute to sustainable electricity supply security. In the case of Benin, however, only 5.55% of the electricity generated domestically came from renewable sources in 2015, and the generation of electricity based on renewable sources has never exceeded such amount over the period 1996-2015. This indicates that in 2015, 94.45% of the electricity generated domestically in Benin came from non-renewable sources. Therefore the sustainability of Benin's domestic electricity production becomes a concern.

Third, the Beninese electricity sector encounters a high quantity of technical and non-technical electricity losses: according to the USEIA (2017), 19.358% of the electricity supply was lost during transmission and distribution in 2015. These losses constitute a reduction in the quantity of electricity supply available for consumers.

In the context of the Beninese electricity sector, electricity security risks can therefore be defined as exposure of electricity supply to electricity losses, foreign outages of electricity due to high dependency on electricity importation, and fluctuations in the price of oil which is a limited and non-renewable energy resource. Losses of electricity, heavy dependency on importation of electricity, heavy dependency on oil/fossil fuel (a non-renewable energy resource for domestic electricity generation) therefore constitute three major indicators of the vulnerability of the Beninese electricity sector. For this study, five additional indicators will be added.

The first is a governance index. The "control of corruption" in a country, the "rule of law", the "quality of the regulatory system", the "political stability and absence of violence", and "government effectiveness", represent governance indicators (Worldwide Governance Indicators, 2017) which influence the effectiveness of the delivery of electricity to consumers. An insufficient rule of law and an ineffective law enforcement system can cause thefts of electricity. A poor quality of the regulatory system and corruption can lead to mismanagement in the distribution of electricity and delays in the access to electricity for households and firms. Violence and terrorism can damage electricity infrastructure and this can lead to significant disruptions to electricity supply. The governance index comprises the governance indicators previously mentioned, and each indicator has been converted to positive values by adding 100 for ease of calculation of the index; further explanation is provided in the methodology, section 2.4.1.

The second is the ratio of growth of access to electricity in urban areas to the growth of the urbanization rate. The urbanization rate is defined as the share of the population that lives in urban areas, and is expressed as a percentage of total population. For ease of comparison between the growth of the urbanization rate and the growth of urban access to electricity, this ratio has been transformed into a ratio with solely positive values by adding 100% to both numerator and denominator (further explanation is provided in the methodology, section 2.4.1). The transformed ratio is multiplied by 100 in order to have all its values as percentages. As reported by the IEA (2016), rapid urbanization increases energy consumption and in 2013, cities accounted for 64% of the world's use of primary energy. Other studies, such as Sheng, He and Guo (2017) on 78 countries and Jones (1991) on 59 developing countries, also established that urbanization increases energy consumption. Urbanization increases the demand for energy and if the supply of energy is unable to meet the demand, then energy shortages occur. In other words, urbanization must go along with urban access to electricity/energy in order to avoid disruption to the supply of energy, including electricity. The ratio of the rate of growth of access to electricity in urban areas to the rate of growth of urbanization compares the urbanization speed to the speed of urban access to electricity. It measures the ability of countries to meet the increases in electricity demand caused by urbanization, by increasing urban access to electricity. On one hand, if this ratio is less than 100, it indicates that urbanization is growing faster than urban access to electricity. This situation can result in electricity supply disruption in urban areas, as the urban supply of electricity may not be able to meet the urban demand for electricity. On the other hand, if this ratio is greater than 100, it indicates that urban access to electricity is growing faster than urbanization. Therefore, promoting urban access to electricity can help cities to meet their growing electricity demand.

The third is the rate of access to electricity, which is defined as the ratio of the population that has access to electricity to the total population. For the purpose of simplicity it will be expressed as a percentage. A rate below 100 indicates that the country has a supply gap as there is a proportion of its population that does not have access to electricity. In other words, a proportion of the population is left without electricity and therefore is facing a total disruption of electricity. A value equal to 100 indicates that the entire population of the country has access to electricity and there is no supply gap. Promoting access to electricity can enable a country to minimize the electricity supply gap or total disruption of electricity supply.

The fourth is real GDP per capita (expressed as a percentage of the world annual average real GDP per capita; further explanation is provided in the conceptual framework on electricity supply security and the methodology, sections 2.2.2 and 2.4.1 respectively). It highlights how wealthy the country is, and indicates the country's ability to avoid or prevent disruptions of electricity supply by investing in electricity infrastructure and utilities. A country with a high GDP per capita is financially more able to invest in electricity utilities in order to reduce or avoid supply disruptions than a

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country with a low GDP per capita. As argued by Ferguson et al. (2000), a positive correlation exists between countries' wealth and their electricity consumption.

The fifth is the share of real GDP that is not dedicated to cover the cost of electricity supply (expressed as percentage of real GDP; further explanation is provided in the conceptual framework on electricity supply security and the methodology, sections 2.2.2 and 2.4.1 respectively). It highlights the cost of electricity supply compared to the national income (SeeKendell and James (1998)). If the share of real GDP not dedicated to cover the cost of electricity supply is high, it indicates that the country can easily afford to cover the cost of its electricity supply. When the share of real GDP not dedicated to cover the cost of electricity supply is low, it indicates that supplying electricity is very costly for the country; in other words, it it difficult for the country to cover the cost of its electricity supply.

The aim of this study is to build a composite index of electricity supply security risks, which account for the three major indicators of the vulnerability of the Beninese electricity sector as described above (losses of electricity, heavy dependency on importation of electricity, and heavy dependency on oil/fossil fuel), plus the governance index, the transformed ratio of growth of access to electricity in urban areas to growth of the urbanization rate, the rate of access to electricity, real GDP per capita (expressed as a percentage of the world annual average real GDP per capita), and the share of real GDP that is not dedicated to cover the cost of electricity supply. Such an index will measure the disruption risk to electricity supply on an annual basis. The index does not measure the daily, weekly, monthly, and quarterly disruption risk to electricity supply, because of lack of data (For example, there is no data for the governance index, on a daily, or weekly, or monthly, or quarterly basis). However, first a framework will be provided to explain the dimensions of energy and electricity supply security.

2.2 CONCEPTUAL FRAMEWORK FOR ENERGY AND ELECTRICITY SUPPLY SECURITY

2.2.1 Conceptual framework for energy supply security

The definitions of energy security have evolved over time according to the context and the types of exposure to energy risks. According to Chevalier (2006), the IEA (2007), APERC (2007), and the Clingendael Institute/Clingendael International Energy Programme (CIEP) (2004), four main pillars ("the four As") characterize energy security: The first is the "availability" of energy. This implies the physical existence of energy resources in an economy or a country. Losses of energy/electricity supply reduce the quantity of energy available for consumers. Rapid urbanization without a sound plan to promote urban access to energy will cause a supply gap of energy in urban areas. Lack of access to energy/electricity by a proportion of the population in a country is due to a supply gap.

The second pillar is "accessibility". In many countries, production and consumption of energy occur in separate places. Many countries have to import energy from places where there is political

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instability, or other geopolitical issues. Although energy might be available to be imported, it may not be easily accessible. On the other hand, energy may be available in a country, but access to such energy by domestic consumers can be a challenge within that country if there are governance issues (corruption, lack of rule of law, poor quality of the regulatory system, political instability and violence) which affect the delivery of energy to consumers.

The third pillar is the “affordability” of energy. Although energy might be available and accessible, it may not be easy to purchase it at an affordable price. In the oil industry, affordability of energy is a concern for importing countries, as oil prices are often volatile. Affordability can also be interpreted as a country’s financial ability to invest in energy infrastructure and provide energy utilities services in order to prevent or avoid supply disruption of energy among its population. Countries that have a high GDP per capita are considered wealthy and able to achieve such a goal, while countries that have a low GDP per capita lack the necessary financial resources to enable them to achieve such a goal. “Affordability” is therefore an important aspect of energy security.

The fourth pillar is “acceptability”, which indicates the acceptability of the energy types by society (the production or consumption of such energies should not cause heavy environmental damage to society), and the sustainability of the energies produced or consumed. The production and consumption of many energy types affects the environment. For instance, production and consumption of oil/fossil fuel energy pollute the environment by generating CO_2 emissions in the atmosphere. The generation of electricity using oil also pollutes the atmosphere with CO_2 emissions, and CO_2 emissions in the atmosphere are one of the climate change issues. Hence, many countries are concerned about producing and consuming energy without damaging the environment significantly.

As explained previously, oil and other types of fossil fuel are limited and non-renewable energy resources. Long-term and sustainable production of electricity/energy implies the use of sustainable energy resources, such as renewable energy. Ellabban, Abu-Rub, and Blaabjerg (2014, p. 749) defined renewable energy as: “energy sources that are continually replenished by nature and derived directly from the sun (such as thermal, photo-chemical, and photo-electric), indirectly from the sun (such as wind, hydropower, and photosynthetic energy stored in biomass), or from other natural movements and mechanisms of the environment (such as geothermal and tidal energy)”. The World Commission on Environment and Development (1987) defined sustainable development as a development which satisfies the needs of the current generation without jeopardizing future generation’s capability to satisfy their own needs. Renewable energies are unlimited and their stock will still be available for future generations as they can be renewed. Therefore, increases in the share of renewable energy in the total domestic production of energy matters for a sustainable energy supply security.

While previously-mentioned studies have characterized energy security according to concepts of “availability”, “accessibility”, “affordability” and “acceptability”, the IEA (2007) distinguishes between long- and short-run security of energy supply. Short-run energy security refers to the ability to avoid interruptions of energy supply, while long-run energy security refers to structural patterns of the energy sector, and the causes of energy supply interruptions. The lack of long-term investments to increase energy supply will lead to short-term interruptions of energy supply in the future.

Although the concepts of “availability”, “accessibility”, “affordability” and “acceptability” have been identified as the four pillars of energy security, their importance will evolve over time and according to the context. On the one hand, in a world where globalization, multilateralism and market cooperation are the pattern, the issue of energy dependence of one region on another will not matter, as geopolitical issues will be easily solved. The focus will rather be on the existence of a sufficient quantity of energy resources and their production costs. In other words, the focus will be on the concepts of “availability” and “affordability”. Conversely, in a world where regionalization and political barriers are the pattern, geopolitical issues will matter. The focus will be on energy independence, as access to energy in politically unstable zones will be an issue. The attention will therefore be on the concept of “accessibility”.

On the other hand, in a world where sustainable development and climate change issues matter and where the production and consumption of energy that has low environmental damage is encouraged, the cost of energy may rise, as there is a tradeoff between targeting environmental goals and low energy cost. Solving such a tradeoff will require more innovation in science and technology to reduce the production costs of environmentally safe energy. This will take time. Hence, in such a world the focus will be on the concepts of “acceptability” and “affordability**”.**

2.2.2 Conceptual framework for electricity supply security (electricity supply disruption risks)

As discussed in previous sections, the focus in this study is on sustainable electricity supply security, precisely on electricity supply disruption risks. The attention is on both short- and long-run security. Long-term and sustainable electricity security take into account the ability of countries to rely more on renewable energy resources when producing electricity and to be less dependent on importation of electricity. Renewable energy resources are unlimited, while fossil fuel energy resources used in many countries for the production of electricity are limited. In addition, there are always uncertainties related to dependency on importation of electricity. For instance, Ghana is a politically stable country and has been exporting electricity to Benin and Togo for decades. However, because of natural disasters such as droughts which have reduced the level of water in the Akossombo dam and limited its capacity to produce electricity, Ghana was constrained in 1983, 1994 and 2004 to reduce its export of electricity to Benin and Togo. Therefore, even in the absence of geopolitical issues there are still uncertainties which can affect countries’ importation of

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electricity. Because of this, this study considers dependency on importation of electricity as one of the sources of risks for electricity security in both the short and the long run. Countries that are self-sufficient in terms of their domestic electricity supply are not exposed to uncertainties related to importation of electricity. They may be exposed to uncertainties related to fluctuation of the international demand for electricity if they are exporters. As mentioned previously, security of electricity demand is not the focus of this study; rather the focus is on the supply side of electricity security.

The analysis of electricity supply security will be based on the four pillars of energy security mentioned previously ("the four As"). The security risks related to these traditional four pillars have been proxied by a variety of indicators. First, on the one hand, the electricity security risk related to the concept of "accessibility" can be proxied by either the share of net imports of electricity in the total domestic supply of electricity, or the rate of electricity supply self-sufficiency. Such rate is defined as the ratio of electricity not imported to total domestic supply of electricity, while the share of net imports of electricity is defined as the ratio of net imports of electricity to total domestic supply of electricity. The rate of electricity supply self-sufficiency is positively correlated to countries' efforts to avoid disruption to electricity supply. In other words, it is positively correlated to the composite index of electricity supply disruption risk ("positive polarity", further explanation is provided in the methodology, section 2.4.1.), whereas the share of net imports of electricity in the total domestic supply of electricity is negatively correlated with the composite index ("negative polarity", further explanation is provided in the methodology, section 2.4.1).

Because of the negative values of net imports of electricity for exporting countries, a geometric mean will be used to calculate the electricity supply disruption risk index (all numbers must have the same sign, when taking their geometric mean, further explanation is provided in the methodology, section 2.4.1), and because of the necessity of a "positive polarity" (see Mazziotta and Pareto (2013)), the rate of electricity supply self-sufficiency has been chosen as a proxy for security risk related to the concept of "accessibility". Such a rate reflects a country's ability to be self-sufficient in terms of its domestic electricity supply. It also points out the self-sufficiency gap, in other words the dependency on importation of electricity (in countries that import electricity). A value of such a rate below 100 indicates that the country has a deficit of electricity supply and is dependent on the importation of electricity. A value equal to 100 indicates that the country has no electricity supply deficit or is self-sufficient in terms of its domestic electricity supply, and a value above 100 indicates that the country has a surplus of electricity supply, in other words, the country is self-sufficient in terms of its domestic electricity supply, and exports its surplus of electricity. Such a rate highlights the exposure of importing countries to outages and shortages of electricity occurring in exporting countries.

The political stability of exporting countries also matters for easy importation of electricity. It is one of the causes of sudden reductions in exports of electricity within exporting countries, and can be considered as one of the indicators related to the concept of accessibility. However, because of lack of data on exporting countries and the countries to which they supply electricity, the political stability of exporting countries has not been included as a proxy for electricity security risks related to the concept of "accessibility". In addition, the political stability of exporting countries highlights exclusively the risks related to access to electricity by importing countries: it does not provide any information on the degree of a country's dependency on the importation of electricity. A country can rely heavily on the importation of electricity while its supplier countries are politically stable. In this case, there is no risk related to political stability, but there is a risk related to high import dependency, because exporting countries also face a growing domestic demand for electricity, and they can suddenly reduce their exports of electricity in order to meet their growing domestic demand for electricity. This has been the case with Ghana, a politically stable country which has suddenly reduced its exportation of electricity to Benin and Togo. This situation has been the cause of electricity shortages in Benin and Togo. The self-sufficiency rate in terms of domestic electricity supply or the proportion of imported electricity highlights – in the case of Benin – the exposure of the country to sudden reductions, outages and shortages of electricity occurring in its supplier countries such as Ghana.

On the other hand, the electricity security risk related to the concept of "accessibility" can also be proxied by the quality of governance within a country. As explained previously, the effectiveness of the delivery of electricity to consumers within a country can be influenced by the quality of governance prevailing in such a country. The effectiveness of the delivery of electricity to consumers influences consumers' accessibility to electricity. Consequently, the quality of the governance within a country influences consumers' accessibility to electricity. Five governance indicators ("control of corruption", "rule of law", "quality of the regulatory system", "political stability and absence of violence", and "government effectiveness") (Worldwide Governance Indicators, 2017) have been identified to construct a composite governance index which will be used as a proxy for the concept of "accessibility".

Second, on the one hand, the electricity security risks related to the concept of "availability" can be proxied either by the share of electricity losses in the total supply, or by the rate of electricity efficiency. The rate of electricity efficiency is the ratio of the quantity of electricity that is not lost to the total supply of electricity, while the share of losses of electricity in the total supply of electricity is the ratio of the electricity lost to the total supply of electricity. Losses of electricity reduce the available quantity of electricity generated, and they can be technical or non-technical. Non-technical losses are mostly due to human behaviours such as thefts of electricity. Technical losses are related to the technology used for the transmission and distribution of electricity. Countries should try to invest in electricity-efficient technology for transmission and distribution. The rate of electricity efficiency is positively correlated with a country's effort to avoid disruption to electricity supply. In other words, it is positively correlated with the composite index of electricity supply disruption risk ("positive polarity"; further explanation is provided in the methodology section 2.4.1). The share of electricity losses in total supply is negatively correlated with countries' effort to avoid disruption to electricity supply. Therefore, it has not been chosen. Rather, the rate of electricity efficiency has been chosen as a proxy for the concept of "availability": it highlights a country's ability to reduce the losses of electricity, and it also points out the electricity efficiency gap, in other words the proportion of losses of electricity in the total supply.

On the other hand, the electricity security risks related to the concept of "availability" can also be proxied by the ratio of growth of access to electricity in urban areas to the growth of the urbanization rate, or the rate of access to electricity. As mentioned previously, for ease of comparison between the growth of the urbanization rate and the growth of urban access to electricity, the ratio of growth of access to electricity in urban areas to growth of the urbanization rate has been transformed (further explanation is provided in the methodology, section 2.4.1). As reported by the IEA (2016), Sheng et al. (2017) on 78 countries, and Jones (1991) on 59 developing countries, urbanization increases energy consumption. As explained previously, if countries fail to promote urban access to electricity, the available supply of electricity in urban areas may not be able to meet the urban demand. Consequently, a supply disruption of electricity may occur in urban areas. As said before, the ratio of growth of access to electricity in urban areas to growth of the urbanization rate compares the speed of urban access to electricity to the speed of urbanization expressed as a percentage. If the value is less than 100, it indicates that the available urban supply of electricity may not be able to meet the demand. Conversely, if its value is greater than or equal to 100, it indicates that promoting urban access to electricity can help to satisfy the increased demand for electricity caused by urbanization.

The rate of access to electricity indicates the existence or not of a supply gap in the country. As said previously, it is defined as the proportion of the total population that has access to electricity. In other words, it is the ratio of the population that has access to electricity to the total population. If the rate of access to electricity is less than 100%, this indicates that a proportion of the population does not have access to electricity. This situation is due to a supply gap, and indicates that the available electricity in the country is not enough to satisfy the electricity needs of the entire population and the country does not have enough financial resources to provide full access to electricity to its entire population. For the proportion of the population that does not have access to electricity, this situation is comparable to a total and continual disruption of electricity supply. Conversely, if the rate of access to electricity is equal to 100%, this indicates that the entire population of the country has access to electricity. In other words, there is no electricity supply gap

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or none of the population is facing a total and continual disruption of electricity supply. A country with a high rate of access to electricity has a smaller supply gap of electricity to fill while a country with a low rate has a high supply gap to fill. The rate of access to electricity is therefore a decreasing function of electricity supply gap. In other words, it is a decreasing function of a total and continual disruption of electricity. Increasing access to electricity will contribute to reduce the supply gap of electricity or total disruption of electricity supply.

Third, following APERC (2007), the share of renewable electricity in total domestic production of electricity will be used as a proxy of the electricity security risks related to the concept of "acceptability". APERC (2007) argued that the share of renewable and nuclear energy in the total supply of energy can be used as an indicator for the concept of acceptability. It represents the "share of zero carbon fuel" in the total fuel supply and is considered as a country's efforts to increase its use of low carbon intensive energy and decrease its use of high carbon intensive energy. It also represents countries' efforts to have sustainable sources of electricity production. As said previously, renewable energies are unlimited energy resources, while fossil fuels are limited energy resources. For the sustainability of their energy supply security, countries should increase the share of sustainable energy resources such as renewable energy in their total energy supply. Gnansounou (2008) argued that increasing the share of renewable electricity in the total supply is one of the ways of diversifying the sources of electricity generation. Hence, the share of renewable electricity in the total domestic production of electricity can also be considered as an indicator of diversification of sources of electricity generation. In alignment with Gnansounou (2008), Kruyt et al. (2009) stipulated that a diversity of sources of energy supply enables countries to mitigate risks related to physical disruption of supply.

Fourth, the electricity security risks related to the concept of "affordability" can be proxied by the price of electricity or the share of electricity expenditures in real GDP, or real GDP per capita. Real GDP per capita indicates countries' ability to improve the standard of living of their population by investing in electricity infrastructure and providing utility services such as electricity to their populations with the purpose of preventing or avoiding supply disruption of electricity among these populations. As mentioned before, Ferguson et al. (2000) argued that there is a positive correlation between a country's wealth and its energy consumption. Countries that have high real GDP per capita are more financially capable of investing in electricity infrastructure and utilities in order to avoid disruption of electricity supply among their populations, while countries that have a low real GDP per capita are less financially capable of achieving such goals. Real GDP per capita is therefore an increasing function of countries' financial ability to finance electricity infrastructure or utilities services in order to prevent or avoid disruption of electricity supply. For the purpose of simplicity and in order to avoid having an indicator with a very high numerical range, a relative measure of real GDP per capita is used in this study. Real GDP per capita is expressed here as a percentage of the world annual average real GDP per capita (further explanation is provided in the methodology section 2.4.1).

Kendell (1998) argued that energy expenditures are an indicator of energy affordability. Their rationale is that high energy expenditures indicate that a country has some difficulties in supplying energy. They recommend using the share of energy expenditures in income. The USEIA (2018) has also used the share of energy expenditures in GDP to highlight the importance of energy in the economies of the United States and other countries. Economies for which the share of energy expenditures in GDP is high are more vulnerable to increases in energy prices, because the increase in energy costs resulting from increases in energy prices is significant. Because of a lack of data on electricity prices in Benin and many other African countries, the concept of affordability with electricity prices cannot be proxied in this study. Rather, in alignment with Kendell (1998), either the ratio of the total cost of electricity supply to real GDP or the share of real GDP which is not dedicated to cover the cost of electricity supply (which is equal to total real GDP minus the share of real GDP dedicated to cover the cost of electricity supply) will be used. The ratio of the total cost of electricity supply to real GDP highlights the proportion of real GDP dedicated to cover the cost related to electricity supply.

On the one hand, a high proportion of real GDP dedicated to cover the cost of electricity supply indicates that supplying electricity is very costly for the country, and affordability of electricity by the country may become an issue if there are some unpredicted negative shocks to real GDP. This situation can result in a limited capacity for the country to purchase electricity: consequently supply disruption can occur. On the other hand, a low proportion of real GDP dedicated to cover the cost of electricity supply indicates that supplying electricity is not very costly. In other words, electricity is affordable by the country. In the same way, if the share of real GDP not dedicated to cover the cost of electricity supply is high, this indicates that supplying electricity is not very costly, and is affordable by the country. However, if the share of real GDP not dedicated to cover the cost of electricity supply is low, this indicates that supplying electricity is very costly for the country, and affordability of electricity by the country may become an issue if unpredicted negative shocks affect real GDP. Such a situation can result in disruption of electricity supply in the country.

Between these two indicators (ratio of the total cost of electricity supply to real GDP and the share of real GDP which is not dedicated to cover the cost of electricity supply), this study uses the share of real GDP which is not dedicated to cover the cost of electricity supply as a proxy for the concept of “affordability” because its numerical range is very similar to that of the other indicators used in the calculation of the composite index of electricity supply disruption risk. The ratio of the total cost of electricity supply to real GDP has a very small numerical range when compared to the numerical ranges of the other indicators used in the calculation of the composite index of electricity supply disruption risk. In addition, for an easy interpretation of the composite index, it is important that all

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the indicators included in its calculation have similar numerical interpretation; in other words it is important that all these indicators are positively correlated with the composite index ("positive polarity"; see Mazziotta and Pareto (2013). Further explanation is provided in the methodology section 2.4.1.

Small values of all the previous indicators highlight a low performance in terms of effort to avoid a disruption to electricity supply, while high values of these indicators point out a high performance in terms of effort to avoid disruption to electricity supply. Only the numerical interpretation of the share of real GDP which is not dedicated to cover the cost of electricity supply aligns with the numerical interpretation of the previous indicators. As mentioned previously, high values of the share of real GDP which is not dedicated to cover the cost of electricity supply, indicate that supplying electricity is not costly for the country. In other words, the country is financially capable to invest in electricity infrastructure that will prevent disruption to electricity supply. Conversely, low values of the share of real GDP which is not dedicated to cover the cost of electricity supply indicate that supplying electricity is costly for the country. In other words, the country financially struggles to invest in electricity infrastructure that will prevent disruption to electricity supply.

Based on these four pillars of energy security and the proxies used as indicators of electricity security risks, the following framework of electricity security (Figure 2.1) has been designed to depict a composite index of electricity supply disruption risks. Before describing the procedure used for the construction of such composite index, it is important to review past studies on energy security indicators and indexes.

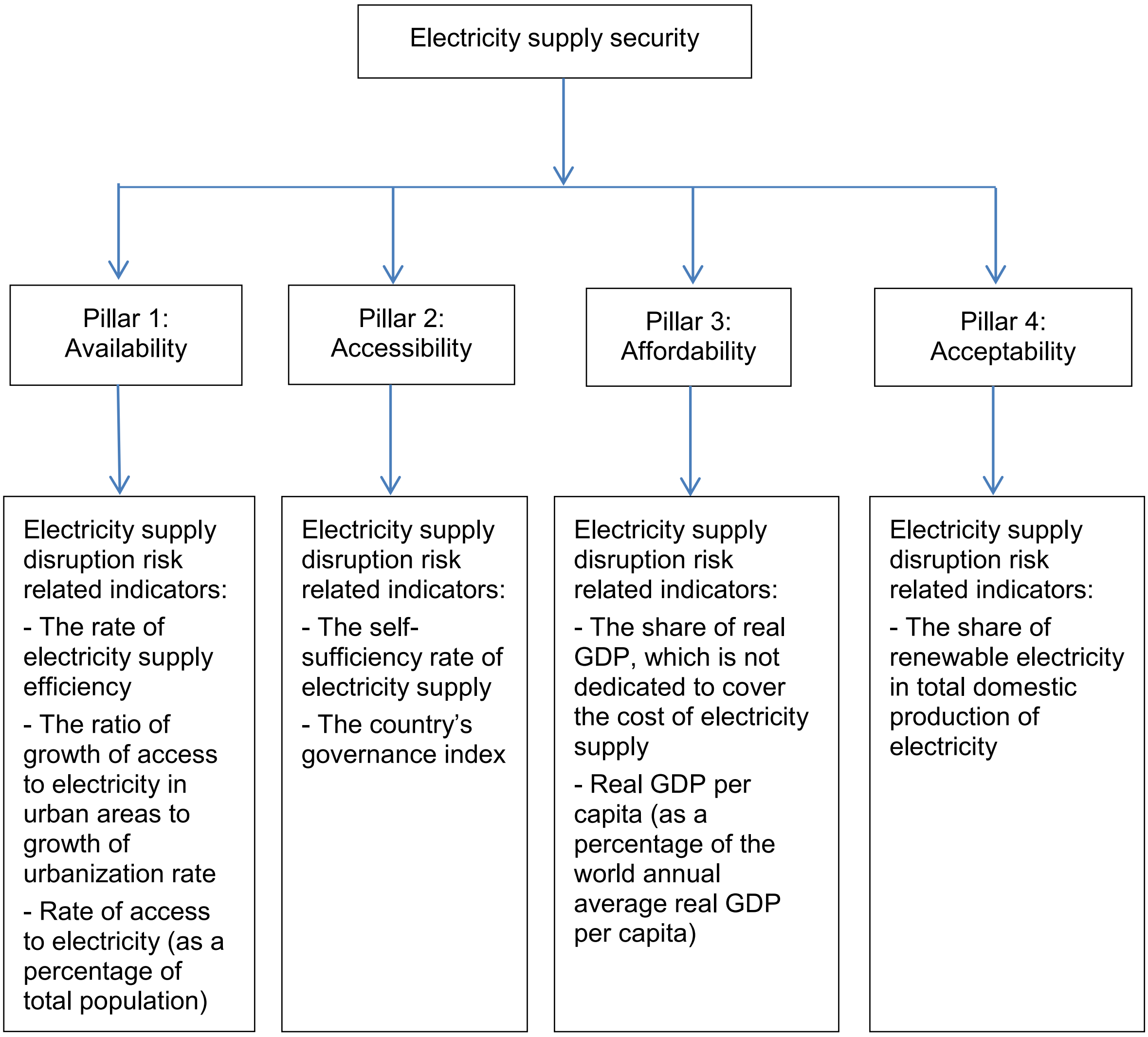

Figure 2.1: Summary of conceptual framework for electricity supply security

Source: Author's own conceptualization based on Chevalier (2005), IEA (2007), APERC (2007), and CIEP (2004)

2.3 Review of past studies on energy security indicators and indexes

Throughout the literature, there have been several studies which have attempted to measure energy security. Some have analysed only one aspect of energy security, while others have attempted to measure several aspects using either an aggregated or a disaggregated indicator. Although many of these indicators have attempted to quantify one or several aspects of energy security, most of them have been designed based on a certain context, and they are subject to improvement or change as contexts evolve.

2.3.1 Studies on disaggregated indicators of energy security

First, the availability or physical existence of energy is important for the security of the energy supply. As a result, the "resources estimates" have been used as an indicator of the availability of energy. However, there are issues related to the available quantity of hydrocarbon resources and

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their possible extraction. Among the few studies which attempted to estimate fossil fuel resources, the United States Geological Survey (USGS, 2000) is the most comprehensive. While some studies, such as Mulders, Hettelaar and van Bergen (2006), argued that USGS (2000) is the most reliable source for energy resource estimates, other studies, such as Greene, Hopson and Li (2005), highlighted the limitations of the USGS (2000) in measuring energy estimates. Hence there is a lack of consensus among studies with regard to the measurement of available resources.

Second, as stipulated by Feygin and Satkin (2004), the reserves to production ratios (R/P ratios or RPRs) had been used as an indicator of security of energy supply in several studies. It can also be defined as the remaining years of production considering the current speed, quantity or level of production. This indicator is highly dependent on time, as both existing reserves and production of energy resources are not static but evolve over time.

Third, another indicator of energy security that has been used is the “diversity index”. The most comprehensive studies which explained the concept of diversity in the context of energy security, are the Asia Pacific Energy Research Centre (APERC) (2007), Jansen, van Arkel and Boots (2004) and the IEA (2004, 2007). Jansen et al. (2004) and APERC (2007) argued that a diversity of energy types and geographical location of production and importation of energy will contribute to reduce energy security risks related to supply. According to the IEA (2004, 2007), a diversity of energy suppliers is a way of reducing energy security risks related to market power. A diversity index is therefore a quantitative measurement of either the diversity of energy types and sources of production or the diversity of energy suppliers.

Stirling (1999) stipulated that a diversity index comprises three aspects. One aspect, called the “variety”, is defined as the “number of categories”. Another aspect, called the “balance”, is defined as “the spread across categories”. A third aspect, called the “disparity”, is defined as “the degree to which categories are different from each other”. In practice, measuring aspects related to disparity are very challenging, hence most diversity indexes focus on aspects of “variety” and “balance”. One of the limitations of diversity indexes as indicators of energy security is that they do not capture risks related to each energy type. Each type of energy carries different types of risks. Risks related to electricity supply are not exactly the same as risks related to gas or oil supply. In addition, diversification of energy types, sources and suppliers will not necessarily prevent physical disruption of energy supply. Price shocks can occur as a result of unexpected geopolitical issues or natural disasters, and can be transmitted from one energy market to another and this can lead to physical disruption of an energy supply.

Fourth, another indicator of energy security that has often been used is “import dependency”, which can be measured for total energy as well as disaggregate energy, and is expressed in monetary form or as a percentage of total or disaggregate energy consumption. In the oil sector, for instance, the total oil imported relative to total oil consumption can be used to indicate “import

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dependency" (Alhajji and Williams, 2003). Because some countries import and export oil, gas and/or electricity, it is important to use net imports in the calculation of the "import dependency" indicator. Net imports are obtained after subtracting exports from imports. Net imports reflect accurately the "import dependency" of the economy in terms of energy.

APERC (2007) improved the "import dependency" indicator by including some diversity aspects: it used an adapted version of the Shanon index to measure both the import dependency and the energy diversity of an economy. In a context of mutual dependency in terms of energy, the international trade of energy, or the energy traded globally, can be used as indicators of mutual dependency. As said in the previous section, in the context of globalization and cooperation, an "import dependency" indicator will not matter, as there will be fewer barriers to importation of energy. Conversely, in the context of regionalization, an "import dependency" indicator will matter, as there will be political and economic barriers to importation of energy.

Fifth, another indicator of energy security widely used is the "political stability" of supplier countries. In many countries, the government directly oversees the supply of energy or regulates the energy market. A stable government and fair regulations matter for both importing and exporting countries. Political instability, such as military coups, can affect the energy trade between countries. Some studies such as IEA (2007) used an average of two of the World Bank Worldwide Governance Indicators (2018) – "regulatory quality" and "political stability and absence of violence and terrorism" – to calculate the "political stability" score of each country. Other studies such as Jansen et al. (2004) calculated the long-term social and political risk of each country using UNDP indicators such as the Human Development Index.

Sixth, another indicator of energy security that has been used is energy price. This is an expression of energy supply as related to energy demand or vice versa. Energy prices balance supply and demand, and they are also an indication of economic impact. A reduction in oil prices affects the economy of countries whose production systems are not diversified and whose main export is oil. Energy prices can also indicate the scarcity of energy resources. However, Kruyt et al. (2009) argued that there are some limitations when using energy prices as an indicator of energy security: in the oil sector, for instance, oil prices can be influenced by speculation.

Seventh, another indicator of energy security is the "Mean Variance Portfolio" (MVP) which is often used in contexts of diversification of energy generation sources. The MVP is used for optimization of different investment options according to their costs and risks. It is often used to assess the financial viability of electricity generating projects (Awerbuch and Berger, 2003; Awerbuch, 2006) and other energy projects (Lesbirel, 2004) and to predict future energy costs and risks such as price volatility. It accounts for the energy generating unit costs and the variance, as well as the correlation between energy costs.

One of the advantages of using the MVP to assess the financial viability of energy projects is that rather than offering only one investment option for energy projects, it provides a cost-risk frontier (also called the “efficient frontier”) beyond which the cost of investing in energy projects cannot be reduced without increasing the uncertainties and risks, and the uncertainties and risks related to energy projects cannot be reduced without increasing the investment costs. In a context of energy insecurity and necessity to diversify the sources of energy generation, the use of the MPV helps to analyse different energy diversification options according to their financial costs, and to predict future energy security risks and their associated costs. One of the limitations of the MVP is that it uses past data on energy costs to predict future energy prices and risks. As argued by Stirling (1999), in a context where there is no information on the future, there is no evidence that future patterns will be similar to past patterns.

Eighth, another indicator of energy security is the “share of zero-carbon fuels”, which has been used by APERC as an indicator of “acceptability”. The aim was to measure countries’ efforts to transition their energy mix portofolio from carbon intensive to non-carbon intensive. APERC (2007) uses the share of nuclear and renewable energy in the total supply of primary energy as a proxy for such indicator. However, concerns about the acceptability of nuclear energy have been raised and therefore APERC’s (2007) approach to proxy the “share of zero-carbon fuels” is still questionable.

Ninth, another indicator of energy security is “market liquidity”, which is related to price elasticity. It is the ability of markets to adapt to fluctuations in demand and supply of energy. The IEA (2004) defines “market liquidity” as a function of the ratio of total energy consumption to total available energy on the market. In stock markets, Datar (2000) suggested proxying “market liquidity” by a “coefficient of elasticity of trading (CET)”, which is defined as the ratio of the relative variations in volume of trade to the relative variations in price. A value of CET that is greater than one indicates that the stock market is elastic, and a value of CET that is less than one indicates that the stock market is inelastic.

Tenth, there are some energy demand side indicators which are relevant to the security of energy supply as they help to measure the magnitude and impacts of disruption in energy supply. Among them are “energy intensity”, “energy consumption per capita”, and the “share of energy used”. “Energy intensity” is defined as the ratio of total energy consumption to GDP, while “energy consumption per capita” is defined as the ratio of total energy consumption to total population. The “share of energy used” indicates the proportion of energy used in a sector. If a sector uses high proportions of a particular energy type, this indicates that that sector is highly dependent on that energy type to function. For instance the share of oil used in the transportation sector is important and indicates the dependency of the sector on oil. In addition to these three indicators, Kendell (1998) included “energy expenditures”, another demand side indicator, among energy security indicators. Although it is a demand side indicator, it can be used to highlight risks related to disruption of the energy supply. The rationale is that high energy expenditures in a country imply that it faces great difficulties in supplying energy, and disruption of energy supply can occur.

Eleventh, another indicator of energy security is the electricity index developed by the African Development Bank (2013). Although it is called electricity composite index, it only focuses on the generation of electricity. It is defined as the net generation of electricity and is measured in KWh per hour and per inhabitant. The limitation of such an indicator is that it only focuses on one pillar of energy/electricity security: the availability of energy/electricity. In addition it is only calculated for African countries.

2.3.2 Studies on aggregated indicators (indexes) of energy security

There have been several composite indexes of energy security (energy affinity index, geoeconomic vulnerability index, security of supply index, geopolitical energy security measure, risky external energy supply index, etc.), among which six are the most comprehensive. The first is Jansen et al.'s (2004) aggregated indicator which uses the "Shanon index" to account for diversity of energy types supplied and diversity among suppliers of each type of imported energy. Each supplier of an imported energy type is allocated a political stability weight based on a modified version of the UNDP Human Development Index. The rationale is that politically stable suppliers have more weight than those that are politically unstable. In addition to considerations of political stability, other aspects such as resource depletion are added to the aggregate indicator. Resource depletion is measured by a depletion index which is allocated to the energy-exporting countries. The rationale for this index is that markets will respond to a low value of a ratio of reserve to production. Low values of such a ratio indicate that the energy reserves are decreasing, and this can lead to a situation of energy scarcity.

While Jansen et al.'s (2004) aggregated indicator is related to several dimensions of energy security, it has some limitations. The IEA (2007) argued that there is no objective basis to balance between resource depletion, political stability, diversity of energy types, and diversity of suppliers of imported energy types, and there is no objective threshold as a basis to analyse the reserve-to-production ratio. Moreover, the diversity of suppliers of imported energy types can become irrelevant in a context of globalization, as there will be fewer political barriers to imports of energy.

The second is the "IEA's energy security index" which is composed of different indicators. The first targets the physical availability of energy and is relevant for markets where energy prices are regulated. The second indicator uses a Herfindhal–Hirschman Index to evaluate market concentration among energy suppliers. It specifically targets risks related to energy prices. Aspects related to political stability have been included in the IEA's index using two of the World Bank's "worldwide governance indicators". The limitation of the IEA's energy security index is that there is no objective basis to balance between political stability and concentration of energy suppliers. In

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addition, some important aspects of energy security such as depletion of energy resources are not included in the construction of the IEA's energy security index.

The third is the "supply demand index (S/D index)" developed by Scheepers et al. (2007). It is very comprehensive as it covers many aspects of energy security such as energy supply and demand, energy conversion and transportation in both long and medium run. Each aspect of energy security is allocated a score based on criteria such as energy efficiency, energy refinery, energy reserve, energy storage, sources of energy supply, etc. One of the advantages of the S/D index is that it accounts for the demand aspect of energy security while many of the previous indexes and indicators do not. However, because it covers many aspects of energy security, it has become complex and lacks transparency.

The fourth is the "willingness to pay" developed by Bollen (2008). It is defined as the share of GDP a country is willing to pay in order to reduce energy security risks. It is expressed in monetary terms and represents the costs to pay in order to reduce energy security risks. The rationale is that the higher the risks, the higher the costs to pay. The energy security risks included in Bollen's (2008) "willingness to pay" are energy intensity, import dependency, and share of oil and gas in the total primary energy supply. One of its limitations is that some of the indicators may not be relevant depending on the worldview. Issues of import dependency may not be relevant in a context of globalization where there are fewer political barriers to importation of electricity.

The fifth is the "oil vulnerability index" of Gupta (2008). This index has seven components: " i) the ratio of net value of imported oil to GDP; ii) the ratio of oil consumption to GDP; iii) GDP per capita; iv) the proportion of oil supply in the total energy supply; v) the ratio of internal energy reserves to oil consumption; iv) exposure to geopolitical risks related to oil supply concentration, and vii) "market liquidity" (see Gupta, 2008, p.1196). Weights were assigned to each of these indicators using a statistical tool named principal component analysis (PCA), based on the covariance between indicators. The allocation of weights based on the PCA methodology has increased the robustness of the "oil vulnerability index" compared to other energy security indexes where weights are allocated without any objective basis. However, as with the MVP theory, the "oil vulnerability index" is criticized for using past values of covariance to predict future information related to the set of indicators which compose the oil vulnerability index.

The sixth is the World Bank (2018a) index that measures the quality of electricity supply. Such an index is based on a participatory approach, which consists of a survey where respondents are asked to rank the reliability of electricity supply (absence of voltage fluctuations or lack of disruption) in their countries, using scores ranging from 1 to 7. The limitation of such an index is that respondents' allocation of scores to rate the reliability of electricity supply can be subjective and biased. In addition, such an index does not take into account important pillars of energy/electricity security such as acceptability.

2.3.3 Contribution of this study

A research paper of this nature can contribute to the advancement of knowledge in three areas: theory and concept, application (policy), and methodology.

First, this study’s contribution is in terms of application or policy. Studies on disaggregate indicators of energy security have focused mostly on one or two particular pillars of energy security; hence they are very limited in terms of measuring the whole spectrum of energy security. Studies on aggregate indicators of energy security have accounted for several pillars of energy security. However, most of them have focused on either total energy or a particular type of energy such as oil. To the best of the writer’s knowledge, there is no study which has constructed an aggregate indicator (index) of electricity security risk which takes into account the whole spectrum of energy security (availability, accessibility, affordability, and acceptability). The index developed by the World Bank (2018a) to measure the quality of electricity supply does not take into account the whole spectrum of energy/electricity security. Important aspects such as the use of electricity produced based on renewable sources in order to ensure the sustainability of electricity supply security (part of the energy security pillar called acceptability) are not included in its construction. Therefore, the use of such index is very limited when it comes to the implementation of policies that will ensure the sustainability ofelectricity supply security. As mentioned previously, the electricity index developed by the African Development Bank (2013) focused mostly on the availability of electricity (net generation). Other pillars of energy/electricity security (accessibility, affordability, and acceptability) are not included in its construction, and it is only calculated for African countries. Therefore, its use is also very limited when it comes to the implementation of policies that can ensure the sustainability of electricity supply security. This study has filled that gap by constructing a composite index of electricity security which takes into account the whole spectrum of energy security. Such an index is relevant for policy in the field of electricity security. It focuses essentially on security risks related to supply disruption of electricity in both the short and the long run.

Long-run and sustainable electricity security is essential for countries relying heavily on non-renewable energy resources to produce electricity. In addition, in the long run, countries aim to be self-sufficient in terms of electricity supply, because there are always uncertainties and risks related to dependency and importation of electricity. The study has not modelled the security risk index related to fluctuations in electricity demand: the electricity security risk index has been constructed only from the supply side perspective. A composite index of electricity supply security risk (electricity supply disruption risk) will be a great tool for policy makers in the assessment of the vulnerability of countries’ electricity supply. It will also be an important tool in the assessment of the ease of doing business in various countries, as easy access to electricity and affordable electricity are important indicators of the ease of doing business in a geographic area.

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The study has generated a data set that measures annual disruption risk to electricity supply over 17 years (1996, 1998, 2000, 2002-2015) for more than 172 countries (see the data set for the measurement of electricity security risk in Dakpogan (2018)). Such a data set will be useful for simulations and policy decision in the field of electricity security. Such a data set is the first extensive database that measures disruption risk to electricity supply for all countries of the world (countries for which data is available for each sub-component of the composite index of disruption risk to electricity supply). Therefore, this study adds value to the body of knowledge in the field of energy security in general and in the field of electricity security in particular.

Second, the study brings a methodological contribution by providing a model to measure disruption risk to electricity supply in urban area. Such a model is the ratio of change in the growth rate of access to electricity in urban area to change in the growth rate of urbanisation (RUB), and was previously non-existent (further explanation is provided in the methodology section 2.4.1). In addition, for the construction of the composite index of disruption risk to electricity supply this study has developed a new variable which was previously non-existent: the governance index (GI) (further explanation is provided in the methodology section 2.4.1). Moreover, the study developed a formula to measure the disruption risk to electricity supply for each country of the world. Such a formula is the inverse of the geometric mean of a set of selected sub-indicators, and did not exist previously. (Although electricity security is an important concern, none of the previous studies has developed a formula that can be used worldwide to measure electricity security, while taking into account the whole spectrum of energy/electricity security: accessibility, availability, affordability, and acceptability of electricity). As mentioned previously, the methodology used by the World Bank (2018a) to develop an index that measures the reliability of electricity supply is a participatory approach based on survey. Such a participatory approach can result in an inaccurate assessment of the reliability of electricity supply, because the surveyees' answers can be subjective.

Third, the study delivers a conceptual contribution. It extends the understanding of the concept of accessibility of electricity to issues related to governance, corruption which can affect the delivery of electricity (see the conceptual framework for energy and electricity supply security, sections 2.2.1 and 2.2.2). Previous studies did not include aspects related to governance in the understanding of the concept of accessibility. The study has also extended the understanding of the concept of availability to issues related to electricity losses, rapid urbanisation and disruption risk to electricity supply in urban area (see the conceptual framework for energy and electricity supply security, sections 2.2.1 and 2.2.2). These aspects were not included in the understanding of the concept of availability in previous studies.

2.4 METHODOLOGY

According to OECD (2008) and Mazziotta and Pareto (2012) several steps are required for the design of a composite index: the first is to develop a theoretical or a conceptual framework for the composite index and the second is the selection of variables. These steps have been completed in section 2.2 (conceptual framework for energy and electricity security). The following steps are: the choice of techniques for the imputation of missing values, the normalization of the indicators selected for the construction of the composite index, the choice of the weighing and aggregation techniques, and the sensitivity and uncertainty analysis. The composite index is calculated for Benin, and in order to compare the performance of Benin to that of the rest of the world in terms of disruption to electricity supply, it was also calculated for all countries for which data is available. In other words, when data was not available for a country or for a given year, the composite index was not calculated. In addition, this chapter does not aim to use values of the composite index in regression analyses where it is sometimes important to increase the size of samples by imputing missing values. Hence, at this stage the step related to the choice of techniques for the imputation of missing values was not required.

2.4.1 Definition and normalisation of variables

Normalization is important because each indicator included in the calculation of the composite index has a different measurement unit. Hence, prior to any aggregation of these indicators, it is necessary to transform these indicators into dimensionless values or quantities. Another reason for normalizing the indicators is that some of them can be negatively correlated with the problem or phenomenon to be assessed (“negative polarity”), while other can be positively correlated with it (“positive polarity”). For an easy interpretation of the composite index, it is better that it moves in the same direction with the normalized indicators included in its calculation. In other words, it is better that normalized indicators and the composite index are positively correlated. Several techniques can be used for the normalization of the indicators: the “standardization” also called “z-scores”, the “distance to a reference country”, the “balance of opinion”, the “ranking”, the “min-max” method, the “indicators below or above the mean”, the “percentage of annual difference over consecutive years”, the “categorical scales”, the “cyclical indicators” (Mazziotta and Pareto, 2012, OECD, 2008, pp. 27-30).

The “ranking” method is often used in cross-country analyses. For a given indicator, it allocates a rank to each country. Such rank is then considered as the score or performance of that country, for this indicator (see Fagerberg (2003)). One of the limitations of the “ranking” method is that it does not take into account the absolute performance of countries for a given indicator (the value obtained by countries for a given indicator). For example, if the absolute performance of country A, B, C, D is 50, 60, 75, 100 respectively, then, their scores based on the “ranking” method will be respectively 1, 2, 3, and 4. With the scores obtained based on the “ranking” method, the difference in terms of performance between two consecutive countries does not vary: it remains always 1. Conversely, the difference between two consecutive countries in terms of absolute performance varies: it can be either 10, or 14, or 25. Hence, the “ranking” method does not allow measuring properly the dispersion of countries' absolute performance. Another limitation of the "ranking" method is that it is sensitive to the sample size. The scores can change depending on the addition of new countries or the removal of any country. Because of these limitations, this study did not use the "ranking" method.

The method called "categorical scale" allocates scores to each indicator. Such a score can be quantitative or qualitative (very excellent, excellent, very good, good, fairly good, etc). The allocation of scores is usually done according to the percentiles of distribution of the indicators (see OECD (2008)). For example, the values which represent the top 10% (values that are between the 90th and the 100th percentile) can receive the score 90. Following them, the values that are between the 80th and the 90th percentile can receive the score 80; then, the values that are between the 70th and the 80th percentile can receive the score 70; and so forth. As in the case of the "ranking" method, one of the limitations of the "categorical scale" is that it does not allow measuring properly the dispersion of countries' absolute performance. It reduces information about the variance of the transformed indicators. For example, countries A, B, C, D can respectively have 71, 74, 77, and 79 as absolute performance for a given indicator. If they are normalized using the "categorical scale" method, they can all have 70 as a score (if we refer to the example of allocation of score using the "categorical scale", described previously). The "categorical scale" method therefore reduces information about the variance of the indicators, while such information can be very useful. Because of these limitations, this study did not use the "categorical scale" method to normalize the indicators included in the calculation of the composite index of electricity supply disruption risk.

The "z-scores" method converts all the indicators to a common scale with one as standard deviation and zero as mean (see OECD (2008)). The method called "indicators below or above the mean" allocates the score 0 to indicators' values that are around the mean, and gives to the indicators' values that are below and above the mean the score -1 and 1 respectively (see European Commission (2001a)). The method called "percentage of annual difference over consecutive years" normalises the indicators by transforming them into the growth of their values with respect to the previous year. Such growth values are in percentage and represent the new values of the normalised indicators (see European Commission (2001b); Tarantola, Saisana, Saltelli, Schmiedel and Leapman (2002); Tarantola, Liska, Saltelli, Leapman and Grant (2004)). Such a method is very useful in times series analysis. The method called "cyclical indicators" normalises the indicators by first substracting the mean (µ), and then by dividing the result of the substraction by the mean of the distances to the mean (µ) (see European Commission (2004)).

The use of these methods of normalisation (the "z-scores", the "indicators below or above the mean", the "percentage of annual difference over consecutive years", the "cyclical indicators") has generated both positive and negative values of the indicators included in the calculation of the composite index of electricity supply security risk. Because we will be using the geometric mean as a method of aggregation, all the values of the normalised indicators to be included in the calculation of the composite index, have to be of same sign. In order to avoid having both positive and negative values of the normalised indicators, this study did not use these normalisation methods ("z-scores", "indicators below or above the mean", "percentage of annual difference over consecutive years", the "cyclical indicators").

The method called "balance of opinion" asks different respondents to express their opinions about the performance of firms, or institutions, for a given indicator (see OECD (2008)). The limitiation of this method is that it is very subjective as it depends solely on respondents' perspectives. Respondents' opinions can be biased as they are not always based on quantitative evidence. Because of the possible existence of such bias in the respondents' opinion, this study did not use the "balance of opinion" method for the normalisation of the indicators.

The "min-max" method converts the indicators to a scale of 0 to 1 by substraction of the smallest value (the minimum value) and then by dividing the result of the substraction by the difference between the maximum and the minimum values (see Jacobs, Smith and Goddard (2004); Freudenberger (2003)). The "distance to a reference" method normalises the indicators by calculating the distance between their position and a given point of reference (see OECD (2008)). Such a point of reference can be an external target in term of good practices. For example, the ECA (2008) suggested that the international target for losses of electricity should not exceed 12%. In other words, countries in which electricity losses are below 12% have a good performance. The point of reference can also be an external country which is an example in terms of best practices. It can also be the average country of the sample of countries, or the country that is leading the group of countries in term of best practices.

Six out of the eight indicators selected (the self-sufficiency rate in terms of electricity supply, the governance index, the rate of electricity supply efficiency, the ratio of growth of access to electricity in urban areas to growth of the urbanization rate, the rate of access to electricity, the share of renewable electricity in the total domestic production of electricity, the share of GDP not dedicated to cover the cost of electricity supply, and real GDP per capita) for the calculation of the composite index of electricity supply disruption risk have their absolute values expressed as a ratio and are in percentage. Hence, their values are dimensionless. The absolute values of the seventh indicator (the governance indicators/index) are also dimensionless quantities (see Worldwide Governance Indicators (2018)). Therefore, it is not necessary to normalize these seven indicators (the self-sufficiency rate in terms of electricity supply, the governance index, the rate of electricity supply efficiency, the ratio of growth of access to electricity in urban areas to growth of the urbanization rate, the rate of access to electricity, the share of renewable electricity in the total domestic production of electricity, the share of GDP not dedicated to cover the cost of electricity supply) in order for their values to become dimensionless. Only the values of the eighth indicator (real GDP per capita (RGDPc)) are not dimensionless. They are expressed in $US constant 2010. Hence, it is important to normalize RGDPc.

The “distance to a reference” method was used to normalize RGDPc, rather than the “min-max” method, in order to avoid having 0 among the values of the normalised RGDPc. If the study had used the “min-max” method, the normalisation of the minimum value of RGDPc (min RGDPc) would have generated a score equal to zero (normalised minimum value of RGDPc = ((min RGDPc - min RGDPc)/(the difference between the maximum and the minimum values of RGDPc)). As the study is using the geometric mean, all indicators included in the calculation of the composite index have to be of the same sign. If the normalized RGDPc is equal to 0, while the values of the other indicators included in the calculation of the composite index are not equal to 0, the value of the composite index will be equal to 0. This may not reflect the true performance of the country that has the minimum (smallest) RGDPc. Because of all this, the “distance to a reference” method was used to normalize RGDPc. The real GDP per capita of the average country was first calculated by summing the real GDP per capita of all countries (for which data was available) and by dividing the sum by the total number of countries. Then, the real GDP per capita of every country was divided by the real GDP per capita of the average country to obtain the normalised values of RGDPc (RGDPcW).

Real GDP per capita (*RGDPc*) is one of the indicators of a country’s wealth and standard of living. Countries that have a high real GDP per capita (*RGDPc*) are wealthier and can offer a high standard of living to their population: this includes access to electricity, internet, decent housing and health care, public transport, and so forth. These countries are financially able to invest in electricity infrastructure and utilities in order to prevent or avoid future disruptions of the electricity supply. Conversely, countries that have a low real GDP per capita (*RGDPc*) are less wealthy and unable to offer a high standard of living, which will include access to electricity, internet, decent housing and health care, public transport, and so forth. In addition, these countries are financially limited in terms of investing in electricity infrastructure and utilities in order to prevent or avoid future disruptions of electricity supply. This is the case with a country such as Benin. As reported by the National policy framework for electricity (République du Bénin, 2008), one of the major causes of the supply gap in Benin is that the country is financially limited in terms of investing in electricity infrastructure which would increase the available supply. As a result of that, the rate of access to electricity in the country was only 41.40% in 2016, below the sub-Saharan Africa and world average rate of access to electricity, which were 42.81% and 87.35% respectively. The normalised real GDP per capita (*RGDPc*) of countries has been expressed as a percentage of the world average real GDP per capita (*WRGDPc*). This normalised real GDP per capita is denoted by *RGDPcW* and is expressed as follows:

$$RGDPcW = \frac{RGDPc}{WRGDPc} \times 100 \qquad 2.1$$

The focus of the study is to construct a composite index of security of electricity supply, more precisely, a composite index of electricity supply disruption risk. As mentioned previously in the framework for electricity supply security, the composite index for electricity supply disruption risks will be constructed based on the four pillars of energy security: “accessibility”, “availability”, “affordability” and “acceptability”. To construct this index, the set of indicators of electricity supply disruption risks previously identified have been defined as a proxy for each of the four pillars. The self-sufficiency rate in terms of electricity supply and a governance index have been identified as proxies for the concept of “accessibility”; the rate of electricity supply efficiency, the ratio of growth of access to electricity in urban areas to growth of the urbanization rate, and the rate of access to electricity have been identified as proxies for the concept of “availability”; the share of renewable electricity in the total domestic production of electricity has been identified as a proxy for the concept of “acceptability” (which also implies “sustainability”); and the share of GDP not dedicated to cover the cost of electricity supply, and real GDP per capita (as a percentage of the world annual average GDP per capita) have been identified as proxies for the concept of “affordability”.

Although initially, they are all dimensionless (except RGDPc which has been normalized to become RGDPcW), some of the indicators included in the calculation of the composite index have been transformed because of the presence of negative or zero values in their series. First, the governance index (*GI*) has been transformed because the governance indicators used to construct it have both positive and negative values, depending on the years. As the study uses a geometric mean for the calculation of the composite index of electricity supply security risk, all values to be used have to be of the same sign. Hence, all these governance indicators were transformed by adding 100 to their annual value in order for them to be essentially positive. In this way, there are only positive values for the governance index which itself is the geometric mean of the governance indicators (see equation 2.1, further explanation of the choice of geometric mean is provided in the method section below).

The governance indicators are provided by the Worldwide Governance Indicators (2018) and are the following: “rule of law” (*RLA*), “control of corruption” (*COC*), “quality of the regulatory system” (*QAR*), “government effectiveness” (*GEF*), “political stability and absence of violence” (*POS*). Each of these indicators is respectively an increasing function of a country’s efforts in terms of rule of law, efforts to control corruption, efforts to improve the quality of their regulatory system, efforts to improve the effectiveness of their government system, a country’s level of political stability and attempts to reduce violence. High values of the governance index (*GI*) indicate a high quality of governance in the country, while low values of the governance index indicate a low quality of the country's governance. This indicates that the governance index (GI) is an increasing function of a country's governance.

As said previously, the quality of governance within a country influences the effectiveness of the delivery of electricity to consumers. Ineffective planning and mismanagement in the distribution of electricity can occur because of corruption, poor quality of the regulatory system, and political instability. This situation can result in a lack of foresight of increases in electricity demand and unpredicted disruptions of electricity supply. In addition, corruption and a lack of rule of law can lead to mismanagement in the electricity billing system and thefts of electricity. This situation can cause non-technical losses of electricity, and can reduce the available quantity of electricity supplied to legal consumers, and therefore can be considered as one of the risks of electricity supply disruption. The governance indicator (GI) is one of the proxies for the concept of "accessibility" and is expressed as follows:

$$GI = \sqrt[5]{\left[(RLA+100)\times(COC+100)\times(QAR+100)\times(GEF+100)\times(POS+100)\right]} \qquad 2.2$$

Second, the ratio (*RUB*) of growth of access to electricity in urban areas (ΔUAE) to growth of the urbanization rate (ΔUR) measures a country's ability to avoid an electricity supply gap caused by rapid urbanization. Such a supply gap is considered as a total and continuous disruption to electricity supply in urban area. If the urbanization rate (*UR*) evolves more rapidly than urban access to electricity (*UAE*), then there will be a rapid increase in the urban demand for electricity which will not be met by the urban supply of electricity. A supply gap will occur and there will be a disruption of electricity supply in urban areas. If urban access to electricity (*UAE*) evolves more rapidly than the urbanization rate (*UR*), then promoting access to electricity in urban areas can contribute to reducing the urban supply gap and preventing the urban disruption of the electricity supply.

The series of the ratio (*RUB*) of growth of access to electricity in urban areas (ΔUAE) to growth of the urbanization rate (ΔUR) also possesses both positive and negative values, and values that are equal to zero. As said before, the study uses a geometric mean for the calculation of the electricity supply disruption risks index, and this requires all values to be of same sign. Hence, the number 100 has been added to both the numerator and the denominator of the ratio (*RUB*) of growth of access to electricity in urban areas (ΔUAE) to growth of the urbanization rate (ΔUR), in order for that ratio to have essentially positive values. High values of that ratio (*RUB*) indicate that a country's effectiveness in filling the urban supply gap of electricity (caused by rapid urbanization) is increasing in order to contribute to satisfying the urban demand for electricity (also caused by urbanization). Therefore, that ratio is an increasing function of a country's effectiveness in filling the urban supply gap of electricity caused by rapid urbanization. It is one of the proxies for the concept of "availability", and is expressed as a percentage as follows:

$$RUB = \frac{\Delta UAE + 100}{\Delta UR + 100} \times 100 \qquad 2.3$$

Third, as said previously, the self-sufficiency rate in terms of domestic electricity supply (*ESS*), which is defined as one minus the ratio of net imports of electricity (*NIE*) to total domestic supply of electricity (*TDES*), has been used as one of the proxies for the concept of “accessibility”, instead of the share of net imports of electricity in the total domestic supply. The share of net imports of electricity in the total domestic supply possesses both positive and negative values in its series. As noted previously, it is defined as the ratio of net imports of electricity to the total domestic supply of electricity. Net imports of electricity are defined as imports of electricity minus exports of electricity. Negative values of the share of net imports of electricity in the total domestic supply indicate that the country is self-sufficient in terms of domestic electricity supply, and exports its surplus of electricity. Positive values of the share of net imports of electricity in total domestic supply indicate that the country is not self-sufficient in terms of domestic electricity supply and imports electricity. A share of net imports of electricity in the total domestic supply that is equal to zero, simply indicates that the country is self-sufficient in terms of domestic electricity supply.

As explained previously, because the study uses a geometric mean for the calculation of the electricity supply disruption risk index, all values of indicators have to be of same sign. The share of net imports of electricity in the total domestic supply does not fulfill this requirement, and this is why the self-sufficiency rate in terms of domestic electricity supply (*ESS*) has been chosen as one of the proxies for the concept of “accessibility”. It highlights both a country’s dependency on importation of electricity and its ability to produce its electricity supply domestically. It is an increasing function of a country’s ability to produce its electricity supply domestically and a decreasing function of a country’s dependency on importation of electricity. It is expressed as a percentage as follows:

General expression

$$ESS = \left(1 - \frac{NIE}{TDES}\right) \times 100 \qquad 2.4$$

Case of importing countries

$$ESS = \left(1 - \frac{NIE}{ED + IE}\right) \times 100 \qquad 2.5$$

Case of exporting countries

$$ESS = \left(1 - \frac{NIE}{ED - EXE}\right) \times 100 \qquad 2.6$$

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Case of countries which neither import nor export electricity

$$ESS = \left(1 - \frac{NIE}{ED}\right) \times 100 \qquad 2.7$$

where *IE* represents imports of electricity and *IE* is equal to zero for countries that are self-sufficient in terms of domestic electricity supply. On the one hand, if a country has a surplus of electricity and exports it, then the total domestic supply of electricity (*TDES*) is equal to the domestic production of electricity (*ED*) minus the export of electricity (*EXE*). On the other hand, if a country has a deficit of electricity and relies on importation to fill the supply gap, then the total domestic supply of electricity (*TDES*) is equal to the sum of the domestic production of electricity (*ED*) and the importation of electricity (*IE*). If a country neither imports nor exports electricity, then its total domestic supply of electricity (*TDES*) is equal to its domestic production of electricity (*ED*). If the rate of electricity supply self-sufficiency (*ESS*) is less than 100, this indicates that the country has an electricity supply gap and relies on importation of electricity to fill this gap: net imports of electricity are positive in this case. If the electricity supply self-sufficiency rate (*ESS*) is equal to 100, this indicates that the country is self-sufficient in terms of its domestic electricity supply: net imports of electricity are equal to zero in this case. Finally, if the rate of electricity supply self-sufficiency (*ESS*) is greater than 100, this indicates that the country is self-sufficient in terms of its domestic electricity supply, and has a surplus of electricity which is exported: net imports of electricity are negative in this case.

Fourth, the share (*RRE*) of renewable electricity (*RE*) in the total domestic production of electricity (*ED*) has been used as a proxy for the concept of “acceptability”. As pointed out previously, the concept of “acceptability” also implies “sustainability”. Acceptability means that the type of energy used does not cause significant damage to the environment or to society. Such type of energy is a sustainable energy resource. For long-term and sustainable electricity supply security it is important to account for the concept of “acceptability”. As noted earlier, renewable electricity (*RE*) is a sustainable energy resource. The share (*RRE*) of renewable electricity (*RE*) in the total domestic production of electricity (*ED*) is defined as the ratio (*RRE*) of electricity produced domestically based on renewable sources (*RE*) to the total domestic production of electricity (*ED*). The denominator of the ratio is not the total domestic electricity supply (*TDES*) (for importing countries, *TDES* is equal to the sum of total domestic production of electricity (*ED*) and imports of electricity (*IE*)), because countries do not always have control over the sources of electricity imported. Electricity imported can be renewable or non-renewable, and importing countries do not necessarily have control over the production of such electricity. One of the ways for importing countries to increase the share (*RRE*) of renewable electricity (*RE*) in the total domestic supply of electricity (*TDES*) is to increase both their electricity supply self-sufficiency rate (*ESS*), and their share (*RRE*) of renewable electricity (*RE*) in the total domestic production of electricity (*ED*).

Annual series on the share of renewable electricity in the total domestic production of electricity comprise the value zero for some of the years. As this study uses a geometric mean to calculate the electricity supply disruption risks index, all indicators identified for the calculation of such index have to be of same sign. All indicators (*RUB, ESS, GI*) identified previously are of positive sign, and 100 has been added to each value of the series on the share (*RRE*) of renewable electricity (*RE*) in the total domestic production of electricity (*ED*), in order for all values of that series to be essentially positive. The share (*RRE*) of renewable electricity (RE) in the total domestic production of electricity (*ED*) highlights both countries' ability to improve the sustainability of their electricity supply, and countries' dependency on non-renewable electricity (*NRE*) in their domestic production of electricity. It is an increasing function of a country's ability to improve the sustainability of its electricity supply by using more renewable electricity, and a decreasing function of a country's dependency on non-renewable electricity (*NRE*) in its domestic production of electricity (*ED*). It is expressed as a percentage as follows:

$$RRE = \frac{RE}{ED} \times 100 + 100 \qquad 2.8$$

or

$$RRE = \left(1 - \frac{NRE}{ED}\right) \times 100 + 100 \qquad 2.9$$

Other indicators, however, did not need any transformation. First, as noted previously, the rate of electricity supply efficiency (*ESE*) which is defined as the ratio of electricity not lost (*ENL*) to the total electricity supply (*TES*) has been used as one of the proxies for the concept of "availability" (in addition to the ratio of growth of urban access to electricity to growth of the urbanization rate), rather than the share of electricity losses (*EL*) in the total supply (*TES*). Total supply of electricity (*TES*) is equal to the sum of domestic production of electricity (ED) and imports of electricity (IE) in the case of an importing country. In other words, in that case *TES* is equal to *TDES* (total domestic supply of electricity). In the case of an exporting country, *TES* is equal to the domestic production of electricity (*ED*). In other words, *TES* is equal to the sum of *TDES* (in that case *TDES* is equal to the domestic production of electricity (ED) minus exports of electricity (EXE) and exports of electricity (*EXE*). In the case of countries which neither import nor export electricity, *TES* is equal to the total domestic production of electricity (ED). In other words, *TES* is equal to *TDES* (*TDES* in that case is equal to the domestic production of electricity). Electricity that is not lost (*ENL*), is the electricity distributed which reaches legal consumers. Electricity that reaches illegal consumers is considered stolen electricity and therefore is a loss of electricity. Electricity not lost (*ENL*) comprises only the domestic legal consumption of electricity (*EC*) if the country is not exporting electricity. In the case of countries that export electricity, it comprises both the domestic legal consumption of electricity (*EC*) and exports of electricity (*EXE*). It highlights both the ability of countries' electricity sector to be efficient by minimizing electricity losses, and the exposure of countries to electricity losses. It is an increasing function of a country's ability to minimize electricity losses, and a decreasing function of a country's exposure to electricity losses. It is expressed as a percentage as follows:

General expression

$$ESE = \frac{ENL}{TES} \times 100 \qquad 2.10$$

In other words,

$$ESE = \left(1 - \frac{EL}{TES}\right) \times 100 \qquad 2.11$$

In the case of exporting countries

$$ESE = \frac{EC + EXE}{ED} \times 100 \qquad 2.12$$

In the case of importing countries

$$ESE = \frac{EC}{ED + IE} \times 100 \qquad 2.13$$

In the case of countries that neither import nor export electricity

$$ESE = \frac{EC}{ED} \times 100 \qquad 2.14$$

Second, another proxy for the concept of "availability" is the rate of access to electricity (*RACE*). It is defined as the ratio of the population that has access to electricity (*PACE*) to the total population (*TPO*), and is expressed as a percentage. A value of such a ratio less than 100 indicates that there is a supply gap in the country because a proportion of the population does not have access to electricity. In other words, electricity is not available for a proportion of the population. As in the case of the urban supply gap of electricity, this supply gap is considered as a total and continuous disruption of electricity supply encountered by the population that does not have access to electricity. Increasing access to electricity will contribute to reduce the supply gap of electricity. Conversely, a value of such ratio that is equal to 100 indicates that the entire population of the country has access to electricity, and there is no supply gap. In other words, electricity is available for the entire population. The rate of access to electricity (*RACE*) is a decreasing function of the electricity supply gap of total and continuous disruption of electricity supply. High values of such a rate indicate that the country is making efforts to reduce its electricity supply gap, while low values of such rate indicate the presence of an important electricity supply gap in the country. The rate of access to electricity is expressed as follows:

$$RACE = \frac{PACE}{TPO} \times 100 \qquad 2.15$$

Third, the share of real GDP not dedicated to cover the cost of electricity supply (*RNEEX*) has been used as a proxy for the concept of “affordability”. It is defined as the ratio (*RNEEX*) of the proportion of real GDP not dedicated to cover the electricity supply expenditures (*NEEX*) to real GDP (*RGDP*). It can also be defined as one minus the share of GDP dedicated to cover the cost of the electricity supply (*EEX*). The cost of electricity supply is calculated by multiplying the total quantity of electricity supply converted in barrel of oil equivalent (bbl) by the annual real average crude oil price (*COP*) (US$/bbl; constant 2010 US$). The share of real GDP not dedicated to cover the cost of electricity supply (*RNEEX*) highlights both a country’s ability to minimize the cost of electricity supply, and a country’s vulnerability to the high cost of electricity supply. High values of this ratio indicate that countries are able to minimize the cost of their electricity supply, while low values of this ratio indicate that countries are exposed to high costs of electricity supply. A high cost of electricity supply limits a country’s capacity to afford electricity, which can lead to a supply disruption of electricity. The share of real GDP not dedicated to cover the cost of electricity supply (*RNEEX*) is therefore an increasing function of a country’s ability to minimize the cost of electricity supply, and a decreasing function of a country’s exposure to high costs of electricity supply. It is expressed as a percentage as follows:

$$RNEEX = \frac{NEEX}{RGDP} \times 100 \qquad 2.16$$

or

$$RNEEX = \left(1 - \frac{EEX}{RGDP}\right) \times 100 \qquad 2.17$$

2.4.2 Data

All data collected are secondary and have been collected for the years 1996, 1998 and 2000, and over the period 2002-2015 (years and period for which data is available for all indicators at the same time, and years and period for which data are available for governance indicators) for the calculation of the composite index of electricity supply disruption risk. In order to observe separately the performance of Benin for each of the indicators/index included in the composite electricity supply disruption risk index, data on growth of urban access to electricity (Δ*UAE*) and growth of the urbanization rate (Δ*UR*) have been collected over the period 1996-2016; data on the rate of access to electricity (*RACE*) have been collected over the period 1990-2016; data on the share of renewable electricity in total domestic electricity supply (*RRE*) have been collected over the period 1996-2015; data on real GDP per capita (constant 2010 US$; as a percentage of the world average GDP per capita; (*RGDPcW)*) have been collected over the period 1960-2017; data on real GDP (*RGDP*), average crude oil prices (*COP*), domestic supply of electricity (*ED*), electricity consumption (*EC*), imports of electricity (*IE*), net imports of electricity (*NIE*), exports of electricity (*EXE*), total supply of electricity (*TES*) (sum of domestic production of electricity and imports of electricity), and electricity not lost (*ENL*) (the electricity not lost is the sum of electricity consumption and exports of electricity), and losses of electricity (*EL*), have been gathered over the period 1980-2015.

Sources of data are diverse. With regard to governance indicators, data on “control of corruption” (*COC*), “rule of law” (*RLA*), “quality of the regulatory system” (*QAR*), “government effectiveness” (*GEF*), and “political stability and absence of violence” (*POS*) have been collected from the Worldwide Governance Indicators (2018) website. Data on growth of urban access to electricity (Δ*UAE*), growth of the urbanization rate (Δ*UR*), the share of renewable electricity in the total domestic supply of electricity (*RRE*), real GDP (*RGDP*), real GDP per capita (constant 2010 US$) (*RGDPcW*), and the rate of access to electricity (*RACE*) have been collected from the World Development Indicators (2018) website. The series on annual real average prices of crude oil (COP) (US$/bbl; constant 2010 US$) has been collected from the World Bank’s Commodity Markets (2018) website (see World Bank (2018b) for reference). Data on domestic electricity production (*ED*), imports of electricity (*IE*), net imports of electricity (*NIE*), exports of electricity (*EXE*), electricity consumption (*EC*), total supply of electricity (*TES*), electricity not lost (*ENL*) and losses of electricity (*EL*) have been gathered from the US Energy Information Administration’s (2018) website.

2.4.3 Weighting and aggregation method

Depending on the aspect of the phenomenon they measured, each indicator can have a specific importance in the calculation of the composite indicator. Such a specific importance also called weight can be estimated using different assumptions and techniques. First, some techniques are based on participatory approaches. Significant among them are the Budget Allocation, the Conjoint Analysis, the Public Opinion, and the Analytic Hierarchy Process. The allocation of weights using these participatory approaches is based on expert opinion, which can be very subjective. Different experts can allocate different weights to the same indicator, depending on their preferences, knowledge, and perceptions. Because of such subjectivity, it is impossible to come to a consensus on the true weight of indicators. This constitutes one of the reasons why this study did not use the participatory approaches for the calculation of weights.

Second, other techniques are based on statistical and mathematical modelling. Significant among them are the Benefit of the Doubt Approach (BOD), the Principal Component Analysis (PCA),

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Factor Analysis (FA), the Unobserved Component Models (UCM), and the regression approach. The FA and the PCA use linear transformation methods to decrease the data's dimensionlity, while avoiding at the same time information loss (DeCoster and Hall, 1998; Dunteman, 1989). Because of their capacity to reduce the dimensionality of the data, FA and PCA are very useful when working on a large number of indicators (Yeheyis, Hewage, Alam, Eskicioglu, and Sadiq, 2013).

Originally, FA and PCA were designed in order to analyse the relationship between different variables; they were not designed for the calculation of weights (Hermans, Van den Bossche, and Wets, 2008); hence these two techniques have some limitations in terms of weights' calculation. Some of these limitations are that they can gather in the same dimension correlated indicators for which the interrelationship or correlation is meaningless (the correlation cannot be supported by theories or the real-world facts (historical, social or economic facts, etc.) (OECD, 2008). In addition, weighing of dimensions is based on correlation rather than real-world facts. An important dimension (in term of real-world facts) can be allocated a low weight, because its correlation with other dimensions is weak (Hermans et al., 2008). According to Mikulić, Kožić, and Krešić (2015), the allocation of weights using PCA and FA can be inconsistent, because the relative importance of these weights does not always correspond to the real-world facts.

Other types of limitations are that the use of FA and PCA requires an adequate number of indicators and these indicators need to show a certain level of correlation with each other (OECD, 2008). All these constitute some of the reasons why this study did not use FA or PCA for the allocation of weights. For instance, among the indicators used in this study for the construction of a composite index, the share of renewable electricity (RRE) in total supply of electricity is important as its highlights countries' effort to have a sustainable source of electricity supply, and thus, countries' effort to ensure a sustainable security of electricity supply. However, it is weakly correlated with all the other indicators included in the calculation of the composite index (the governance index (GI), the rate of electricity supply self-sufficiency (ESS), the rate of electricity supply efficiency (ESE), the normalized real GDP per capita (RGDPcW), the share of real GDP not dedicated to cover the cost of electricity supply (RNEEX), the rate of access to electricity (RACE), the ratio of the growth of urban access to electricity to the growth of the urbanization rate (RUB)) because high share of renewable electricity in the total supply of electricity in a country does not necessarily imply good governance, high rates of electricity supply self-sufficiency, or electricity supply efficiency, or access to electricity, high GDP per capita, and low cost of electricity supply. PCA or FA methods can assign a low weight to RRE because of its weak correlation to other indicators, while RRE is an important indicator when it comes to the assessment of the sustainability of electricity supply security.

Kleinbaum, Kupper, Nizam, and Rosenberg (2013), define the regression approach as a multivariate technique that uses statistical methods to model relationships between different variables. Nardo, Saisana, Saltelli, and Tarantola (2005) argued that a regression approach assigns weights to indicators by identifying the relationship between each of these indicators and a common output called the dependent variable. However, some assumptions required for the regression approach constitute a limitation in its ability to assign weights for the construction of a composite index. For instance, in a regression analysis, multicolinearity between variables must be avoided. When the set of indicators selected for the construction of the composite index are correlated, it becomes difficult to use a regression approach for the weights allocation, because of the issue of multicolinearity (Muldur, 2001). In addition, if the number of indicators selected as independent variables is not sufficient enough, omitted variables bias can occur in a regression analysis, and this can hinder the consistency of weights allocated. For instance, health, income and education are the dimensions and indicators used for the construction of the Human Development Index. These three indicators are positively correlated, and if a regression approach were used for the construction of the Human Dvelopment Index, multicolinearity issues will occur. In the case of this study, for instance, the normalized governance index (GI), the normalized real GDP per capita (RGDPcW), the rate of access to electricity (RACE), the share of real GDP not dedicated to cover the cost of electricity supply (RNEEX) are positively correlelated. If a regression approach were used for the allocation of weights, the issue of multicolinearity would have occurred.

As mentioned by Nardo et al. (2005), the Benefit of a Doubt Approach (BOD) uses the Data Envelopment Analysis (DEA) techniques. The BOD expressed indicators’ weights as a ratio, based on the relative performance of these indicators, and using optimisation techniques (Shwartz, Burgess, and Berlowitz, 2009; Cherchye, Moesen, Rogge, and Van Puyenbroeck, 2007). One of the avantages of BOD is its ability to combine aggregation, weighing, and index calculation methods. Another advantage is that some of the limitations of the linear aggregation are overcome when using the weighing method of BOD (Nardo et al., 2005). Some of the limitations of the BOD mentioned by Nardo et al. (2005) and Shwartz et al. (2009) are that it can provide multiple results in term of weighing of indicators and these results can be incompatible. For example, it can assign the score 1 to many units or countries, while such value is the maximum score of the composite index (when using the BOD approach). At the same time, it can also assign the weight 0 to some selected indicators included in the calculation of the composite index. In the case of this study, and according to the data obtained from different sources to quantify all selected indicators, it is impossible for any of them to have the value 0 as weight. A modified BOD subject to some restrictions on the selected indicators included in the calculation of the composite index was proposed. However, the identification of such restrictions sometimes requires an expert opinion (policy makers, government, international organization, simple citizens, etc) (Cherchye et al., 2007), which can be subjective. Because of these limitations, this study did not use the BOD approach for the calculation of the composite index of disruption risk to electricity supply.

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The Unobserved Component Models (UCM) have been primarily used in economics for the design of governance indicators (Kaufmann, Kraay, and Zoido-Lobatón, 1999). Like the Benefit of a Doubt Approach (BOD) they combine aggregation, weighing and index calculation methods. One of their advantages is that they are able to provide interval estimates of a composite index, rather than just specific values of such index (Kaufmann, Kraay, and Mastruzzi, 2011). A limitation of the UCM is that the calculation of weighing may not be reliable and accurate if the data set used is small. Another limitation is that when using UCM, the correlation between the indicators selected for the construction of the composite index should not be strong (Nardo et al., 2005). In the case of this study, indicators such as RENEEX and RGDPcW and RACE are strongly correlated (countries that have high GDP per capia also have high rates of access to electricity; they can easily afford their electricity supply; consequently, their shares of real GDP not dedicated to cover the cost of electricity supply are high; see Ferguson et al. (2000), IEA (2002), and ECA (2004)). Hence, this study did not use the UCM approach for the calculation of weights.

Finally, some studies have used none of these techniques, but are based on equal weighing, which means that all indicators have the same importance. As mentioned by Land (2006), one of the advantages of the equal weighing is its simplicity; another advantage is that equal weighing is an approach that can be easily replicated by other researchers. The construction of several composite indexes that have been used worldwide, such as the Genuine Saving Index (see Hamilton, 2000), the Living Planet Index (see Loh, Green, Ricketts, Lamoreux, Jenkins, Kapos, Randers, 2005; Loh, Randers, MacGillivray, Kapos, Jenkins, Groombridge, 1998), the Human Development Index (see UNDP, 1990), is based on equal weighing. In a survey of 96 studies related to the construction of composite indexes, Gan, Fernandez, Guo, Wilson, Zhao, Zhou, and Wu (2017) established that 21.88% of these studies have used the weighing techniques based on statistical modeling, while 23.95% of them used the weighing techniques based on participatory approaches, and 46.88% of them are based on equal weighing. Because of its simplicity and its easy replicability, the equal weighing approach has been used in this study.

Although the equal weighing approach is simple and easy to replicate, its validity has been criticized by different studies such as Mikulić et al. (2015), Finnveden (1999), McClelland (1978), Geniaux, Bellon, Deverre, and Powell (2009), Gordon (1995), and Rowley, Peters, Lundie, and Moore (2012). Further researches on the construction of a composite index of disruption to electricity supply will explore other innovative weighing approaches that are simple, easy to replicate, and have fewer concerns in term of validity. While the weight allocation is an essential step in the construction of a composite index, the choice of the aggregation approach also matters as it influences the values of the composite. The most common approaches of aggregation are the non-compensatory aggregation, the additive aggregation, and the geometric aggregation.

The non-compensatory aggregation is very useful when a substitution between the components of an index is inappropriate. It does not allow that the low performance of some indicators be compensated by the high performance of other indicators, and uses a multicriteria decision making approach (Munda, 2005; Guitouni and Martel, 1998). With the non-compensatory aggregation approach, quantitative and qualitative inforamtion can be used jointly. In addition, it does not require a nornalisation of indicators. One of its main disadvantages is the incompatible results obtained when ranking different countries or units. Such incompatibility in the ranking, also called rank reversal or cycle can occur and affect the comparison of countries or units' performance (Munda and Nardo, 2005). For instance, when using the non-compensatory aggregation, it is possible to establish that country G is prefered to country H, country H is prefered to country I, and country I is prefered to country G. In such a situation, it is impossible to rank a country's performance with accuracy. Because of the possibility of rank reversal issue, this study did not explore the possibility of using a non-compensatory aggregation approach.

The additive aggregation approach consists of using a function that sums up the values of the normalised indicators that have been selected. The value of such a sum is the value of the composite index. The most used additive aggregation approach is the weighted arithmetic mean (Pollesch and Dale, 2015), which sums up the value of the selected indicators and divides such sum by the total number of selected indicators. One of the disadvantages of the arithmetic mean is that it gives more weight to indicators that have a high numerical range. One indicator A may not be as important as other indicators B and C. If A has a higher numerical range than B and C, the arithmetic mean of A, B, and C will allocate more weight to A. For example, let us assume that A ranges from 1 to 100, and B and C range from 2 to 6. If the value of A is 30, and B or C is equal to 3, the arithmetic mean of A, B and C will be 12, If the value of A increases by 50%, in other words, if the value of A becomes 45, while the values of B and C remain 3, then the arithmetic mean of A, B and C will be equal to 17. If the value of B increases by 100%, in other words if the value of B becomes 6, while the values of A and C remain 30 and 3 respectively, then the arithmetic mean of A, B and C will be 13. This example shows that although the percentage change in B (100% increase in B) is far greater than the percentage change in A (50% increase in A), the arithmetic mean in the case of a change in B is only 13, while the arithmetic mean in the case of a change in A is 17. This situation is caused by the difference in numerical range between A and B. A has a higher numerical range, and thus change in A has a greater impact on the arithmetic mean, compared to change in B. Therefore, it is worth concluding that the arithmetic mean allocates more weight to A because of its higher numerical range. In the case of this study, the selected indicators for the calculation of the composite index of disruption risk to electricity supply do not have exactly the same numerical range. Using the arithmetic mean will allocate more weight to indicators that have higher numerical ranges.

As mentioned by Gan et al. (2017), another disadvantage of the arithmetic mean is the compensability between indicators. In other words, low socres or values of some indicators are compensated by high scores or values of other indicators. For example, countries D and E may respectively have the values (10, 2, 3, 1) and (4, 4, 4, 4) for the following indicators: I_1, I_2, I_3, I_4. If the arithmetic mean were used as the aggregation approach, the value of the composite index will be equal to 4 for both countries, while the country D has a lower performance for three indicators when compared to the country E. For the country D, the low performance of these three indicators has been compensated by the high performance of the fourth indicator. Therefore, using the arithmetic mean as an aggregation approach, does not allow the composite index to reflect the difference between countries D and E in regard to these three indicators. Because of these two disadvantages, the current study did not use the arithmetic mean as an aggregation approach.

The current study has rather used the geometric mean which is an aggregation approach that is less compensatory (see Bullen, 2013; OECD, 2008; Beliakov, Pradera, Calvo, 2007). For example, if the geometric mean were used as an aggregation approach, country D would have a much lower value for the composite index when compared to country E. The value of the composite index would be 2.78 for country D, while it would be 4 for country E. Unlike the arithmetic mean which uses an additive function, the geometric mean uses a multiplicative function (Pollesch and Dale, 2015; Beliakov et al., 2007; Munda and Nardo, 2005; OECD, 2008) and is defined as the p^{th} root of the product of a set of scalars or numbers $y_1, y_2, \ldots y_p$. Its general expression is as follows:

$$\left(\prod_{i=1}^{p} y_i\right)^{\frac{1}{p}} = \sqrt[p]{y_1 \times y_2 \times \ldots \times y_p} \qquad 2.18$$

The geometric mean is often used to calculate the average of a set of variables which have different properties and different numerical ranges. The geometric mean levels the variables' numerical ranges when averaging them, so that no numerical range has more weight than the others. In that way, a percentage change d in any variable y_i has the same impact on the geometric mean. There have been previous uses of the geometric mean in the calculation of indexes such as the United Nation Development Program (UNDP)'s 2010 Human Development Index (HDI). The 2010 HDI is the geometric mean of Life Expectancy Index (LEI), Education Index (EI), and Income Index (II). Although the geometric mean has different advantages compared to the arithmetic mean, it also has some limitations. First, as mentioned by OECD (2008) and Keeney (2006 & 2008), it is not a fully non-compensatory approach. However, as mentioned before, it is an aggregation approach that is less compensatory when compared to the arithmetic mean. Second, as explained by Beliakov et al (2007) and Calvo, Kolesárová, Komorníková, Mesiar (2002), with the geometric mean approach it is impossible to undertake sensitivity analysis for the composite index using its components (sub-indicators)' measurement errors. Further researches on the composite index of disruption risk to electricity supply will investigate the existence of innovative aggregation approaches that are less compensatory, and with which it is possible to use measurement errors of sub-indicators to undertake sensitivity analysis.

In this study, the geometric mean has been used to calculate a composite index of electricity supply disruption risk (*ESRI*) based on the following indicators/index: *GI* (country's governance index), *RUB* (the ratio of the growth of access to electricity in urban areas to the growth of the urbanization rate), *RACE* (rate of access to electricity), *ESS* (electricity supply self-sufficiency), *ESE* (the rate of electricity supply efficiency), *RNEEX* (the share of real GDP not dedicated to cover the cost of electricity supply), *RGDPcW* (real GDP per capita expressed as a percentage of the world average real GDP per capita), and *RRE* (the share of renewable electricity in total domestic supply of electricity). As stated previously, the geometric mean has also been used to calculate the governance index (GI). The composite index of electricity supply disruption risk is expressed as follows:

$$ESRI = \sqrt[8]{GI \times RUB \times ESS \times ESE \times RNEEX \times RRE \times RACE \times RGDPcW} \qquad 2.19$$

High values of *ESRI* indicate that the country has a low risk of electricity supply disruption, while low values of *ESRI* indicate the country has a high risk of electricity supply disruption. In other words, *ESRI* is a decreasing function of disruption risks in electricity supply. For the purposes of simplicity, this study uses a composite index of electricity supply disruption risk (*ESRI*) which values are small numbers. Hence, the inverse values of the initial electricity supply disruption risk index (*ESRI*) have been calculated and each has been multiplied by 100. These transformed values of the initial electricity supply disruption risk index *(ESRI)* constitute the values of a new index called the modified electricity supply disruption risk index (*MESRI*). High values of *MESRI* indicate that the country has a high risk of electricity supply disruption, while low values of *MESRI* indicate that the country has a low risk of electricity supply disruption. In other words, *MESRI* is an increasing function of disruption risk to electricity supply. It is expressed as follows:

$$MESRI = \frac{1}{\sqrt[8]{GI \times RUB \times ESS \times ESE \times RNEEX \times RRE \times RACE \times RGDPcW}} \times 100 \qquad 2.20$$

2.5 EMPIRICAL RESULTS

Empirical results on the performance of Benin with regard to each of the indicators included in the calculation of the composite index of electricity supply disruption risks have been analysed in order to understand better why Benin is a country that has a disruption risk to electricity supply. First, the performance of Benin with regard to the governance index *(GI)* is shown in Figure 2.2, which represents the history of Benin's performance in terms of governance for the year 1996, 1998, 2000, and over the period 2002-2015. On the vertical axis are the governance index (*GI*) values,

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while on the abscissa line, we have the corresponding years. We notice that the performance of Benin in regard to the governance index (*GI*) has been decreasing as shown by the overall downward trend on Figure 2.2. In other words, Benin's combined performance in terms of "control of corruption", "rule of law", "quality of the regulatory system", "government effectiveness", "political stability and absence of violence" has a downward trend. In the electricity sector, this overall reduction of governance performance can be illustrated by the mismanagement of the delivery of electricity to consumers in the country. As mentioned in the national policy framework for electricity ("document de politique et de strategie de development du secteur de l'energie electrique", see Republique du Bénin (2008, pp. 30-31)) there have been mismanagements in the Beninese electricity sector, low quality of the delivery of service to consumers, low technical and financial performance of transmission and distribution's companies (SBEE and CEB). The low performance of these two public companies is mainly due to unprofitable investments made because of political considerations. In addition, because of the government's social and political agenda, the national pricing policy imposes on these companies a price of electricity that is below the production cost of electricity.

When compared to other countries, Benin is ranked 70th out of 183 countries in the world and 37th out of 50 countries in Africa in terms of risks associated with governance, with a five years average governance index value of 99.592 (Table A.1 in Appendix A). The governance index (*GI*) as presented in Table A.1 is a decreasing function of countries' risks associated with governance (Countries with low values of governance index (*GI*) have high risks related to governance, while countries with high values of governance index (*GI*) have low risks related to governance).

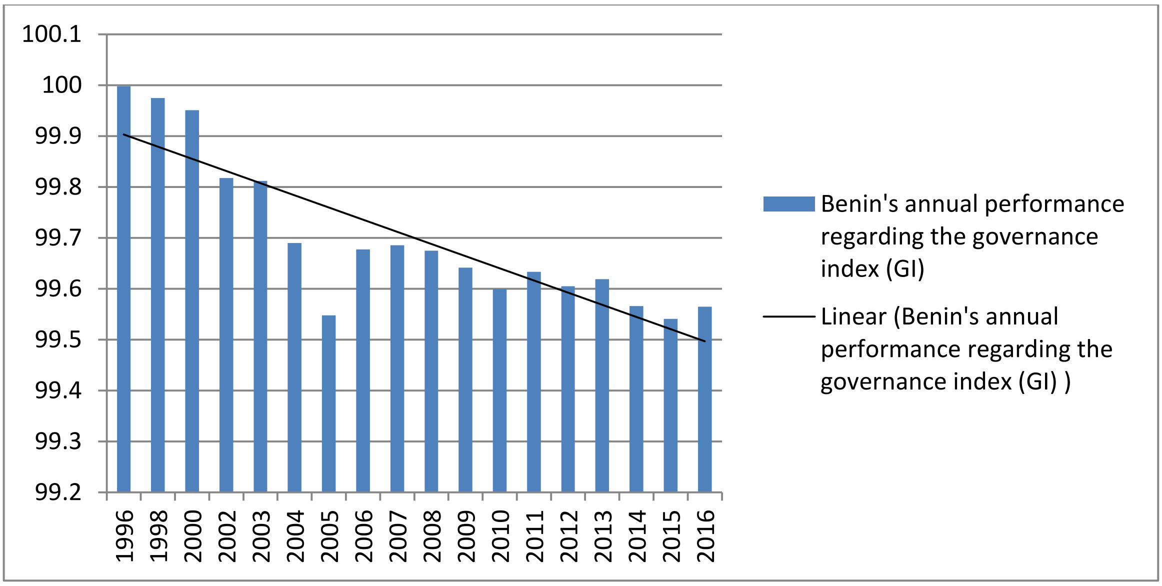

Figure 2.2: Evolution of Benin's performance in term of governance (1996, 1998, 2000, 2002-2016)

Source: Author's own calculation based on Worldwide Governance Indicators (2018)

Second, the performance of Benin in terms of effort to avoid a supply gap of electricity in urban areas is shown in Figure 2.3, which represents the history of the ratio of growth of access to electricity in urbans area to growth of urbanization (*RUB*), in Benin over the period 1996-2016. On the abscissa line are the years, and on the vertical axis are the values of the ratio (*RUB*) expressed as percentages. Noticeably the values of the ratio (*RUB*) have remained below 100% over the entire period, fluctuating between 96.06% and 96.39%. The periods of a significant reduction in *RUB* (1996, 2000, 2002, 2007, 2013, and 2014, 2016) correspond to some of the years that Benin has faced severe electricity crises. During these periods, there have been severe shortages of electricity in the country (including the urban areas), and the growth rate of access to electricity in urban areas has been far smaller than the growth rate of urbanization. The periods of significant increase in *RUB* (1997, 2010, and 2015) correspond to the years that access to electricity in urban areas has been significantly improved, although its growth rate has remained smaller than the growth rate of urbanization. All this indicates that in Benin, urbanization has been growing more rapidly than access to electricity in urban areas. This situation is one of the causes of the electricity supply gap in urban areas. However, the ratio (*RUB*) has an upward overall trend over the entire period (1996-2016). This indicates that though growth of urbanization is higher than urban access to electricity, the overall trend of access to electricity in urban areas is upward.

When compared to other countries in terms of performance related to the ratio of growth of access to electricity in urban areas to growth of urbanization (*RUB*), Benin is ranked 36th out of 183 countries in the world and 24th out of 50 countries in Africa, with a five years (2011-2015) average ratio (*RUB*)'s value of 96.388% (Table A.2 in Appendix A). The ratio of growth of access to electricity in urban areas to growth of urbanization (*RUB*) is a decreasing function of risks associated with the electricity supply gap in urban areas (low values of the ratio indicates high risks of electricity supply gap in urban areas, while high values of the ratio indicates low risks of the electricity supply gap in urban areas).

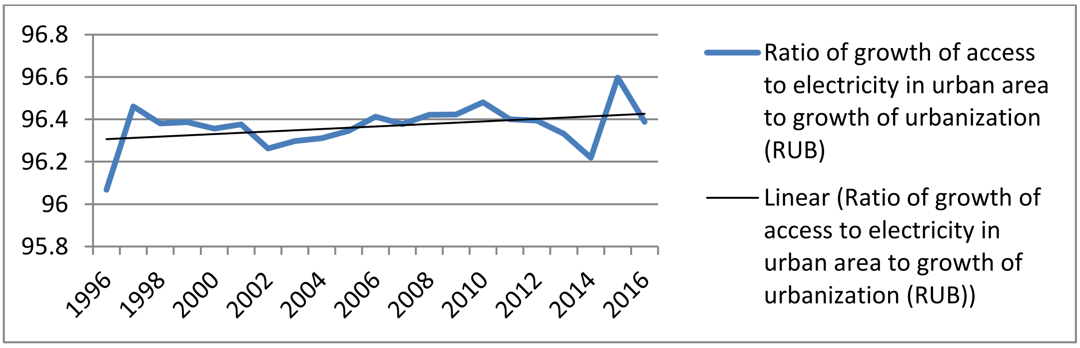

Figure 2.3: History of the ratio of growth of access to electricity in urban areas to growth of urbanization in Benin (1996-2016)

Source: Author's own calculation based on data from the World Development Indicators (2018)

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Third, Benin's performance in terms of affordability of electricity supply is shown in Figure 2.4, which represents the history of the share of GDP not dedicated to cover the cost of electricity supply (*RNEEX*). The horizontal axis shows the years, and the vertical axis shows the share of GDP not dedicated to cover the cost of electricity supply (*RNEEX*) expressed as a percentage of real GDP (constant 2010 US$). It can be seen that the share of GDP not dedicated to cover the cost of electricity supply has remained above 99% for the entire period (1980-2015). In other words, the cost of electricity in Benin has never exceeded 1% of GDP over the period 1980-2015. However, the overall trend of the share of GDP not dedicated to cover the cost of electricity supply (*RNEEX*) is downward. This indicates that although the share of the cost of electricity supply in GDP has remained small (less than 1%), it has an overall upward trend. In other words, the general observation over the period 1980-2015 is that electricity supply has become more costly, although its overall cost has remained less than 1% of GDP.

When compared to other countries in terms of affordability risk (proxied by the share of GDP not dedicated to cover the cost of electricity), Benin is ranked 156th out of 183 countries in the world and 33rd out of 50 countries in Africa (Table A.3 in Appendix A). Table A.3 shows that the lower the share of GDP not used to cover the cost of electricity supply, the higher the risk associated with affordability of electricity supply. In other words the share of GDP not used to cover the cost of electricity supply (*RNEEX*) is a decreasing function of electricity supply disruption risks associated with affordability of electricity supply.

It is recommended that Benin attempts to minimize the cost of electricity supply by for instance relying less on oil for its domestic electricity production. According to the World Development Indicators (2018), 99.457% of the domestic production of electricity in Benin was based on oil in 2014. As stated previously, increases in oil prices augment the production costs of electricity and therefore limit the capacity of the country to supply electricity. As mentioned in the national policy framework for electricity (République du Bénin, 2008, p. 31), one of the reasons for the poor financial performance of the national distribution company (SBEE) is the use of fossil fuels such as gasoil and jet A-1 (a type of aviation fuel) for the domestic production of electricity. Jet A-1 is expensive and the price of both fossil fuels can fluctuate. This situation has significantly increased the financial cost borne by the company while the company's financial revenue is under pressure because electricity is sold to consumers at a price below its production cost.

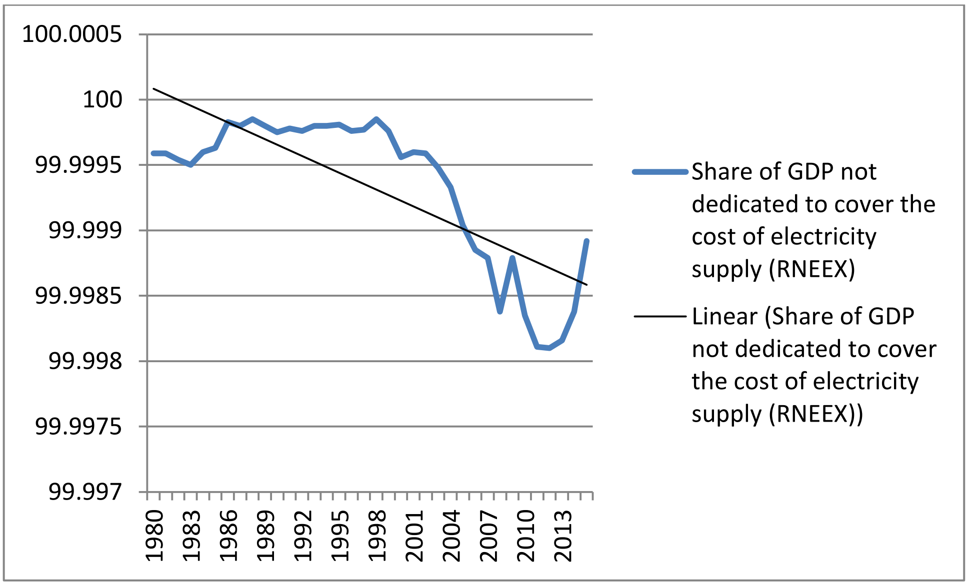

Figure 2.4: History of the share of GDP not dedicated to cover the cost of electricity supply in Benin (1980-2015)

Source: Author's own calculation based on data from USEIA (2018), World Bank (2018b), and World Development Indicators (2018)

Fourth, Benin's performance in terms of "acceptability" of the type of electricity produced, in other words in terms of the sustainability of the production of electricity (production of electricity using unlimited energy resources, and with little damage to the environment) is shown in Figure 2.5. The figure represents the history of the share of renewable electricity in total domestic production of electricity (*RRE*) over the period 1996-2016. The horizontal axis shows the years, and the vertical axis shows the share of renewable electricity in total domestic production of electricity (*RRE*). In Figure 2.5, the origin of the reference frame *X* (horizontal axis) and *Y* (vertical axis) is not 0, but 100, the indicator *RRE* has been transformed (the number 100 has been added to each values of the series on *RRE*, a detailed explanation has been provided in the methodological section). It can be seen that the share of renewable electricity in total domestic production of electricity has remained less than 6% over the entire period, which indicates that the electricity produced domestically in Benin is mainly non-renewable. This constitutes a major risk for the country in terms of sustainability of domestic electricity production. As noted before, fossil fuel energy constitutes limited energy resources.

When compared to other countries in terms of long-term disruption risk of electricity supply related to the use of unsustainable energy resources, Benin is ranked 34th out of 183 countries in the world and 10th out of 50 countries in Africa (Table A.4 in Appendix A). This makes Benin one of the countries in Africa and in the world with high risks associated with sustainability of electricity supply security. Table A.4 shows that the share of renewable electricity in total domestic production of electricity (*RRE*) is a decreasing function of long-term disruption risks of electricity supply related to the use of unsustainable energy resources (countries with a low *RRE* have high long-term disruption risks of electricity supply related to the use of unsustainable energy resources, while countries with a high *RRE* have low long-term disruption risks of electricity supply related to the use of unsustainable energy resources).

For a long-term and sustainable security of electricity supply, Benin should try to increase its production of renewable electricity, which is an unlimited energy resource, rather than electricity produced using fossil fuels. In other words, increasing the share of renewable electricity in total domestic production of electricity will contribute to minimizing long-term electricity supply disruption risks related to the use of unsustainable energy resources as inputs for electricity production. As mentioned in the national policy framework for electricity (République du Bénin, 2008, pp. 30–31), because of a lack of financial investment, there is very low usage of Benin's potential in terms of renewable electricity, as the country has significant hydro, solar and wind potential: 85 zones were identified for the construction of hydroelectric dams, the solar potential varies between 3.9 and 6.2 kWh per square metre per day (kWh/m^2/day), and the wind speed measured at an altitude of 10 metre (m) above sea level varies between 3 and 6 metres per second (m/s). How to attract private investment in the renewable electricity sector should be one of the priorities of the country if it aims to ensure a long-term and sustainable security of electricity supply.

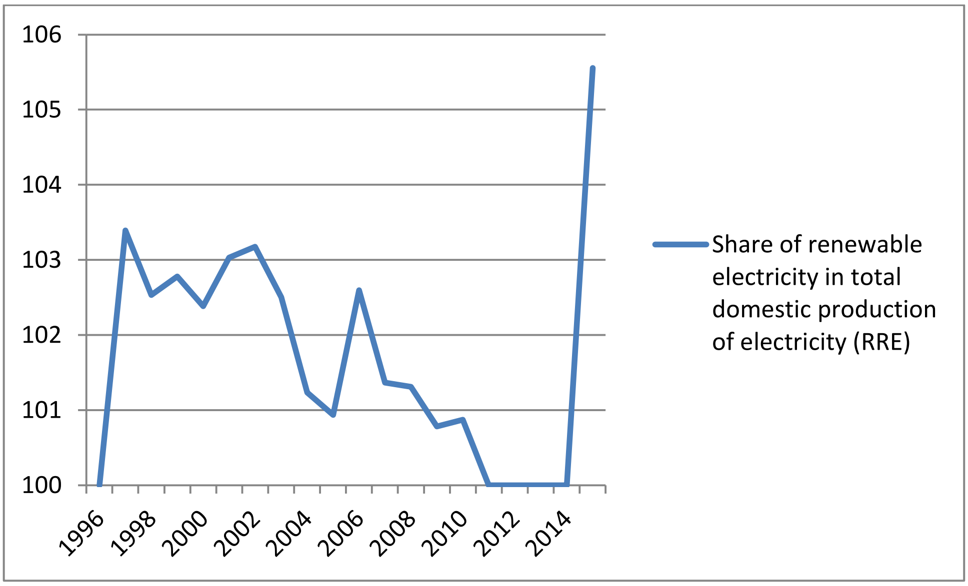

Figure 2.5: History of the share of renewable electricity in total domestic production of electricity (*RRE*) in Benin (1996-2015)

Source: World Development Indicators (2018)

Fifth, Benin's performance in terms of electricity supply self-sufficiency (*ESS*) (supply disruption risks related to the concept of "accessibility") is shown in Figure 2.6 which represents the history of electricity supply self-sufficiency rate (*ESS*) over the period 1980-2015. The horizontal axis shows the years, and the vertical axis shows the self-sufficiency rate of electricity supply expressed as a

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percentage of total domestic supply of electricity (*TDES*). It can be seen that over the entire period, Benin's self-sufficiency rate of electricity supply has not exceeded 27%. In 2015 the self-sufficiency rate of electricity supply was 22.424%. All this indicates that Benin is heavily dependent on the importation of electricity in order to reduce its electricity supply gap. As mentioned previously, this situation exposes the countries to electricity crises which occur in its supplier countries such as Ghana and Nigeria. Whenever these countries reduce their exports of electricity to Benin because of the necessity to satisfy their domestic growing demand for electricity, electricity supply disruption occurs in Benin. The self-sufficiency rate of electricity supply (*ESS*) is a decreasing function of electricity supply disruption risks related to the importation of electricity: in other words, a high *ESS* is associated with low supply disruption risks related to importation of electricity, while a low *ESS* is associated with high supply disruption risks related to importation of electricity.

Figure 2.6 shows a significant reduction of the rate of electricity supply self-sufficiency (*ESS*) in 1989, 1992, 2002 and 2012. For instance, *ESS* falls to 4.11% in 2012 because of the severe electricity crisis due to both a reduction of electricity importation and the weakened capacity of the national distribution company (SBEE) to fill the gap caused by the import deficit. Other electricity crises also occurred in 1983, 1995 and 2004, and these can be seen in Figure 2.6 by a sudden reduction of the rate of electricity supply self-sufficiency in these years. As mentioned in the previous chapter, droughts in Ghana in 1983, 1994 and 2004 limited the capacity of the Akossombo dam to generate electricity, which caused Ghana to reduce its exportation of electricity to Benin during these years. The consequence was the sudden reduction of Benin's electricity supply self-sufficiency rate observed in Figure 2.6 in 1983, 1995 and 2004. Although the self-sufficiency rate of electricity supply in Benin has remained less than 27% over the entire period of 1980 to 2015, it can be seen in Figure 2.6 that there is an upward trend of *ESS*.

When compared to other countries in terms of supply disruption risk of electricity related to importation of electricity, Benin is ranked 2nd out of 194 countries in the world, and 2nd out of 53 countries in Africa (Table A.5 in Appendix A). As proposed in the national policy framework for electricity (République du Bénin, 2008, p. 30), Benin should try to increase its self-sufficiency rate of electricity supply in order to minimize its dependency vis-à-vis its supplier countries. One of the targets of the national policy framework for electricity (République du Bénin, 2008, p. 56) is to increase the self-sufficiency rate of electricity supply to 70% by 2025.

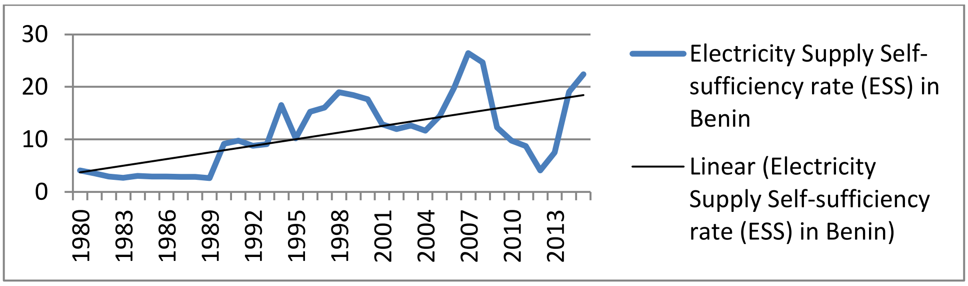

Figure 2.6: History of electricity supply self-sufficiency rate (ESS) in Benin (1980-2015)

Source: Author's own calculation based on USEIA (2018) data

Sixth, the performance of Benin with regard to the electricity supply efficiency rate (*ESE*) (a proxy for supply risk related to the concept of availability of electricity) is shown in Figure 2.7 which represents the history of Benin's rate of electricity efficiency over the period 1980-2015. In this figure, the horizontal axis represents the years and the vertical axis represents the efficiency rate of electricity supply (*ESE*) expressed as a percentage of total supply of electricity (*TES*). As said previously, this rate is defined as the ratio of electricity not lost to total supply of electricity. It can be seen that over the entire period, the rate of electricity supply efficiency has fluctuated between 74.86% and 90.65%. In other words, losses of electricity have fluctuated between 9.35% and 25.14% over the period 1980-2015. The ECA (2008) reported that the international standard for maximum electricity losses is 12%. Apart from the electricity losses for 1982, which were 9.35%, losses of electricity in Benin have always exceeded this international standard.

Compared to other countries in terms of rate of electricity supply efficiency, Benin is ranked 24th out of 194 countries in the world and 11th out of 53 countries in Africa (Table A.6 in Appendix A). This indicates that the Beninese electricity sector is not efficient. As mentioned before, losses of electricity can be technical or non-technical. Technical losses are related to the technology used for the distribution of electricity, while non-technical losses are caused by human behaviour such as electricity thefts, errors in the electricity billing system, corruption and poor governance of the electricity distribution system etc. As reported by the République du Bénin (2008), rapid urbanization and the insufficiency of urban distribution lines have caused the development of illegal distribution networks by a proportion of the urban population that does not have access to electricity. This situation has increased the non-technical losses of electricity. As mentioned by the République du Bénin (2008), among its goals for energy efficiency, the Beninese Ministry of Energy has targeted to reduce electricity losses by 14% from 2020 to 2025, from its level of 15.93% in 2008.

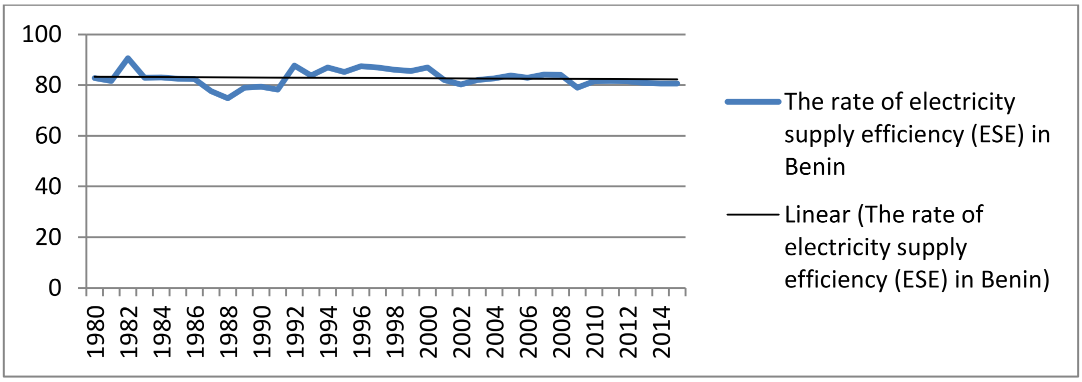

Figure 2.7: History of the rate of electricity supply efficiency in Benin (1980-2015)

Source: Author's own calculation based on USEIA (2018)

Seventh, the performance of Benin with regard to access to electricity (RACE) (a proxy for electricity supply disruption risks related to the concept of "availability") is shown in Figure 2.8, which represents the history of access to electricity (RACE) in Benin over the period 1990-2016. The horizontal axis shows the years, and the vertical axis shows the rate of access to electricity as a percentage of total population. It can be seen that apart from the years 2013 and 2014, access to electricity has been growing in Benin. Despite this continuous growth, it has remained below 41.5% over the entire period. The reduction in access to electricity observed in 2013 and 2014 are the consequences of the severe electricity crisis faced by the country during these years (a detailed explanation has been provided in the chapter 1, section 1.1.4). As said previously, access to electricity in Benin in 2016 was 41.40%, which is lower than both the sub-Saharan Africa and the world average access to electricity for this year, which are 42.81% and 87.35% respectively. This indicates that there is a huge supply gap of electricity in Benin, as a large proportion of the population is still without access to electricity. In other words, there is a total and continuous supply disruption of electricity encountered daily by the proportion of the population that does not have access to electricity. In addition, when compared to other countries, Benin is ranked 29th in the world out of 195 countries and 27th in Africa out of 54 countries in terms of rate of access to electricity (Table A.7 in Appendix A). In order to reduce this supply gap of electricity, the national framework for electricity (République du Bénin, 2008, p. 40) aimed to increase access to electricity to 95% in urban areas and 65% in rural areas by 2025.

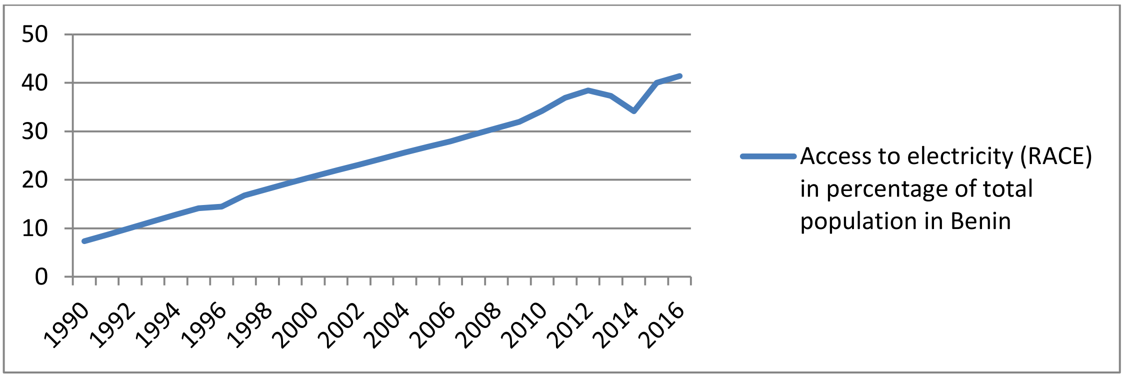

Figure 2.8: History of access to electricity (RACE) in Benin (1990-2016)

Source: World Development Indicators (2018)

Eighth, the performance of Benin with regard to real GDP per capita (*RGDPcW*) (expressed as a percentage of the world annual average real GDP per capita) is shown in Figure 2.9, which represents the history of Benin's real GDP per capita (*RGDPcW*) (expressed as a percentage of the world annual average real GDP per capita) over the period 1960-2017. The vertical axis shows Benin's real GDP per capita (*RGDPcW*) expressed as a percentage of the world annual average real GDP per capita, and the horizontal axis shows the corresponding years. It can be seen that on average, the *RGDPcW* has been decreasing over the period 1960-2017 (as shown by the overall downward trend line in Figure 2.9). This indicates that over the period 1960-2017, the average person living in Benin has become poorer compared to the average person living in the world. This also indicates that over the period 1960-2017, Benin as a country has become more financially unable to offer to its population a standard of living similar to the average standard of living of the population of the rest of the world.

However, the absolute value of real GDP per capita (*RGDPc*) has been increasing over the period 1960-2017 (Figure 2.10). This indicates that although Benin as a country has become more financially unable to offer its population a standard of living similar to the average standard of living of the population of the rest of the world, the country's wealth has increased over the period 1960-2017. In other words, Benin has become more financially capable of investing in electricity infrastructure and utilities, even if such financial capability is very low compared to the financial capability of the average country of the world. Such an increase in real GDP per capita (*RGDPc*) did not prevent the country from needing some financial investment in the electricity sector. As reported by the national policy framework for electricity (République du Bénin, 2008 pp. 30–31), one of the major causes of the supply gap of electricity is the lack of financial investment in electricity infrastructure and utilities. Compared to other countries of the world in terms of real GDP per capita (*RGDPcW*) (expressed as a percentage of the world annual average real GDP per capita), Benin is ranked 25th in the world out of 189 countries and 22nd in Africa out of 51 countries (Table A.8 in Appendix A).

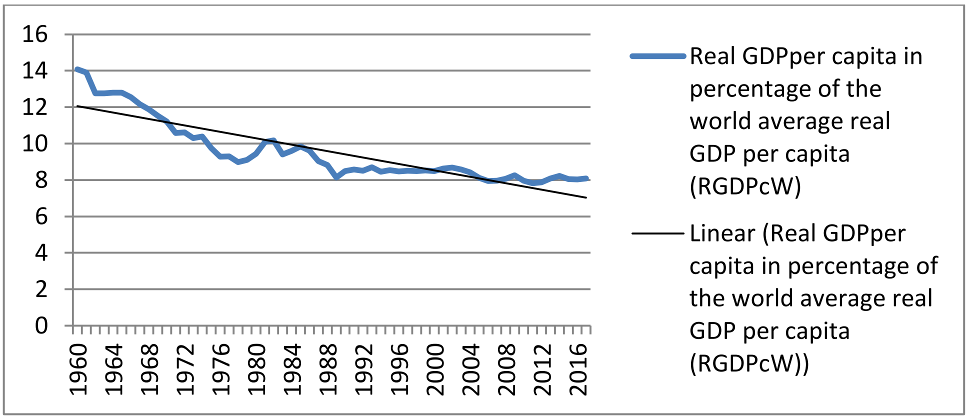

Figure 2.9: History of Benin's real GDP per capita (RGDPcW) (as a percentage of the world annual average real GDP per capita) (1960-2017)

Source: Author's own calculation based on the World Development Indicators (2018) data

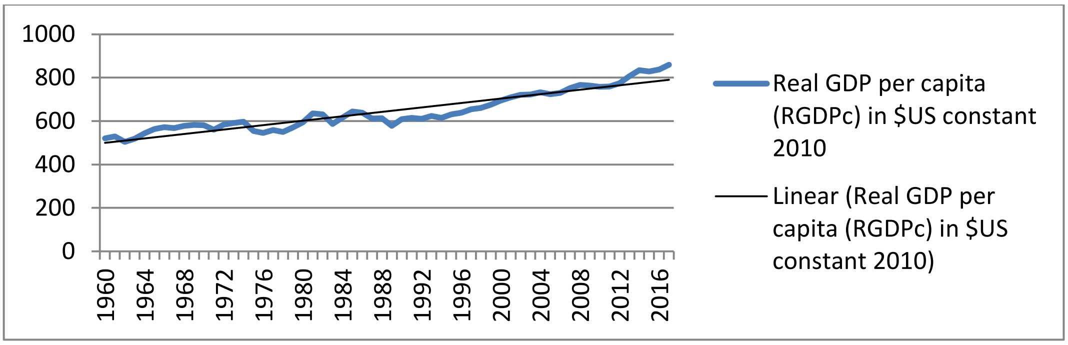

Figure 2.10: History of Benin's real GDP per capita (RGDPc) (1960-2017)

Source: World Development Indicators (2018)

The performance of Benin as related to the disruption risk to electricity supply has been measured by the modified index of electricity supply disruption risk (MESRI). It can be seen in Tables B.1, B.2 in Appendix B that Benin has remained among countries that have a very high level of disruption to electricity supply and was ranked the fourth country in the world in terms of disruption to electricity supply over the periods 2002-2005 and 2006-2010, and with an index (MESRI) score of 2.157 and 2.036 for both periods respectively. In the period 2011-2015, Benin was ranked third country in the world in terms of disruption to electricity supply with a score of 2.132 for the index (MESRI) (Table B.3 in Appendix B). These results emphasize the fact that Benin is among the most vulnerable countries in the world in terms of disruption of electricity supply. It can be seen in Tables B.1, B.2, B.3 that sub-Saharan African countries tend to constitute the group of countries that have an extreme, a very high or high disruption to electricity supply, while most of the wealthiest countries in the world constitute the group of countries that have a low disruption to electricity supply. This aligns with the IEA (2018), statistics from the World Development Indicators (2018) and the USEIA (2018) which emphasize that sub-Saharan African countries have the lowest access to electricity and the lowest consumption of electricity. This also aligns with Ferguson et al. (2000) who argued that a positive correlation exists between a country's wealth and its energy consumption. Wealthy countries have high access to energy/electricity and a high consumption of energy/electricity. In other words, they have less supply gap of energy/electricity or less disruption to energy/electricity. Conversely, poor countries have low access to energy/electricity and a low consumption of energy/electricity. In other words, they have more supply gaps in energy/electricity or more disruption to energy/electricity supply.

Figure 2.11 represents the history of the annual performance of Benin as related to disruption of electricity supply in 1996, 1998, 2000, and over the period 2002-2015. On the vertical axis are the values of the modified index of electricity supply disruption risk (*MESRI*), while on the abscissa line are the corresponding years. *MESRI* is an increasing function of the level of disruption to electricity supply. It is clear that the level of disruption of electricity in the country has remained very high or high over the entire period of time. The years 1996, 1998, 2000, the periods 2002-2006 and 2009-2013, correspond to times of very high levels of disruption to electricity supply, while the periods 2007-2008 and 2014-2015 correspond to times of high levels of disruption to electricity supply. These observed patterns of the modified index of electricity supply disruption risk (MESRI) in Figure 2.11 align with the historical facts observed in the Beninese electricity sector. The years or periods of very high level of disruption to electricity supply correspond to years of severe electricity crises such as 1994, 1998, 2006, 2007, 2008, 2012 and 2013. These electricity crises have affected the country over consecutive years, which is the reason why, for instance in 1996, the country was still facing a very high level of disruption to electricity supply which started in 1994.

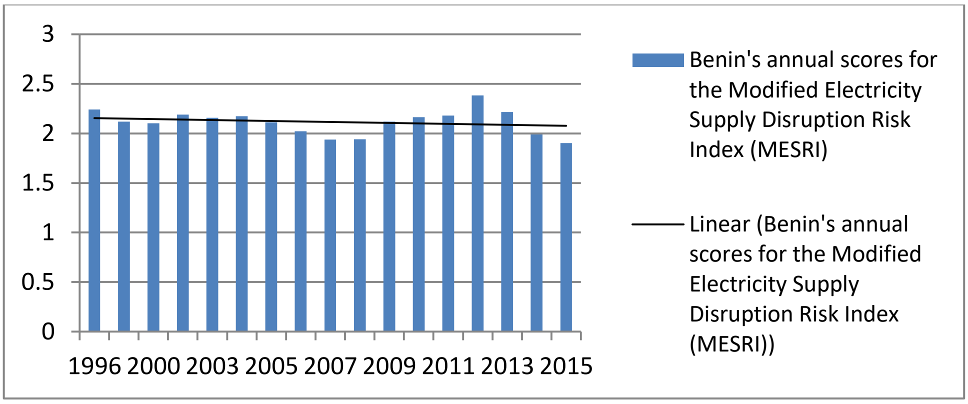

Figure 2.11: History of the Modified Electricity Supply Disruption Risk Index of Benin (MESRI) (1996, 1998, 2000, 2002-2015)

Source: Author's own calculation based on data from USEIA (2018), World Development Indicators (2018), Worldwide Governance Indicators (2018), World Bank (2018b)

2.6 CONCLUSION AND RECOMMENDATION

In this chapter an index of electricity supply security that focuses on the disruption risk to electricity has been constructed. Such an index is called the Modified Index of Electricity Supply Disruption

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Risks (MESRI), and can provide several benefits. First, it will be a very useful tool in the hands of policy makers for the monitoring and evaluation of a country's performance related to electricity security. In Benin, it will contribute to the achievement of one of the sub-objectives of the national policy framework for electricity (République du Bénin, 2008): to define and improve performance indicators for the electricity sectors and the national electricity distribution company. In Benin, no performance indicator exists to measure the security of electricity supply. The current Modified Index of Disruption Risks to Electricity Supply will contribute to fill this gap by being a tool for the measurement of the performance of the country in terms of electricity supply security.

Second, MESRI will be a useful tool for domestic and foreign private investors when assessing the ease of doing business in Benin and other countries of the world. As noted previously, some of the criteria when assessing the ease of doing business in a country are easy access to electricity and the absence or low frequency of disruption risks to electricity supply. MESRI measures the overall performance of a country in terms of disruption risks to electricity supply. It also facilitates the understanding of how a country performs according to access to electricity, electricity supply efficiency, electricity supply self-sufficiency, sustainability of electricity supply (in other words the share of renewable electricity used), influence of urbanization on electricity supply, governance, capacity to cover the cost of electricity supply and electricity infrastructure. Therefore, it provides for domestic and foreign private investors, a whole spectrum of indicators by which countries can be assessed in terms of ease of doing business.

Third, MESRI will be a useful tool for development finance institutions such as the African Development Bank (AfDB), the World Bank, the Asian Development Bank (ADB), and the Inter-American Development Bank (IADB) when assessing a country's need for investments in infrastructure (physical infrastructure such as power plant, or institutional infrastructure such as governance systems or regulatory systems in the electricity sector, etc.) as related to a disruption to the electricity supply. A high or very high level of disruption risk to electricity supply in a country indicates the need for investment in electricity infrastructure (either physical infrastructure, or institutional infrastructure, or both).

Fourth, MESRI is the first composite index of electricity supply security. It will be a useful tool for research institutions such as the International Energy Agency (IEA), the United States Energy Information Administration (USEIA), and research departments of development finance institutions such as AfDB, ADB, IADB and the World Bank in assessing a country's performance in terms of electricity security, and in forecasting electricity supply security for countries.

With this index (MESRI), an assessment of the overall performance of Benin in terms of disruption risks to electricity supply has been done, which revealed that Benin has a very high level of electricity supply disruption risk. An assessment of the performance of Benin according to each component of the index has been carried out which revealed that the performance of Benin in

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terms of the self-sufficiency rate of electricity supply, rate of access to electricity, rate of electricity supply efficiency, share of renewable electricity in total domestic production of electricity, governance, and ratio of growth of urban access to electricity to growth of the urbanization rate, are all low. Especially in the case of electricity supply self-sufficiency, Benin is the second worst in the world after Togo over the period 2011-2015 (see Table A.5). This suggests that in order to improve its overall performance in terms of disruption risk to electricity supply, Benin must first improve its governance system as it affects the delivery of electricity to consumers.

Second, the country must improve its level of domestic production of electricity. The aim of the national policy framework is to increase the self-sufficiency rate of electricity supply to 70% by 2025. A reduction of its dependency on importation, will significantly improve Benin’s overall performance in terms of disruption risk to electricity supply. Third, the country must improve its electricity supply efficiency rate by reducing electricity losses. Finally, in order to align the speed of urbanization with the speed of urban access to electricity, Benin must create incentives for the rural population to stay in rural areas by building more social and economic infrastructure in those areas. Failing this, the high rate of migration from urban to rural area will continue, and will increase the rate of urbanization which can become higher than the rate of urban access to electricity. The consequence will be an increasing urban supply gap of electricity.

Both the improvement of the self-sufficiency rate of electricity supply and of the electricity supply efficiency rate require important investments in electricity infrastructure, while Benin’s wealth as measured by its GDP per capita is very low. This requires the country to create incentives for foreign and domestic private investors and development finance institutions to invest in the Beninese electricity sector. Other ways of financing electricity infrastructure have also been identified in the national policy framework for electricity. One of these is an indirect financing mechanism, which suggests using donor or national budget funds to finance electricity infrastructure in order to contribute to minimizing electricity losses. The financing mechanism then recommends using the gain in GDP caused by reductions in electricity loss to reimburse the donors or national budget funds. These recommendations of the national policy framework require an assessment of the gain in GDP resulting from reductions in electricity losses. In other words, they require an assessment of the effects of electricity losses on GDP. This assessment is the focus of the following chapter.

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CHAPTER 3[2]

THE EFFECTS OF ELECTRICITY LOSSES ON GDP

3.1 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 generators, as electricity is available and at low prices. Conversely, the 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 find it difficult to exist. Outages of electricity generate inefficiencies in the economy as they increase costs for firms, delay production of goods and services and even affect 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.

As mentioned in Chapter 1, 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 the USEIA (2018). According to the World Development Indicators (2017), electricity losses include transmission losses which occur between the sources of production and the sources of distribution, and distribution losses which occur between the sources of distribution and the 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 electricity supply that do not reach legal consumers. As explained in the Introduction, illegal consumers steal electricity from the national distribution lines. As reported by the République du

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[2] This chapter has been accepted for publication in the International Journal of Energy Economics and Policy (IJEEP). The chapter has also been presented as a paper titled "*The effects of electricity losses on GDP in Benin*", at the 2018 British Institute of Energy Economics (BIEE) conference, held at Oxford University, in the UK, in September 2018.

Bénin (2008), stolen electricity from the national distribution lines forms part of the non-technical electricity losses in Benin. As mentioned previously, technical losses of electricity are related to the types of technology used for the transmission and distribution of electricity. Figure 3.1 represents the history of electricity supply and electricity consumption. The vertical axis shows electricity supply and electricity consumption expressed in billions of kilowatt hour (kWh), and the horizontal axis shows time measured in years. There is a gap between electricity supply and electricity consumption, and this gap represents electricity losses.

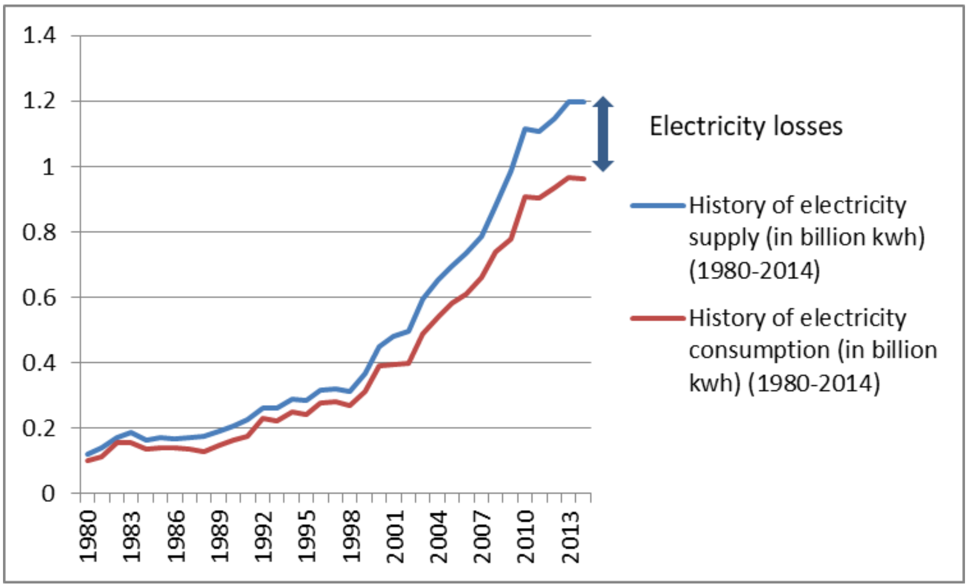

Figure 3.1: History of electricity supply and consumption (in billions kWh) in Benin (1980-2014)

Source: USEIA (2017)

In Benin, losses of electricity ranged between 9.35% and 25.14% of the total electricity supply for the period 1980-2014; in 2014, the proportion was 19.403% of the total electricity supply (USEIA, 2017), while the ECA (2008) suggested that the international maximum target for electricity losses should not exceed 12% of the total electricity supply. The 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 are 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% each year from 2005 to 2010, and by 15% in 2015. However, the actual losses of electricity were above the targets set by the Ministry for 2010 and 2015, respectively 18.56% and 19.35% (République du Bénin, 2008; USEIA, 2018). The cost of these

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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 on the Beninese economy. As mentioned in the Introduction, the promotion of electricity efficiency on both the 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 a 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). As explained in the Introduction, 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 using electricity efficient technology. In order to reduce non-technical losses of electricity, Benin targets to implement an emergency plan aiming at fighting corruption and the 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, it is to use donor 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 the 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 were allocated to cover the costs of the 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 a reduction in electricity losses to reimburse the costs of projects aimed at reducing electricity losses. It therefore becomes important to evaluate the effect of electricity losses on GDP. There is no empirical study on Benin which has investigated the effect of electricity losses on GDP. Hence, the current study conducts such investigation. It will evaluate the effect of electricity losses on GDP; in other words, it will evaluate the gain in GDP

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resulting from reductions in electricity losses in the Beninese context. By doing so, 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 advance 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 (electricity supply under the hypothesis of existence of electricity losses or electricity supply net of losses) and electricity supply (electricity supply under the hypothesis of non-existence of electricity losses) on GDP. As said before, electricity consumption in the Beninese context is equal to electricity supply minus electricity losses. Then, following on 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.

3.2 LITERATURE REVIEW

The goal of this chapter is to examine the effect of electricity losses on economic growth (proxied by real GDP). 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. As mentioned in previous chapters, 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.

3.2.1 Theoretical foundation

3.2.1.1 Relationship between economic growth and energy consumption/supply

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 denoted "learning by doing", Hicks's (1932) model 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,

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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 had coal mines. Consequently, only the British economy experienced the industrial revolution. Following Wrigley (1998), Stern (2010) and Allen (2009) highlighted the crucial role of energy in the industrial revolution in the British economy. Theorists in ecological economics 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.

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 main cause of economic growth. Stern (2010) held that energy is not the main cause of economic growth, but highlighted the crucial role played by energy in economic growth and 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 consumption/supply are expected to have a positive relationship.

3.2.1.2 The relationship between economic growth, technology, 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 accumulation 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) established that physical capital proxied by investment can have a significant and negative relationship with economic growth, depending on the economic and social context of the countries of analysis. 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, rather, it varies according to the economic, social, and political context of the countries of analysis.

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, the country of analysis.

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

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

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3.2.2.1 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, 2011; 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; Tang, 2008, 2009; Odhiambo, 2009a; Lean and Smyth, 2010; Ouédraogo, 2010) established a bidirectional causal relationship between economic growth and electricity consumption. According to these studies, economic growth and electricity consumption/supply are interdependent. Any energy efficiency policy aiming to reduce electricity consumption will negatively affect economic growth, and any negative shock to economic growth will reduce 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. These studies consider that electricity consumption/supply drives economic growth, but not the reverse. Therefore an energy efficiency policy aiming to lower electricity consumption will have a negative effect on economic growth. However, negative shocks to economic growth will not reduce electricity consumption.

Yet other studies (Ghosh, 2002; Narayan and Smyth, 2005; Yoo and Kim, 2006; Ho and Sui, 2007; Mozumder and Marathe, 2007; Jamil and Ahmad, 2010) established a unidirectional causal relationship running from economic growth to electricity consumption. According to these studies, economic growth drives electricity consumption, but not the reverse. Hence, any energy efficiency policy aiming to reduce electricity consumption will not have a negative effect on economic growth. 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. The mixed results observed among country-specific studies are due to the differences in the social, economic, and political context of each country, with differences in: the methodology used, the sample size, the proxies used for the variables, the omitted variables, the data, and the energy policy of each country (Chen, Kuo and Chen, 2007). Results established in country-specific studies are limited to a specific context and cannot be generalized. They are very relevant for country-specific policy decision, but cannot serve as a reference for regional or international policy decision.

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Multiple country studies have also established mixed results. In some countries they established that electricity consumption drives economic growth or economic growth and electricity consumption are interdependent. In such countries, any energy efficiency policy aiming to reduce electricity consumption will negatively affect economic growth. In other countries, they established that economic growth drives electricity consumption or there is no causal relationship between the two variables. In these countries, any energy efficiency policy aiming to reduce electricity consumption will have no negative effect on economic growth. For example, Yoo (2006) investigated the causal relationship between economic growth and electricity consumption for Singapore, Indonesia, Thailand, and Malaysia. He 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 et al. (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, while there was 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 such as 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. They 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 People Republic and the Czech People Republic, they

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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. Narayan and Smyth (2005) established a cointegration relationship between electricity consumption, real income and employment in Australia. Yoo and Kwak (2010) analysed 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 respectively 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 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. When compared to country-specific studies, multiple country studies cover many different contexts.

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Therefore their results and conclusions can often be generalized to a certain extent. They are most relevant for regional and international policy decisions.

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 country's 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 ("conservation", "growth", "feedback", "neutrality") 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

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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 that, the next section will present both studies on energy consumption and economic growth, and studies on electricity consumption and economic growth.

3.2.2.2 Specific studies on Benin and some African countries on the relationship between economic growth and energy/electricity consumption

There have been very few studies on Benin (Wolde-Rufael, 2009; Wolde-Rufael, 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 analysed the relationship between electricity/energy consumption and economic growth. There is no consensus on the true direction of causality among these studies. Most of them have focused on Benin and other countries. Depending on the type of analysis (bivariate or multivariate), and the methodology used, these studies have established for Benin either a causal relationship running from energy consumption to economic growth (growth hypothesis), or a causal relationship running from economic growth to energy consumption (conservation hypothesis), or the absence of a causal relationship between economic growth and energy consumption (neutrality hypothesis). In the case of other countries, not only have these studies established the previous hypotheses found in the case of Benin (either the growth hypothesis, or the conservation hypothesis, or the neutrality hypothesis) but they have also found a bidirectional causality between energy consumption and economic growth (feedback hypothesis). For example, 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 a country like 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 even 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 should increase its supply of energy 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

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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 in these countries such as CO_2 emissions. 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, the DRC, and 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. Rault et al. (2014) explained that the negative causality observed in these countries is the result of their energy deficit. According to them, these three countries are net importers of total energy. In South Africa for example, the electricity shortages have affected the manufacturing industry and the mining sector. Workers in the mining industry (underground mining) have to cease working sometimes for up to a week, because the mining company cannot garantee an alternative supply of electricity whenever there is a disruption to electricity supply. Zambia and Cameroun have also been facing disruptions to electricity shortages which have affected several industries. 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 national income (proxied by GDP) for 42 African countries, including Benin. Ouedraogo (2013) found opposite results for countries of the Economic Community of West African States (ECOWAS), including Benin: she established a causal relationship running from energy consumption to economic growth (proxied by GDP) in the long run, and a causal relationship running from economic growth (proxied by 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 a 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 (Ouedraogo, 2013; Wolde-Rufael, 2006). These studies have focused on Benin in addition to other countries. In the case of Benin, they have only established that causality runs from electricity consumption to economic growth (proxied by GDP or GDP per capita) (the growth hypothesis). In the case of other countries, they have established either a causal relationship running from economic growth to electricity consumption (the conservation hypothesis), or a bidirectional causality beween electricity consumption and economic growth (the feedback hypothesis), or the absence of causality between electricity consumption and economic growth (the neutrality hypothesis), or the growth hypothesis. For example, 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 coefficient on the error correction term of his model was positive and not significant. Such coefficient, also called speed of adjustment to the long run equilibrium represents the pace at which the dependent variable goes back to equilibrium when there is a variation in the explanatory variables.

If the speed of adjustment is positive, it indicates that the dependent variable is not returning to the long run equilibrium, and this can be due to issues such as misspecification of the model, failure to account for structural change (existence of structural breaks). For the dependent variable to return to equilibrium, the speed of adjustment to the long run equilibrium needs to be negative and significant. For the Democratic Republic of Congo and Benin, Wolde-Rufael 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. The explanation provided by his study for the negative causality found in the case of Tunisia is that as the Tunisian economy grows, it requires less energy. However, Tunisia's energy consumption has been growing and the country has been a net exporter of electricity for many years (see USEIA (2018)). Hence, disruptions to electricity supply are not common in this country as they are in countries such as Benin (See World Bank (2016)). Therefore, the negaitive causality found could be due to the omitted variable bias, because Wolde-Rufael' study is a bivariate analysis, 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. While his study provided no explanation for the negative causality observed, it is important to notice that Gabon has been selfsufficient in term of electricity supply for many years (see USEIA (2018)). Hence, the negative causality observed cannot be due essentially to an electricity supply deficit. Again, it could be due to the omitted variable bias, as the study of Wold-Rufael (2006) is a bivariate analysis.

As reported previously, Ouedraogo (2013) investigated the causal relationship between energy consumption and economic growth for ECOWAS countries, including Benin. Her study was not limited to the relationship between energy consumption and economic growth: she 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 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 recommendation for a specific country. Moreover, only a few of these studies have focused on electricity consumption. No study on Benin has evaluated the losses in GDP resulting from electricity losses. This study fills these gaps by evaluating the losses of GDP due to electricity losses in the Beninese context. It estimates both the effects of electricity supply and consumption on GDP, and then derives 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.

3.2.3 Summary of the current study's contribution

Three main areas of contribution are possible in a dissertation: 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 in previous studies on Benin. Knowledge of the effect of electricity losses on GDP can be of great importance for planning policies on electricity efficiency and electricity supply security in Benin. As mentioned in the introduction, this study is an assessment of the feasibility of the indirect financing mechanism proposed by the national policy framework for electricity to fund the costs of reductions of

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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. Prior to this study, there has been no empirical evaluation of the loss of GDP resulting from electricity losses in Benin.

3.3 METHODOLOGY

3.3.1 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 a factor 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 is 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 Shabaz (2015) and Odularu and Okonkwo (2009), an endogenous growth model was developed for this specific study where energy is one of the independent variables. This model is:

$$G_t = f(A, E_{j,t}, K_t, L_t) \tag{3.1}$$

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 one of the following alternatives: the first is the case where the energy supply variable (*E*) in Equation 3.1 is electricity supply under the hypothesis of absence of losses (*ES*); the second is the case where the energy supply variable (*E*) in Equation 3.1 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 an increase in real GDP? In other words, what is the loss in terms of real GDP as a result of electricity losses? There are two scenarios in Equation 3.1: 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 3.1 becomes:

$$G_t = AE_{j,t}^{\phi_j} K_t^{\rho_j} L_t^{\theta_j} \varepsilon_{j,t} \tag{3.2}$$

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 3.1.

When taking the logarithm of Equation 3.2 we obtain:

$$Ln(G_t) = Ln(A) + \phi_j Ln(E_{j,t}) + \rho_j Ln(K_t) + \theta_j Ln(L_t) + Ln(\varepsilon_{j,t}) \tag{3.3}$$

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 3.1. Equation 3.3 can be re-expressed as follows:

$$LnG_t = \beta + \phi_j Ln(E_{j,t}) + \rho_j Ln(K_t) + \theta_j Ln(L_t) + \omega_{j,t} \tag{3.4}$$

In Equation 3.4, *β* is a constant term and is equal to *Ln(A)* (see Equation 3.3), and ω_t represents the residual terms and is equal to $Ln(\varepsilon_t)$ (see Equation 3.3). From Equation 3.4, we can infer that growth in output is a function of growth in labour, electricity supply/consumption and capital. The study first analyses 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 4.4. 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), Narayan and Smyth (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), Soytas, Sari and Ewing (2007), this study uses labour force (population (number of individuals) 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 the variables of interest in this model. The variables of interest here are electricity supply (*ES*), electricity consumption (*EC*) and real GDP.

3.3.2 Data

We have 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

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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. Series on *RGDP* and *GCF* have been collected from the World Development Indicators' (2016) website, while series on electricity consumption (*EC*) and total electricity supplied (*ES*) were collected from the USEIA (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 Shabaz, 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 distributional properties of the data.

3.3.3 Analytical framework

The Akaike Information Criteria (AIC) was used to select the optimal lag in the models in this study. It is crucial to check for the stationarity of the study'sseries 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 a unit root against the alternative hypothesis of no evidence of a 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 free market in 1990 (Constant, 2012; Hounkpatin, 2013; Schneider, 2000). Hence, it becomes necessary to apply to this study's series a unit root test which accounts for structural breaks. Because of the small size of the sample (35 observations), more than one breakpoint in the series was not accounted for, hence the Narayan and Popp (2010),

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Lumsdaine and Papell (1997), Lee and Strazicich (2003), Bai and Perron (1998, 2003), and Bai (1997) unit root tests were not applied. Instead, the MADF (which can be found in eviews 9.5 or 10), and the Zivot Andrew test (ZA), which determine one break date endogenously, have been used. The results of these unit roots with structural break have also been cross-checked with a stationarity test (KPSS). The next step was to investigate the existence of a cointegration relationship among variables of the models.The autoregressive distributive lags (ARDL) bound testing approach developed by Pesaran and Shin (1999), Pesaran, Shin and Smith (2001) and Pesaran and Pesaran (2009) was used 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. The ARDL 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 simultaneously correct 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 do 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:

$$\begin{aligned}\Delta\log RGDP_t &= a_{10} + \sum_{i=1}^{q_1}\beta_{11,i}\Delta\log RGDP_{t-i} + \sum_{i=0}^{q_2}\beta_{12,j,i}\Delta\log E_{j,t-i} + \sum_{i=0}^{q_2}\beta_{13,i}\Delta\log GCF_{t-i}\\ &+ \sum_{i=0}^{q_2}\beta_{14,i}\Delta\log LF_{t-i} + \phi_{11}\log RGDP_{t-1} + \phi_{12,j}\log E_{j,t-1} + \phi_{13}\log GCF_{t-1} + \phi_{14}\log LF_{t-1} + \varepsilon_{1,t}\end{aligned} \tag{3.5}$$

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

$$\begin{aligned}\Delta\log E_{j,t} &= a_{20} + \sum_{i=1}^{q_1}\beta_{21,i}\Delta\log E_{j,t-i} + \sum_{i=0}^{q_2}\beta_{22,j,i}\Delta\log RGDP_{t-i} + \sum_{i=0}^{q_2}\beta_{23,i}\Delta\log GCF_{t-i}\\ &+ \sum_{i=0}^{q_2}\beta_{24,i}\Delta\log LF_{t-i} + \phi_{21}\log E_{j,t-1} + \phi_{22,j}\log RGDP_{t-1} + \phi_{23}\log GCF_{t-1} + \phi_{24}\log LF_{t-1} + \varepsilon_{2,t}\end{aligned} \tag{3.6}$$

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

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

$$+\sum_{i=0}^{q_2}\beta_{34,i}\Delta\log LF_{t-i} + \phi_{31}\log GCF_{t-1} + \phi_{32,j}\log E_{j,t-1} + \phi_{33}\log RGDP_{t-1} + \phi_{34}\log LF_{t-1} + \varepsilon_{3,t} \qquad (3.7)$$

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

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

$$+\sum_{i=0}^{q_2}\beta_{44,i}\Delta\log RGDP_{t-i} + \phi_{41}\log LF_{t-1} + \phi_{42,j}\log E_{j,t-1} + \phi_{43}\log GCF_{t-1} + \phi_{44}\log RGDP_{t-1} + \varepsilon_{4,t} \qquad (3.8)$$

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 noted 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 3.5 to 3.8, the main interest for purposes of this study is the relationship between electricity supply/consumption and economic growth of Equation 3.5. UECMs of Equations 3.6, 3.7 and 3.8 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 3.5, implies an assumption that the UECM in Equation 3.5 is the only viable cointegration vector and the UECMs of equations 3.6, 3.7 and 3.8 are not viable. In order to verify such an assumption, the weak exogeneity test is used, which applies a Wald restriction on the error correction terms (*ECT*) of each of the models 3.5, 3.6, 3.7 and 3.8. 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 3.5, 3.6, 3.7 and 3.8. 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 3.5, 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 lag 1 and 3 (further details are provided in Table 3.2 and Figures 3.2 and 3.3 in the section 3.4.1 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 3.6, 3.7 and 3.8). The result of the lag selection criteria are discussed further (see the section 3.4.1 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 3.5, 3.6, 3.7 and 3.8. The null hypothesis (H0) for each UECM stipulates that there is no cointegration relationship and is:

H0:

$$\forall(h,i) \in \{1,2,3,4\} \text{ x } \{1,2,3,4\}, \phi_{h,i} = 0 \tag{3.9}$$

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

HA:

$$\forall(h,i) \in \{1,2,3,4\} \text{ x } \{1,2,3,4\},\ \exists \phi_{h,i} \in \mathbb{R},\ \phi_{h,i} \neq 0 \tag{3.10}$$

where $\phi_{h,i}$ represents the long-run coefficients of each of the UECMs of Equations 3.5, 3.6, 3.7 and 3.8. In other words:

For the UECM of Equation 3.5, the null hypothesis is:

$$H01: \phi_{11} = \phi_{12} = \phi_{13} = \phi_{14} = 0 \tag{3.11}$$

and the alternative hypothesis is:

$$HA1: \phi_{11} \neq 0; \text{ or } \phi_{12} \neq 0; \text{ or } \phi_{13} \neq 0; \text{ or } \phi_{14} \neq 0 \tag{3.12}$$

For the UECM of Equation 3.6, the null hypothesis is:

$$H02: \phi_{21} = \phi_{22} = \phi_{23} = \phi_{24} = 0 \tag{3.13}$$

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and the alternative hypothesis is:

$$HA2: \phi_{21} \neq 0; \text{ or } \phi_{22} \neq 0; \text{ or } \phi_{23} \neq 0; \text{ or } \phi_{24} \neq 0 \tag{3.14}$$

For the UECM of Equation 3.7, the null hypothesis is:

$$H03: \phi_{31} = \phi_{32} = \phi_{33} = \phi_{34} = 0 \tag{3.15}$$

and the alternative hypothesis is:

$$HA3: \phi_{31} \neq 0; \text{ or } \phi_{32} \neq 0; \text{ or } \phi_{33} \neq 0; \text{ or } \phi_{34} \neq 0 \tag{3.16}$$

For the UECM of Equation 3.8, the null hypothesis is:

$$H04: \phi_{41} = \phi_{42} = \phi_{43} = \phi_{44} = 0 \tag{3.17}$$

and the alternative hypothesis is:

$$HA3: \phi_{41} \neq 0; \text{ or } \phi_{42} \neq 0; \text{ or } \phi_{43} \neq 0; \text{ or } \phi_{44} \neq 0 \tag{3.18}$$

Narayan (2004) stipulated that critical values of Pesaran et al. (2001) were computed on sample sizes that range from 500 to 1000 and are not consistent with small sample sizes. He established a new set of critical values for small samples that range between 30 and 80 observations. Because of the small size of the annual series (35 observations), the reformulated critical value of Narayan (2004), which is more consistent with small samples, will be used, instead of the critical value of Pesaran et al. (2001). The F statistic of the bounds test has a distribution that depends on the number of explanatory variables in the ARDL model, the order of integration of the variables included in the ARDL model, and the existence or not of intercept and/or trend in the ARDL model (see Narayan, 2004, p. 13). Because there is no trend specification, but only an intercept in the unrestricted error correction models (UECM) described previously in equations 3.5, 3.6, 3.7, and 3.8, a critical values’ table on restricted intercept and no trend at 5% significance level will be used, when comparing the value of the bounds test’s F statistic to the reformulated critical values of Narayan (2004). 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 larger than the upper bound critical value of Narayan (2004), then there is evidence of a cointegration relationship between the variables. If the F statistic is less than 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

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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 3.5 (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:

$$\log RGDP_t = b_0 + \sum_{i=1}^{k} b_{1,i} \log RGDP_{t-i} + \sum_{i=0}^{l} b_{2,j,i} \log E_{j,t-i} + \sum_{i=0}^{m} b_{3,i} \log GCF_{t-i} + \sum_{i=0}^{n} b_{4,i} \log LF_{t-i} + \mu_t \qquad (3.19)$$

Short-run model (restricted error correction model):

$$\Delta \log RGDP_t = c_0 + \sum_{i=1}^{k} c_{1,i} \Delta \log RGDP_{t-i} + \sum_{i=1}^{k} c_{2,j,i} \Delta \log E_{j,t-i} + \sum_{i=1}^{k} c_{3,i} \Delta \log GCF_{t-i} + \sum_{i=1}^{k} c_{4,i} \Delta \log LF_{t-i} + \lambda ect_{t-1} + \varepsilon_t \qquad (3.20)$$

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 long-run causality can be inferred; as mentioned before, λ is defined as the pace at which the dependent variables go back to equilibrium, when there is a change in the explanatory variables. If it is positive, then the dependent variable is not returning to equilibrium, and this can be due to structural change issues (failure to account for existing breaks), or a misspecification of the model; for the dependent variable to return to equilibrium, λ must be negative; 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 a structural break. In case such an assumption might appear

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to be wrong, it is necessary to ensure the parameters' stability by inserting a dummy variable in the long- and short-run specification of these models in order to account for a structural break.

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*).

3.4 EMPIRICAL RESULTS

3.4.1 Descriptive statistics and optimal lag selection

Table 3.1 shows that all the variables have a normal distribution and electricity consumption (logEC)/electricity supply (logES), gross capital formation (logGCF) and labour force (logLF) are positively correlated with real GDP (logRGDP). This aligns with the a priori expectation explained previously (in section 3.2.1 on theoretical foundation). Enders (2004) argued that the optimal lag for annual series should range between 1 and 3. At lags 1 and 3, the models of interest F(logRGDP\logEC, logGCF, logLF) and F(logRGDP\logES, logGCF, logLF) are affected by heteroskedasticity and instability of parameters (see Table 3.2 and Figures 3.2 and 3.3 below**.** Hence, lag 2 has been chosen as maximal lag in the lag selection procedure for the annual series. In Table 3.3, 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).

Table 3.1: Descriptive statistics of variables

Descriptive statistics	**Real GDP (logRGDP)**	**Electricity consumption (logEC)**	**Electricity supply (logES)**	**Gross capital formation (logGCF)**	**Labour force (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					

Source: Author’s estimation

Table 3.2: Heteroskedasticity test (Breusch Pagan-Godfrey) at lag 1 for UECMs F(logRGDP\logEC, logGCF, logLF) and F(logRGDP\logES, logGCF, logLF)

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

Source: Author’s estimation

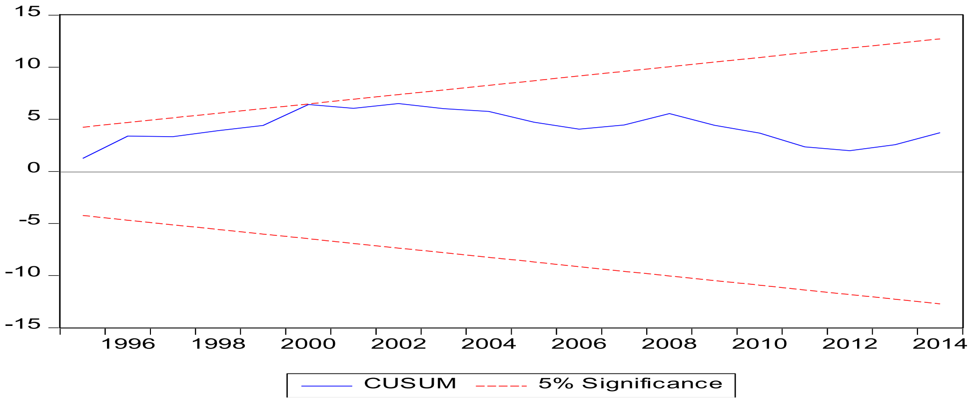

Figure 3.2: Stability test (CUSUM test) at lag 3 for the UECM F(logRGDP\logEC, logGCF, logLF)

Source: Author’s estimation

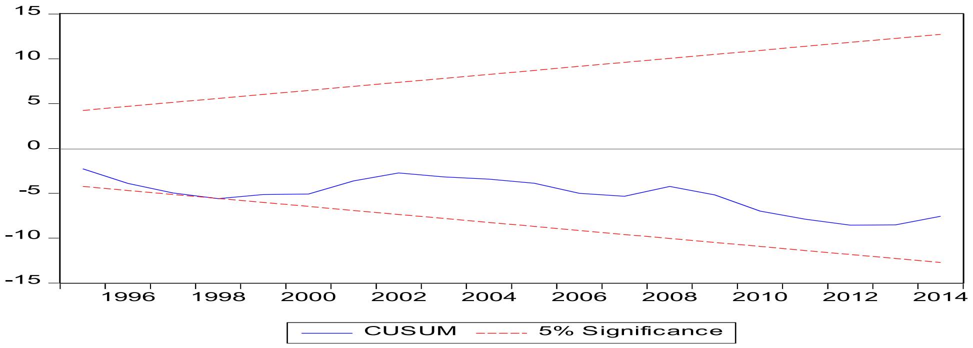

Figure 3.3: Stability test (CUSUM test) at lag 3 for the UECM F(logRGDP\logES, logGCF, logLF)

Source: Author's estimation

Table 3.3: 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
	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

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: Author's estimation

3.4.2 Results of unit root and stationarity tests

Graphs of the series were first observed and it was noticed that they all have a trend and an intercept (Figures 3.4, 3.5, 3.6, 3.7 and 3.8). Next, the ZA unit root, the MADF test with breakpoint, and the 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 3.4 below. The existence of a cointegration relationship among the variables was then investigated, using the bounds testing approach to cointegration.

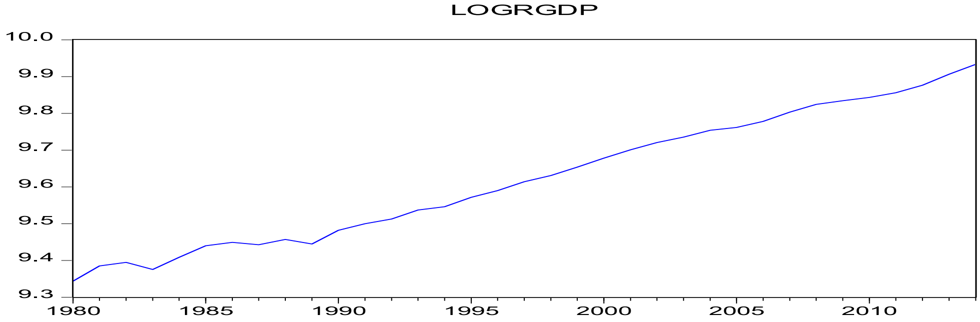

Figure 3.4: History of real GDP (logRGDP*)* in Benin (1980-2014)

Source: Author’s estimation based on data from World Development Indicators (2016)

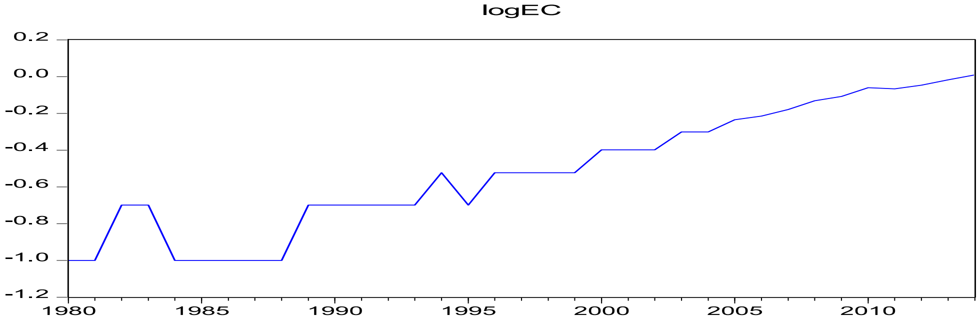

Figure 3.5: History of electricity consumption (logEC) in Benin (1980-2014)

Source: Author’s estimation based on data from USEIA (2016)

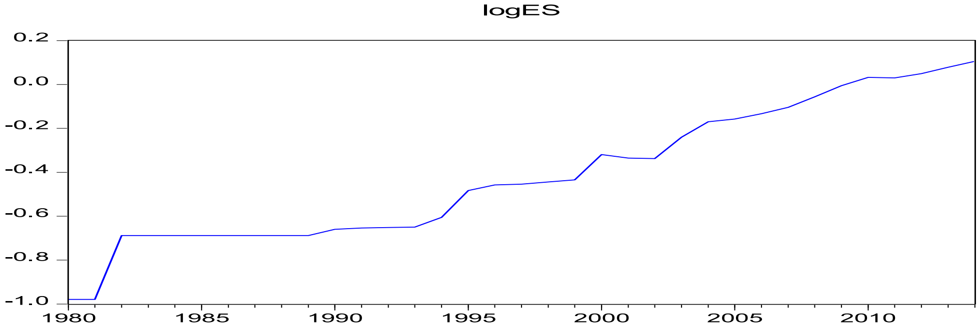

Figure 3.6: History of electricity supply (logES*)* in Benin (1980-2014)

Source: Author’s estimation based on data from USEIA (2016)

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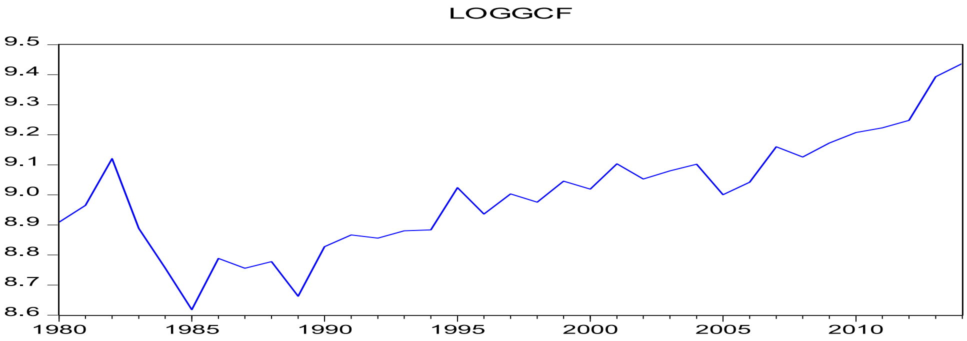

Figure 3.7: History of gross capital formation (logGCF*)* in Benin (1980-2014)

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

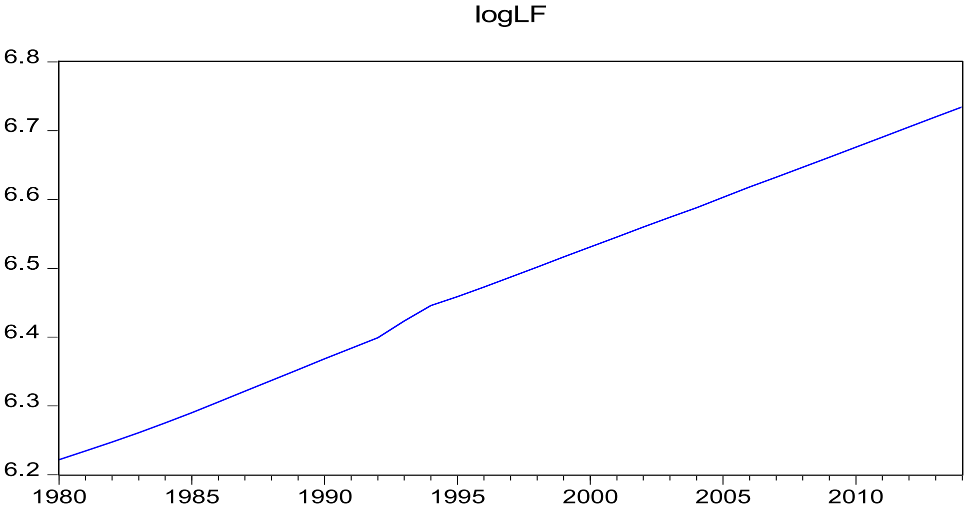

Figure 3.8: History of labour force (*logLF)* in Benin (1980-2014)

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

Table 3.4: 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]

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	1st difference	Intercept and trend	-6.9210 (2)*** [1987]	---	---	-7.1472 (2)*** [1991]	---

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: Author's estimation

3.4.3 Results of cointegration and diagnostic tests

Table 3.5 shows that for both model 1 F(logRGDP\logEC, logGCF, logLF) and model 2 F(logRGDP\logES, logGCF, logLF), the F statistic of the bound 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 3.5). 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), and labour force (LF)).

Table 3.5: Cointegration results for all UECMs

	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,	3.3518	ARDL (1,1,0,0)	2.1937	0.3499	0.4484	4.5537***	0.0036

	logLF)						
	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					

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

The cells in bold represent the models of interest.

Source: Author's estimation

The next step was to verify if the UECMs (F(logRGDP\logEC, logGCF, logLF) and F(logRGDP\logES, logGCF, logLF) were 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 constituted 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 3.6 and 3.7 present the results of the weak exogeneity test.

Table 3.6: Results of the weak exogeneity test (models with logEC as one of the variables)

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)	ΔlogRGDP	-0.348799***	0.0003	17.74745***	0.0000
F(logEC\logRGDP, logGCF, logLF)	ΔlogEC	1.835386**$^{(a)}$	0.0293	5.294696**	0.0214

F(logGCF\logRGDP, logEC, logLF)	ΔlogGCF	0.247019(a)	0.7528	0.101236	0.7504
F(logLF\logRGDP, logEC, logGCF)	ΔlogLF	0.005818(a)	0.7641	0.091864	0.7618

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

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

Source: Author's estimation

Table 3.7: Results of the weak exogeneity test (models with logES as one of the variables)

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

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

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

Source: Author's estimation

Tables 3.6 and 3.7 above show that only the coefficient on the error correction of the models of interest (models in bold in Tables 3.6 and 3.7) (F(logRGDP\logEC, logGCF, logLF) and F(logRGDP\logES, logGCF, logLF)) are significant at 1% and 10%. Tables 3.6 and 3.7 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.

When looking at the results of the Wald test, it can be seen 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 noted 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 the 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. It was 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 3.8 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 model 1 and 2 were stable, there was no need to ensure parameter stability by inserting a dummy variable which accounts for structural break in the long and short run specifications of these models.

Table 3.8: Diagnostic test results for our models of interest

	Models	**Normality (Jarque-Bera)**	**(LM test) Serial correlation**	**Hetero-skedasticity test (Breusch Pagan-Godfrey)**	**Ramsey test**	**CUSUM**	**CUSUM of Sq**
Model with electricity consumption (EC) (Model 1)	**F(logRGDP\logEC, logGCF, logLF)**	3.5607 (0.1685)	(0.5565)	(0.9610)	(0.9889)	stable	stable
Model with electricity supply (ES) (Model 2)	**F(logRGDP\logES, logGCF, logLF)**	1.0427 (0.5937)	(0.9262)	(0.5445)	(0.1033)	stable	stable

Notes:

Numbers in parentheses represent probability.

Source: Author’s estimation

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

As stated previously, the 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 3.9. 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 per year 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 3.10) 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 in 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 would 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). 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 3.9 and 3.10), a positive sign on the coefficient on gross capital formation and labour force in the current period is observed. This aligns with the 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; Hamilton and Monteagudo (1998); Benos and Zotou (2014)) which states that the correlation between real GDP and each of the independent variables (gross capital formation and labour force) depends on the country context: it can be positive or negative based on the country's economic context. A negative sign on the coefficients on gross capital formation in the past period (GCF(-1)) was observed: 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.

Table 3.9: Long-run models

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

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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

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

Source: Author‘s estimation

Table 3.10: Short-run models

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

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

Source: Author‘s estimation

3.4.5 Discussion and policy recommendations

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 human illegal 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. This 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. As noted in the introduction chapter, based on data from USEIA (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 per year because of electricity losses. In 2014, for instance, Benin lost about US$ 13,7 million constant 2010 because of losses of electricity (Figure 3.9). Based on statistics from the World Development Indicators (2018), such loss represents 1.022% of total government expenditure in 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 meant some economic gains for the country. As Figure 3.9 shows, the annual GDP losses due to electricity losses have been increasing from 1980 to 2014.

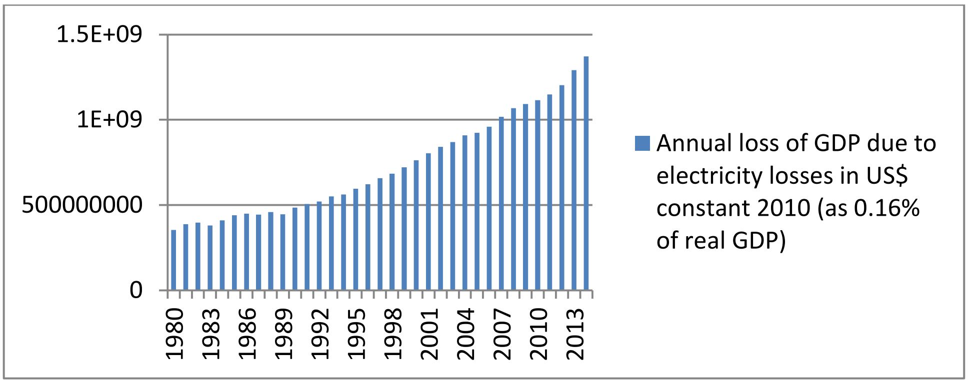

Figure 3.9: History of losses of GDP due to losses of electricity (in US$ constant 2010, and as 0.16% of GDP) in Benin (1980-2014)

Source: Author's estimation based on data from USEIA (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

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electricity is to ensure electricity efficiency in Benin. In order to align with such a 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 a 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 the 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 a mechanism proposed to use funds from donors or the national budget to finance the costs of activities that would 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 a 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 theft 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 an increase will correspond to a reduction in electricity imports. Consequently, the 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 contributes to the advancement of electricity efficiency policy and electricity security policy, which target to reduce disruptions to electricity supply caused by electricity losses.

3.5 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. Definitively, the 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 shown 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 therefore contributes to advance electricity efficiency and electricity security policy aiming at reducing disruption to electricity supply caused by electricity losses. It also adds value to the existing literature on electricity efficiency and electricity security in Benin.

Although losses of electricity constitute a major source of vulnerability of the Beninese electricity sector, they are just one challenge among many. The country has also encountered significant shortages of electricity. These shortages of electricity constitute negative shocks on electricity supply (electricity supply net of losses; see definition in section 3.3.1). The national policy framework for electricity (République du Bénin, 2008) has reported that these negative shocks to electricity supply cause negative shocks to economic growth in Benin. There is no empirical study on Benin which has verified whether negative shocks to electricity supply cause negative shocks to economic growth. As reported by the World Development Indicators (2017), the share of electricity consumption (electricity supply net of losses or electricity supply minus electricity losses (in the case of Benin); see IEA statistics (2018)) 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 or electricity supply net of losses have no causal effect on negative shocks to economic growth. It therefore becomes important to verify empirically whether

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or not negative shocks to electricity consumption or electricity supply net of losses cause negative shocks to economic growth. This constitutes the focus of the next chapter.

CHAPTER 4[3]

THE EFFECT OF NEGATIVE SHOCKS TO ELECTRICITY SUPPLY ON NEGATIVE SHOCKS TO ECONOMIC GROWTH

4.1 INTRODUCTION

As explained in chapter 1 (section 1.3), the electricity that is distributed to consumers after exclusion of electricity losses is the electricity supply net of losses, and is also called electricity consumption. In this chapter, electricity supply should be understood as electricity supply net of losses. In general, there are four different hypotheses that have been established in the literature on the causal relationship between energy consumption and economic growth (Payne, 2010; Lee, 2006; Apergis and Payne, 2011; Ozturk, 2010, Ewing, Sari and Soytas, 2007; Soytas and Sari, 2003; Apergis and Payne 2009a, 2009b; Bowden and Payne, 2009, 2010). The first is the growth hypothesis, which stipulates that causality runs from energy consumption to economic growth. The second is the conservation hypothesis, which stipulates that causality runs from economic growth to energy consumption. The third is the feedback hypothesis, which states that there is bidirectional causality between energy consumption and economic growth. The fourth is the neutrality hypothesis, which stipulates that no causal relationship exists between energy consumption and economic growth. These four hypotheses are largely discussed among the very few studies which have investigated the relationship between economic growth and energy/electricity consumption for Benin. Most of these studies are cross-country analyses.

Wolde-Rufael's (2009) study of 17 African countries, using a Vector Autoregressive (VAR) model comprising variables such as growth, energy consumption, capital and labour, established for three of these countries, including Benin, the existence of a causal relationship that runs from energy consumption to economic growth. He argued that in these three countries any energy conservation policy would harm economic growth. He suggested that a country like Benin must increase its energy use in terms of quantity and quality for sustainable economic growth. However, Wolde-Ruafel's (2005) study of 19 African countries, using the bound test and Toda Yamamoto approaches to Granger causality in a bivariate framework, established for nine of these countries, including Benin, that there is no causal relationship between energy and growth. This absence of causality can be the result of omitted variables bias related to bivariate models as explained earlier by Lütkepohl (1982) and further by Wolde-Rufael (2009).

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Al-mulali and Binti Che Sab (2012) established for 30 African countries including Benin, that total primary energy consumption causes economic growth and financial development but with CO_2 pollution in these countries. Rault et al. (2014) using a VAR model and 16 African countries, including Benin, established a causal relationship that runs from economic growth to energy consumption for Algeria. They established a bidirectional causal relationship between economic growth and energy consumption for Ethiopia, and a positive causal relationship that runs from energy consumption to economic growth for seven of these countries (Tunisia, Egypt, Kenya, Senegal, Tanzania, DRC, Morocco). They established a negative causal relationship that runs from energy consumption to economic growth for South Africa, Zambia and Cameroun. They found no causal relationship between economic growth and energy consumption in the case of Benin.

Dogan (2014) established a causal relationship that runs from energy consumption to economic growth in the case of Kenya. However, he posited that no causality exists between energy consumption and economic growth in the case of Benin, Zimbabwe and Congo. Menegaki and Tugcu (2016) found no evidence of causality between GDP and energy consumption for 42 African countries, including Benin. Ouedraogo (2013) for countries of the Economic Community of West African States (ECOWAS), including Benin, found opposite results: causality from GDP to energy consumption in the short run and causality from energy consumption to GDP in the long run. She also established a causal relationship that runs from electricity consumption to GDP in the long run. Fatai (2014) investigated the causal relationship between economic growth and energy consumption for 18 sub-Sahara African countries, and established the absence of a causal relationship between energy consumption and economic growth in Central and Western Africa, including Benin, while in Eastern and Southern Africa he established a causal relationship that runs from energy consumption to economic growth.

Zerbo (2017) investigated the relationship between economic growth and energy consumption for 13 sub-Saharan African economies, including Benin, and established a long-run relationship between economic growth and energy consumption for eight of these 13 economies. He also established the absence of a causal relationship between energy consumption and economic growth for Benin, Togo, Senegal, Côte d'Ivoire, Congo, Ghana, and South Africa. For Kenya, Gabon and Nigeria, he established a causal relationship that runs from energy consumption to economic growth, while for Zambia and Sudan; he established a causal relationship that runs from economic growth to energy consumption. He established a bidirectional causal relationship between economic growth and energy consumption for Cameroon. Kahsai, Nondo, Schaeffer and Gebremedhin (2012) for a group of 40 sub-Saharan African countries, including Benin, established a long run bidirectional causality between economic growth and energy consumption. In the short run, their finding supports the neutrality hypothesis for the low-income countries of this group, including Benin.

Very few of the studies which have investigated the relationship between energy consumption and economic growth in Benin, have focused on electricity consumption (Wolde-Rufael (2006), Ouedraogo (2013)). Wolde-Rufael (2006) considered 17 African countries, including Benin, using the bound testing and Toda Yamamoto approaches to Granger causality in a bivariate framework with electricity consumption per capita as dependent variable. He established for four of these countries, including Benin, a long-run relationship between GDP per capita and electricity consumption per capita. However, in the case of Benin and two other African countries the error correction term was neither negative nor significant. In addition, there was a positive unidirectional causality running from electricity consumption per capita to GDP per capita in the case of Benin and the Democratic Republic of Congo, while in Tunisia the same unidirectional causality was established but was negative. In Gabon, there was a positive causal relationship running from GDP per capita to electricity consumption per capita, and a negative unidirectional causality running from electricity consumption per capita to GDP per capita. As mentioned previously, Ouedraogo (2013) established a causal relationship that runs from electricity consumption to GDP in the long run for ECOWAS countries, including Benin.

While these studies have attempted to analyse the causal relationship between energy and economic growth in different countries, including Benin, it is important to acknowledge that with the differing results provided by these studies, it becomes impossible to conclude the true direction of the causal relationship between energy/electricity consumption and economic growth. These differing results highlight the complexity of the causal relationship between economic growth and energy/electricity consumption, and indicate the necessity of investigating the possibility of a nonlinear or asymmetric relationship between these two variables. Accounting for asymmetry is important as positive shocks or negative shocks on one variable may not necessarily have the same impact on another variable. The existence of an asymmetric relationship can be the result of the complexity of the structure of the economy and the various channels through which one variable influences the other. As argued by Chiou-Wei, Chen and Zhu (2008) such complexity appears because of economic shocks, regime change, and change in the economic structure and environment such as modifications in energy prices and policy.

In the case of Benin, the country's economic and political regime has encountered different changes. From 1960 to 1971 the country allowed free market and free enterprise, but was shaken by several military coups which have affected its macroeconomic and political stability. From 1972 to 1989, the country was under a socialist and military regime where free market, free enterprise and democracy were restricted. Most major companies and banks were owned by the state, and because of government political and social agenda, most energy prices were subsidised. Since 1990, when the country returned to democracy, free market and free enterprise (Schneider, 2000), energy prices (oil and electricity prices) are still subsidised (Hounkpatin, 2013) but to a lower extent compared to the previous period. These changes in the economic system (from an economy with a restricted free market and free enterprise to an economy with total free market and free enterprise), and changes in the political regime (from a socialist and military dictatorship to a democracy), are some of the causes of the complexity of the economic structure in Benin, as well as the complexity of the various channels through which economic growth and energy consumption influence each other. Therefore, this study uses an asymmetric approach to differentiate between the effect on economic growth of positive and negative shocks to electricity supply, in keeping with the aim of the study which is to verify if negative shocks to electricity supply (electricity supply net of losses or electricity consumption) cause a negative shock on real GDP in Benin.

As mentioned before, there have been several electricity crises in Benin due to outages of electricity supply to consumers: in 1994, 1998, 2006, 2007, 2008, 2012 and 2013 for instance. These outages of electricity supply to consumers (electricity consumption) or negative shocks on electricity consumption were mainly due to factors such as high dependency on the importation of electricity, high rates of electricity losses, a growing domestic demand for electricity, and the inability of the country to invest sufficiently in electricity infrastructure (République du Bénin, 2008). Benin depends on countries such as Ghana, Côte d'Ivoire and Nigeria for the importation of electricity, while these countries also face a growing domestic demand for electricity. Whenever electricity outages occur in these countries, there are severe electricity outages in Benin. This has been the case especially with Ghana, which faced droughts in 1983, 1994 and 1998 which reduced the level of water in the Akossombo hydroelectric dam and limited Ghana's capacity for domestic electricity production. In order to fill its domestic electricity supply gap that was caused by these droughts, Ghana reduced its exports of electricity to Benin and Togo.

During the drought of 1983, Ghana reduced its exportation of electricity to Benin and Togo by 50%. During the drought of 1994, exportation of electricity toward Benin and Togo was reduced to 40 Mw whereas the initial quantity to be exported was 50 Mw. The drought of 1998 affected both Akossombo and Nangbeto dams. The Nangbeto dam owned by Benin and Togo contributes to the domestic production of electricity of these two countries. In 1998, Benin and Togo both faced a reduction in exports of electricity from Ghana, and a reduction of their domestic production of electricity. The initial quantity of electricity that the Beninese Electrical Community (CEB), which ensures the importation of electricity from Ghana, was supposed to supply to Benin and Togo suddenly decreased from 40 Mw to 16 Mw in February 1998, and to 4 Mw in April of the same year (République du Bénin, 2008; Hounkpatin, 2013).

These reductions in the imports of electricity resulted in severe electricity outages in Benin and have affected the revenues of firms in the country as well as the ease of doing business. As reported by the World Development Indicators (2016), because of electricity outages in 2009 and 2016, firms lost 6.2% and 9.4% respectively of their sales value in Benin.

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Table 4.1 presents the state of access to electricity by firms in Benin in 2016. It can be seen that 95.6% of firms in Benin experienced electricity outages in that year. The number of electrical outages per month was 28; the average duration for the total outages per month was 103.6 hours, while each outage lasted for 3.7 hours on average (Table 4.1). This situation generated additional costs for firms because they had to acquire electrical generators in order to reduce the impact of electricity outages. Hence, 59.9% of firms in the country own or share a generator, which supplies them with only 37% of their need in terms of electricity (Table 4.1). This indicates that although many firms use or share a generator, 63% of their electricity consumption is still exposed to outages. With all these significant electricity outages encountered by firms in the country, 60.4% of them have identified electricity as a major constraint for the ease of doing business in Benin (Table 4.1).

Table 4.1: The state of access to electricity by firms in Benin in 2016

Indicators of ease of doing business as related to access to electricity	**All countries average**	**Sub-Saharan Africa average**	**Benin average**
Percentage of firms experiencing electrical outages	59.1	78.7	95.6
Number of electrical outages in a typical month	6.3	8.5	28.0
If there were outages, average duration of a typical electrical outage (hours)	4.5	5.8	3.7
Average duration of the total outages in a typical month (hours)	28.35	49.3	103.6
Percentage of firms owning or sharing a generator	34.4	53.2	59.9
If a generator is used, average proportion of electricity from a generator (%)	20.7	28.2	37.0
Percentage of firms identifying electricity as a major constraint	31.3	39.8	60.4

Source: World Bank (2016) (enterprise survey data)

While electricity outages have negatively affected the ease of doing business and firms' sales values, it is not obvious that they have impeded economic growth. The national policy framework for electricity (République du Bénin, 2008) reported that these electricity outages have impeded economic growth. However, to the best of the writer's knowledge, there is no empirical evidence which has demonstrated that negative shocks on electricity supply have caused negative shocks on economic growth in Benin. In addition, according to the World Development Indicators (2017), over 44 years (1971-2014) (the period for which data was available at the time of analysis), the share of electricity consumption in total primary energy consumption in the country has been very low: it never exceeded 2.07%. This indicates that it is possible that negative shocks on electricity consumption have not caused negative shocks on economic growth, because the proportion of electricity consumption in total primary energy consumption is very low.

It becomes necessary therefore to verify empirically if negative shocks on electricity consumption have caused negative shocks on economic growth. The current study conducts such verification. As stated previously, the study uses an asymmetric approach to separate the effect on economic growth of negative shocks on electricity supply (electricity supply net of losses, in other words electricity consumption) from that of positive shocks on electricity supply. Using a symmetric approach would not allow such separation, which is essential as the study focuses specifically on the effect of negative shocks. The study seeks to verify if negative shocks on electricity supply have caused negative shocks on real GDP, since this will add value to the policy dialogue on electricity security in Benin, and will contribute to the formulation of the national policy framework on electricity security in the country. It will also add value to the existing literature on asymmetric causality between energy supply/consumption and economic growth. This chapter now goes on to review the theoretical foundation of the relationship between economic growth and energy consumption, as well as previous studies on the asymmetric relationship between electricity consumption and economic growth.

4.2 LITERATURE REVIEW

4.2.1 Theoretical foundation of the relationship between energy and economic growth

For several decades, energy was not considered as factor of production as are capital and labour. Growth models of Solow (1956) which consider technological change as exogenous, and endogenous growth models such as the Schumpeterian model, the “learning by doing“ model developed by Arrow (1962), and the “induced innovation” model of Hicks (1932), do not account for energy among factor of production.

Differing from theorists of these growth models, ecological economists (Ayres and Warr, 2005, 2009; Costanza, 1980; Georgescu-Roegen (1971), Murphy and Hall, 2010; Cleveland et al., 1984; Hall et al., 1986, 2001, 2003) argued that energy is fundamental for economic growth. In alignment with them, some scholars in economic history (Allen, 2009; Wrigley, 1988) and geography (Smil, 1994) argued that energy is an important factor of economic growth and was also one of the main factors which determined the industrial revolution. Wrigley (1998) argued that the use of a new type of energy such as fossil fuel has leveraged existing constraints on the supply of energy, the production process, and economic growth. He compared British and Dutch economies: in the Dutch economy, capital accumulation was constrained by the lack of a continuous availability of energy, while that constraint was lifted in the British economy because of the availability of coal mines. Hence, the industrial revolution occurred in the British economy while it could have occurred in both economies. In alignment with Wrigley (1988), Allen (2009) and Stern (2010) point out the importance of energy in the industrial revolution in the British economy. Ecological economists such as Hall et al. (1986, 2003) and Cleveland et al. (1984) argued that an increase in

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productivity is mainly the result of an increase in the use of energy, and economic growth occurs only as a result of increases in the use of energy.

In contrast to Solow (1956) and theorists of the endogenous growth model, Stern (2010) argued that energy is fundamental for economic growth and should be considered as a factor of production, as are capital and labour. His view differs from the ecological economists' views as he posits that energy is not the only factor of production. According to Stern (1997), there is a limit to the substitution of capital and labour for energy, hence energy remains an important factor of production as are capital and labour. Stern (2010) posits that energy is fundamental for economic growth; and the production process requires energy, labour and capital. He proposed a modified version of Solow's (1956) model of economic growth by including energy as a factor of production. Based on these theories on the relationship between energy and economic growth, a positive correlation between economic growth and energy can be expected. In other words, positive shocks on energy supply/consumption are associated with positive shocks on economic growth, while negative shocks on energy supply/consumption are associated with negative shocks on economic growth.

4.2.2 Empirical literature on the asymmetric relationship between energy/electricity consumption and economic growth

There have been very few studies which have used an asymmetric approach to differentiate between the effect of positive and negative shocks when investigating the relationship between energy/electricity consumption and economic growth. The main reason is that the ability to make such differentiation was only made possible recently with Granger and Yoon's (2002) asymmetric cointegration (denoted "hidden cointegration") and Hatemi-J's (2012) asymmetric causality test. Because the aim of this study is to investigate the causal effect on the economic growth of negative shocks on electricity supply (electricity supply net of losses, in other words electricity consumption), the focus is mostly on studies that have investigated the asymmetric causal relationship between economic growth and energy/electricity consumption, and differentiated between the causal effect of positive and negative shocks. Among the few studies which have done such an investigation, some have focused on total renewable energy, others on total energy, but very few have focused on disaggregated energy.

Shahbaz et al. (2017) investigated the asymmetric causal relationship between growth and energy consumption in India, and established an asymmetric causality that runs from negative shocks on energy consumption to economic growth. Ranjbar, Chang, Nel and Gupta (2017) investigated the growth-energy nexus in South Africa using the asymmetric frequency domain methodology, and established that negative shocks on energy consumption cause negative shocks to economic growth. One of their main conclusions was that when energy consumption decreases, economic growth also decreases, however an increase in energy consumption will not necessarily lead to an

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increase in economic growth. Destek (2016) established that negative shocks on renewable energy consumption in newly industrialized countries lead to positive shocks in real GDP for Mexico and South Africa, while negative shocks in renewable energy consumption lead to negative shocks in real GDP for India. There was no causal relationship between renewable energy consumption and real GDP for Malaysia and Brazil. He argued that investments made by these countries in their renewable energy sector are initially expensive. Hence, an increase in these costly investments can temporarily be harmful to the economy, while a reduction can temporarily be beneficial. This was the case with South Africa and Mexico.

Bayramoglu and Yildirim (2017) established an asymmetric relationship between energy consumption and economic growth in the long run in the USA, while there was no asymmetric relationship between these two variables in the short run. Ocal, Ozturk and Aslan (2013) found no asymmetric causality between coal consumption and economic growth in Turkey. Alper and Oguz (2016), in a study of new members of the European Union, found mixed results on the relationship between renewable energy consumption and economic growth from a group of countries to another: the growth hypothesis was supported for some countries while the neutrality hypothesis was supported for others, and the conservation hypothesis was supported for Czech Republic.

Bayat, Kayhan and Senturk (2017) established that positive shocks on electricity consumption in Turkey do not induce an increase in economic growth, while negative shocks on electricity consumption induce a reduction in economic growth. They also established that both positive and negative shocks on economic growth have a causal effect on electricity consumption. Chen, Inglesi-Lotz and Chang (2017) established the existence of an asymmetric causal relationship between energy consumption (coal and oil) and economic growth in China. Tugcu and Topcu (2018) established an asymmetric relationship between total energy consumption and economic growth in G7 countries. Hatemi-J and Uddin (2012) established that negative shocks on energy consumption per capita cause negative shocks on GDP per capita in the USA, while no evidence of causality was found between positive shocks on energy consumption per capita and positive shocks on GDP per capita.

Tiwari (2014) established an asymmetric causality between economic growth and growths of coal consumption, natural gas consumption, total primary energy consumption, total renewable energy consumption, and electricity consumption in the US economy. Particularly, he established that positive shocks on economic growth caused positive shocks on coal consumption, while positive shocks to electricity consumption caused positive shocks on economic growth. In addition, he established a bidirectional causal relationship between economic growth and growth of natural gas consumption, growth of total primary energy consumption and economic growth, and growth of total renewable energy and economic growth. Moreover, Tiwari (2014) ascertained that negative shocks on the growth of coal consumption caused negative shocks on economic growth, and

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negative shocks on the growth of total renewable energy caused negative shocks on economic growth.

One of the limitations of these studies is that many of them are cross-country analyses, hence are very limited in terms of country-specific policy recommendations. Some, even though they have focused on a specific country, have investigated the link between total energy (aggregate energy) and growth; therefore, they are very limited in terms of policy recommendations for disaggregated energy. Only a few have focused on specific types of energy such as coal, oil, and electricity (Tiwari, 2014; Bayat et al., 2017; Chen et al., 2017; Ocal et al., 2013). As mentioned previously, not all types of energy have the same weight in an economy: some countries are oil dependent, while others rely heavily on imports of electricity, and yet others rely heavily on natural gas revenues. Hence, studies on the disaggregate energy-growth nexus are important for policy recommendations on specific types of energy.

Olayeni (2012) used the hidden cointegration approach to analyse the growth-energy nexus of 12 sub-Saharan African countries, including Benin. He did not extend the analysis to the asymmetric causal relationship between energy consumption and growth, and his study focused on total energy. No study thus far has investigated the causal effect on economic growth of negative shocks on electricity consumption in the context of Benin in a country-specific analysis. As mentioned before, investigating such a causal effect involves a separation of the effect on economic growth of negative shocks on electricity consumption from that of positive shocks on electricity consumption. As mentioned previously, using a symmetric approach will not allow such differentiation, but an asymmetric approach will allow such differentiation. As the relationship between electricity consumption and economic growth can be asymmetric because of the complexity of the channels and mechanisms through which these two variables influence each other, an asymmetric approach will be used when investigating the effect on economic growth of negative shocks on electricity consumption. The current study therefore investigates the causal effect on economic growth (real GDP) of negative shocks on electricity consumption using an asymmetric approach.

4.2.3 Contribution of the study

The current study contributes to the dialogue on the economic burden of disruption risks to the electricity supply in Benin. It also contributes to the formulation of policies for electricity supply security in that country. As noted previously, although the national policy framework for electricity has stipulated that electricity shortages caused a reduction in economic growth in Benin, there is no empirical evidence (to the best of the writer’s knowledge) which has demonstrated that negative shocks on electricity consumption have caused negative shocks on economic growth. The current study will ascertain for the national policy framework for electricity the existence or not of a causal effect of electricity shortages on economic growth. In addition to its contribution to electricity supply

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policy in Benin, the current study will also add value to the literature on electricity security and economic growth.

4.3 METHODOLOGY

4.3.1 Empirical model

Unlike neoclassic economists who consider labour, capital and technology as factors of production, Alam (2006) indicated the necessity to include energy among factors of production. He indicated that energy was used as a factor of production, and is a driver of economic growth, therefore it should be considered as a factor of production such as capital and labour. Following the work of Odularu and Okonkwo (2009) andShabaz (2015), an endogenous growth model (where electricity is among the independent variables) was developed to describe the relationship between electricity consumption (electricity supply net of losses) and economic growth. This model is as:

$$Y_t = f(A, EC_t, K_t, L_t) \tag{4.1}$$

where*, A, EC, L* and *K* are respectively technology, electricity consumption, labour and capital, and where *Y* represents real GDP.

However, the focus of this study is not to model the relationship between electricity consumption and economic growth and to estimate the coefficients on the different explanatory variables (electricity consumption, labour and capital). Rather, the focus is to verify if negative shocks on electricity consumption have caused negative shocks on economic growth. As discussed previously, such verification will be done using an asymmetric approach described in the analytical framework.

4.3.2 Analytical framework

First, in order to avoid spurious regression, it is important to check the stationarity of the series. A variety of unit root procedures tests the null hypothesis of the existence of a unit root against the alternative hypothesis of the absence of a unit root. Significant among them are the Elliott, Rothenberg and Stock (1996) (DF-GLS), Augmented Dickey Fuller (ADF), and Phillip Perron (PP) tests. Other tests such as Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test the null hypothesis of the absence of a unit root (evidence of stationarity) against the alternative hypothesis of the presence of a unit root. However, the PP and ADF tests have a lower power in testing for unit roots when compared to DF-GLS, because they fail to detect I(0) series with patterns which resemble I(1) series. Hence, the unit root tests used in this study were the ADF, PP, KPSS and DF-GLS tests.

Perron (1989) argued that the results of the ADF test are biased when there is evidence of structural breaks among data. The Beninese economy encountered several different shocks over the last few years: the devaluation of the CFA currency by 50% in 1994, the electricity crises of

1984, 1994, 1998, 2006, 2007, 2008, 2012 and 2013, and the shift from a socialist regime to free market, private ownership and democracy in 1990 (Hounkpatin, 2013; Schneider, 2000; Constant, 2012). Hence it was important to also apply to the series, a unit root test which accounts for structural breaks in addition to the above tests. Such a unit root test with structural break is the Zivot Andrews (ZA) unit root test, which allows a single breakpoint. A unit root test with single breakpoint was therefore applied rather than a unit root test with multiple breakpoints because of the small size of the series (44 observations).

Second, the asymmetric causality test proposed by Hatemi-J (2012) was used to investigate the causal relationship between the variables. It follows the procedure of Toda and Yamamoto (1995) and separates the effect of positive shocks from that of negative shocks. The idea of separating the effect of positive shocks from that of negative shocks was initially developed by Granger and Yoon (2002). Their work was limited to cointegration analysis where they differentiated between the effect of positive and negative shocks. As stated before, their asymmetric cointegration was denoted the “hidden cointegration”. Hatemi-J (2012) extended their work to asymmetric causality. He defined integrated variables Z_1 and Z_2 as a random walk in the following general expressions:

$$Z_{1t} = Z_{1t-1} + e_{1t} = Z_{10} + \sum_{i=1}^{t} e_{1i}, \qquad t \in \mathbb{N}^* \tag{4.2}$$

$$Z_{2t} = Z_{2t-1} + e_{2t} = Z_{20} + \sum_{i=1}^{t} e_{2i}, \qquad t \in \mathbb{N}^* \tag{4.3}$$

where Z_{10}, Z_{20} represent the initial values of Z_{1t} and Z_{2t}, respectively, and e_{1i}, e_{2i} represent the error terms (white noise) in equations 4.2 and 4.3 respectively. Hatemi-J (2012) argued that the error terms could be decomposed into positive and negative shocks in the following equations:

$$e_{1i} = e_{1i}^{+} + e_{1i}^{-} \qquad i \in \mathbb{N}^* \tag{4.4}$$

$$e_{2i} = e_{2i}^{+} + e_{2i}^{-} \qquad i \in \mathbb{N}^* \tag{4.5}$$

where e_{1i}^{+} and e_{1i}^{-} represent respectively the positive and negative shocks on the variable Z_1, and e_{2i}^{+} and e_{2i}^{-} represent respectively the positive and negative shocks on the variable Z_2. These positive and negative shocks can also be expressed as follows:

$$e_{1i}^{+} = (\max e_{1i}, 0) \text{ and } e_{1i}^{-} = (\min e_{1i}, 0), \qquad i \in \mathbb{N}^* \tag{4.6}$$

$$e_{2i}^{+} = (\max e_{2i}, 0) \text{ and } e_{2i}^{-} = (\min e_{2i}, 0), \qquad i \in \mathbb{N}^* \tag{4.7}$$

where the expression *(max e_i, 0)* indicates that the values of e_i (whether e_{1i} or e_{2i}) are superior to 0, while the expression (*min e_i, 0*) indicates that values of e_i (whether e_{1i} or e_{2i}) are smaller than 0.

Hence, Equations 4.2 and 4.3 can respectively be re-expressed in an asymmetric framework as:

$$Z_{1t} = Z_{1t-1} + e_{1t} = Z_{10} + \sum_{i=1}^{t} e_{1i}{}^{+} + \sum_{i=1}^{t} e_{1i}{}^{-}, \qquad t \in \mathbb{N}^* \qquad 4.8$$

$$Z_{2t} = Z_{2t-1} + e_{2t} = Z_{20} + \sum_{i=1}^{t} e_{2i}{}^{+} + \sum_{i=1}^{t} e_{2i}{}^{-}, \qquad t \in \mathbb{N}^* \qquad 4.9$$

where Z_{1t} is a function of its initial value Z_{10} and the sum of its positive and negative variations (shocks) ($\sum e_{1i}{}^{+}$ and $\sum e_{1i}{}^{-}$), and Z_{2t} is a function of its initial value Z_{20} and the sum of its positive and negative variations (shocks) ($\sum e_{2i}{}^{+}$ and $\sum e_{2i}{}^{-}$). The graphs of electricity consumption and real GDP, as well as the unit root tests results, showed that these two variables followed random walk processes (see empirical results section). Following the asymmetric framework of Hatemi-J (2012) which separates negative shocks from positive shocks in Equations 4.8 and 4.9, the real GDP (*RGDP*) and electricity consumption (*EC*) (both variables are random walks; see Section 4.3.3 for further explanation) have been expressed as a function of their initial value and the sum of their positive and negative shocks as:

$$RGDP_t = RGDP_0 + \sum_{i=1}^{t} \Delta RGDP_i^{+} + \sum_{i=1}^{t} \Delta RGDP_i^{-} \qquad 4.10$$

$$EC_t = EC_0 + \sum_{i=1}^{t} \Delta EC_i^{+} + \sum_{i=1}^{t} \Delta EC_i^{-} \qquad 4.11$$

where $RGDP_0$ and EC_0, represent the initial value of real GDP and total electricity consumption in their respective series, $\Delta RGDP^{+}$ and ΔEC^{+} represent the positive variations of real GDP and electricity consumption respectively, and $\Delta RGDP^{-}$ and ΔEC^{-} represent the negative variations of real GDP and electricity consumption respectively. For simplicity, the sum of positive variations of any variables will be denoted by the name of the variable and the suffix Pos and the sum of negative variations of any variables will be denoted by the name of the variable and the suffix Neg. In other words as seen in the following:

For real GDP:

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$$\sum_{i=1}^{t} \Delta RGDP_i^{+} = \sum_{i=1}^{t} \max(\Delta RGDP_i, 0) = RGDPPos_t, \quad t \in \mathbb{N}^* \tag{4.12}$$

$$\sum_{i=1}^{t} \Delta RGDP_i^{-} = \sum_{i=1}^{t} \min(\Delta RGDP_i, 0) = RGDPNeg_t, \quad t \in \mathbb{N}^* \tag{4.13}$$

For electricity consumption:

$$\sum_{i=1}^{t} \Delta EC_i^{+} = \sum_{i=1}^{t} \max(\Delta EC_i, 0) = ECPos_t, \quad t \in \mathbb{N}^* \tag{4.14}$$

$$\sum_{i=1}^{t} \Delta EC_i^{-} = \sum_{i=1}^{t} \min(\Delta EC_i, 0) = ECNeg_t, \quad t \in \mathbb{N}^* \tag{4.15}$$

where *RGDPPos* and *ECPos* represent the sums of the positive variation of real GDP and electricity consumption respectively; and *RGDPNeg* and *ECNeg* represent the sums of the negative variation of real GDP and electricity consumption respectively. As said previously, max (variable, 0) indicates that the values of such variable (either $\Delta RGDP$ or ΔEC) are positive, while min (variable, 0) indicates that the values of such a variable (either $\Delta RGDP$ or ΔEC) are negative. Positive shocks on real GDP and electricity consumption are represented respectively by *RGDPPos* and *ECPos*, while *RGDPNeg* and *ECNeg* represent negative shocks on real GDP and electricity consumption respectively. The aim of the study is to verify if negative shocks on electricity consumption have caused negative shocks on economic growth (proxied here by real GDP). In other words, the aim is to verify if *ECNeg* has caused *RGDPNeg*. To make such verification, the asymmetric causality test of Hatemi-J (2012) is used, which separates the effect of negative shocks from that of positive shocks.

Hatemi-J (2012) used the following VAR framework to run the asymmetric causality test:

In the case of causality between positive shocks:

$$Z_t^{+} = w + B_1 Z_{t-1}^{+} + \ldots\ldots + B_p Z_{t-p}^{+} + \varepsilon_t^{+} \tag{4.16}$$

In the case of causality between negative shocks:

$$Z_t^{-} = w + B_1 Z_{t-1}^{-} + \ldots\ldots + B_p Z_{t-p}^{-} + \varepsilon_t^{-} \tag{4.17}$$

In the case of causality between positive shocks and negative shocks

$$Z_t = w + B_1 Z_{t-1} + \ldots\ldots + B_p Z_{t-p} + \varepsilon_t \tag{4.18}$$

where w represents a 2x1 intercepts' vectors, Z_t^+ represents a 2x1 variables' vector (Z_{1t}^+, Z_{2t}^+), Z_t^- represents a 2x1 variables' vector (Z_{1t}^-, Z_{2t}^-), Z_t represents a 2x1 variables' vector (Z_{1t}^+, Z_{2t}^-) or a 2x1 variables' vector (Z_{1t}^-, Z_{2t}^+), B_k represent a 2x2 matrix parameters with lag order k ($k = 1,\ldots.p$), ε_t^+, ε_t^+ and ε_t^- represent a 2x1 error terms' vector. Prior to running a causality test using a VAR framework, it is necessary to identify the optimal lag length of such a VAR framework. Hatemi-J (2012) developed a new lag selection criterion as:

$$HJC = \ln(\left|\widehat{\theta}_k\right|) + k[\left(n^2 \ln T + 2n^2 \ln(\ln T)\right)/2\mathrm{T}], \qquad k = 0,\ldots, p \qquad 4.19$$

where $|\theta_k|$ represents the determinant of the computed variance-covariance matrix of the VAR model's residuals, k represents the lag order in the VAR model, and T and n represent respectively the number of observations and the number of equations in the VAR model with lag order k. The lag order that minimizes Hatemi-J's (2012) new criteria is the optimal. Hatemi-J (2012) also argued that a Wald test could be used to investigate asymmetric causality between variables. This is possible as long as the asymptotic properties of the Wald test are not violated. Once the selection of the optimal lag is completed, the next step is to test the validity of the null hypothesis stated as:

i) in the case of the causal effects of positive shocks:

the kth element of Z_{1t}^+ does not impact on the wth element of Z_{2t}^+

ii) in the case of the causal effect of negative shocks:

the kth element of Z_{1t}^- does not impact on the wth element of Z_{2t}^-

iii) in the case where positive shocks cause negative shocks:
the kth element of Z_{1t}^+ does not impact on the wth element of Z_{2t}^-

iv) in the case where negative shocks cause positive shocks:
the kth element of Z_{1t}^- does not impact on the wth element of Z_{2t}^+.

In other words and according to Hatemi-J (2012) the null hypothesis (H0) in all cases is:

H0: the row w, column k element in B_r equals zero for $r = 1,\ldots p$.

In general, causality tests designed on the basis of bootstrapping distributions have superior power and size properties compared to causality tests designed on the basis of asymptotic distribution, especially in cases where the asymptotic properties of the latter are violated (Hatemi-J, 2012). One of the advantages of using the asymmetric causality test of Hatemi-J (2012) is that it overcomes the limitation of the Wald test in terms of normality and the ARCH effect. When there is the presence of the ARCH effect and when the data does not have a normal distribution, then the asymptotic properties of the Wald test are violated.

To solve these issues, Hatemi-J (2012) proposed the use of bootstrapping simulations. These simulations are done repeatedly for ten thousand times and during each simulation the Wald test statistic is calculated. This approach helps to generate the distribution of the Wald test. After generating the distribution of the bootstrapped Wald test, the next step is to calculate the bootstrapped critical values. For any β-level of significance, the bootstrapped critical values (CV_β) are estimated by identifying the β^{th} upper quantile of the bootstrapped Wald test's distribution.

Lastly, the Wald test statistic is estimated based on the original data, and its value is compared to the bootstrapped critical values (CV_β). If the value of the Wald test statistic estimated last (estimated based on the original data) is greater than the bootstrapped critical values (CV_β), then the null hypothesis stating that there is no causality is rejected. In other words, there is evidence of an asymmetric causality between the variables (either between the positive shocks Z_{1t}^+ and Z_{2t}^+, or between the negative shocks Z_{1t}^- and Z_{2t}^-, or between positive and negative shocks (Z_{1t}^+ and Z_{2t}^-; or Z_{1t}^- and Z_{2t}^+)).

Apart from the statistical development of his asymmetric causality test, Hatemi-J (2012) also developed some written codes in GAUSS which are used to run the test. This study makes use of such GAUSS codes to run the asymmetric causality test between the variables.

4.3.3 Data

As said previously, following Shabaz et al. (2017) and Hoang, Lhiani and Heller (2016), initially all variables were converted into their logarithmic form, in order for them to have proper distributional properties. The annual series of real GDP (RGDP) and electricity consumption (EC) were collected over the period 1971-2014. Series of RGDP are expressed in constant 2010 US$, while series of EC are expressed in kilowatt-hours (kWh). All series (RGDP and total EC) have been collected from the World Development Indicators (2018) website. Data on total electricity consumption was not available on the World Development Indicators (2018) website. It was available on the United States Energy Information Administration (2018) website, but not for the period prior to 1980. Data on electricity consumption per capita was available on the World Development Indicators (2018) website for the period 1971-2014. In other to have a larger sample size by taking into account the data existing prior to 1980, the series for total EC was not collected from the United States Energy Information Administration (2018) website; rather, it was obtained by multiplying total EC per capita by total population (also collected from the World Development Indicators (2018) website). Graphs of all variables (EC, RGDP, logEC, logRGDP) show that they all have an intercept and a trend (Figures 4.1, 4.2, 4.3 and 4.4).

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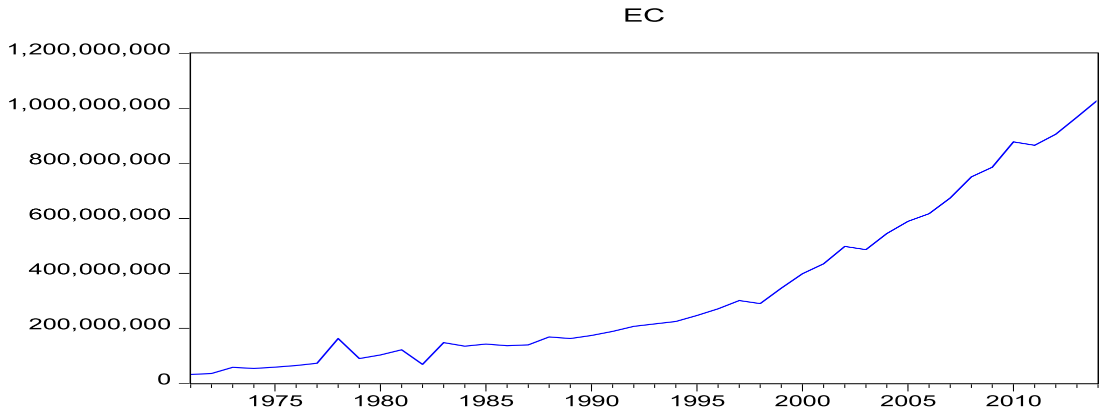

Figure 4.1: History of electricity consumption (in kWh) in Benin (1971-2014)

Source: World Development Indicators (2018)

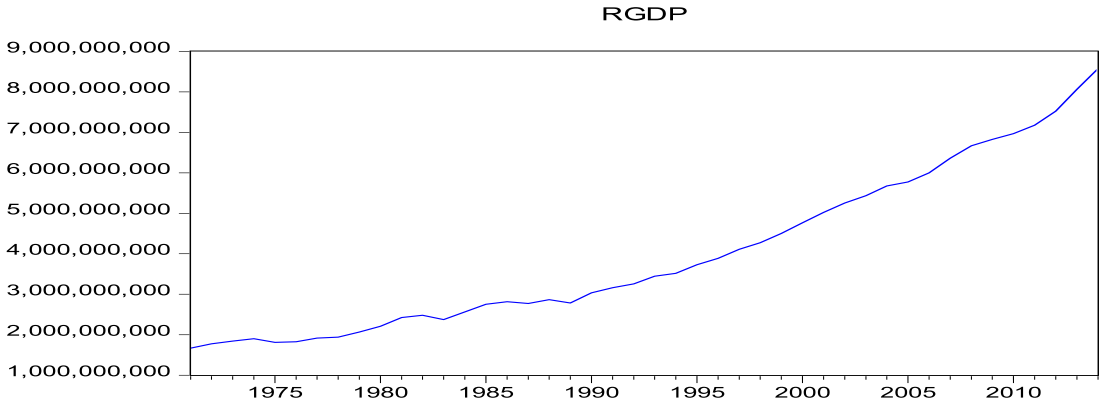

Figure 4.2: History of real GDP at constant 2010 US$ in Benin (1971-2014)

Source: World Development Indicators (2018)

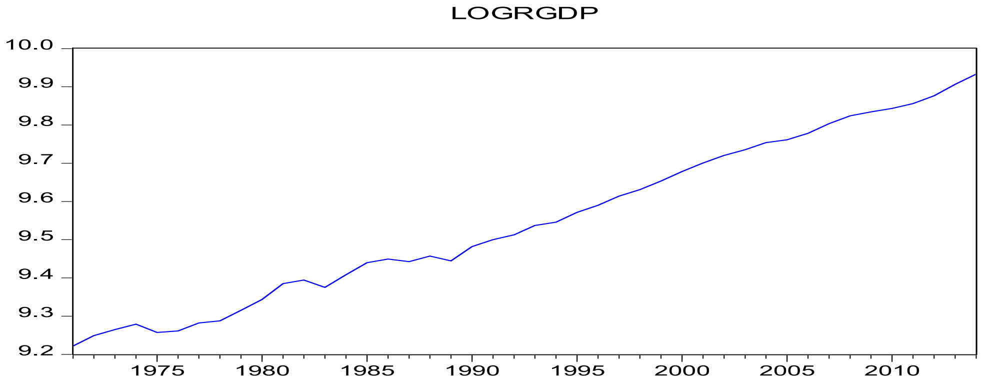

Figure 4.3: History of the logarithm of real GDP in Benin (1971-2014)

Source: World Development Indicators (2018)

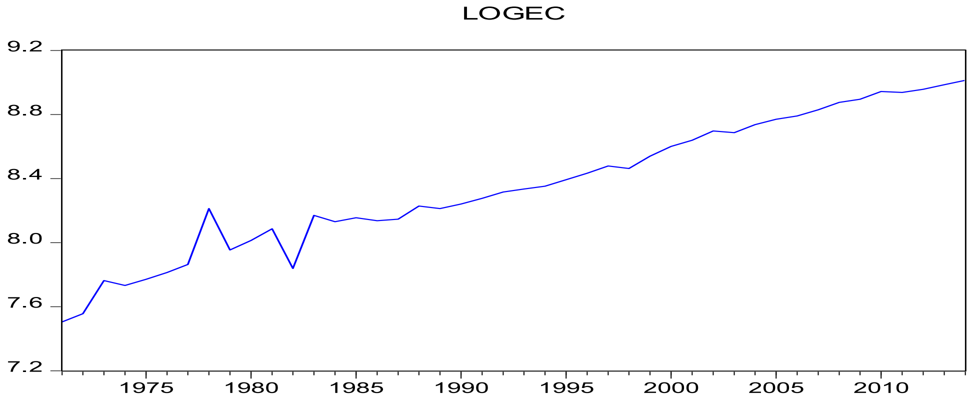

Figure 4.4: History of the logarithm of electricity consumption in Benin (1971-2014)

Source: World Development Indicators (2018)

Hatemi-J, Chang, Chen, Lin and Gupta (2015) argued that it is important to ensure that variables are a random walk before using an asymmetric approach to decompose them into the cumulative sum of their positive and negative variations. On one hand the different unit root tests (ADF test, PP and KPSS tests, and ZA test with structural break) revealed that the logarithm of electricity consumption (logEC) is stationary at level with intercept and trend (see empirical results on unit root tests in Section 4.4 for further details). Hence, logEC does not follow the pattern of a random walk, and therefore in alignment with Hatemi-J et al. (2015) logEC cannot be decomposed in the partial cumulative sum of its positive and negative variation. On the other hand, the different unit root tests applied at both level and first difference with intercept and trend revealed that both EC and RGDP (in their natural form) are I(1) (stationary at first difference). Hence, they follow the patterns of a random walk, and in alignment with Hatemi-J et al. (2015) can be decomposed in the partial cumulative sum of their positive and negative variation. Consequently, this study did not use the variables (EC and RGDP) in their logarithmic form; rather these variables were used in their natural form without any transformation. In other words, the variables used in this study were EC and RGDP rather than logEC and logRGDP.

4.4 EMPIRICAL RESULTS

4.4.1 Results of the lag selection procedures and unit root tests

Before running unit root tests for each of these variables, it is important to identify the optimal lag. Enders (2004) stipulates that the selection of lags for annual data should be in the range of 1 to 3. Hence, first 1, then 2, and finally 3 were chosen as the maximum lag when proceeding for lag specification in the optimum lag selection procedure. The results of the lag selection criteria are described below in Table 4.2, which shows that three criteria (the sequential modified LR statistic, Schwarz information criterion, and Hannan-Quinn information criterion) out of five (sequential modified LR statistic, Akaike information criterion, Final prediction error, Schwarz information criterion, Hanan-Quinn information criterion) selected one (01) as the optimal lag when the

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maximum lag chosen is two (02) or three (03). When the maximum lag chosen is one (01), all five criteria choose one (01) as optimal lag. Hence, one (01) was chosen as the maximum lag when running unit root tests (see maximum lag in round brackets, in table 4.3). However, two (02) was chosen as the maximum lag when running the Zivot Andrews (ZA) unit root test on electricity consumption (EC) at first difference with intercept and trend (see maximum lag in round brackets, in table 4.3): the ZA test cannot be run with one (01) as the maximum lag in that specific case (the ZA test run with one (01) as the maximum lag is inconclusive in that specific case).

As noted previously (in Section 4.3.3), graphs of both electricity consumption and real GDP show that both variables (EC and RGDP) have an intercept and a trend. Hence, different unit root tests have been applied at level with intercept and trend and at first difference with intercept and trend. Table 4.3 presents the results of the different unit root tests (DF-GLS, ADF, PP, KPSS and ZA tests). All tests revealed that EC and RGDP are I(1) (non-stationary at level, but stationary at first difference). Hence, as said before, they have the pattern of a random walk, and in alignment with Hatemi-J et al. (2015), they can be split into the partial cumulative sum of their positive and negative variations. As mentioned previously, the logarithm of EC (logEC) is stationary at level according to the result of the ADF, PP, KPSS and ZA tests. Hence, it does not follow strictly the patterns of a random walk, and in alignment with Hatemi-J et al. (2015), log(EC) cannot be split into the partial cumulative sum of its positive and negative variations. As explained previously, because the logarithm of EC (logEC) is not a random walk, logEC and the logarithm of real GDP (logRGDP) was not used in this study. Instead, EC and RGDP, which are random walks, were used. Both RGDP and EC have been split into the partial cumulative sum of their positive and negative variations in order to run an asymmetric causality test.

Table 4.2: Results of the optimal lag selection

Lag	LogL	LR	FPE	AIC	SC	HQ
Choice of 1 as maximum lag						
0	-1800.284	NA	8.72e+33	83.82717	83.90909	83.85738
1	-1648.780	281.8681*	9.15e+30*	76.96652*	77.21226*	77.05714*
Choice of 2 as maximum lag						
0	-1758.565	NA	8.81e+33	83.83642	83.91917	83.86675
1	-1611.205	273.6689*	9.55e+30	77.00975	77.25798*	77.10073*
2	-1606.239	8.748740	9.14e+30*	76.96377*	77.37750	77.11542
Choice of 3 as maximum lag						
0	-1716.631	NA	8.80e+33	83.83567	83.91926	83.86611
1	-1573.453	265.4032*	9.91e+30	77.04650	77.29726*	77.13781*
2	-1568.563	8.586780	9.51e+30*	77.00310*	77.42104	77.15529
3	-1566.278	3.789997	1.04e+31	77.08675	77.67187	77.29982

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

LR: sequential modified LR statistic

FPE: Final prediction error;

AIC: Akaike information criterion

SC: Schwarz information criterion

HQ: Hannan-Quinn information criterion

Source: Author's estimation

Table 4.3: Unit root tests results

Unit root tests			**Variables**			
			RGDP	**EC**	**logRGDP**	**logEC**
ADF	Level	Intercept and trend	1.372837 (1)	0.798372 (1)	-2.285061 (1)	-6.173720 (1)***
	1st difference	Intercept and trend	-4.883822 (1)***	-10.19749 (1)***	-6.270955 (1)***	---
DF-GLS	Level	Intercept and trend	-0.201127 (1)	-0.227188 (1)	-2.115119 (1)	-3.155564 (1)
	1st difference	Intercept and trend	-4.793749 (1)***	-10.39263 (1)***	-6.068452 (1)***	-8.448562 (1)***
PP	Level	Intercept and trend	2.650053	0.765350	-1.979705	-6.173717***
	1st difference	Intercept and trend	-4.603013***	-10.19749***	-6.875425***	.
KPSS	Level	Intercept and trend	0.226184***	0.216648***	0.186708**	0.079509

	1st difference	Intercept and trend	0.119100	0.118253	0.146000**	---
ZA	Level	Intercept and trend	-0.942944 (1) [1987]	-3.595469 (1) [1997]	-3.696128 (1) [1987]	-8.065377 (1)*** [1982]
	1st difference	Intercept and trend	-5.470700 (1)** [2005]	-11.67329 (2)*** [1979]	-6.753444 (1)*** [1982]	---

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: Author's estimation

4.4.2 Causality test results

4.4.2.1 History of the partial sums of positive and negative variations of electricity consumption and real GDP

Figure 4.5 represents the history of the partial cumulative sums of positive variations (ECPos) and negative variations (ECNeg) of EC, while Figure 4.6 represents the history of the partial cumulative sums of positive and negative variations of RGDP in Benin. It can be seen in both figures that the partial cumulative sums of positive variations tend to grow faster than the partial cumulative sums of negative variations. However, this does not indicate that the partial cumulative sums of positive variations of one variable may cause the partial cumulative sums of positive variations of the other variable. This also does not indicate that the partial cumulative sums of negative variations of one variable may cause the partial cumulative sums of negative variations of the other variable.

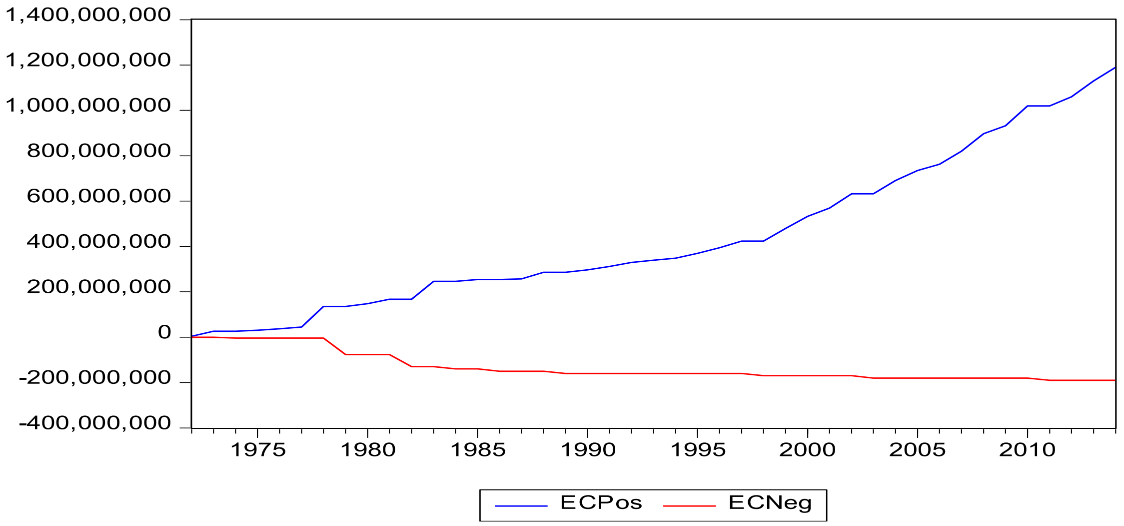

Figure 4.5: History of the partial cumulative sums of positive and negative variations of electricity consumption in Benin (1972-2014)

Source: Author's estimation based on data from the World Development Indicators (2018)

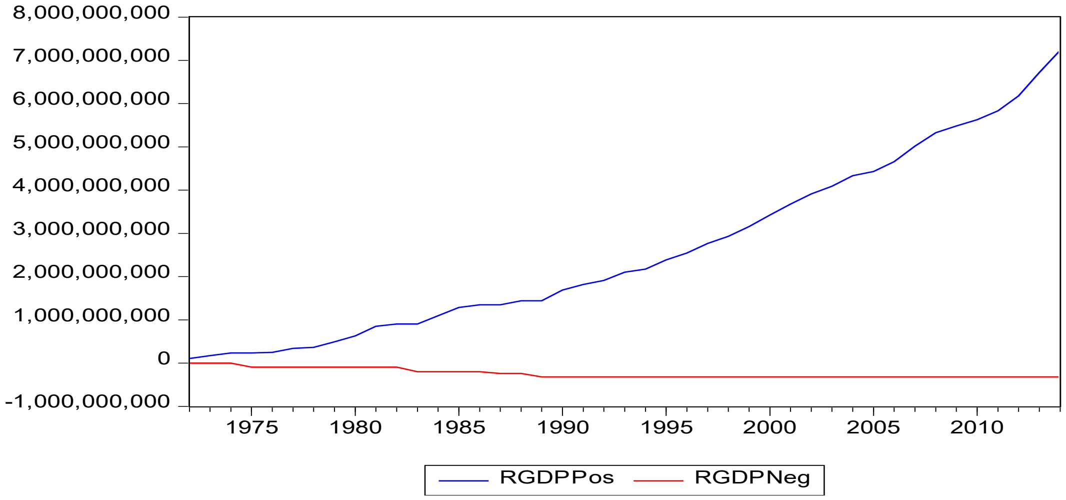

Figure 4.6: History of the partial cumulative sums of positive and negative variations of real GDP in Benin (1972-2014)

Source: Author’s estimation based on data from the World Development Indicators (2018)

4.4.2.2 Results of the Doornik-Hansen (2008) multivariate normality test and the multivariate ARCH test of Hacker and Hatemi-J (2005)

Before using Hatemi-J’s (2012) asymmetric causality test, it was ascertained if it was possible to use a Wald test that has an asymptotic distribution to investigate the asymmetric causality between ECNeg and RGDPNeg, ECPos and RGDPPos, ECNeg and RGDPPos, and between ECPos and RGDPNeg. To do this, whether there was an ARCH effect present in the data, and whether the data had a normal distribution property, were verified. Therefore, the Doornik-Hansen (2008) multivariate normality test and the multivariate ARCH test of Hacker and Hatemi-J (2005) were applied to the partial cumulative sums of negative variations of both variables (ECNeg, RGDPNeg), to the partial cumulative sums of positive variations of both variables (ECPos, RGDPPos), and to the partial cumulative sums of positive and negatve variations of both variables ((ECNeg, RGDPPos), and (ECPos, RGDPNeg)). Table 4.4 presents the results of the multivariate ARCH test of Hacker and Hatemi-J (2005) applied to the models (ECNeg, RGDPNeg), (ECPos, RGDPPos), (ECNeg, RGDPPos), and the model (ECPos, RGDPNeg). Both p-values based on asymptotic and the p-value based on bootstrapping are more than 5% (and even more than 10%) for all models. This indicates that there is no ARCH effect among the data in the models (ECNeg, RGDPNeg), (ECPos, RGDPPos), (ECNeg, RGDPPos), and (ECPos, RGDPNeg). However, it was necessary to ensure the normality property of the data before running an asymmetric causality test using the Wald test.

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Table 4.4: Results of the multivariate ARCH test of Hacker and Hatemi-J (2005) for the models (ECNeg, RGDPNeg), (ECPos, RGDPPos), (ECNeg, RGPPos) and (ECPos, RGDPNeg)

Model (ECNeg, RGDPNeg)	
p-values based on asymptotics, for ARCH orders of 1, 2, 3 respectively.	0.595280
p-values based on bootstrapping, for ARCH orders of 1, 2, 3 respectively.	0.272000
Model (ECPos, RGDPPos)	
p-values based on asymptotics, for ARCH orders of 1, 2, 3 respectively.	0.668370
p-values based on bootstrapping, for ARCH orders of 1, 2, 3 respectively.	0.602000
Model (ECNeg, RGDPPos)	
p-values based on asymptotics, for ARCH orders of 1, 2, 3 respectively.	0.870032
p-values based on bootstrapping, for ARCH orders of 1, 2, 3 respectively.	0.760000
Model (ECPos, RGDPNeg)	
p-values based on asymptotics, for ARCH orders of 1, 2, 3 respectively.	0.973169
pvalues based on bootstrapping, for ARCH orders of 1, 2, 3 respectively	0.934000

Source: Author’s estimation in using the GAUSS codes provided by Hacker and Hatemi-J (2005) and based on data from the World Development Indicators (2018)

Before running the Doornik-Hansen’s (2008) multivariate normality test, a lag selection was first performed. Tables 4.5 and 4.6 present the results of the lag selection procedures for VAR models (ECNeg, RGDPNeg; ECPos, RGDPPos; ECNeg, RGDPPos; and ECPos, RGDPNeg). It can be seen that all five criteria (sequential modified LR statistic, Akaike information criterion (AIC), Final prediction error (FPE), Schwarz information criterion (SC), Hanan-Quinn information criterion (HQ)) suggested one (01) as optimal lag in all VAR models.

Table 4.5: Results of the optimal lag selection for the VAR model (ECNeg, RGDPNeg) and (ECNeg, RGDPPos)

Lag	LogL	LR	FPE	AIC	SC	HQ
			Model (ECNeg, RGDPNeg)			
Choice of 1 as maximum lag						
0	-1608.974	NA	7.10e+30	76.71306	76.79581	76.74339
1	-1514.309	175.8067*	9.47e+28*	72.39567*	72.64391*	72.48666*
Choice of 2 as maximum lag						
0	-1568.645	NA	6.45e+30	76.61681	76.70040	76.64725
1	-1477.716	168.5498*	9.29e+28*	72.37641*	72.62718*	72.46773*
2	-1476.533	2.077772	1.07e+29	72.51382	72.93176	72.66601
Choice of 3 as maximum lag						
0	-1527.777	NA	5.67e+30	76.48886	76.57331	76.51939
1	-1440.899	160.7256*	9.00e+28*	72.34493*	72.59826*	72.43653*
2	-1439.146	3.066548	1.01e+29	72.45731	72.87953	72.60997

3	-1433.778	8.857151	9.47e+28	72.38891	72.98002	72.60264
Model (ECNeg, RGDPPos)						
Choice of 1 as maximum lag						
0	-1754.851	NA	7.38e+33	83.65956	83.74231	83.68989
1	-1573.446	336.8941*	1.58e+30*	75.21173*	75.45997*	75.30272*
Choice of 2 as maximum lag						
0	-1711.129	NA	6.73e+33	83.56726	83.65085	83.59770
1	-1536.351	323.9782*	1.62e+30*	75.23664*	75.48741*	75.32795*
2	-1534.643	2.999831	1.82e+30	75.34843	75.76638	75.50063
Choice of 3 as maximum lag						
0	-1667.089	NA	6.01e+33	83.45446	83.53891	83.48499
1	-1499.400	310.2253*	1.68e+30*	75.26999*	75.52333*	75.36159*
2	-1497.641	3.077382	1.88e+30	75.38207	75.80429	75.53473
3	-1493.465	6.891524	1.87e+30	75.37323	75.96434	75.58696

Notes: (*) indicates the optimal length selected by the criterion
LR: sequential modified LR statistic
FPE: Final prediction error;
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hanan-Quinn information criterion

Source: Author's estimation

Table 4.6: Results of the optimal lag selection for the VAR model (ECPos, RGDPPos) and (ECPos, RGDPNeg)

Lag	LogL	LR	FPE	AIC	SC	HQ
Model (ECPos, RGDPPos)						
Choice of 1 as maximum lag						
0	-1750.432	NA	5.98e+33	83.44916	83.53190	83.47949
1	-1595.021	288.6201*	4.42e+30*	76.23912*	76.48736*	76.33011*
Choice of 2 as maximum lag						
0	-1708.804	NA	6.01e+33	83.45385	83.53744	83.48428
1	-1557.995	279.5477*	4.66e+30*	76.29245*	76.54322*	76.38376*
2	-1555.442	4.482903	5.01e+30	76.36305	76.78099	76.51524
.Choice of 3 as maximum lag						
0	-1666.944	NA	5.97e+33	83.44721	83.53165	83.47774
1	-1520.730	270.4958*	4.87e+30*	76.33651*	76.58984*	76.42811*
2	-1518.305	4.243825	5.28e+30	76.41526	76.83748	76.56792
3	-1517.385	1.517566	6.19e+30	76.56927	77.16038	76.78300
Model (ECPos, RGDPNeg)						
Choice of 1 as maximum lag						

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0	-1703.869	NA	6.51e+32	81.231.85	81.31459	81.26218
1	-1544.998	295.0458*	4.08e+29*	73.85705*	74.10529*	73.94804*
Choice of 2 as maximum lag						
0	-1661.142	NA	5.87e+32	81.12890	81.21249	81.15934
1	-1508.393	283.1462*	4.15e+29*	73.87281*	74.12357*	73.96412*
2	-1505.761	4.620571	4.44e+29	73.93958	74.35752	74.09177
.Choice of 3 as maximum lag						
0	-1617.787	NA	5.11e+32	80.98937	81.07382	81.01991
1	-1471.431	270.7586*	4.14e+29*	73.87157*	74.12491*	73.96317*
2	-1468.712	4.759852	4.43e+29	73.93558	74.35780	74.08824
3	-1467.365	2.222600	5.08e+29	74.06823	74.65933	74.28195

Notes: (*) indicates the optimal length selected by the criterion
LR: sequential modified LR statistic
FPE: Final prediction error;
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hanan-Quinn information criterion

Source: Author’s estimation

The Doornik-Hansen (2008) multivariate normality test was then run for all VAR models ((ECNeg, RGDPNeg), (ECPos, RGDPPos), (ECNeg, RGDPPos), and (ECPos, RGDPNeg)). Tables 4.7 and 4.8 present the results of the Doornik-Hansen multivariate normality tests. It can be seen that on both tables the p value for joint normality is significant: this indicates that the residuals are not normal. In addition, ECNeg and RGDPNeg do not have a normal distribution property (the p value for the Jarque-Bera statistic is significant). These results indicate that the asymptotic property of the Wald test will be violated if it is used to run an asymmetric causality test between ECNeg and RGDPNeg, between ECPos and RGDPPos, between ECNeg and RGDPPos, and between ECPos and RGDPNeg. Consequently, the Hatemi-J’s (2012) asymmetric causality test was used instead of the Wald test to investigate the causal relationship between negative shocks (ECNeg and RGDPNeg), between positive shocks (ECPos and RGDPPos), and between positive and negative shocks ((ECNeg and RGDPPos), (ECPos and RGDPNeg)).

Table 4.7: Results of the Doornik-Hansen multivariate normality test for the VAR model (ECNeg, RGDPNeg), and (ECNeg, RGDPPos)

Variables	**Jarque-Bera**	**df**	**Prob.**
Model (ECNeg, RGDPNeg)			
ECNeg	101.1020	2	0.0000
RGDPNeg	17.82731	2	0.0001

Joint	118.9293	4	0.0000
	Model (ECNeg, RGDPPos)		
ECNeg	103.4870	2	0.0000
RGDPPos	0.039593	2	0.9804
Joint	103.5266	4	0.0000

Source: Author’s estimation in eviews 10 based on data from the World Development Indicators (2018)

Table 4.8: Results of the Doornik-Hansen multivariate normality test for the VAR model (ECPos, RGDPPos), and (ECPos, RGDPNeg)

Variables	**Jarque-Bera**	**df**	**Prob.**
	Model (ECPos, RGDPPos)		
ECPos	10.67402	2	0.0048
RGDPPos	0.186097	2	0.9111
Joint	10.86011	4	0.0282
	Model (ECPos, RGDPNeg)		
ECPos	5.930785	2	0.0515
RGDPNeg	81.18373	2	0.0000
Joint	87.11452	4	0.0000

Source: Author’s estimation in eviews 10 based on data from the World Development Indicators (2018)

4.4.2.3 Results of the Hatemi-J (2012) asymmetric causality test

As noted previously, the Hatemi-J’s (2012) asymmetric causality test is based on a bootstrapping distribution and has superior power and size properties compared to the Wald test that has an asymptotic distribution. It overcomes the limitation of such a Wald test in terms of the violation of normality property and the presence of an ARCH effect among the data. There was no ARCH effect among the data used in the models (ECNeg, RGDPNeg), (ECPos, RGDPPos), (ECNeg, RGDPPos), and (ECPos, RGDPNeg); however, the data used in these models do not have a normal distribution property. All these justified the use of a causality based on a bootstrapping distribution such as Hatemi-J’s (2012) asymmetric causality test. The results of this test are presented in Table 4.9.

Table 4.9: The Hatemi-J (2012) asymmetric causality test results

Direction of Causality	Test value (Wald statistic)	Level of significance	Bootstrapped critical value	Decision
From ECNeg to RGDPNeg	22.883**	1%	23.291	Causality at 5% significance level
		5%	13.275	
		10%	9.630	
From RGDPNeg to ECNeg	11.632**	1%	16.554	Causality at 5% significance level
		5%	11.428	
		10%	8.236	
From ECPos to RGDPPos	0.016	1%	7.556	No causality
		5%	4.258	
		10%	3.005	
From RGDPPos to ECPos	0.750	1%	8.527	No causality
		5%	4.578	
		10%	3.149	
From ECNeg to RGDPPos	0.024	1%	8.208	No causality
		5%	4.309	
		10%	3.011	
From RGDPPos to ECNeg	0.173	1%	6.998	No causality
		5%	4.095	
		10%	2.712	
From ECPos to RGDPNeg	0.605	1%	8.290	No causality
		5%	4.583	
		10%	3.304	
From RGDPNeg to ECPos	0.735	1%	7.863	No causality
		5%	4.158	
		10%	2.710	

(**) indicates 5% significance level

Source: Author's estimation using Hatemi-J's (2012) GAUSS code for asymmetric causality, and based on data from the World Development Indicators (2018)

On one hand, it can be seen that the estimated Wald statistic is greater than the bootstrapped critical value at 5% significance level for cases of causality from ECNeg to RGDPNeg and from

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RGDPNeg to ECNeg (see Table 4.9 above). This indicates that there is bidirectional[4] causality between negative shocks on electricity consumption (ECNeg) and negative shocks on real GDP (RGDPNeg). This result answers the research question Q.3 (stated in the introduction chapter) which was to verify if negative shocks on electricity consumption have caused negative shocks on economic growth, proxied here by real GDP. Negative shocks on electricity consumption have caused negative shocks on real GDP; therefore it can be inferred that shortages of electricity have contributed to cause reductions in real GDP in Benin over the period 1971-2014, even though the share of electricity consumption in total primary energy consumption is still very low in the country. According to the World Development Indicators (2017), it was less than 2.07% of total primary energy consumption over the period 1971-2014. This result also ascertains the conclusions of the national policy framework for electricity (République du Bénin, 2008), which stipulated that shortages or disruptions to electricity supply have been a burden to economic growth in Benin.

On the other hand, it can be seen in Table 4.9 above that the estimated Wald statistic is lower than the bootstrapped critical values at all levels of significance (1%, 5% and 10%) for cases of causality from ECPos to RGDPPos, from RGDPPos to ECPos, from ECNeg to RGDPPos, from RGDPPos to ECNeg, from ECPos to RGDPNeg, and from RGDPNeg to ECPos. This indicates that there is no causality between positive shocks on electricity consumption (ECPos) and positive shocks on real GDP (RGDPPos); between positive shocks on electricity consumption (ECPos) and negative shocks on real GDP (RGDPNeg); and between negative shocks on electricity consumption (ECNeg) and positive shocks on real GDP (RGDPPos). This result aligns with the historical fact in the Beninese context, where according to the World Development Indicators (2017), the share of total electricity consumption has remained less than 2.07% of the total primary energy consumption over 44 years (1971-2014) and the highest rate of access to electricity in the country over the period 1990-2016 is 41.40%. In other words, over the period 1990-2016, less than 50% of the population had access to electricity. Electricity consumption is still very low in Benin and did not yet reach the threshold at which it can begin causing an increase in economic growth. Positive shocks on economic growth do not cause positive shocks on electricity consumption although electricity is used in different sectors of the economy, such as the service sector, the industrial sector and the residential sector (households' use of electricity is classified as the residential sector's use of electricity or residential electricity consumption).

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[4] A bidirectional causality means a causality from the first variable to the second variable and from the second variable to the first variable. In this specific case, it means a causality from negative shocks on electricity consumption to negative shocks on real GDP, and a causality from negative shocks on real GDP to negative shocks on electricity consumption.

4.4.2.4 Results of the Scott Hacker and Hatemi-J (2006) symmetric bootstrapped causality test

While the aim of this study is not to investigate the causal relationship between electricity consumption and economic growth using a symmetric approach, the results of the symmetric causality between these two variables is presented in Table 4.10 below in order to confirm the importance of applying an asymmetric approach. Table 4.10 shows that there is no symmetric causal relationship between electricity consumption and economic growth. This result does not allow us to understand the causal effect of negative shocks on both variables, nor does it allow us to understand the causal effect of positive shocks on both variables. Based on the symmetric approach we cannot understand that there is bidirectional causality between negative shocks on electricity consumption and negative shocks on economic growth, while there is no causal relationship between positive shocks on electricity consumption and positive shocks on economic growth. All these highlight the limitation of the symmetric approach, and confirm the complexity of channels through which economic growth and electricity/energy consumption influence each other and the necessity of applying an asymmetric approach.

Table 4.10: Results of the Scott Hacker and Hatemi-J (2006) symmetric bootstrapped causality test

Direction of Causality	Test value	Level of significance	Critical value	Decision
From EC to RGDP	0.017	1%	7.062	No causality
		5%	3.954	
		10%	2.646	
From EC to RGDP	0.752	1%	8.494	No causality
		5%	4.999	
		10%	3.326	

Source: Author's estimation using Hatemi-J's (2012)s GAUSS code for symmetric causality

The aim of this study is to verify if negative shocks on electricity consumption have caused negative shocks on the real GDP in Benin over the period (1971-2014). Hence, the conclusions, recommendations and policy implications that follow will focus on this.

4.5 CONCLUSIONS, RECOMMENDATIONS AND POLICY IMPLICATIONS

This study has fundamentally established that negative shocks on electricity consumption have caused negative shocks on real GDP in Benin, although the World Development Indicators (2018) reported that electricity consumption is very low in the country, compared to biomass or oil consumption. In other words, disruptions of electricity in Benin have been a burden on the economy and caused reductions in real GDP. As stated previously, this study has ascertained the

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conclusions of the national policy framework for electricity (République du Bénin, 2008) stipulating that shortages of electricity have caused a reduction of economic growth. Until this study no empirical evidence had verified such conclusions. The results of this study highlight the importance of electricity security in Benin. It is important for the country to ensure its electricity security as disruptions of electricity have caused reductions in economic growth.

Until recently (2015), Benin imported 77.575% of its electricity supply. As noted previously, dependency on the importation of electricity and losses of electricity have been major causes of electricity disruptions. Dependency on the importation of electricity from neighbouring countries such as Ghana resulted in major disruptions of electricity in Benin in the 1980s, 1990s and 2000s and has been a burden on the economy. It is therefore important for Benin to reduce its dependency on the importation of electricity by increasing its self-sufficiency rate of electricity supply. The national policy framework for electricity has targeted to increase the self-sufficiency rate of the electricity supply to 70% by 2025 (see République du Bénin, 2008, pp. 54, 56). Losses of electricity caused a reduction in the available quantity of electricity that is supplied to consumers, and they also constitute a burden on the economy. The national policy framework for electricity has targeted to reduce losses of electricity to 14% from 2020 to 2025 (see République du Bénin, 2008, pp. 38, 41). The results of this study emphasize the importance of these policy decisions concerning the self-sufficiency rate of electricity supply and the reduction of losses of electricity. Dependency on the importation of electricity and electricity losses are disruption risks to electricity, which have led to negative shocks on electricity consumption, while negative shocks on electricity consumption have caused negative shocks on real GDP over the period 1971-2014.

Results of this study showed that there is a bidirectional causal relationship between negative shocks on electricity consumption and negative shocks on real GDP, and that the level of electricity consumption is not yet high enough to start impacting positively on economic growth in Benin. This aligns with the theoretical views of Stern (1997, 2010), Hall et al. (1986, 2003) and Cleveland et al. (1984), which stipulate that there is a positive correlation between energy supply/consumption and economic growth. This also aligns with some of the studies found in the empirical literature which have established that negative shocks on total energy/disaggregated energy consumption cause negative shocks on economic growth. Significant among these few studies are Ranjbar et al. (2017) on South Africa, Tiwari (2014) on the US economy, Hatemi-J and Uddin (2012) on the US economy, Bayat et al. (2017) on Turkey, Shahbaz et al. (2017) on India, and Destek (2016) on India. However, throughout the empirical literature on the asymmetric causal relationship between economic growth and energy consumption, no study has investigated whether negative shocks on electricity consumption cause negative shocks on economic growth in the Beninese context. This study has filled this gap, and is a contribution to the existing literature on electricity security and economic growth in general, and particularly a contribution to the existing literature on disruptions

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of electricity and economic growth. This study will be of importance for the current debate and formulation of electricity security policy in Benin where disruption of electricity supply is a major concern.

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CHAPTER 5

CONCLUSION, FINDINGS AND POLICY RECOMMENDATIONS

5.1 INTRODUCTION

Turkson and Wohlgemuth (2001) argued that there is a consensus on the fundamental role of access to electricity in African countries regarding sustainable economic growth and poverty reduction. However, access to electricity is still low in many African countries, including Benin. As reported by the World Development Indicators (2018), access to electricity in Benin has never exceeded 41.5% over 26 years (1990-2016). The Beninese electricity sector faces three major challenges. The first is its dependency on the importation of electricity. There is a huge supply gap of electricity, hence the country has to rely on the importation of electricity from neighbouring countries such as Ghana, Nigeria and Côte d'Ivoire, which have also faced a growing domestic demand of electricity. A country such as Ghana has, furthermore, faced droughts, which has limited the generation capacity of its Akossombo hydroelectric dam. The consequence of this was the reduction of Ghana's exports of electricity to Benin. This situation, added to Benin's weak capacity to produce its electricity domestically, resulted in several disruptions to the electricity supply in Benin in the 1980s, 1990s and 2000s (République du Bénin, 2008).

The second challenge, which is a cause of disruption to the electricity supply in Benin, is electricity losses. Benin has encountered important transmission and distribution losses of electricity. According to the United States Energy Information Administration (USEIA, 2018), transmission and distribution losses of electricity ranged between 9.35% and 25.14% of total electricity supply over the period 1980-2015. Their value in 2015 was 19.358% of total electricity supply (USEIA, 2018), while the ECA (2008) has defined the international standard in terms of maximum electricity losses as 12% of total electricity supply. Electricity losses reduce the quantity of electricity supplied that reaches legal consumers. In other words, they reduce the quantity of electricity available for consumers. Hence, they constitute a source of disruptions to electricity supply.

The third challenge which contributes to increasing disruptions to electricity supply in Benin is the dependency on oil to generate electricity domestically. According to the World Development Indicators (2017), more than 95% of electricity generated domestically in Benin over 42 years (1973-2014) was based on oil, and so the country's domestic production of electricity is vulnerable to fluctuations in oil prices. Whenever oil prices rise, the production costs of electricity increase, and this limits Benin's capacity to generate electricity domestically. Such a reduction in domestic capacity of electricity production increases disruption risks to the overall supply of electricity in the country.

The World Development Indicators (2018) reported that disruptions to electricity supply have negatively affected sales values in Benin. According to the World Bank (2016), 60.4% of firms in

Benin have identified outages or disruptions to the electricity supply as a major constraint for the ease of doing business. The national policy framework for electricity has reported that these electricity shortages have impeded economic growth. However, there is no empirical evidence on Benin which has evaluated the effect of such disruption risks to electricity supply on economic growth. In addition, according to the World Development Indicators (2018), electricity consumption has never exceeded 2.07% of the total energy consumption over 34 years (1971-2014) in the country. Because of this, it is, arguably, possible that such disruptions to electricity supply have no effect on economic growth, as consumption of electricity is still low in the country. It was therefore important to assess the effect of disruptions to the electricity supply on economic growth, which formed the focus of the current study. The study first measured the disruption risks to the electricity supply in Benin by constructing a composite index of disruption risks to electricity supply. It then assessed the effect of disruptions such as electricity losses to the electricity supply on real GDP. Finally, the study verified if shortages or negative shocks to electricity consumption caused negative shocks to economic growth. Summaries of the findings of these three assessments and investigations as well as their policy implications and recommendations are presented in the next sections.

5.2 SUMMARY OF FINDINGS AND POLICY RECOMMENDTIONS

This section presents a summary of the findings and policy implications related to, first, the composite index of disruption risks to electricity supply; second, the effect of electricity losses on real GDP; and third, the causal effect of negative shocks to electricity supply on negative shocks to economic growth. This is followed by policy recommendations and a discussion of priorities going forward.

5.2.1 Measuring electricity security risks

Prior to the current study, there was no performance indicator that could measure electricity supply security in Benin and other countries of the world, while taking into account the whole spectrum of energy supply security (“affordability”, “acceptability”, “accessibility” and “availability” of energy). The African Development Bank has designed a composite index of electricity, but it only focuses on the generation of electricity and only targets African countries: it does not take into account disruption risks to the electricity supply, which represent an important challenge not only in Benin, but also in Africa and in many other countries of the world. The World Bank (2018a) developed, as part of the second pillar of its global competitiveness index, an indicator measuring the quality of electricity supply for countries of the world. This indicator is based on surveys where respondents in each country are asked to rank the reliability of the electricity supply in their country in terms of “lack of interruptions” and “low voltage”, based on a score ranging from 1 (the worst quality) to 7 (the best quality). Respondents’ opinions and allocation of scores can be very subjective. In addition, such an indicator does not take into account the whole spectrum of energy supply security (“affordability”, “acceptability”, “accessibility” and “availability” of energy), it focuses only on the “availability” of electricity, and values obtained can be subjective as they depend on respondents’ answers rather than on a quantitative measurement of the availability of electricity supply. Aspects such as the sustainability of electricity supply using renewable energy and the affordability of electricity are not considered when using such an indicator.

In alignment with one of the sub-objectives of the national policy framework for electricity (République du Bénin, 2008), which is the definition and improvement of performance indicators for the electricity sector as a whole as well for the national distribution company, the current study has constructed a composite index of disruption risks to electricity supply, which take into account the whole spectrum of energy security (“affordability”, “acceptability”, “accessibility” and “availability” of energy). According to such an index, Benin is among the countries in the world with a very high level of disruption risk to electricity supply. Averages of the annual index over the periods 2002-2005 and 2006-2010 are 2.157 and 2.036 respectively. Based on these averages, Benin has been ranked fourth in the world with a very high level of disruption risk to electricity supply over these periods. Over the period 2011-2015, Benin has remained among the countries of the world with a very high level of disruptions to electricity supply, being ranked third highest in the world according to the level of disruption to electricity supply. The value of the index for that period was 2.132. Such an index constitutes an important tool that can be used to monitor and evaluate a country’s performance in terms of security of electricity supply.

The construction of such a composite index is a contribution to the achievement of the national policy framework for electricity’s goal of defining and improving performance indicators for the Beninese electricity sector. In Benin, this index can be used by policy makers to evaluate the effectivess of policies related to the security of electricity supply. As mentioned before, the World Bank (2016) reported that 60.4% of firms have identified electricity as a major constraint for the ease of doing business, and 95.6% of them have experienced electricity outages. In its effort to attract private investments and to improve the ease of doing business in the country, the government of Benin can use this index as a barometer to annually evaluate the country’s effort in terms of infrastructure development in the electricity sector. The more effective the infrastructure development in the electricity sector and the policies related to the security of electricity supply will be, the lower the annual values of the index will be (see the index values classified according to the level of disruption risk to electricity supply, in Appendix B, Tables B1, B2, and B3).

This index has shown that Benin has a low performance in terms of effort to avoid disruptions to electricity supply. It has shown that a sustainable security of electricity supply in Benin should not just be limited to reducing the supply gap of electricity: other aspects such as governance in the country (control of corruption, rule of law, quality of the regulatory system, government effectiveness), more use of renewable electricity, and urbanization, also matter. For a sustainable

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security of electricity supply, reducing the supply gap of electricity is important, but not sufficient in Benin. The country must improve the quality of its regulatory system, and its government effectiveness, and it must also reduce corruption. As mentioned in Chapter 2, the quality of governance affects the delivery of electricity to consumers. For instance, the lack of competition in the distribution of electricity has been a great handicap to an effective supply of electricity in Benin, as the importation and transportation of electricity have been for decades allocated to the CEB (the Electrical Community of Benin), which is a state-owned monopoly. This has prevented private firms from investing in the electricity sector (République du Bénin, 2008).

On April 13th 2018, the Beninese parliament withdrew the monopoly of importation and transportation of electricity to the CEB and liberalized the importation and transportation of electricity through an amended act. However, such legislation is still recent and its impact on the willingness of the private sector to invest in the Beninese electricity sector is yet to be seen. Sustainable security of electricity supply also requires Benin to increase the share of renewable electricity in the total electricity supply and to rely less on fossil fuels for its domestic electricity production. Fossil fuels are limited energy resources and the volatility of their prices affects the domestic capacity of Benin to produce electricity. Sustainable security of electricity supply also involves aspects related to urbanization. Improving the living conditions of the rural population will contribute to reduce its massive migration toward urban areas, and slow down rapid urbanization. As explained before, when the urbanization rate exceeds the rate of urban access to electricity there will always be a supply gap of electricity in urban areas.

5.2.2 The effect of electricity losses on GDP

By investigating the effect of electricity losses on GDP, the current study has contributed to assessing the feasibility of the indirect financing mechanism proposed by the national policy framework for electricity to fund the cost of reducing electricity losses. Electricity efficiency is one of the pillars of the second objective of the national strategy for access to electricity in Benin. In alignment with this pillar, the Beninese Ministry of Energy has planed to reduce electricity losses to 14% from 2020 to 2025. Achieving such targets requires Benin to modernize its distribution lines and improve its electricity billing system. These requirements have significant financial costs (République du Bénin, 2008).

As mentioned previously, the Regulatory Indicators for Sustainable Energy (2018) reported that there is no direct financing mechanism in Benin to fund the costs of activities, implementation of which will contribute to reduce electricity losses. To solve this problem, the national policy framework for electricity (République du Bénin, 2008, p. 65) proposed an indirect financing mechanism of the costs associated with reducing electricity losses. As explained previously, such a mechanism proposed to finance the costs associated with reducing electricity losses with funding by donors or the national budget, and using the gains in GDP resulting from reductions in electricity losses to reimburse donors or the national budget for the funds allocated to reduction of electricity losses. It was therefore important to assess the effect of electricity losses on GDP. In other words, it was important to assess the gain in GDP resulting from reductions in electricity losses. This was a focus of this study. The third chapter of this study established that a 1% reduction in electricity losses will lead to a 0.16% increase in GDP. By doing so, the current study has assessed the feasibility of the indirect financing mechanism proposed by the national policy framework for electricity. It has provided some evidence on the viability of such a mechanism. In other words, results of the current study have provided some valuable evidence, which will help Benin's strategy of financing its electricity efficiency policy. They also align with Antmann (2009) who stipulated that there are GDP losses in sub-Saharan African countries because of electricity losses. Based on these results, and because of its limited financial resources, Benin, should implement the indirect financing mechanism proposed in its policy framework for electricity.

5.2.3 The effect of negative shocks to electricity supply on negative shocks to economic growth

The fourth chapter of this study established that negative shocks to electricity consumption (electricity supply net of losses) cause negative shocks to real GDP. It also demonstrated that negative shocks to real GDP cause negative shocks to electricity consumption, and that there was no causal relationship between positive shocks to electricity consumption and positive shocks to real GDP. However, reductions in the quantity of electricity consumed have a negative effect on economic growth. As reported by the Republic of Benin (République du Bénin, 2008), there have been many negative shocks to electricity consumption in Benin such as shortages of electricity supply caused by sudden reductions in the importation of electricity. The national policy framework for electricity stipulated that these negative shocks to electricity consumption have caused negative shocks to economic growth. However, there has been no empirical study which has verified if negative shocks to electricity consumption have in fact caused negative shocks to economic growth. In addition, the share of electricity consumption in total primary energy consumption is very low, and because of this, it is possible that negative shocks to electricity consumption have no causal effect on negative shocks to economic growth. Therefore, it was necessary to verify empirically if negative shocks to electricity consumption caused negative shocks to real GDP (a proxy for economic growth).

Results of this study have ascertained the conclusions of the national policy framework stating that negative shocks to electricity consumption have impeded economic growth. They highlight the fact that the electricity security policy in Benin must, as a priority, avoid disruptions to the electricity supply, as they constitute a burden for economic growth. The electricity security policy in Benin must consist of diversifying the production sources of electricity and having a security park composed of installed power plants, which can at any time fill any supply gap caused by sudden

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disruptions to the electricity supply. The distribution of electricity must be decentralised. There must be local or municipal solar farms which can fill any supply gap of electricity whithin a given municipality. In addition, more effort must be made to develop the off grid distribution of electricity, in order to provide electricity to the remote villages where the grid distribution of electricity is inexistent. For example, solar lanterns can be provided to schools, health centers, and households located in remote villages where there is no electricity. The provision of solar lanterns should be a temporary solution, and should not prevent the country from extending the provision of grid electricity to remote villages, when financially able.

5.2.4 Recommendations

Results of this study call for four main policy recommendations. The first is the limitation of the dependency on the importation of electricity, and oil as the main source of domestically generated electricity. This study recommends that Benin should try to minimize the high level of vulnerability of its electricity sector concerning shocks related to sudden decreases in imports of electricity, and increases in oil prices, which can limit the domestic capacity of electricity generation. The country should attempt to increase its domestic generation of electricity to mitigate risks related to a sudden decrease in electricity imports. This will require a large amount of investments in electricity infrastructure. As mentioned in the chapter 1 section 1.1.4, a new law called “The bill authorizing the ratification of the international agreement on the amended Beninese-Togolese Act for Electricity”, voted by the Beninese parliament on April 13th 2018, has opened the electricity market to private firms. This will allow private investments to flow in the Beninese electricity sector. Private investments will complement public investments in financing the electricity infrastructure that will help to meet both the present and the future demand of electricity. If Benin as a small economy is unable to absorb all the electric power generated through these investments in electricity infrastructure, the country will ultimately become an exporter of electricity like Nigeria and Ghana. .

Benin should diversify its sources of domestically-generated electricity in order to leverage its heavy reliance on oil. The country must increase the share of electricity produced based on renewable sources, such as solar and wind electricity, in the total domestically-generated electricity. Heavy reliance on hydroelectric dams is also a risk which can lead to outages of electricity, as severe droughts can occur and reduce the speed of flow and the level of water in the dams, limiting its capacity for electricity generation.

The second recommendation is to increase access to electricity and minimize electricity losses. Results of this study showed that a reduction in electricity consumption would cause reductions in GDP. It is therefore recommended that when implementing its energy efficiency strategy, Benin must not accept an energy conservation policy which aims to decrease electricity consumption, as a reduction in electricity consumption will impede economic growth. The country should rather increase access and consumption of electricity and save wasted electricity by minimizing both technical and non-technical losses.

The third policy recommendation is law enforcement with regard to non-technical losses of electricity. The study recommends that the government must enforce laws and regulations to protect the transmission and distribution lines of electricity against illegal behaviour such as theft of electricity. The national company for electricity distribution (SBEE) also has an important role to play with regard to the reduction of defaults in electricity bill payments, which constitutes inefficiency in the economy.

This leads to the fourth policy recommendation, which is the adoption for instance of the *prepaid* system in the electricity sector. The SBEE should adopt the *prepaid* electricity system, in which consumers purchase their consumption of electricity before usage. In other words, with the *prepaid* system consumers will be required to purchase electricity as they purchase any items or food in the supermarket, paying the costs of such items or food before consuming them. This system is economically more effective than the *post-paid* system in which consumers pay for electricity after usage. In the post-paid system, consumers make use of electricity without paying the cost initially. Every month, the SBEE will send the electricity bill to consumers who then can decide whether to pay the bill or not. In addition, many errors occur in the calculation of bills sent by the SBEE to consumers. These reasons help to explain why the *post-paid* system is economically inefficient and generates important commercial losses of electricity. Technical losses can be avoided by improving the technology used for transmission and distribution of electricity. This requires investments in electricity infrastructure, which should be among the first priorities of the government in its effort to promote economic growth and reduce poverty and inequality. The implementation of the indirect financing mechanism proposed by the national policy framework for electricity will enable the country to fund these investments in electricity infrastructure. As explained before, this study has proven that such indirect financing mechanism is feasible.

5.2.5 Priorities

Benin has targeted to increase its self-sufficiency rate in terms of electricity supply to 70% by 2025 according to the national policy framework for electricity (République du Bénin, 2008). This will require important investment in electricity infrastructure. The public sector alone will not be able to fund these investments: it will require a partnership with the private sector and international donors through multilateral and bilateral cooperation. The country has recently benefited from an investment in electricity infrastructure by the United States Millennium Challenge Account (MCA). Such support from the US started in 2017, and will last until 2022 (see MCA, 2014) for further details). Other sources of funds for electricity infrastructure must be explored. Above all, it is important for the country to invest in solar electricity. Solar energy can never be depleted, unlike fossil fuel, coal, etc. Benin is located next to the equator in the Inter-tropical Convergence Zone

(ICZ), where the solar rays are almost perpendicular; hence it receives a huge intensity of solar heat. Benin naturally has the potential to develop solar electricity in order to diversify its sources of domestically-generated electricity.

5.3 CONTRIBUTION OF THE STUDY

The contribution of a dissertation can be in terms of concept and theory, in terms of policy or in terms of methodology. The current study did not contribute to the advancement of theories; rather, its contribution is in terms of concept, policy and methodology.

5.3.1 Contribution for policy on electricity supply efficiency and electricity supply security in Benin

First, by investigating the effect of electricity losses on GDP, the current study has theoretically assessed the feasibility of the indirect financing mechanism proposed by the national policy framework for electricity to fund the cost associated with reduction of electricity losses. The current study has proved that such a financing mechanism is feasible. Therefore, it has contributed to advance the implementation of the national policy framework for electricity. More specifically, the study has contributed to advance the implementation of the Beninese Act for electricity efficiency and the national strategy for electricity efficiency. Results of the study provide government with a reliable option for financing costs associated with the reduction of electricity losses.

Second, by constructing a composite index of disruption risks to electricity supply to measure the performance of Benin in terms of electricity supply security, the current study has contributed to the achievement of one of the sub-objectives of the national policy framework for electricity, namely the definition and improvement of performance indicators for the electricity sector and the national distribution company. The composite index of disruption risks to electricity supply measures the overall performance of Benin in terms of efforts to avoid disruption risks to electricity supply. It takes into account the country’s performance in terms of electricity efficiency, the self-sufficiency rate of electricity supply, sustainable electricity production (through the share of renewable electricity in total supply), and effectiveness of the delivery of electricity (through the governance index). It is an important tool which can be used to monitor the progress of the country in terms of sustainable security of electricity supply.

By establishing that negative shocks to electricity consumption cause negative shocks to GDP, the current study has ascertained the conclusions of the national policy framework for electricity stipulating that shortages of electricity have impeded economic growth. In so doing, it highlights the importance of the national policy framework’s objective aiming to increase Benin’s self-sufficiency rate of electricity supply to 70% by 2025. Being able to produce 70% of its electricity supply domestically will contribute to reducing electricity shortages in Benin, as the country will rely less on the importation of electricity. The study has also established that electricity consumption is not

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yet high enough to cause increases in economic growth. In other words, shortages of electricity consumption are a burden for economic growth, while increases of electricity consumption do not yet cause increases in economic growth. Hence, it is very important for the country to avoid electricity shortages and to continue investing in electricity infrastructure until electricity consumption reaches the threshold at which it can start boosting economic growth.

5.3.2 Contribution to international policies in terms of security of electricity supply

The current study has created data that did not exist before by calculating the annual values of the composite index of disruption risk to electricity supply for at least 172 countries over the period 2002-2015 and for the years 1996, 1998 and 2000 (see the data for measuring electricity security risk, in Dakpogan (2018)). Such data constitutes the annual series of each country's composite index of disruption risks to electricity supply. Future studies all over the world can examine the relationship between electricity security and economic growth using the annual series of such an index. The series of the constructed composite index of disruption risks to electricity supply has revealed that Norway is the country with the lowest level of disruption risk to electricity supply. The data also revealed that OECD countries have the lowest level of disruption risk to electricity supply while most African countries and low-income economies have the highest levels of disruption risk to electricity supply, and most emerging economies and middle-income countries have medium disruption risks to electricity supply. These results are important for global security of electricity supplies and they constitute relevant information that can help development finance and business finance institutions in their analysis of the ease of doing business in various regions of the world in order to advise investors or allocate investments. Countries where disruption risks to electricity supply are high or very high have investment needs in terms of electricity infrastructure, or capacity building in terms of governance, and so forth. Two countries A and B may have a high level of disruption risk to electricity supply. If the value of their governance index (GI) shows that country A has a better governance system than country B, then country A is more likely to attract investments in terms of electricity infrastructure than country B.

5.3.3 Contribution in terms of methodology

Apart from its contribution to the advancement of policy related to electricity supply efficiency and electricity supply security in Benin and in the world, this study has also brought some contributions in terms of methodology. It has designed a new way of measuring electricity supply security using a set of indicators/index. More precisely, this study has designed a new formula that can be used to measure the disruption risk to electricity supply, while taking into account the whole spectrum of energy/electricity security (accessibility, availability, affordability, and acceptability of energy/electricity). Such a formula is the inverse of the geometric mean of a set of indicators/index and did not exist previously. Some of these indicators, such as the ratio of growth of urban access to electricity to growth of urbanization rate (RUB) and the governance index (GI), did not exist previously (to the best of the writer’s knowledge). They have been designed for the purpose of constructing the composite index of disruption risks to electricity supply (MESRI). They constitute new ways of measuring some components of electricity supply security.

5.3.4 Contribution in terms of concepts

First, the current study has extended the understanding of the concepts of accessibility of electricity to issues related to governance, corruption, and rule of law. As explained previously, corruption, the quality of the regulatory system, and the rule of law, affect the delivery of electricity in a country. Previous studies did not consider these aspects in their description of the concept of accessibility. Second, the current study has also extended the understanding of the concept of availability to issues related to electricity losses, rapid urbanization and supply gap of electricity in urban areas. As explained previously, losses of electricity reduce the electricity supplied to legal consumers; rapid urbanisation increases the urban demand of electricity, and if the rate of urban access to electricity is smaller than the urbanisation rate, there will be supply gap of electricity in an urban area. Previous studies did not take into account these aspects in their definitions of the concept of availability.

5.4 LIMITATIONS OF THE STUDY

Because of the shortness of series on industrial and service sectors’ electricity consumption, the current study was not able to investigate the causal effect of negative shocks to electricity consumption on negative shocks to industrial value added or negative shocks to service value added. Knowledge of the type of causal relationship which exists at the disaggregated level between electricity consumption and economic growth will be of great importance for electricity security policy in each economic sector. Electricity consumption patterns vary from one sector to another, and electricity security policy may differ from one sector to another. Electricity efficiency policies may also differ from one sector to another. Losses of electricity encountered in the industrial sector may not be the same as in the residential sector (households), and the costs associated with a reduction of electricity losses in the residential sector may not be the same as the costs associated with reduction of electricity losses in the industrial sector. It is therefore important to verify if the relationship observed between electricity consumption/supply and economic growth at the aggregated level remains the same at the disaggregated or sectorial level. However, there is no data for electricity supply under the hypothesis of an absence of losses at the disaggregated level (industry, service, residential). Further research can reflect on ways to overcome these constraints related to a lack of data or shortness of time series data in order to investigate the relationship between electricity consumption/supply and economic growth at the disaggregated level in Benin.

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APPENDICES

APPENDIX A

RANKING OF AFRICAN COUNTRIES ACCORDING TO THE SUB-INDICATORS OF THE COMPOSITE INDEX (MESRI)

Table A1: African countries' ranking according to their performance in terms of governance (*GI*) (average 2011-2015) (only countries for which data are available)

Countries	Average *GI* (2011-2015)	World ranking	Africa ranking
Libya	98.38290638	2	1
Congo (Kinshasa)	98.38827761	3	2
Sudan	98.43187786	4	3
Central African Republic	98.47710277	5	4
Zimbabwe	98.64315481	8	5
Chad	98.72074994	10	6
Guinea-Bissau	98.77794398	11	7
Nigeria	98.78024322	12	8
Equatorial Guinea	98.81305282	14	9
Burundi	98.81754307	15	10
Guinea	98.87508104	18	11
Congo (Brazzaville)	98.97011097	21	12
Angola	98.9891335	22	13
Comoros	99.03208796	23	14
Cameroon	99.06118556	25	15
Mali	99.1157457	27	16
Liberia	99.12312191	28	17
Mauritania	99.12677987	29	18
Côte d'Ivoire	99.13355442	30	19
Algeria	99.13702376	31	20
Togo	99.15103423	34	21
Ethiopia	99.16483503	35	22
Egypt, Arab Rep.	99.17798929	36	23
Madagascar	99.21350248	38	24
Sierra Leone	99.21569522	39	25
Kenya	99.26972217	41	26
Niger	99.27185802	42	27
Uganda	99.39480897	54	28
Mozambique	99.49538401	56	29
Gabon	99.50819165	57	30
Tanzania	99.51362915	59	31
Burkina Faso	99.520991	60	32
Gambia, The	99.5233781	61	33
Swaziland	99.53366145	62	34
São Tomé and Principe	99.54344147	65	35

Malawi	99.57168156	68	36
Benin	99.59274034	70	37
Tunisia	99.73909142	84	38
Zambia	99.74832098	85	39
Senegal	99.76983258	87	40
Morocco	99.77281892	88	41
Lesotho	99.81741275	94	42
Ghana	99.97996793	105	43
Rwanda	100.0681044	109	44
South Africa	100.1478267	115	45
Seychelles	100.279436	120	46
Namibia	100.3037207	121	47
Cape Verde	100.4389105	127	48
Botswana	100.7178659	141	49
Mauritius	100.8287029	147	50

Source: Author’s own calculation based on data from Worldwide Governance Indicators (2018)

Table A.2: African countries’ ranking according to their performance in terms of the ratio of growth of urban access to electricity to growth of urbanization (*RUB*) (average 2011-2015) (only countries for which data is available)

Countries	**Average *RUB* (2011-2015)**	**World ranking**	**Africa ranking**
Rwanda	94.24252036	4	1
Burkina Faso	94.37520092	5	2
Burundi	94.77205278	6	3
Uganda	94.81692181	7	4
Tanzania	94.84446582	9	5
Angola	94.92335282	11	6
Niger	95.13831153	13	7
Mali	95.27612607	14	8
Ethiopia	95.29776228	15	9
Madagascar	95.60521901	17	10
Equatorial Guinea	95.60979508	18	11
Nigeria	95.65355695	19	12
Congo (Kinshasa)	95.67035186	20	13
Namibia	95.71273182	21	14
Kenya	95.90904976	26	15
Gambia, The	95.92410973	27	16
Zambia	96.10948939	28	17
Guinea-Bissau	96.12526088	29	18
Mauritania	96.15142574	30	19
Côte d’Ivoire	96.29174699	31	20

Togo	96.30984121	32	21
Malawi	96.35111274	33	22
Cameroon	96.38441995	35	23
Benin	96.38850118	36	24
Senegal	96.48816319	38	25
Mozambique	96.49618401	39	26
Ghana	96.50294122	40	27
Chad	96.53196795	41	28
Gabon	96.53602863	42	29
Guinea	96.59176672	43	30
São Tomé and Principe	96.86267582	47	31
Congo (Brazzaville)	96.89308672	49	32
Lesotho	96.92138832	51	33
Liberia	96.98889964	54	34
Sierra Leone	96.99710808	56	35
Algeria	97.1782761	61	36
Sudan	97.3096598	63	37
Comoros	97.4256678	66	38
Cape Verde	97.71694638	75	39
Morocco	97.77843067	77	40
Egypt, Arab Rep.	97.81882693	79	41
Botswana	97.82009676	80	42
South Africa	97.85122947	81	43
Zimbabwe	98.25427882	93	44
Swaziland	98.39942375	103	45
Tunisia	98.58967243	108	46
Seychelles	98.6616994	109	47
Central African Republic	99.02075133	125	48
Libya	99.55653212	149	49
Mauritius	100.2538186	172	50

Source: Author’s own calculation based on data from the World Development Indicators (2018)

Table A.3: African countries’ ranking according to their performance in terms of share of GDP not used to cover the cost of electricity supply (*RNEEX*) (only countries for which data is available)

Countries	**Average *RNEEX* (2011-2015)**	**World ranking**	**Africa ranking**
Mozambique	89.89835382	5	1
Zimbabwe	96.08402116	18	2
Libya	96.28013947	20	3

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Egypt, Arab Rep.	96.59577449	22	4
South Africa	96.91035609	27	5
Zambia	97.27247539	34	6
Tunisia	98.11899677	53	7
Congo (Kinshasa)	98.36107382	64	8
Algeria	98.39890283	69	9
Namibia	98.41045591	70	10
Togo	98.47229599	74	11
Morocco	98.49489588	76	12
Seychelles	98.53827752	78	13
Swaziland	98.5583192	80	14
Lesotho	98.56171802	81	15
Ghana	98.56993606	82	16
São Tomé and Principe	98.61461637	87	17
Côte d'Ivoire	98.74602536	98	18
Gambia, The	98.7548455	102	19
Botswana	98.75610133	104	20
Malawi	98.7694487	106	21
Mauritius	98.77364831	107	22
Cameroon	98.85465186	114	23
Senegal	98.85766483	115	24
Cape Verde	98.87534255	116	25
Ethiopia	98.96554568	129	26
Mauritania	99.03035476	136	27
Liberia	99.0367424	137	28
Kenya	99.08301584	141	29
Mali	99.20019467	149	30
Niger	99.22392626	152	31
Madagascar	99.24878248	155	32
Benin	99.25073761	156	33
Sudan	99.25784214	157	34
Tanzania	99.26241206	158	35
Gabon	99.35797079	163	36
Congo (Brazzaville)	99.40204725	165	37
Uganda	99.40268114	166	38
Guinea	99.4168149	168	39
Burundi	99.42799911	169	40
Burkina Faso	99.43341101	170	41
Central African Republic	99.45800361	172	42
Comoros	99.50838943	174	43

Angola	99.61164683	177	44
Rwanda	99.63458391	178	45
Nigeria	99.6733151	179	46
Sierra Leone	99.7395526	180	47
Guinea-Bissau	99.82639839	181	48
Equatorial Guinea	99.8909833	182	49
Chad	99.91430533	183	50

Source: Author’s own calculation based on data from USEIA (2018), World Bank (2018b), and World Development Indicators (2018)

Table A.4: Ranking of African countries according to their average score related to the share of renewable electricity in total domestic production of electricity (average 2011-2015) (only countries for which data is available)

Countries	**Average *RRE* (2011-2015)**	**World ranking**	**Africa ranking**
Chad	100.0000000	1	1
Comoros	100.0000000	1	1
Gambia, The	100.0000000	1	1
Guinea-Bissau	100.0000000	1	1
Liberia	100.0000000	1	1
Libya	100.0000000	1	1
Botswana	100.0370561	22	7
Niger	100.5118329	28	8
Algeria	100.6665527	31	9
Benin	101.1111111	34	10
South Africa	101.1357147	36	11
Seychelles	101.2985909	38	12
Tunisia	102.190804	45	13
Mauritania	104.6463238	51	14
Egypt, Arab Rep.	108.8436646	61	15
São Tomé and Principe	109.3011241	63	16
Senegal	110.3547894	66	17
Morocco	112.1528063	71	18
Burkina Faso	113.0202246	76	19
Cape Verde	116.6294332	86	20
Nigeria	119.140297	89	21
Mauritius	120.9062318	92	22
Côte d’Ivoire	123.8231839	97	23
Equatorial Guinea	125.3664093	100	24
Tanzania	135.5877234	114	25

Gabon	142.6372076	121	26
Rwanda	145.2775501	123	27
Swaziland	147.0459505	126	28
Madagascar	151.2768005	129	29
Mali	152.2608527	130	30
Zimbabwe	156.1036698	137	31
Congo (Brazzaville)	156.8217494	138	32
Angola	159.2156513	142	33
Ghana	162.8488429	146	34
Sierra Leone	168.7838795	150	35
Guinea	170.8747503	151	36
Sudan	174.0744704	152	37
Cameroon	175.4868921	154	38
Kenya	175.9876044	156	39
Togo	182.9278807	162	40
Uganda	185.7379413	164	41
Burundi	187.8535743	165	42
Malawi	191.1693512	166	43
Central African Republic	193.4505669	169	44
Mozambique	194.9936181	170	45
Namibia	197.6953163	173	46
Zambia	198.7475990	174	47
Congo (Kinshasa)	199.6710700	176	48
Ethiopia	199.8192374	178	49
Lesotho	200.0000000	183	50

Source: World Development Indicators (2018)

Table A.5: Ranking of African countries according to their self-sufficiency rate of electricity supply (*ESS*) (Average 2011-2015) (only countries for which data is available)

Countries	Average ESS (2011-2015)	World ranking	Africa ranking
Togo	9.862617174	1	1
Benin	12.3593826	2	2
Botswana	33.41263613	5	3
Namibia	37.51515785	6	4
Niger	37.65697224	7	5
Swaziland	38.58293401	8	6
Cameroon	51.22466602	11	7
Burkina Faso	58.97757748	13	8
Liberia	66.20746827	15	9

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Madagascar	69.17464028	16	10
Rwanda	83.58873605	24	11
Mozambique	83.68722615	25	12
Morocco	85.00837286	28	13
Mauritania	90.76176035	35	14
Gambia, The	92.13495134	38	15
Djibouti	92.68070243	39	16
Equatorial Guinea	95.03307144	44	17
Egypt, Arab Rep.	97.02400069	49	18
Zimbabwe	97.18919606	50	19
Lesotho	97.43798323	52	20
Tanzania	98.91422371	58	21
Congo (Kinshasa)	98.94142518	59	22
Côte d’Ivoire	99.76524247	64	23
Kenya	99.92685877	68	24
Angola	100.00000000	72	25
Burundi	100.00000000	72	25
Central African Republic	100.00000000	72	25
Chad	100.00000000	72	25
Congo (Brazzaville)	100.00000000	72	25
Eritrea	100.00000000	72	25
Guinea-Bissau	100.00000000	72	25
Libya	100.00000000	72	25
Malawi	100.00000000	72	25
Mali	100.00000000	72	25
Mauritius	100.00000000	72	25
Nigeria	100.00000000	72	25
São Tomé and Principe	100.00000000	72	25
Senegal	100.00000000	72	25
Seychelles	100.00000000	72	25
Sierra Leone	100.00000000	72	25
Somalia	100.00000000	72	25
Sudan	100.00000000	72	25
Algeria	100.1794753	151	43
Tunisia	100.3529335	155	44
South Africa	101.3508327	160	45
Comoros	101.4984976	162	46
Guinea	101.7920328	164	47
Uganda	102.5272239	169	48
Ghana	104.3359451	172	49

Zambia	104.978801	174	50
Cape Verde	107.4761353	179	51
Gabon	110.2680772	184	52
Ethiopia	117.7773539	190	53

Source: Author's own calculation based on USEIA (2018) data

Table A.6: Ranking of African countries according to their rate of electricity supply efficiency (only countries for which data is available)

Countries	Average ESE (2011-2015)	World ranking	Africa ranking
Libya	37.49682826	2	1
Congo (Brazzaville)	53.35449536	3	2
Cameroon	74.54729069	10	3
Ghana	77.64081428	13	4
Côte d'Ivoire	79.44146525	16	5
Gabon	79.77281677	17	6
Tanzania	80.02139063	18	7
Sudan	80.49059024	21	8
Algeria	80.98891141	22	9
Ethiopia	81.02990656	23	10
Benin	81.04121372	24	11
Kenya	81.65983843	25	12
Senegal	82.23062219	27	13
Zimbabwe	84.15358445	32	14
Tunisia	84.289576	34	15
Niger	84.48230799	36	16
Eritrea	84.66502736	38	17
Nigeria	86.06372319	46	18
Zambia	87.17433755	53	19
Egypt, Arab Rep.	87.92315088	59	20
Morocco	87.94276629	60	21
Angola	88.3782508	64	22
Mozambique	89.50814057	73	23
Botswana	89.71851966	76	24
Congo (Kinshasa)	89.78523629	77	25
Namibia	90.49429483	83	26
Togo	91.29580153	87	27
South Africa	91.42614439	91	28
Cape Verde	92.97878788	106	29
Central African Republic	93.00000000	107	30

Chad	93.00000000	107	30
Comoros	93.00000000	107	30
Djibouti	93.00000000	107	30
Equatorial Guinea	93.00000000	107	30
Gambia, The	93.00000000	107	30
Guinea	93.00000000	107	30
Guinea-Bissau	93.00000000	107	30
Liberia	93.00000000	107	30
Madagascar	93.00000000	107	30
Malawi	93.00000000	107	30
Mali	93.00000000	107	30
São Tomé and Principe	93.00000000	107	30
Seychelles	93.00000000	107	30
Sierra Leone	93.00000000	107	30
Somalia	93.00405797	143	45
Uganda	93.09802424	145	46
Mauritania	93.09937598	146	47
Mauritius	93.19316922	149	48
Rwanda	94.19389814	162	49
Lesotho	95.36547722	171	50
Burundi	95.58587586	175	51
Burkina Faso	95.87156958	177	52
Swaziland	97.29919462	188	53

Source: Author's own calculation based on USEIA (2018) data

Table A.7: Ranking of African countries according to their rate of access to electricity (RACE) (Average 2011-2015) (only countries for which data is available)

Countries	Average RACE (2011-2015)	World ranking	Africa ranking
South Sudan	5.921040773	1	1
Burundi	6.654797745	2	2
Chad	7.372249832	3	3
Liberia	9.147955093	4	4
Malawi	9.340000000	5	5
Central African Republic	12.19305954	6	6
Guinea-Bissau	13.48163208	7	7
Congo (Kinshasa)	14.76484974	8	8
Niger	14.95419975	9	9
Sierra Leone	15.07525162	10	10
Madagascar	16.5128157	11	11

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Tanzania	16.66203583	12	12
Uganda	16.72299278	13	13
Rwanda	16.93395531	14	14
Burkina Faso	17.37564377	15	15
Mozambique	21.26170906	17	16
Lesotho	24.65037857	18	17
Somalia	25.10658989	19	18
Zambia	26.73860245	20	19
Ethiopia	28.40510506	21	20
Guinea	28.55957359	22	21
Mali	30.44441093	23	22
Kenya	33.68440201	24	23
Zimbabwe	35.34113815	26	24
Angola	36.28249084	27	25
Mauritania	37.03605591	28	26
Benin	37.34653671	29	27
Sudan	38.46251953	31	28
Togo	42.20080536	33	29
Eritrea	43.18904495	35	30
Gambia, The	44.06586838	36	31
Namibia	48.32556351	38	32
Congo (Brazzaville)	49.64273224	39	33
Djibouti	52.8882457	40	34
Botswana	54.88303418	42	35
Nigeria	54.9283638	43	36
Cameroon	56.21290131	44	37
Swaziland	58.37334824	46	38
Senegal	58.43111954	47	39
Côte d’Ivoire	60.40220932	48	40
São Tomé and Principe	62.89689407	50	41
Equatorial Guinea	66.70395233	51	42
Comoros	70.72298981	54	43
Ghana	71.61287974	55	44
South Africa	85.38000000	63	45
Cape Verde	85.51855621	64	46
Gabon	88.24295868	68	47
Morocco	95.34494354	83	48
Libya	98.52285156	94	49
Seychelles	98.66741638	95	50
Mauritius	98.82798584	97	51

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Algeria	99.08559963	98	52
Tunisia	99.70000000	110	53
Egypt, Arab Rep.	99.86965332	120	54

Source: World Development Indicators (2018)

Table A.8: Ranking of African countries according to their real GDP per capita (RGDPcW) (expressed as a percentage of the world annual average real GDP per capita) (Average 2011-2015) (only countries for which data is available)

Countries	Average RGDPcW (2011-2015)	World ranking	Africa ranking
Eritrea	1.06001201	1	1
Burundi	2.361895346	2	2
Liberia	3.670503183	3	3
Central African Republic	3.725700527	4	4
Niger	3.726104872	5	5
Congo (Kinshasa)	3.778579543	6	6
Madagascar	4.090782913	7	7
Ethiopia	4.245007745	8	8
Mozambique	4.738803454	9	9
Malawi	4.74634177	10	10
Sierra Leone	4.87057474	11	11
Togo	5.205088958	12	12
Gambia, The	5.339755082	13	13
Guinea-Bissau	5.599695651	14	14
Burkina Faso	6.264754628	16	15
Uganda	6.393076632	17	16
Rwanda	6.503623674	19	17
Mali	7.020294394	20	18
Guinea	7.022463756	21	19
Comoros	7.770610821	23	20
Tanzania	7.811387113	24	21
Benin	8.01050221	25	22
Zimbabwe	9.098180013	28	23
Chad	9.306923282	30	24
Senegal	10.16671357	32	25
Kenya	10.51066494	34	26
São Tomé and Principe	12.03610606	37	27
Mauritania	12.83368055	38	28
Lesotho	13.00520058	39	29
Côte d’Ivoire	13.06263215	40	30

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Cameroon	13.93976004	42	31
Zambia	15.82861638	47	32
Ghana	16.01417991	48	33
Sudan	17.90507698	51	34
Nigeria	24.82230117	58	35
Egypt, Arab Rep.	26.15700125	59	36
Congo (Brazzaville)	28.42688711	60	37
Morocco	30.70954065	63	38
Cape Verde	33.94089746	67	39
Angola	36.69284688	78	40
Swaziland	38.85854893	80	41
Tunisia	41.83716562	82	42
Algeria	46.28733477	85	43
Namibia	57.18025337	94	44
Botswana	71.46098775	106	45
Libya	72.95814748	108	46
South Africa	75.36093508	110	47
Mauritius	88.86278849	116	48
Gabon	93.74590615	119	49
Seychelles	125.1718355	130	50
Equatorial Guinea	165.1068608	141	51

Source: Author’s own calculation based on the World Development Indicators (2018) data

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APPENDIX B

RANKING OF COUNTRIES OF THE WORLD ACCORDING TO THE MODIFIED INDEX OF ELECTRICITY SUPPLY DISRUPTION RISK (MESRI)

Table B.1: Ranking and classification of countries (for which data are available) according to their Modified Electricity Supply Disruption Risk Index (MESRI) (Average 2002-2005)

Level of overall performance as related to electricity supply disruption	Countries	Average MESRI (2002-2005)	World ranking
Extremely high level of disruption risk (Average MESRI is equal to or above 2.5)	Liberia	4.685771643	1
Very high level of disruption risk (Average MESRI is in the interval [2, 2.5[)	Niger	2.307595741	2
	Burundi	2.214406178	3
	Benin	2.157051004	4
	Congo (Kinshasa)	2.146414594	5
	Rwanda	2.122691463	6
	Chad	2.108546286	7
	Guinea-Bissau	2.006223110	8
High level of disruption risk (Average MESRI is in the interval [1.5, 2[)	Malawi	1.968934759	9
	Togo	1.963270527	10
	Sierra Leone	1.932480649	11
	Mozambique	1.918415224	12
	Burkina Faso	1.918216995	13
	Central African Republic	1.913748313	14
	Ethiopia	1.870598191	15
	Cambodia	1.849833357	16
	Afghanistan	1.841630254	17
	Madagascar	1.806467268	18
	Tanzania	1.797908137	19
	Uganda	1.786997943	20
	Lesotho	1.715178870	21
	Mali	1.687079263	22
	Gambia, The	1.663607179	23
	Solomon Islands	1.662571245	24
	Eritrea	1.662291718	25
	Haiti	1.648202618	26
	Guinea	1.625396587	27
	Mauritania	1.606457882	28
	Bangladesh	1.601982541	29

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	Kenya	1.582577616	30
	Myanmar	1.55108931	31
	Senegal	1.544726169	32
	Papua New Guinea	1.539858288	33
	Nepal	1.536824785	34
	Zimbabwe	1.521797047	35
Medium level of disruption risk (Average MESRI is in the interval [1, 1.5[)	Comoros	1.489649621	36
	Zambia	1.482523448	37
	Sudan	1.482207922	38
	Swaziland	1.452515245	39
	Yemen, Rep.	1.448529362	40
	India	1.44719257	41
	Botswana	1.427063891	42
	São Tomé and Principe	1.422211189	43
	Congo (Brazzaville)	1.392037712	44
	Vanuatu	1.384574081	45
	Nigeria	1.375305659	46
	Pakistan	1.375244369	47
	Angola	1.369902164	48
	Ghana	1.36970696	49
	Côte d’Ivoire	1.367522916	50
	Lao PDR	1.35451535	51
	Tajikistan	1.352703396	52
	Mongolia	1.347712804	53
	Kyrgyz Republic	1.342406543	54
	Cameroon	1.342142044	55
	Uzbekistan	1.324890974	56
	Nicaragua	1.323902993	57
	Vietnam	1.310108366	58
	Moldova	1.307993396	59
	Honduras	1.289163584	60
	Guyana	1.256052299	61
	Bolivia	1.250294084	62
	Cape Verde	1.248661206	63
	Namibia	1.244374564	64
	Philippines	1.242964812	65
	Sri Lanka	1.224042662	66
	Egypt, Arab Rep.	1.21876418	67

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Indonesia	1.205214911	68
Azerbaijan	1.204725603	69
Bhutan	1.199750135	70
Ukraine	1.189839649	71
China	1.181734429	72
Belize	1.180285978	73
Turkmenistan	1.177772145	74
Guatemala	1.175638231	75
Armenia	1.174188092	76
Cuba	1.157282374	77
Jordan	1.156797111	78
Belarus	1.15308081	79
Tunisia	1.147775256	80
Macedonia, FYR	1.145118051	81
Iraq	1.14452219	82
Georgia	1.14307158	83
Dominican Republic	1.135242808	84
Albania	1.130849679	85
El Salvador	1.130336269	86
Jamaica	1.129580531	87
Algeria	1.12887494	88
Thailand	1.124664479	89
Fiji	1.104190064	90
Lebanon	1.102339257	91
Samoa	1.098591787	92
Peru	1.092922287	93
Ecuador	1.091630656	94
South Africa	1.085307494	95
Iran, Islamic Rep.	1.085154268	96
Bosnia and Herzegovina	1.079248233	97
Maldives	1.07827902	98
Saint Vincent/Grenadines	1.06424126	99
Bulgaria	1.063234413	100
Grenada	1.061128514	101
Kazakhstan	1.050735859	102
Dominica	1.04095786	103
Panama	1.040374983	104
Saint Lucia	1.03804551	105
Colombia	1.030749375	106
Libya	1.029544735	107

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	Mauritius	1.028913894	108
	Malaysia	1.02695555	109
	Romania	1.017877985	110
	Paraguay	1.011153523	111
	Argentina	1.010396464	112
	Seychelles	1.009123549	113
	Russian Federation	1.005437524	114
	Mexico	1.005064232	115
	Turkey	1.000464373	116
Low level of disruption risk (Average MESRI is in the interval [0.5, 1[)	Equatorial Guinea	0.998785526	117
	Lithuania	0.996176551	118
	Poland	0.992279535	119
	Hungary	0.987073837	120
	Suriname	0.986951963	121
	Antigua and Barbuda	0.977495904	122
	Gabon	0.973724147	123
	Trinidad and Tobago	0.966708254	124
	Estonia	0.964309429	125
	Uruguay	0.95813056	126
	Brazil	0.954895334	127
	Venezuela, RB	0.950800797	128
	Costa Rica	0.941894147	129
	Slovak Republic	0.938941403	130
	Barbados	0.938520052	131
	Chile	0.937873719	132
	Czech Republic	0.924034575	133
	Malta	0.92211803	134
	Macao SAR, China	0.921789856	135
	Korea, Rep.	0.918745766	136
	Bahrain	0.900168674	137
	Croatia	0.898316557	138
	Hong Kong SAR, China	0.892775689	139
	Latvia	0.890135768	140
	Portugal	0.884389261	141
	Israel	0.878774734	142
	Slovenia	0.873288678	143
	Greece	0.872781451	144
	Bahamas, The	0.863578454	145
	Cyprus	0.86302634	146

	Spain	0.848761673	147
	Brunei Darussalam	0.84604758	148
	Singapore	0.83836002	149
	Germany	0.837510671	150
	United Kingdom	0.836244909	151
	France	0.834357575	152
	Belgium	0.830736928	153
	Netherlands	0.824005275	154
	Italy	0.820578642	155
	Japan	0.814403126	156
	Ireland	0.810829211	157
	Australia	0.807659844	158
	United States	0.807643487	159
	New Zealand	0.803685271	160
	United Arab Emirates	0.802087049	161
	Qatar	0.796220806	162
	Finland	0.79436511	163
	Iceland	0.777427	164
	Sweden	0.776728769	165
	Austria	0.774607643	166
	Canada	0.772876857	167
	Denmark	0.758704439	168
	Bermuda	0.756669032	169
	Switzerland	0.733437378	170
	Luxembourg	0.710063639	171
	Norway	0.695226182	172

Source: Author’s own calculation, based on data from USEIA (2018), World Development Indicators (2018), Worldwide Governance Indicators (2018), World Bank (2018b)

Table B.2: Ranking and classification of countries (for which data are available) according to their Modified Electricity Supply Disruption Risk Index (MESRI) (average 2006-2010)

Level of overall performance as related to electricity supply disruption	**Countries**	**Average MESRI (2006-2010)**	**World ranking**
Extremely high level of disruption risk (Average MESRI is equal to or above 2.5)	Liberia	2.656688662	1
Very high level of disruption risk (Average MESRI is in the interval [2, 2.5[)	Niger	2.346248769	2
	Burundi	2.160915782	3
	Benin	2.036629441	4

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High level of disruption risk (Average MESRI is in the interval [1.5, 2[)	Congo (Kinshasa)	1.995919878	5
	Guinea-Bissau	1.992477318	6
	Togo	1.978843121	7
	Chad	1.977497989	8
	Rwanda	1.9631891	9
	Malawi	1.942206232	10
	Burkina Faso	1.884295247	11
	Sierra Leone	1.86441975	12
	Central African Republic	1.859601736	13
	Mozambique	1.834860809	14
	Madagascar	1.834446658	15
	Tanzania	1.787739228	16
	Uganda	1.771767867	17
	Ethiopia	1.737039543	18
	Cambodia	1.732122353	19
	Afghanistan	1.687328015	20
	Haiti	1.682503188	21
	Eritrea	1.673424407	22
	Gambia, The	1.643827703	23
	Mali	1.620053054	24
	Solomon Islands	1.595772834	25
	Guinea	1.595429997	26
	Lesotho	1.564179605	27
	Kenya	1.554952272	28
	Zimbabwe	1.545649782	29
	Bangladesh	1.531935251	30
	Mauritania	1.51888985	31
Medium level of disruption risk (Average MESRI is in the interval [1, 1.5[)	Papua New Guinea	1.498337097	32
	Nepal	1.489017892	33
	Botswana	1.482518888	34
	Senegal	1.478690593	35
	Comoros	1.476324024	36
	Zambia	1.460428563	37
	Sudan	1.443159821	38
	Yemen, Rep.	1.436188809	39
	Myanmar	1.433334943	40
	São Tomé and Principe	1.401494828	41
	Côte d'Ivoire	1.396336492	42

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Swaziland	1.386533898	43
Cameroon	1.383712075	44
India	1.377807369	45
Pakistan	1.343221065	46
Congo (Brazzaville)	1.341450449	47
Tajikistan	1.338862213	48
Ghana	1.3360555	49
Kiribati	1.334493483	50
Vanuatu	1.330836282	51
Kyrgyz Republic	1.330010737	52
Nigeria	1.315433205	53
Mongolia	1.303706822	54
Nicaragua	1.301809061	55
Uzbekistan	1.293797803	56
Moldova	1.289964638	57
Vietnam	1.289733862	58
Lao PDR	1.286306979	59
Guyana	1.271183103	60
Honduras	1.259132268	61
Angola	1.252651181	62
Namibia	1.249386028	63
Morocco	1.246989772	64
Macedonia, FYR	1.246718684	65
Bolivia	1.226769043	66
Philippines	1.226328413	67
Egypt, Arab Rep.	1.20243546	68
Cape Verde	1.192960498	69
Sri Lanka	1.181597703	70
Indonesia	1.177032089	71
Ukraine	1.164326905	72
Iraq	1.163205584	73
Tonga	1.159765737	74
Guatemala	1.156018811	75
Jordan	1.155969347	76
Belize	1.145052098	77
Jamaica	1.142256509	78
Tunisia	1.138983682	79
Cuba	1.138850693	80
Algeria	1.137946078	81
Turkmenistan	1.135135708	82

	Albania	1.133379937	83
	Bhutan	1.131824448	84
	China	1.122816982	85
	El Salvador	1.122095799	86
	Armenia	1.119443025	87
	Belarus	1.105460968	88
	Georgia	1.104367934	89
	Thailand	1.103888903	90
	Azerbaijan	1.098101335	91
	Samoa	1.097619692	92
	Fiji	1.097318924	93
	Dominican Republic	1.094844315	94
	Iran, Islamic Rep.	1.079375217	95
	Lebanon	1.077798149	96
	South Africa	1.076990857	97
	Ecuador	1.076457914	98
	Peru	1.068085345	99
	Serbia	1.066816047	100
	Bosnia and Herzegovina	1.060344023	101
	Maldives	1.058969646	102
	Grenada	1.053085603	103
	Saint Vincent/Grenadines	1.053022948	104
	Dominica	1.042710156	105
	Bulgaria	1.036632887	106
	Saint Lucia	1.033926933	107
	Montenegro	1.021080779	108
	Kazakhstan	1.020407772	109
	Malaysia	1.018361037	110
	Colombia	1.017644174	111
	Mauritius	1.017243409	112
	Mexico	1.013836369	113
	Paraguay	1.013611271	114
	Panama	1.013148504	115
	Libya	1.007596405	116
	Gabon	1.002628957	117
	Seychelles	1.000930492	118
Low level of disruption risk (Average MESRI is in the interval [0.5, 1[)	Romania	0.995991826	119
	Argentina	0.992913408	120
	Turkey	0.987561964	121

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Russian Federation	0.984484749	122
Suriname	0.981576112	123
Hungary	0.980278212	124
Poland	0.976189434	125
Equatorial Guinea	0.974382486	126
Lithuania	0.96674191	127
Antigua and Barbuda	0.966456249	128
Saint Kitts and Nevis	0.963043537	129
Uruguay	0.950496236	130
Brazil	0.946603585	131
Costa Rica	0.945589638	132
Estonia	0.945282352	133
Trinidad and Tobago	0.938686054	134
Barbados	0.938663559	135
Chile	0.934376643	136
Venezuela, RB	0.930677741	137
Saudi Arabia	0.930183559	138
Slovak Republic	0.923686243	139
Malta	0.923662916	140
Bahrain	0.919839736	141
Czech Republic	0.913041551	142
Korea, Rep.	0.911151335	143
Croatia	0.903875551	144
Macao SAR, China	0.890309516	145
Puerto Rico	0.884024271	146
Portugal	0.883117124	147
Latvia	0.881758364	148
Bahamas, The	0.877471101	149
Israel	0.875543216	150
Guam	0.874146028	151
Hong Kong SAR, China	0.871840662	152
Cyprus	0.864296067	153
Slovenia	0.863764415	154
Greece	0.861708373	155
Brunei Darussalam	0.854455004	156
United Arab Emirates	0.847630362	157
Spain	0.8459923	158
France	0.841283871	159
Virgin Islands (U.S.)	0.839604778	160
United Kingdom	0.838797742	161

Singapore	0.829996043	162
Belgium	0.829241985	163
Italy	0.824992909	164
Japan	0.819575767	165
Germany	0.818297755	166
Ireland	0.817009705	167
Netherlands	0.816994602	168
United States	0.81301747	169
Australia	0.808715063	170
New Zealand	0.806958099	171
Qatar	0.802762861	172
Finland	0.793628017	173
Canada	0.778118775	174
Austria	0.775351574	175
Iceland	0.774207029	176
Sweden	0.773894945	177
Denmark	0.760626331	178
Bermuda	0.758655337	179
Luxembourg	0.740073362	180
Switzerland	0.734803274	181
Norway	0.696877237	182

Source: Author’s own calculation, based on data from USEIA (2018), World Development Indicators (2018), Worldwide Governance Indicators (2018), World Bank (2018b)

Table B.3: Ranking and classification of countries (for which data are available) according to their Modified Electricity Supply Disruption Risk Index (MESRI) (Average 2011-2015)

Level of overall performance as related to electricity supply disruption	**Countries**	**Average MESRI (2011-2015)**	**World ranking**
Very high level of disruption risk (Average MESRI is in the interval [2, 2.5[)	Niger	2.225437266	1
	Liberia	2.202497974	2
	Benin	2.132814665	3
	Burundi	2.102525658	4
	Togo	2.045730524	5
High level of disruption risk (Average MESRI is in the interval [1.5, 2[)	Chad	1.893196024	6
	Madagascar	1.891541179	7
	Burkina Faso	1.878838442	8
	Guinea-Bissau	1.873979825	9
	Malawi	1.848984528	10
	Central African Republic	1.837616989	11

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	Congo (Kinshasa)	1.799327872	12
	Haiti	1.770313729	13
	Sierra Leone	1.758559475	14
	Rwanda	1.750305986	15
	Mozambique	1.726889583	16
	Tanzania	1.721383781	17
	Afghanistan	1.679885887	18
	Uganda	1.658225438	19
	Gambia, The	1.641927961	20
	Ethiopia	1.618884016	21
	Mali	1.56337743	22
	Cambodia	1.546450664	23
	Guinea	1.545755187	24
	Zimbabwe	1.504454766	25
	Mauritania	1.502884237	26
Medium level of disruption risk (Average MESRI is in the interval [1, 1.5[)	Yemen, Rep.	1.471120985	27
	Bangladesh	1.46905552	28
	Kenya	1.46404513	29
	Cameroon	1.463592717	30
	Comoros	1.455184658	31
	Senegal	1.449664267	32
	Papua New Guinea	1.439315874	33
	Solomon Islands	1.436252358	34
	Nepal	1.433968994	35
	Lesotho	1.432648835	36
	Macedonia, FYR	1.399460384	37
	Zambia	1.391499095	38
	Côte d’Ivoire	1.38800356	39
	São Tomé and Principe	1.387002599	40
	Botswana	1.367234517	41
	Myanmar	1.355199023	42
	Sudan	1.34910083	43
	Pakistan	1.329846883	44
	India	1.319039734	45
	Congo (Brazzaville)	1.315808361	46
	Kiribati	1.311159483	47
	Swaziland	1.304850343	48
	Vanuatu	1.304691593	49
	Kyrgyz Republic	1.301135886	50

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Tajikistan	1.293197263	51
Nigeria	1.288693643	52
Ghana	1.274999372	53
Moldova	1.264766849	54
Nicaragua	1.256636854	55
Uzbekistan	1.250549338	56
Vietnam	1.244604874	57
Angola	1.243959794	58
Namibia	1.243942995	59
Honduras	1.24312696	60
Lao PDR	1.232291884	61
Mongolia	1.219884548	62
Guyana	1.214554811	63
Libya	1.205203235	64
Bolivia	1.204828448	65
Egypt, Arab Rep.	1.203530427	66
Philippines	1.202086896	67
Morocco	1.200901517	68
Belize	1.174825317	69
Ukraine	1.172773885	70
Jordan	1.17224932	71
Jamaica	1.162006634	72
Iraq	1.155830624	73
Tonga	1.152220169	74
Cape Verde	1.149742427	75
Indonesia	1.148995455	76
Tunisia	1.141112418	77
Algeria	1.138185982	78
Cuba	1.136244766	79
Guatemala	1.135078043	80
Sri Lanka	1.12743816	81
Albania	1.126802047	82
El Salvador	1.111552382	83
Samoa	1.109953989	84
Armenia	1.098510552	85
Thailand	1.092342947	86
Belarus	1.090577538	87
Iran, Islamic Rep.	1.084836923	88
Azerbaijan	1.081582667	89
Dominican Republic	1.0794525	90

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	Fiji	1.077522944	91
	Turkmenistan	1.077138217	92
	Lebanon	1.075412489	93
	South Africa	1.072194465	94
	Georgia	1.071388112	95
	Serbia	1.068304028	96
	Bhutan	1.067033655	97
	China	1.064667888	98
	Grenada	1.058456816	99
	Nauru	1.05833533	100
	Bosnia and Herzegovina	1.057796124	101
	Ecuador	1.055965156	102
	Saint Vincent/Grenadines	1.050477399	103
	Maldives	1.048914264	104
	Peru	1.045019739	105
	Saint Lucia	1.042461767	106
	Montenegro	1.041906528	107
	Dominica	1.035391299	108
	Bulgaria	1.019453798	109
	Mexico	1.014539548	110
	Kazakhstan	1.008513323	111
	Malaysia	1.003625078	112
	Mauritius	1.001565455	113
	Gabon	1.001231834	114
	Paraguay	1.000457149	115
Low level of disruption risk (Average MESRI is in the interval [0.5, 1[)	Colombia	0.995569668	116
	Argentina	0.992189641	117
	Antigua and Barbuda	0.988946122	118
	Romania	0.988314583	119
	Hungary	0.987420319	120
	Suriname	0.987161007	121
	Equatorial Guinea	0.9861079	122
	Seychelles	0.984425425	123
	Russian Federation	0.980669564	124
	Panama	0.979577998	125
	Turkey	0.967307055	126
	Saint Kitts and Nevis	0.962155082	127
	Costa Rica	0.957311854	128
	Oman	0.956868314	129

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Poland	0.954922656	130
Barbados	0.949194342	131
Brazil	0.942779938	132
Trinidad and Tobago	0.941994428	133
Estonia	0.933170038	134
Lithuania	0.930536022	135
Saudi Arabia	0.926950313	136
Chile	0.925878979	137
Bahrain	0.9210716	138
Slovak Republic	0.915720536	139
Czech Republic	0.910745379	140
Malta	0.910583242	141
Uruguay	0.910304665	142
Croatia	0.906147997	143
Korea, Rep.	0.902011098	144
Bahamas, The	0.890382673	145
Puerto Rico	0.888057913	146
Macao SAR, China	0.88650407	147
Greece	0.883237232	148
Portugal	0.879778706	149
Cyprus	0.876678895	150
Guam	0.875223812	151
Israel	0.874139459	152
Kuwait	0.874012093	153
Virgin Islands (U.S.)	0.873637972	154
Latvia	0.871552129	155
Slovenia	0.870493351	156
Hong Kong SAR, China	0.868079314	157
Brunei Darussalam	0.867408514	158
United Arab Emirates	0.857814509	159
France	0.851896184	160
Spain	0.849248062	161
United Kingdom	0.838411342	162
Belgium	0.835209307	163
Italy	0.824212325	164
Luxembourg	0.822045234	165
Netherlands	0.820635968	166
Japan	0.818453082	167
Singapore	0.817553438	168
Ireland	0.814933512	169

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	United States	0.813762233	170
	Germany	0.810358193	171
	Australia	0.805222568	172
	New Zealand	0.802413885	173
	Canada	0.80090301	174
	Qatar	0.798057171	175
	Finland	0.79699411	176
	Iceland	0.795056822	177
	Greenland	0.786234133	178
	Austria	0.779325759	179
	Sweden	0.764031436	180
	Denmark	0.749499872	181
	Switzerland	0.735915036	182
	Norway	0.698889047	183

Source: Author’s own calculation, based on data from USEIA (2018), World Development Indicators (2018), Worldwide Governance Indicators (2018), World Bank (2018b).