Measuring electricity security risk

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24 September 2018

CHAPTER 2
MEASURING ELECTRICITY SECURITY RISK

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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 growth 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, and the time period (Alhajji, 2007), hence there is no consensus on the definition of energy security (Ang et al., 2015). Some studies focused exclusively of the security of energy supply in importing countries (Andrews-Speed, 2004;, Bahgat, 2007, etc.), 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 safe transportation and transit of energy supply. Energy security in this study will be mostly analyzed from the supply side perspective.

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 interrupted supply of energy commodities. One of the tenants of such definition is the United Kingdom (UK)'s Department of Energy and Climate Change (DECC). According to DECC (2009, p. 19): "Secure energy means that the risks of interruption to energy supply, are low". Other tenants 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 discontinuity in the supply of 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 IEA (2001, p. 76), "Energy security is defined in terms of the physical availability of supplies to satisfy demand at a given price". IEA (2007, p. 160) defines energy security as: "adequate, affordable and reliable supplies of energy",and for IEA (2014, p.13) energy security is the "uninterrupted availability of energy sources at an affordable price". 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 aligns with 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 more focused on the potential impact of energy disruption on the availability of energy services. Significant among them are Patterson (2008), Noel and Findlater (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, etc. 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), 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 agree 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. 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. This study will specifically focus on the sustainable security of electricity supply in the Beninese context.

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 importation of electricity: according to the US EIA (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 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 high quantity of technical and non-technical electricity losses: according to the US EIA (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, four 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. The governance index comprises these governance indicators, 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. 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 growth of the urbanization rate and 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); we also multiply the transformed ratio by 100 in order to have all its values as percentages. As reported by IEA (2016), rapid urbanization increases energy consumption; 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 of 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 high GDP per capita is financially more able to invest in electricity utilities in order to reduce or avoid supply disruptions than a country with low GDP per capita. As argued by Ferguson et al. (2000), a positive correlation exists between countries' wealth and their electricity consumption.

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, and real GDP per capita (expressed as a percentage of the world annual average real GDP per capita). However we first provide a framework to explain the dimensions of energy supply security in general and the dimensions of electricity supply security in particular.

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), IEA (2007), APERC (2007), and 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 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 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 affect 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 photosyntheticenergystored 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”, 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 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 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 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 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 said 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 of 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 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. 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 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. Because of the negative values of net imports of electricity for exporting countries, and because we will be using a geometric mean 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), the rate of electricity supply self-sufficiency has been chosen as a proxy for security risk related to the concept of "accessibility". Such rate reflects countries' ability to be self-sufficient in terms of their 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 rate below 100 indicates that the country has a deficit of electricity supply and is dependent on 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 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 countries' dependency on importation of electricity. A country can rely heavily on 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 causes 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 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, etc. 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 has been chosen as a proxy for the concept of “availability”: it highlights countries’ 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 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 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 supply gap of electricity or total disruption of electricity supply.

Third, following APERC (2007), we will use the share of renewable electricity in total domestic production of electricity 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 countries' efforts to increase their use of low carbon intensive energy and decrease their 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 countries’ wealth and their 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 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 supplies. For the purpose of simplicity and in order to avoid having an indicator with very high numerical range, real GDP per capita is expressed in this study as a percentage of the world annual average real GDP per capita. Kendell and James (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 US EIA (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 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 and James (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 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".

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.

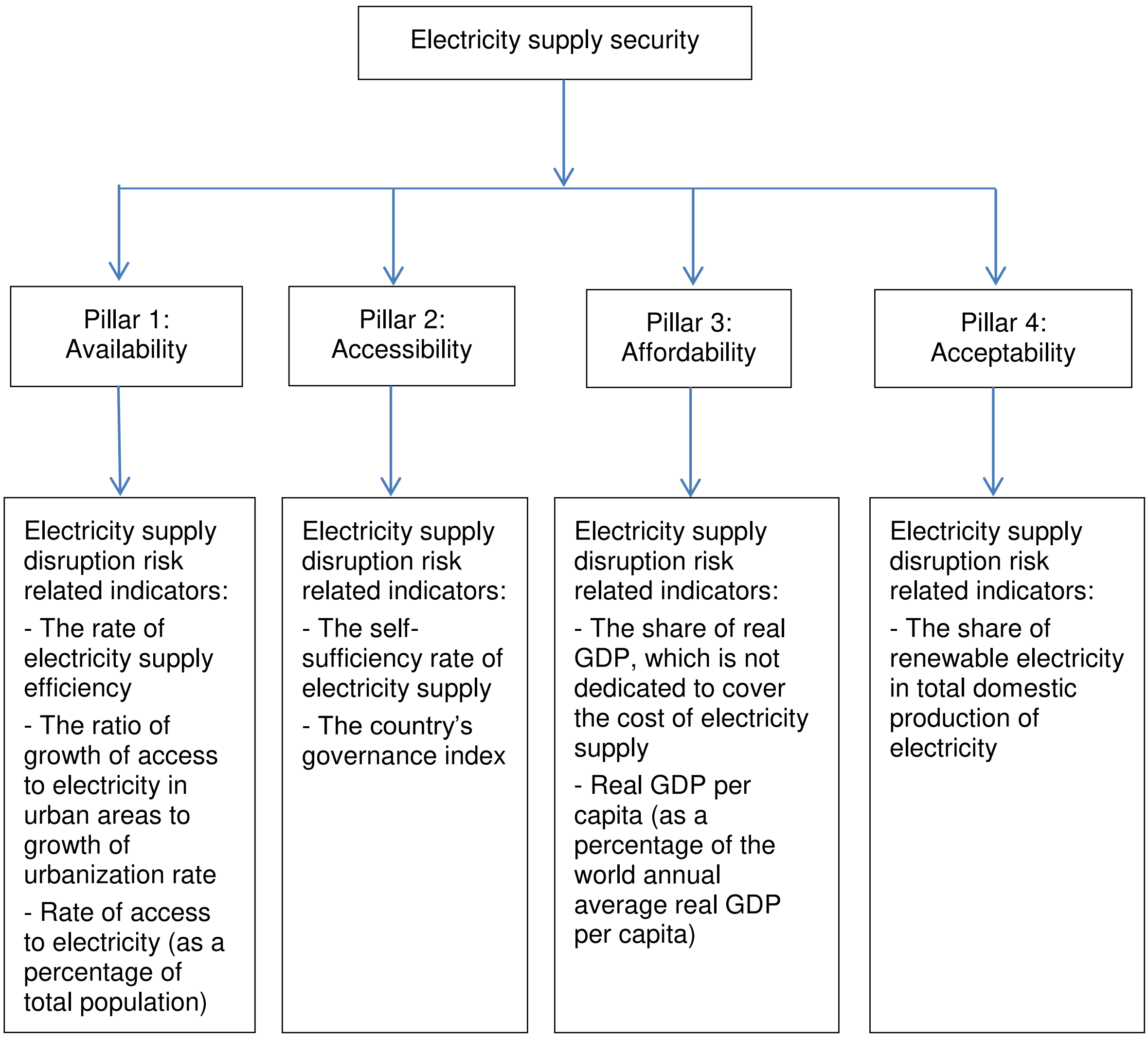

Figure 2.1: Summary of conceptual framework for electricity supply security

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 analyzed 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” has been used as an indicator of the availability of energy. However, there are issues related to the available quantity of hydrocarbon resources and 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) has 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 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 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. Prices 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 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 import is 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 a context of globalization and cooperation, an “import dependency” indicator will not matter, as there will be fewer barriers to importation of energy. Conversely, in a 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 analyze 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 fluctuation in demand and supply of energy. IEA (2004) defines “market liquidity” as the exponential 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.

Tenth, there are some energy demand side indicators which are relevant to 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 and James (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.

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 five 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 value of a ratio of reserve to production that falls below 50. While Jansen et al.’s (2004) aggregated indicator is related to several dimensions of energy security, it has some limitations. 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 analyze 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 has been included to 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 addition, some important aspects of energy security such as depletion of energy resources are not included in the construction of 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 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 lack 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 for 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". Weights were assigned to each of these indicators using a statistical tool named principal component analysis (PCA), and 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.

2.3.3 Contribution of this study

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. This study will fill that gap by constructing a composite index of electricity security. It will focus 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 will not model the security risk index related to fluctuations in electricity demand: the electricity security risk index will be 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 countries, as easy access to electricity and affordable electricity are important indicators of the ease of doing business in a geographic area. Finally it will add value to the body of knowledge in the field of energy security, as there is currently no composite index (to the best of the writer's knowledge) to measure electricity supply disruption risk.

2.4 METHODOLOGY

2.4.1 Definition of variables

The focus of this 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, a set of indicators of electricity supply disruption risks has been identified 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".

Some of these indicators 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 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 are respectively an increasing function of countries’ efforts in terms of rule of law, countries’ efforts to control corruption, countries’ efforts to improve the quality of their regulatory system, countries’ efforts to improve the effectiveness of their government system, countries’ level of political stability and attempts to reduce violence. High values of the governance index (*GI*) indicate high quality of governance in the country, while low values of the governance index indicate low quality of the country’s governance. This indicates that the governance index (GI) is an increasing function of countries’ 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 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:

$$GI = \sqrt[5]{\left[(RLA+100)\times(COC+100)\times(QAR+100)\times(GEF+100)\times(POS+100)\right]} \qquad 2.1$$

Second, the ratio (*RUB*) of growth of access to electricity in urban areas (ΔUAE) to growth of the urbanization rate (ΔUR) measures countries’ ability to avoid an electricity supply gap caused by rapid urbanization. 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 preventing 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*) indicates that countries' 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 countries' 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:

$$RUB = \frac{\Delta UAE + 100}{\Delta UR + 100} \times 100 \qquad 2.2$$

Third, 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 said 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. 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 countries' dependency on importation of electricity and their ability to produce their electricity supply domestically. It is an increasing function of countries' ability to produce their electricity supply domestically and a decreasing function of countries dependency on importation of electricity. It is expressed as a percentage as follows:

General expression

$$ESS = \left(1 - \frac{NIE}{TDES}\right) \times 100 \qquad 2.3$$

Case of importing countries

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

Case of exporting countries

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

Case of countries which neither import nor export electricity

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

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 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 said 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 said previously, 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 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 will be using 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 o 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 countries' ability to improve the sustainability of their electricity supply by using more renewable electricity, and a decreasing function of countries dependency on non-renewable electricity (*NRE*) in their domestic production of electricity (*ED*). It is expressed as a percentage as follows:

$$RRE = \frac{RE}{ED} \times 100 + 100 \qquad 2.7$$

Or

$$RRE = \left(1 - \frac{NRE}{ED}\right) \times 100 + 100 \qquad 2.8$$

Other indicators, however, did not need any transformation. First, 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 as 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 countries' ability to minimize electricity losses, and a decreasing function of countries' exposure to electricity losses. It is expressed as a percentage as follows:

General expression

$$ESE = \frac{ENL}{TES} \times 100 \qquad 2.9$$

In other words,

$$ESE = \left(1 - \frac{EL}{TES}\right) \times 100 \qquad 2.10$$

In the case of exporting countries

$$ESE = \frac{EC + EXE}{ED} \times 100 \qquad 2.11$$

In the case of importing countries

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

In the case of countries that neither import nor export electricity

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

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 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. 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 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:

$$RACE = \frac{PACE}{TPO} \times 100 \qquad 2.14$$

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 countries’ ability to minimize the cost of electricity supply, and countries’ vulnerability to the high cost of electricity supply. High values of this ratio indicates that countries are able to minimize the cost of their electricity supply, while low values of this ratio indicates that countries are exposed to high costs of electricity supply. A high cost of electricity supply limits countries’ 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 countries’ ability to minimize the cost of electricity supply, and a decreasing function of countries exposure to high costs of electricity supply. It is expressed as a percentage as follows:

$$RNEEX = \frac{NEEX}{RGDP} \times 100 \qquad 2.15$$

Or

$$RNEEX = \left(1 - \frac{EEX}{RGDP}\right) \times 100 \qquad 2.16$$

Fourth, another proxy for the concept of "affordability" is real GDP per capita (*RGDPc*), which is one of the indicators of countries' 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, etc. 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, etc. 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. For the purpose of simplicity and in order to avoid having an indicator with a very high numerical range, real GDP per capita (*RGDPc*) of countries has been expressed as a percentage of the world average real GDP per capita (*WRGDPc*). This transformed real GDP per capita is denoted by *RGDPcW* and is expressed as follows:

$$RGDPcW = \frac{RGDPc}{WRGDPc} \times 100 \qquad 2.17$$

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 is 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 (ΔUAE) and growth of the urbanization rate (ΔUR) 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*) (electricity not lost electricity) (sum of electricity consumption and exports of electricity), and losses of electricity (*EL*), have been collected 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 (ΔUAE), growth of the urbanization rate (ΔUR), 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. 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 collected from the US Energy Information Administration’s (2018) website.

2.4.3 Method

The method used for the calculation of the electricity supply disruption risks index is the geometric mean. It 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. Using the arithmetic mean to calculate such average will give more weight to variables which have a high numerical range. The geometric mean levels the variables’ numerical range when averaging them, so that no numerical range has more weight than the others. In that way, a percentage change *d* in any variable *yi* 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). 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 said 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 of electricity supply. For the purposes of simplicity, this study uses a composite index of electricity supply disruption risk (*ESRI*) with values as small numbers, varying in the range 0 to 2. 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 initial electricity supply disruption risk index *(ESRI)* constitute the values of a new index called 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 of 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

The performance of Benin as related to disruption risk to electricity supply has been measured by the modified index of electricity supply disruption risk (MESRI). We can notice in tables 2.1, 2.2 that Benin has remained among countries that have a very high level of disruption to electricity supply and was ranked 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 2.3). These results emphasize the fact that Benin is among the most vulnerable countries in the world in terms of disruption of electricity supply. We can also notice on tables 2.1, 2.2, 2.3 that most sub-Saharan African countries 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 IEA (2018), statistics from the World Development Indicators (2018) and the US EIA (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 countries' wealth and their energy consumption. Wealthy countries have high access to energy/electricity and 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 low consumption of energy/electricity. In other words, they have more supply gap of energy/electricity or more disruption to energy/electricity supply. Figure 2.2 represents the history of the performance of Benin as related to disruption of electricity supply in 1996, 1998, 2000, and over the period 2002-2015. On the vertical axis, we have the modified index of electricity supply disruption risk (*MESRI*), while on the abscissa line, we have the corresponding years. *MESRI* is an increasing function of the level of disruption to electricity supply. We can notice 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 level of disruption to electricity supply, while the periods 2007-2008 and 2014-2015 correspond to time of high level of disruption to electricity supply. These observed patterns of the modified index of electricity supply disruption risk (MESRI) on Figure 2.2 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 consecutives years, that 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.

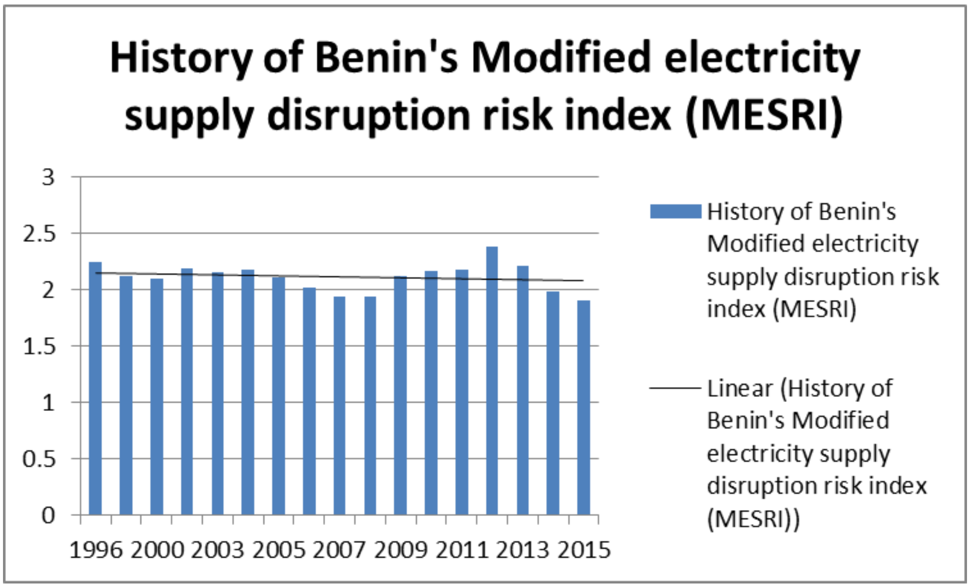

Figure 2.2: History of the modified electricity supply disruption index of Benin (MESRI) (1996, 1998, 2000, 2002-2015)

Source: Author's own calculation based on data from US EIA (2018), World Development Indicators (2018), Worldwide Governance Indicators (2018), World Bank Commodity Markets (2018)

Table 2.1: Ranking and classification of countries (for which data is 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 above 2.5)	Liberia	4.685771643	1
Very high level of disruption risk (Average MESRI is between 2 and 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	2.00622311	8
High level of disruption risk (Average MESRI is between 1.5 and 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	1.71517887	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
	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 between 1 and 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
	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
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 between 0.5 and 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 US EIA (2018), World Development Indicators (2018), Worldwide Governance Indicators (2018), World Bank Commodity Markets (2018)

Table 2.2: Ranking and classification of countries (for which data is 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 above 2.5)	Liberia	2.656688662	1
Very high level of disruption risk (Average MESRI is between 2 and 2.5)	Niger	2.346248769	2
	Burundi	2.160915782	3
	Benin	2.036629441	4
High level of disruption risk (Average MESRI is between 1.5 and 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 between 1 and 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
	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 between 0.5 and 1)	Romania	0.995991826	119
	Argentina	0.992913408	120
	Turkey	0.987561964	121
	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 US EIA (2018), World Development Indicators (2018), Worldwide Governance Indicators (2018), World Bank Commodity Markets (2018)

Table 2.3: Ranking and classification of countries (for which data is 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 between 2 and 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 between 1.5 and 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
	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 between 1 and 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
	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
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 between 0.5 and 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
	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
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 US EIA (2018), World Development Indicators (2018), Worldwide Governance Indicators (2018), World Bank Commodity Markets (2018).

The modified index of electricity supply disruption risks (MESRI) 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 (Républic du Bénin, 2008): to define and improve performance indicators for the electricity sectors and the national electricity distribution company. To the best of the writer's knowledge, 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 said 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 countries' need for investments in infrastructure (physical infrastructure such as power plant, or institutional infrastructure such as governance system or regulatory system in the electricity sector, etc.) as related to disruption to 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 (to the best of the writer's knowledge). It will be a useful tool for research institutions such as the International Energy Agency (IEA), the United States Energy Information Administration (US EIA), and research department of development finance institutions such as AfDB, ADB, IADB and the World Bank in assessing countries' performance in terms of electricity security, and in forecasting electricity supply security for countries.

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 analyzed in order to understand better why Benin is a country with a very high level of disruption risk to electricity supply. First, the performance of Benin with regard to the governance index *(GI)* is shown in Figure 2.3, 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, we have the governance index (*GI*) values, while on the abscissa line, we have the corresponding years. We can 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 2.3. 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", page 30 and 31, by République du Bénin (2008)) 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 government 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 2.4). The governance index (*GI*) as presented in Table 2.4 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).

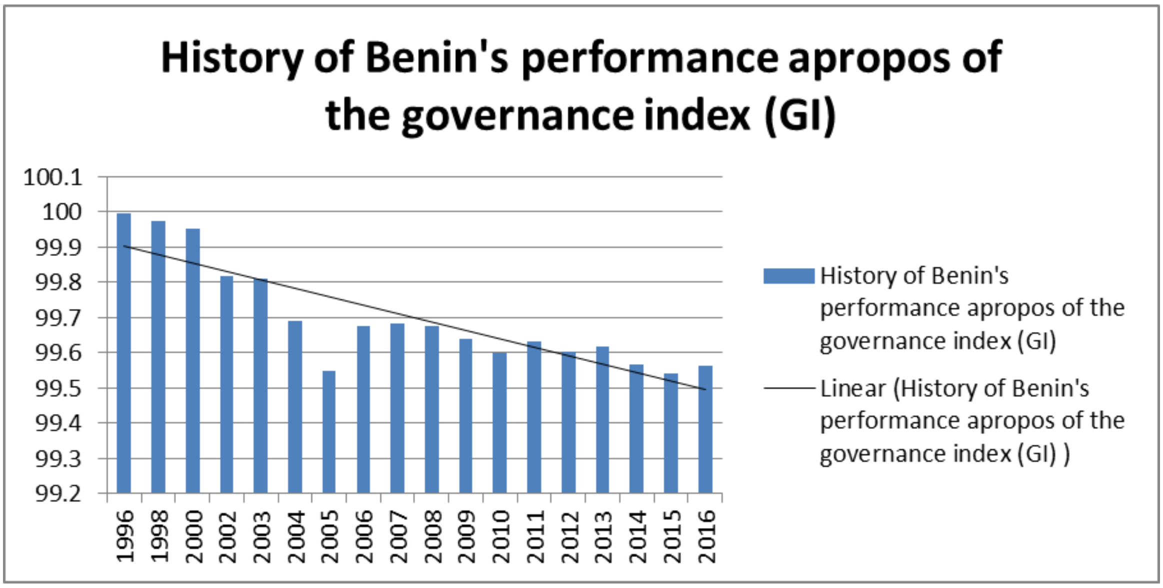

Figure 2.3: Evolution of Benin's governance system (1996, 1998, 2000, 2002-2016)

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

Table 2.4: African countries' ranking according to their performance in terms of governance (*GI*) (average 2011-2015) (only countries for which data is 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)

Second, the performance of Benin in terms of effort to avoid a supply gap of electricity in urban areas is shown in Figure 2.4, 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. We can notice that values of the ratio (*RUB*) have remained below 100% over the entire period. This indicates that in Benin, urbanization has been growing more rapidly than access to electricity in urban area. 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 average ratio (*RUB*)'s value of 96.388% (Table 2.5). The ratio of growth of access to electricity in urban areas to growth of urbanization (*RUB*) is a decreasing function of risks associated withthe 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 electricity supply gap in urban areas).

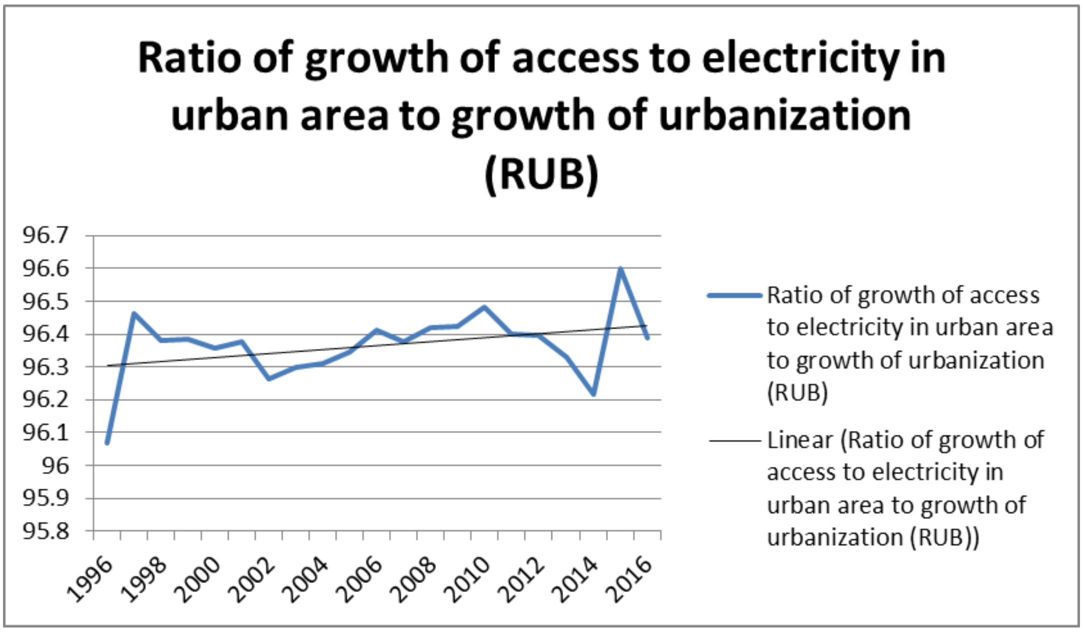

Figure 2.4: History of the ratio of growth of access to electricity in urban areas to growth of urbanization in Benin (1996-2016)

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

Table 2.5: 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)

Third, Benin's performance in terms of affordability of electricity supply is shown in Figure 2.5, 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 2.6). Table 2.6 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 said 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 low financial performance of the national distribution company (SBEE) is the use of fossil fuels such as gasoil and jet A-1 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 already low because electricity is sold to consumers at a price lower than its production cost.

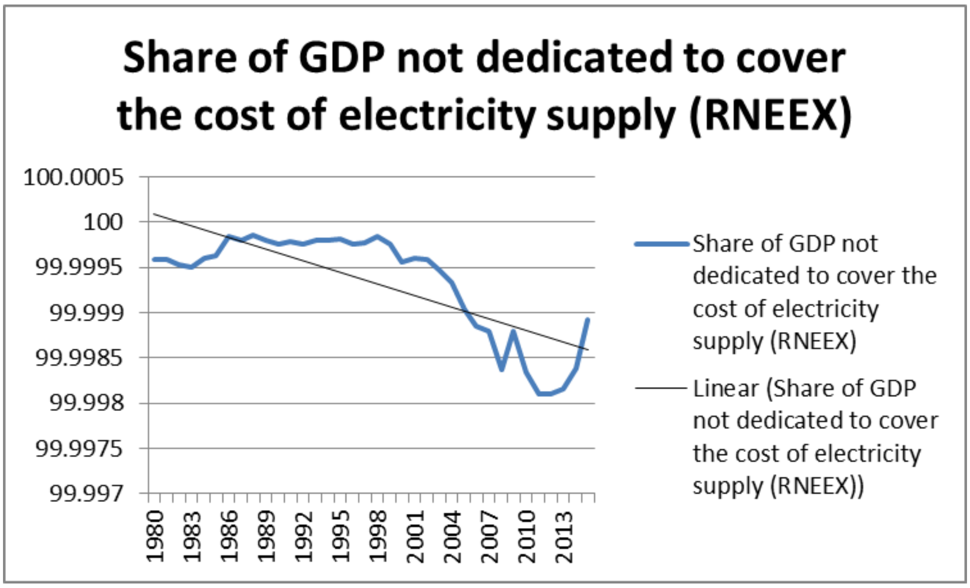

Figure 2.5: History of the share of GDP not dedicated to cover the cost of electricity supply in Benin (1980-2015)

Source: Author's own calculation based on data from US EIA (2018), World Bank Commodity Markets (2018), and World Development Indicators (2018)

Table 2.6: 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
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 US EIA (2018), World Bank Commodity Markets (2018), 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 2.6. 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 2.6, 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 said 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 2.7). This makes Benin one of the countries in Africa and in the world with high risks associated with sustainability of electricity supply security. Table 2.7 shows 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 low *RRE* have high long-term disruption risks of electricity supply related to the use of unsustainable energy resources, while countries with 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 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.

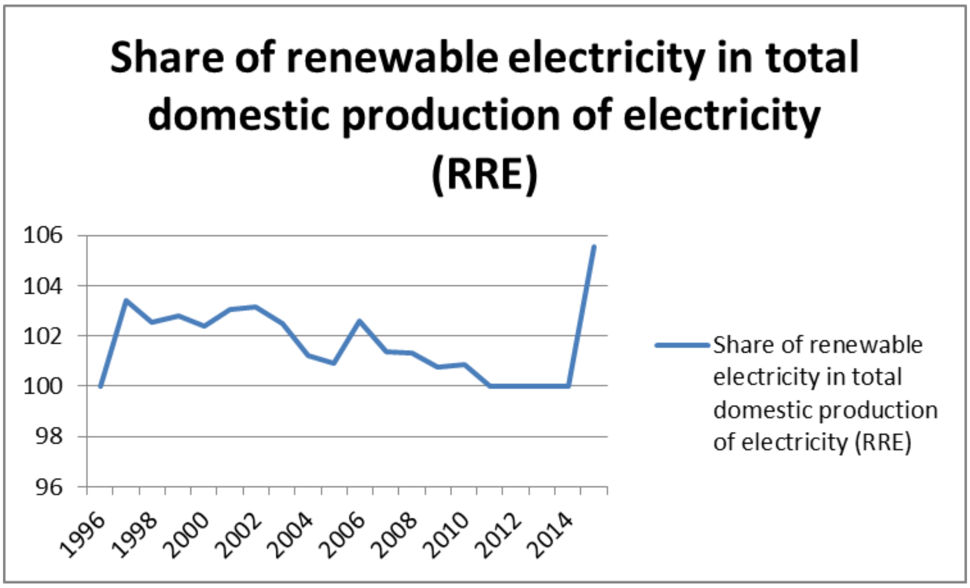

Figure 2.6: History of the share of renewable electricity in total domestic production of electricity (*RRE*) in Benin (1996-2015)

Source: World Development Indicators (2018)

Table 2.7: 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	1	1
Comoros	100	1	1
Gambia, The	100	1	1
Guinea-Bissau	100	1	1
Liberia	100	1	1
Libya	100	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	198.747599	174	47
Congo (Kinshasa)	199.67107	176	48
Ethiopia	199.8192374	178	49
Lesotho	200	183	50

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 2.7which 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 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% over the entire period. In

2015 the self-sufficiency rate of electricity supply was 22.424%. All this indicates that Benin is heavily dependent on 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 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 2.7 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 reduction of electricity importation and 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 2.7 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 in these years. The consequence was the sudden reduction of Benin's electricity supply self-sufficiency rate observed in Figure 2.7 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 2.7 that there is an upward trend of the supply self-sufficiency rate (*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 2.8). 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.

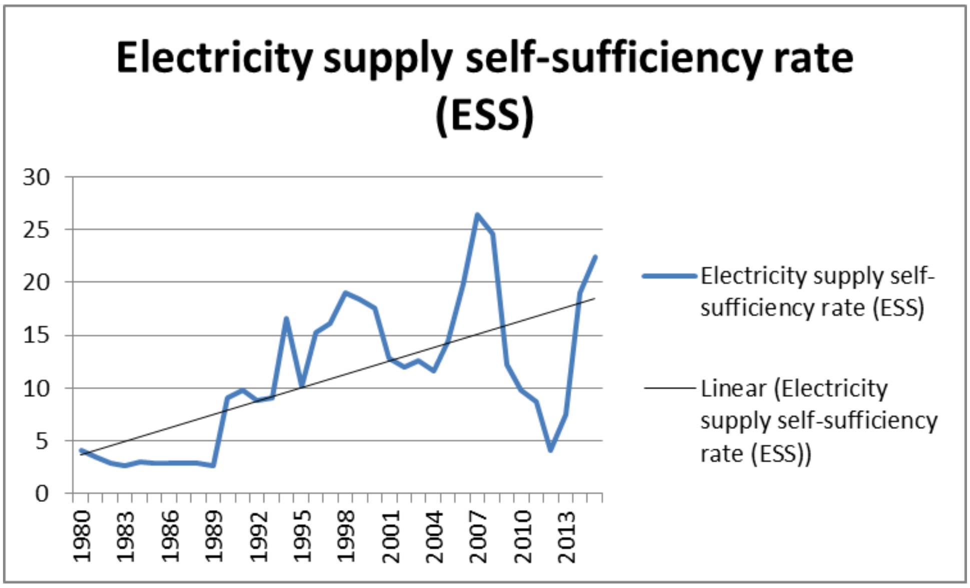

Figure 2.7: History of electricity supply self-sufficiency rate (ESS) in Benin (1980-2015)

Source: Author's own calculation based on US EIA (2019) data

Table 2.8: 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
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	72	25
Burundi	100	72	25
Central African Republic	100	72	25
Chad	100	72	25
Congo (Brazzaville)	100	72	25
Eritrea	100	72	25
Guinea-Bissau	100	72	25
Libya	100	72	25
Malawi	100	72	25
Mali	100	72	25
Mauritius	100	72	25
Nigeria	100	72	25
São Tomé and Principe	100	72	25
Senegal	100	72	25
Seychelles	100	72	25
Sierra Leone	100	72	25
Somalia	100	72	25
Sudan	100	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 US EIA (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 2.8 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. 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 2.9). All 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 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 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.

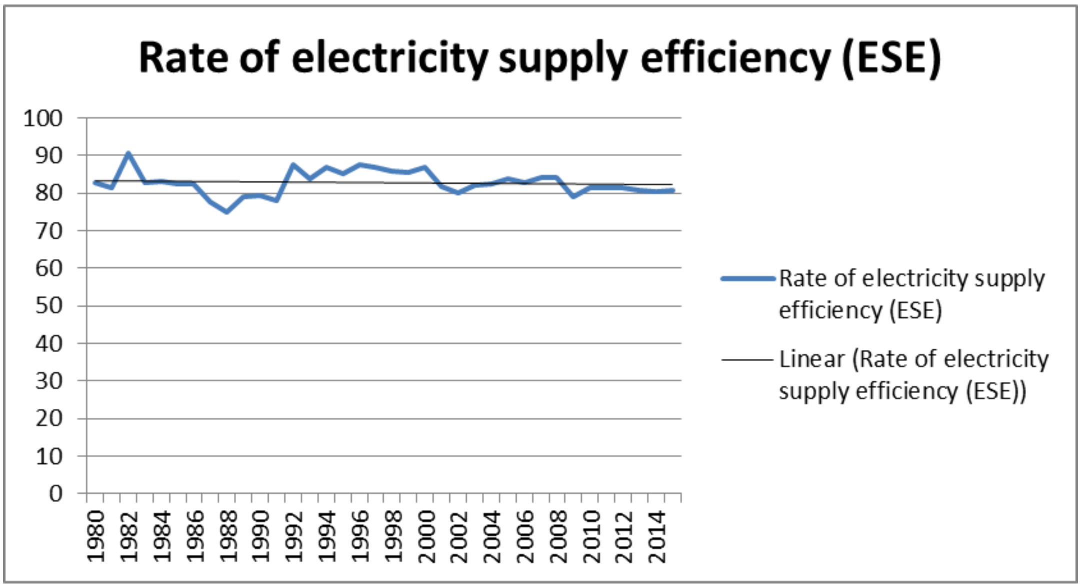

Figure 2.8: History of the rate of electricity supply efficiency in Benin (1980-2015)

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

Table 2.9: 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	111	30
Chad	93	112	30
Comoros	93	113	30
Djibouti	93	114	30
Equatorial Guinea	93	116	30
Gambia, The	93	117	30
Guinea	93	120	30

Guinea-Bissau	93	121	30
Liberia	93	123	30
Madagascar	93	124	30
Malawi	93	125	30
Mali	93	127	30
São Tomé and Principe	93	134	30
Seychelles	93	135	30
Sierra Leone	93	136	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 US EIA (2018) data

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 2.9, 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 although access to electricity has been growing in Benin, it has remained below 41.5% over the entire period. 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 2.10). In order to reduce this supply gap of electricity, the national framework for electricity (République du Bénin, 2008, p. 40) has targeted to increase access to electricity to 95% in urban areas and 65% in rural areas by 2025.

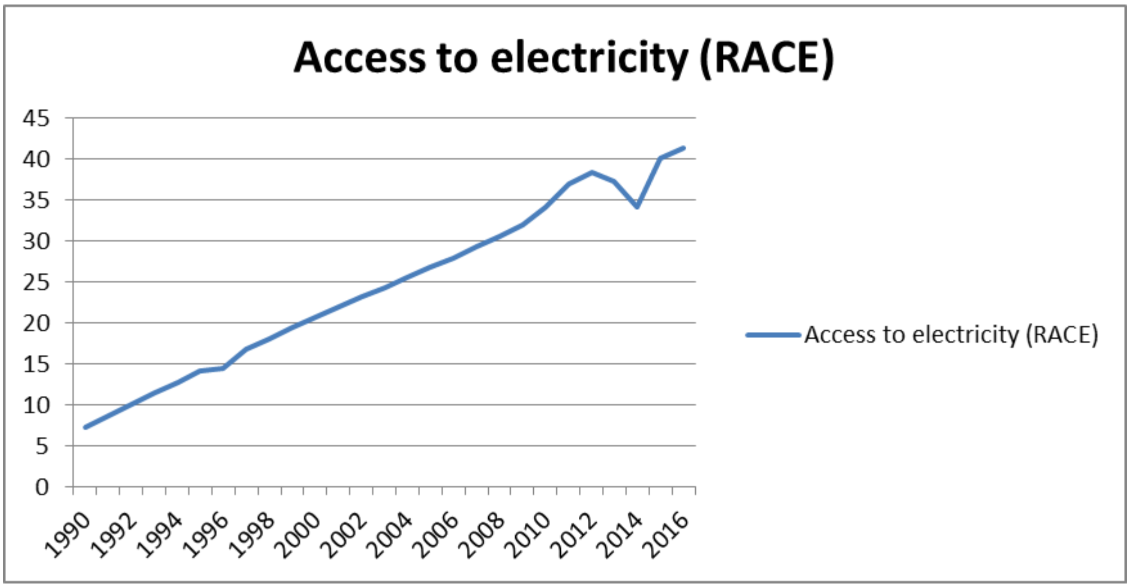

Figure 2.9: History of access to electricity (RACE) in Benin (1990-2016)

Source: World Development Indicators (2018)

Table 2.10: 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	9.34	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
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	85.38	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
Algeria	99.08559963	98	52
Tunisia	99.7	110	53
Egypt, Arab Rep.	99.86965332	120	54

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 2.10, 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, *RGDPcW* has been decreasing over the period 1960-2017 (as shown by the overall downward trend line in Figure 2.10). This indicates that over the period 1960-2017, the average person living in Benin has become more and more less wealthy 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 and 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 (Figure 2.11). This indicates that although Benin as a country has become more and 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 and 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 increase in real GDP per capita (*RGDPc*) did not prevent the country from continuing to need 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 2.11).

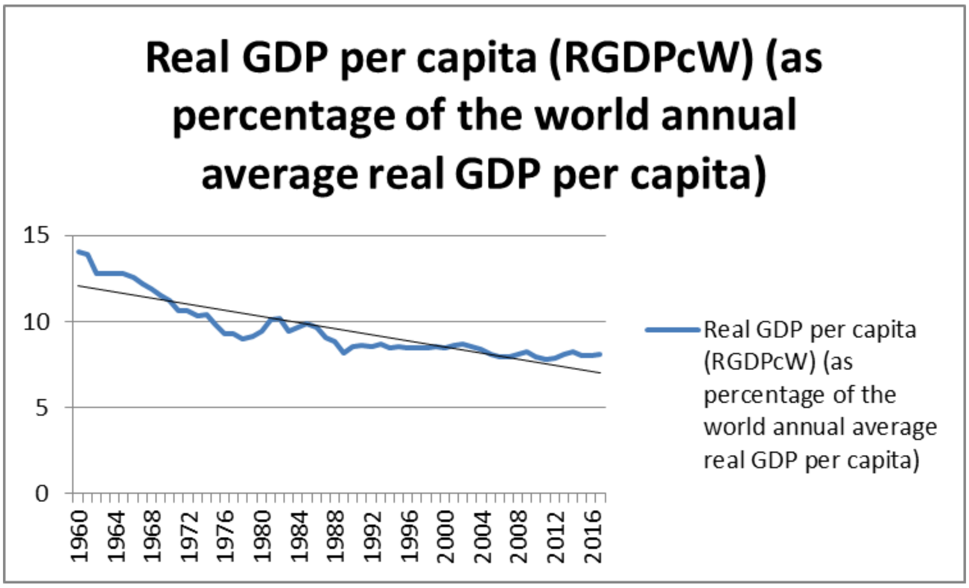

Figure 2.10: History of Benin's real GDP per capita (RGDPcW) (as a percentage of the world annual average real GDP per capita) (1960-2017)

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

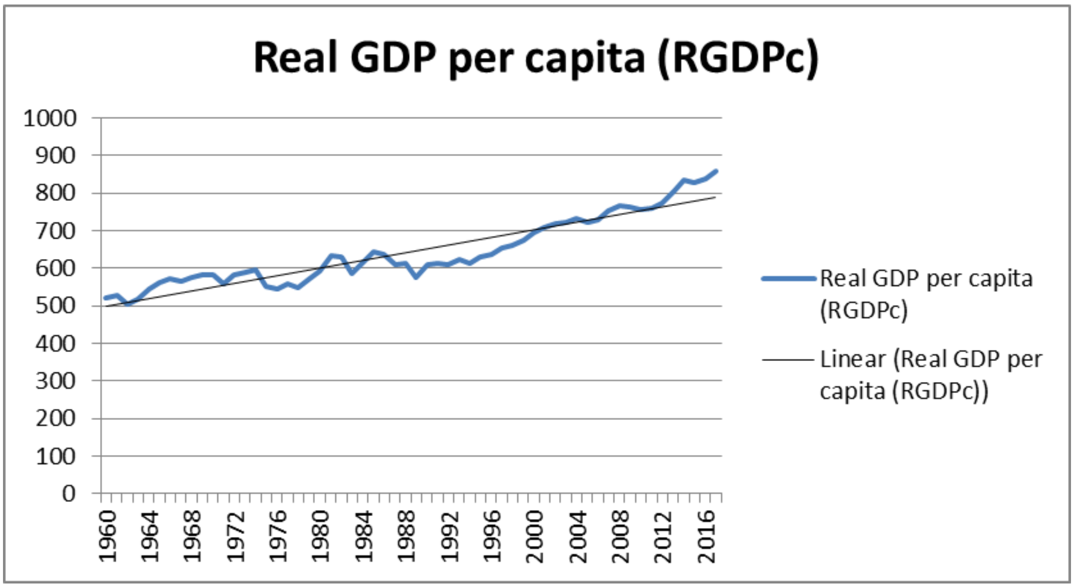

Figure 2.11: History of Benin's real GDP per capita (RGDPc) (1960-2017)

Source: World Development Indicators (2018)

Table 2.11: 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
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

2.6 CONCLUSION AND RECOMMENDATION

In this chapter an index of electricity supply security that focuses on disruption risk to electricity has been constructed. With this index, 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 disruption risk to electricity supply. As a result, an assessment of the performance of Benin according to each component of the index has been done which revealed that the performance of

Benin in terms of 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, ratio of growth of urban access to electricity to growth of the urbanization rate, are all low. Especially for the rate of electricity supply self-sufficiency, Benin is the second worst in the world after Togo over the period 2011-2015 (see Table 2.8). This suggests that 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. Reducing 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 loss. 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. Otherwise, the high rate of migration from urban to rural area will continue, and will increase the rate of urbanization, while the rate of urban access to electricity is not as fast. The consequence will be an increasing urban supply gap of electricity. Both 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 illustrated 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 into the Beninese electricity sector. Other ways of financing electricity infrastructure have also been identified by in the national policy framework for electricity. One of these is an indirect financing mechanism, which suggests first using donors or national budget funds to finance electricity infrastructure that will 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 therefore require an assessment of the gain in GDP resulting from reduction in electricity loss. In other words, they require an assessment of the effect of electricity loss on GDP. This assessment is the focus of the following chapter.

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