ASSESSING MANUFACTURING INDUSTRIES' ELECTRICITY PRODUCTIVITY IN SECONDARY CITIES.

The case of Musanze and Rubavu in Rwanda

Ir. Ndayisaba Ali Ahmed BUREGEYA
March, 2016

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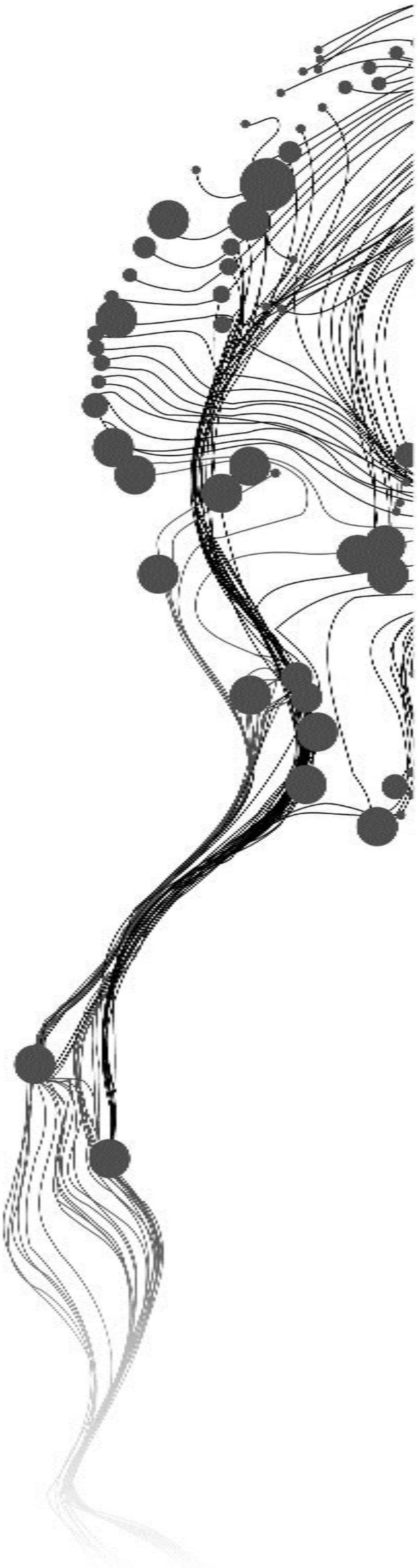

ASSESSING MANUFACTURING INDUSTRIES' ELECTRICITY PRODUCTIVITY IN SECONDARY CITIES. The case of Musanze and Rubavu in Rwanda

Ir. Ndayisaba Ali Ahmed BUREGEYA

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Specialization: Urban Planning and Management

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ABSTRACT

The productivity of manufacturing industries is an important factor for the economic development of every country of which secondary cities are not an exception. It depends on different inputs including electricity, considered a direct and indirect input due to its role, particularly in manufacturing industry processes. Many researches on electricity supply for developing countries are oriented to the percentage of households' connectivity as a basic need. Few are oriented to the productive use of electricity. However, increasing the percentage of connectivity in term of network expansion does not guarantee the productivity which increases with high production of manufacturing industry. Using electricity access multi-tier framework, network analysis and single factor productivity ratio, the electricity supply system and manufacturing industries' electricity productivity are assessed in two Rwanda secondary cities: Musanze and Rubavu. To achieve this, the data for five years (2010-2014) from Rwanda Energy Group (REG) monthly reports were analysed to assess the supply of electricity. The firm turnover and electricity consumption for 16 firms in 2014 were used to analyse their electricity productivity. The result shows that electricity network coverage is not a problem, rather the reliability of electricity supplier is a blockade for the productivity of manufacturing industries. The conclusion is that: in addition to electricity connectivity, availability, reliability and quality (stability of frequency) should be observed by the electricity suppliers to ensure the industrial productivity and economic growth in these cities.

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BNR	Banque National du Rwanda (Rwanda National Bank)
EWSA	Energy, Water and Sanitation Authority (Rwanda)
EDPRS	Economic Development and Poverty Reduction Strategy
GDP	Gross Domestic Product
GIS	Geographic Information System
KV	Kilovolt
KW	Kilowatt
KWh	Kilowatt hour
MINECOFIN	Ministry of Finance and Economic Planning (Rwanda)
MININFRA	Ministry of Infrastructure (Rwanda)
MW	Megawatt (electrical measurement), 1MW = 1000KW
NISR	National Institute of Statistics Rwanda
REG	Rwanda Energy Group
RPSP	Rwanda Private Sector Federation
RRA	Rwanda Revenue Authority
RWf	Rwandan Francs
UNIDO	United Nations Industrial Development Organisation

1. INTRODUCTION

Manufacturing Industries play an important role in the economy of a country**.** On one hand, the products from industries are used in the country reducing the country dependence from foreign countries. This increases the internal money circulation by local sales. On the other hand, when products are locally manufactured, there will be no or less need to import them from outside which decrease the money outflow. When enough products are produced, the country exports them to foreign countries increasing inflow money. Hence, producing more increases the economy of a country.

Industrial productivity depends on inputs to be used. The more inputs are available, the more the chance to get high industrial production. Productivity, being a ratio between outputs and inputs, increases with an increase of outputs and decrease of inputs. This means that a high productivity occurs when more products are produced with fewer inputs used to produce them. The scarcity of inputs as well as their poor quality results to fewer products produced in industry contributing to a decrease in productivity. Electricity is one of these inputs and considered to be an important input for manufacturing industries. It is used as direct input as a requirement in the production process and indirect input and stimulus for other inputs.
Despite the important role of electricity in manufacturing industries, building and maintaining its infrastructure in secondary cities is a challenge in most developing countries. Many electricity supply projects and fund mobilised for them target the centralised or regional grid to supply major cities. Hardly, secondary cities are given priority. However, these secondary cities can be supportive for local economic development and sustainable urbanisation enabled by high industrial production, results of infrastructure provision. Failure to infrastructure provision minimises the secondary cities' competitiveness within them and with major cities as well as at international level. The secondary cities livability decrease by less job created and retained resulting to low employment, less diversification of economic activities as well as fewer investments attraction. Arnold et al.,(2008), using data from 1000 firms in Sub-Saharan African countries, found that improved electricity services enhance the economic activities' performance of a city. Hence, infrastructure provision contributes to secondary cities' economic development and increase competition within cities.

This research assesses electricity supply as a major factor for manufacturing industries' productivity in particular and for economic growth in general. Using data from Rwanda Energy Group (REG) for electricity supply and the firm turnover for manufacturing industries in Musanze and Rubavu, two secondary cities in Rwanda**,** the electricity supply and demand, for manufacturing industries productivity are assessed**.**

In This chapter, general background, the problem statement, the research objectives and questions, research design and context, the conceptual framework and the structure of this thesis are presented.

1.1. General Background

Electricity supply is a special concern for economic operators such small and medium enterprises as well as for heavy companies who consider electricity as a driving force to sustain the economy. Arguably, economic development of countries depends on the availability of and reliability of energy especially electricity: The richness of a country goes together with high access to and high consumption of electricity (Chontanawat et al.,2008). While the level of electrification is almost 100% for developed countries, it still below 30% for eastern and southern Africa countries (Karekezi & Kimani, 2002).

Historically, rich countries promoted industrial production which allowed them to shift from agriculture based economy to industrial based economy before shifting to service based economy. Contrary, the poor countries, which stay in the first stage of economic transformation, rely on aids and manufactured products from rich countries. They have less electricity consumption. An example is that in 2010, United States had 13.4MWh per capita consumption; United Kingdom: 5.7MWh; Ukraine: 3.5MWh; China: 2.9MWh; Cuba: 1.3MWh; South Africa: 4.6MWh, Kenya: 0.16MW, Nigeria: 0.14MWh and Tanzania: 0.09MWh respectively (World Bank, 2016).

The roles played by electricity in manufacturing industries are diverse. It is used for working place lighting; devices powering such as computers and other appliances, information sharing, motors start up, process stimulation and so on. In manufacturing industries, electricity is considered as an input among others in the production line. There, electricity is not a simple cost that creates bills to pay but also a benefit contributing to high production, when available in both quantity and quality. Hence, electricity can be considered as an economic booster. It also contributes to population well-being improvement by job creation through technology innovation that impacts all aspects of life what cannot be possible or easy without the use of electricity.

Despite the universal recognition of electricity necessity for the economic growth of a nation, an increase in its access is not an easy task. On the supply side, electricity supply needs enough investment to build and improve the capacity from production, transport, distribution as well maintenance. On the demand side, low consumption or un-proper use of electricity, as well as the low purchase power of poor people, do not guarantee the return on investment. This creates two possible problems: "low connectivity and/or poor maintenance" due to their high cost. These problems may result in low quality of supply. This dual (connectivity and maintenance) is sometimes forgotten by decision makers who believe that increase in connectivity will increase the economy. This is because they forget that "necessity is not efficiency".

1.1.1. Urbanisation, Infrastructure, Industrial Productivity and Economic Growth of Secondary Cities

Urbanisation is the process of increasing the number of people living in the city in comparison to people living in rural areas (Hardoy & David, 1986). Since 1950 urbanisation has become a worldwide phenomenon (Bocquier, 2005). It grew from 30% in the year 1950 to 54% in 2014 and is projected to be 66% in 2050 (United Nations, 2014; UN-HABITAT, 2013). Today, North America is the most urbanised with 82%, followed by Latin America and Caribbean with 80%, then Europe with 73%, Asia 48% and Africa 40% (United Nations, 2014). Despite the low percentage of urbanisation for Africa and Asia, their projections till 2030 are 56% and 64% respectively. However, some cities are growing rapidly than other. In their study for Udon Thani in Thailand, Phuttharak & Dhiravisit (2014) found employment and income expectation to be among the reasons for city rapid growth with industrial expansion being the response to this expectation.

Without measures to accommodate the change, both demographic and economic, rapid urbanisation constitutes challenges when it is not paired with economic growth. Cohen (2006) found that rapid urbanisation cannot be paired with economic growth without adequate basic infrastructure. That is the case, especially for low and middle-income countries. When these two are paired, the socio-economic activities increase, job are created in industries and surrounding area harbours, living standards are ameliorated leading to high concentration and urban area expansion. Hence, urbanisation can be a source of opportunities or challenges, results of people, infrastructure interaction and economic growth.
The economic growth of a city contributes to rising in the production of economic goods. Based on some countries' economic data, Kuznets (1966) has shown that some of the economic growth factors are: the rising in productivity, the shift from agriculture to industry and from industry to service. Adelman & Morris (1973); Daniel (2010); Njoh (2003) and Berry (1961) supported these arguments and placed industrial productivity in a central point of the economy of a country.

1.1.2. Industrial productivity and electricity supply

Several researchers have found labour force, capital, land availability, change in agriculture, technical progress and resource of raw material to be the most important factors of industrial productivity (Solow, 2015; Thirlwall, 2006; Schumpeter, 1934). The latter argued that industrial productivity depends highly on firms' productivity due to their role to increase the production. In the same perspective UNIDO (2013) shows that manufacturing industries play an important role in industrial productivity.

Sari & Soytas (2007) considers electricity to be an essential production factor in manufacturing due to its role to add value to the product. They concluded that using electricity efficiently in manufacturing industries can increase their growth by value added. The important role of electricity is also reported by World Electricity Outlook (2002) stating that electricity contributes to rising productivity by helping industries to produce more within less time and keep the uniformity of product.

1.2. Problem Statement

Electricity supply is to manufacturing industries' productivity, yet short in secondary cities. The complex use of electricity makes it be a necessity. The presence of electricity increases working time, fuel the motors in production industries, light area and contribute to security, etc. Oriented to the necessity improvement, many studies examined the existence or not of electricity in different countries by showing how much percent are connected to the grid network (on-grid or off-grid).

Although electricity is important for work output, its share in manufacturing industries output is still unknown. Moreover, the extent to which electricity should be supplied to stimulate industrial productivity in secondary cities is rarely studied. Furthermore, to which industries it should be supplied for largest productivity. Despite many researches conducted on electricity connectivity (Nouni et al., 2009; World Bank, 2008; ESMAP, 2002; Cecelski & Glatt, 1982), few were oriented on electricity productivity for manufacturing industries. By analysing how electricity supply can be productive for the end users, Kittelson (1998) identified the factors influencing electricity productivity to be: "1) reliable and affordable electricity, 2) available and reliable electric tools and equipment, 3) available and affordable financing, 4) available and qualified human resources and 5) sufficient demand for the product or service". In his study, he found that electricity supply consider only over-consumers of a great quantity of KWh to ensure their production security. However, his study was not only oriented to manufacturing industries, nor to secondary cities. In addition, the situation in low-income countries, especially for African countries stills obscure and there is no search study yet published for Rwanda according to our today's knowledge. This study will fill this gap and Rwanda secondary cities will laminate it well.

1.3. Research Objectives and Questions

1.3.1. General Objectives

The major objective of this study is to evaluate the spatial distribution of electricity supply for manufacturing industries and their electricity productivity in two Rwandan secondary cities: Musanze and Rubavu.

1.3.2. Specific Objectives

The specific objectives are

i) To assess the current electricity supply system in Musanze and Rubavu secondary cities,
ii) To assess the domestic manufacturing industries' production of Musanze and Rubavu secondary cities,
iii) To assess the electricity productivity of manufacturing industries in Musanze and Rubavu secondary cities,
iv) To compare the secondary cities according to manufacturing industries electricity productivity.
v) To draw conclusions regarding the possibility of selective promotion of manufacturing industries in secondary cities, given their electricity productivity.

1.3.3. Research questions

To achieve the above objectives, the following questions are formulated:

1. What are available sources of electricity in or near Musanze and Rubavu secondary cities?
2. How is electricity supply system in Musanze and Rubavu?
3. What is the manufacturing industries' electricity consumption in Musanze and Rubavu secondary cities?
4. What is the manufacturing industries' production in Musanze and Rubavu Secondary cities?
5. What is the electricity productivity of manufacturing industries in the Musanze and Rubavu secondary cities?
6. Where are problems and opportunities between secondary cities and between manufacturing sectors?

1.4. Research design and Conceptual framework

To conduct this research, two Rwanda secondary cities: Musanze and Rubave, were chosen as a study area. This is because Rwanda has an ambitious target to change its economy from agriculture based to industrial based. To achieve this, six secondary cities were selected to serve as development pole growth. This target cannot be reached without supporting key production factors such as electricity.

Based on the available sources of electricity in the secondary cities under study, I will analyse the generation capacity, the transmission capacity and distribution (supply) capacity toward the manufacturing industries' electricity use. To assess the electricity productivity, the manufacturing industries' production and their electricity consumption will be used and calculation of the ratio between will lead to manufacturing industries' productivity. Figure 1 shows the context and processes involved from the sources of electricity to electricity productivity.

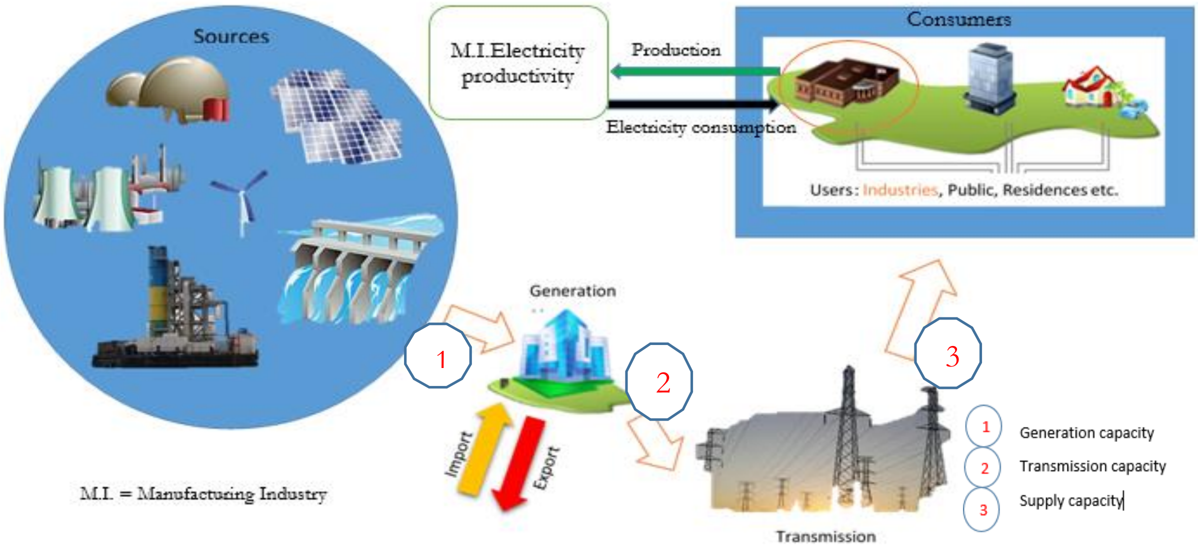


Figure 1: Processes in Electricity Productivity of Manufacturing Industries.
Source: Author.

Industrial productivity is dependent on several combined production factors. It is a ratio of the production to the inputs used to produce them. For the system of electricity productivity, only electricity is considered as input that can be compared to the production or outputs. It depends on the electricity supply, the supply depends on the production and distribution capacity.

The production depends on available sources (renewable or non-renewable) and the distribution depends on the type of grid system. The production of manufacturing industries depends on their mechanical performance and inputs as illustrated in figure 2. Due to lack of data and time limitation, only on-grid for electricity production and distribution was considered. Off-grid electricity both renewable and non-renewable are not considered in our study. The same, other inputs in the production line are not considered.

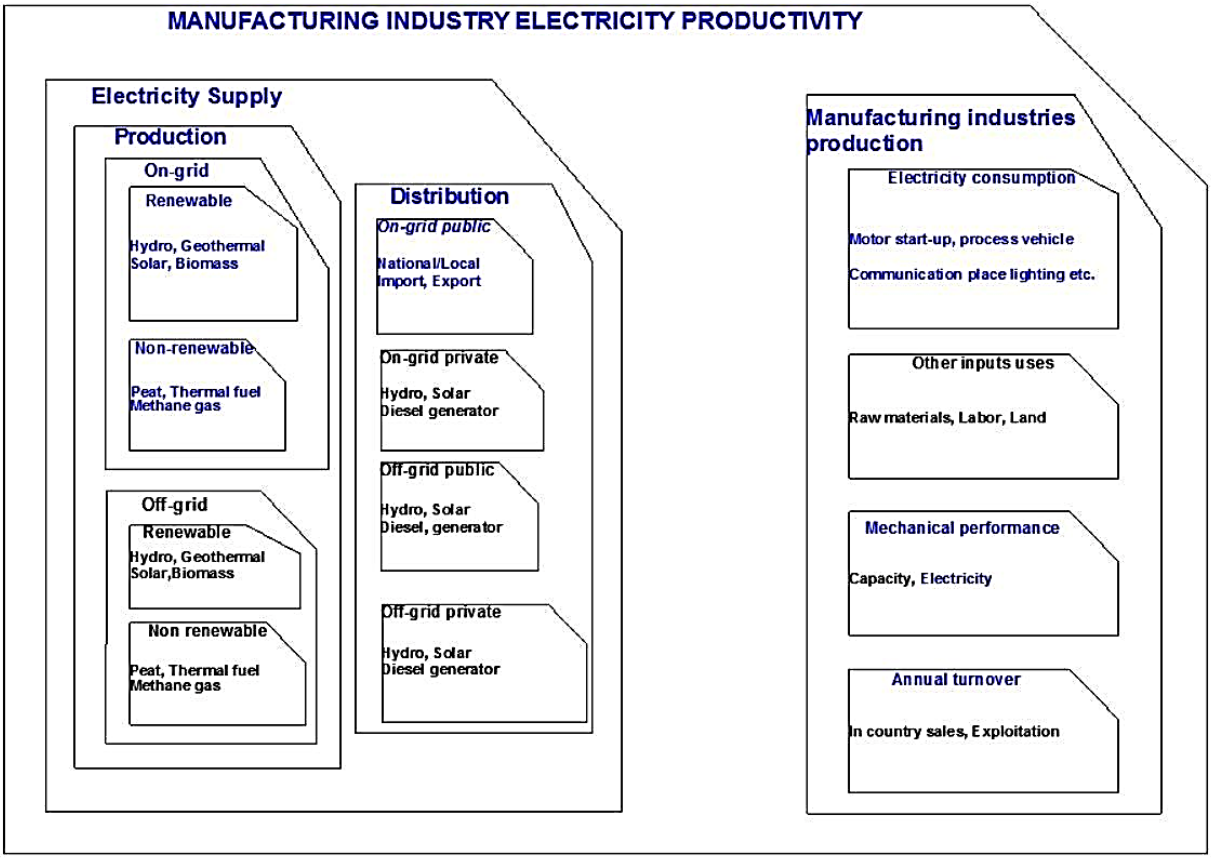


Figure 2: Conceptual framework for manufacturing industries' electricity productivity.

Source: Author.

1.5. Thesis structure

This work is divided into six chapters:

- The first chapter is an introduction providing overall consideration, research problem, objectives, questions and the conceptual framework
- The second chapter is the literature review. It will discuss the role of electricity supply, in general, the quality of electricity supply system and the effect of lack of this quality in manufacturing industries. It will end by giving different factors governing electricity productivity for manufacturing industries.
- The third chapter presents the methodology used in this research. It will describe the study area, how data were collected and how they were analysed.
- In the fourth chapter, I will present and explain the results of our study.
- Chapter five discusses the results.
- The last chapter will give concluding remarks and recommendations for future studies.

2. LITERATURE REVIEW

2.1. Introduction

This chapter presents the review of different researches in our topic. It starts by showing how secondary cities can serve as growth pole, the role played by electricity in economic growth of secondary cities, link between electricity supply, electricity demand and industrial productivity. It explores the literature about the factors influencing manufacturing industries productivity. After a review on electricity productivity for manufacturing industries, a contemplation is made about the method to be used in this research: the method to evaluate electricity supply in which I define access to electricity, measurements of production and the method to evaluate the productivity. This chapter ends with a summary of the method to assess the electricity network.

2.2. Secondary cities as growth pole

By 2050, about 60 percent of African population will be living in cities(United Nations, 2014). This strong demographic growth is neither good nor bad on its own. It may contribute to economic growth if enabling growth factors such as infrastructures, capable institutions, good leadership and capacity building, among others, are provisioned (Rasoolimanesh et al., (2014). In this perspective, demographic growth can be supportive to economic growth when accompanied by jobs creation and high productivity (Un-Habitat, 2010). According to World Bank (2009), all middle-income countries were enabled by industrialisation and urbanisation and all high-income countries experienced vibrant cities. According to the same author, currently, chaotic rush to cities in developing countries was also observed in history (example: China: 1985-2005, USA: 1800-1900, Germany: 1830-1850 and Canada: 1880-1900). In contrast, the rapid growth may result in slums proliferation. Each city has its particularity. Jovanovic (2010) in his study for energy sustainability to support economic growth in urban area concluded that each city should consider its own contextual economic, social and demographic situation.

In addition to the above inconclusive situation, comes the question whether urbanisation leads to economic growth. Advocates of growth argue that urbanisation increases the GDP and labour productivity. Among them are OECD (2006) which found 66/78 metro region to have GDP higher than their national average and 65/78 having fast growth rate than their countries. However the rest of countries were in contradiction: The level of unemployment is higher in this metro region than in intermediate and rural area (44.3% of unemployment against 49.7% and 44.5%). Un-Habitat (2008) in the same line, called African countries to plan for their future economic growth by taking advantage of 2/3 of its population who will be living in intermediate cities (secondary cities) by 2050.

Most of the examples were given including China unprecedented growth. Ravallion (2009) revealed that the China annual growth of around 12% during the period of 1985-2005 was a result of investment especially in infrastructure and the leadership which dresses the proper fund allocation. Despite progress registered for China, inequality grows at 7% per decade. Ravallion (2009) concluded that Africa should find the priority sectors for investments. Critically, Turok & McGranahan (2013) argued that cities and urbanisation, especially in Africa, can lead to productivity and growth if they empower industrialisation atmosphere by providing vital infrastructures, expertise, technological underpinning, investments and reactive governance.

Hence, secondary cities may be growth pole if Turok & McGranahan (2013) critics are taken into consideration. Other ways, if economic activities are not thought of, the urbanisation in Africa will lead to increasing in slums.

2.3. Role of electricity in economic growth for secondary cities

For many countries, most economic activities including industries are located in the major cities due to infrastructure availability. This jeopardises the chance for equitable resource distribution and threatens the economic growth of secondary cities. One of the ways to tackle this challenge is to develop economic activities in secondary cities among which industrial development. This requires infrastructure provision such as road, water and electricity. Yan & Chien (2013) and Georgescu (1975)shown that electricity availability facilitates the use of existing or new technology source of innovation. The presence of electricity increases the industries and firms clustering.

The lack of or inadequate provision of electricity constitutes a major barrier to investment as illustrated by Reinikka & Svensson (1999) in their study for Ugandan industries. They found that during 1998, 243 manufacturing firms faced on-grid electricity outage of 89 working days, causing the losses equivalent to 25% of the whole investments to buy machines and equipment. 77% of the large firm, 44 of medium firms and 16 of small firms were obliged to buy their own electricity generators to cover the losses. They found that 1% day increase of electricity outage result to 0.45% of the decrease in investments.

In contrast, when electricity is available and reliable, more investment may occur in secondary cities including manufacturing industries which may increase their productivity. By interpretation of output equation 1, Agénor & Blanca (2006) demonstrated how investment in infrastructure (road, telecommunication and electricity) increases labour productivity and private capital which in return increase the economy of the city.

$$Y = I^n L^m P^{1-n-m} \tag{1}$$

$$Mp = (1-n-m)(I/P)^n (L/P)^m \tag{2}$$

$$Ml = m(I/P)^n(P/L)^{1-m} \quad (3)$$

Where Y. represents output, I. infrastructure inputs, L. labour, P. private capital, Mp. private capital's marginal product and Ml represents labour's marginal capital.

The equation (1) shows that output from manufacturing industries depends on infrastructure provision including electricity, labour and capital. The equation (2) and (3) show that infrastructure provision increases both marginal products for labour and private capital. By increasing labour productivity, electricity provision may increase the growth as the ratio I/P increases by increasing the infrastructure provision.

With electricity provision in secondary cities, new firms can be created, new technology can be applied and new innovation can get place creating new jobs and leading to a high number of products and cost reduction. When the cost reduces, more buyers will be able to afford them leading to big sales for firm's owners that enrich them more. With enrichment, the business owners will expand their activities with the possibility of new industries that will need electricity. By job creation, people in the peripheral area to secondary cities will join the industries increasing the number of city inhabitants and products consumption which increases the economy of the cities as summarised in figure 3 showing this cycle.

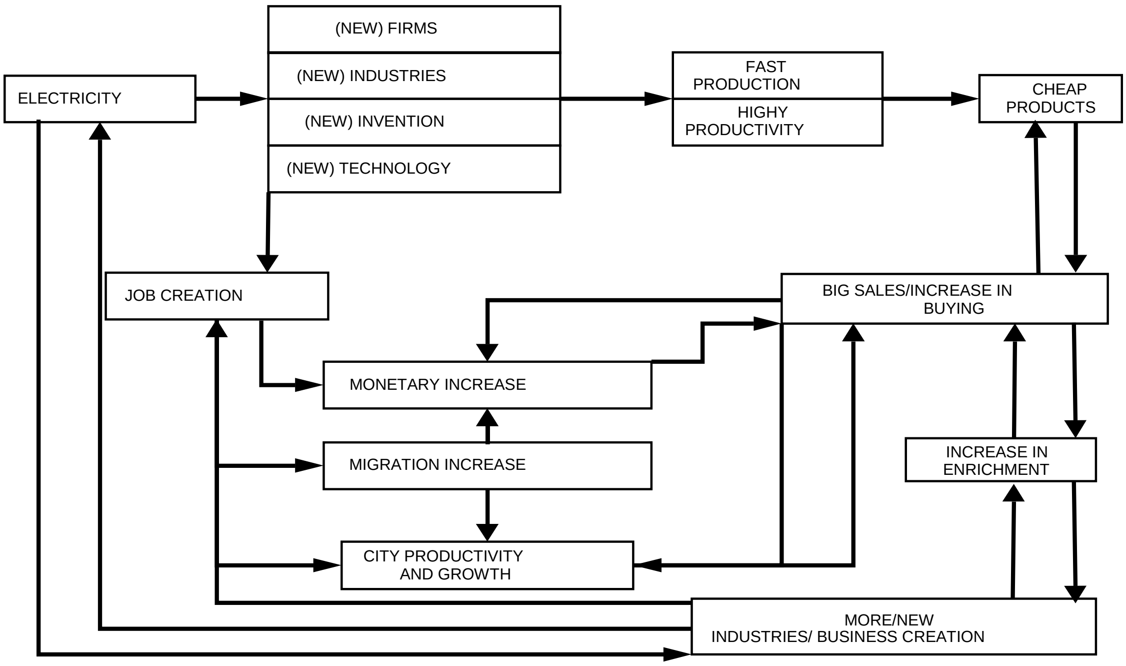


Figure 3. Electricity Supply and Secondary City Economic Growth

Source: Author.

2.4. Link between electricity supply, electricity demand and productivity

When analysing the interdependence between electricity production, supply, availability, reliability, consumption and productivity as identified by Pueyo & Hanna (2015); Lucius Mayer-Tasch et al., (2013) found three links as shown in figure 4: The first is electricity as input that must meet demand in both quality and quantity to be used in manufacturing industries. The need for electricity goes beyond the use in machinery as motive power because it contributes also to lighting, communication, refrigerators, cleaning, electronic appliances and so on.

The second element is the output resulting from quantity and quality of electricity:

a. For place lighting, it will give the opportunities to extend working hours (night shift).
b. For motive power, the mechanisation and/or automation will become possible resulting to uniform and high quality of products,
c. In communication, the use of electricity will reduce its cost and time,
d. For industries that need to preserve products, electricity will be necessary for the use of the refrigerator.

The supplier may also increase the capacity in production both quantity and quality. A high number of produced units may result in unit cost reduction while a high quality of the products may increase their prices. For the finished products, electricity can help to change them with the innovative idea the result to new and improved quality (Dijk & Clancy, 2010).

The third element is the electricity productivity. An electricity used efficiently to produce more product will result in "high productivity". With high productivity, it is likely to have a high profit that increases the income. An increased income increases electricity access affordability that will make easy to recover the cost invested in electricity production, transport, distribution and maintenance (IDS, 2003). With a high purchase power, ambitious projects can be initiated, creating other demand for electricity. This makes an economic circle that can be improved by improving a composing element.

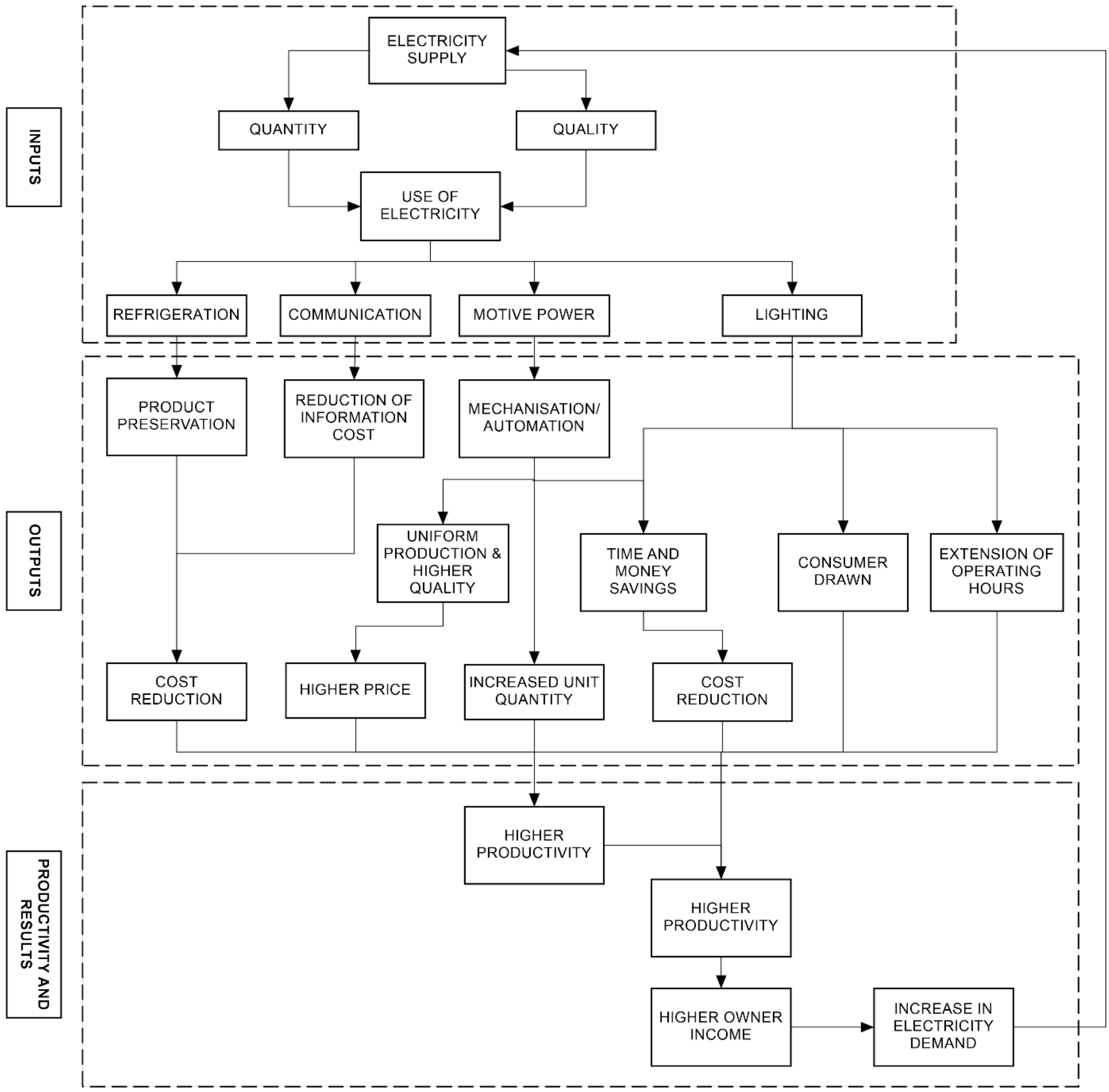


Figure 4: Link between electricity supply, industrial productivity and electricity demand

Source: Adapted from Lucius Mayer-Tasch et al., (2013).

2.5. Factors influencing manufacturing industries productivity

Industrial productivity is defined as the ratio between inputs and outputs (Syverson, 2011). It differs among countries, sector of production and among firms. Syverson (2004) in his study using data from US ready mixed concrete plants, shown that: using the same inputs the outputs may be doubled, tripled or even increase to tenfold defining the high difference in productivity that they attribute to the technology. (Hsieh & J.Klenow,(2009)found the same trend in India and China.
Bartelsman et al., (2013) shown that developed countries have higher productivity than developing countries. The differences depend on firm's managerial skills, technological capacity, human capital and regulatory law (Bartelsman & Doms, 2000). For Syverson (2011), the productivity depends on internal

factors and external factor as shown in figure 5. The internal factors are: managerial skills, technological and innovative capacity, quality and quantity of inputs including electricity and labour, research development and experience; the firm as well as the firm structure and decision-making in the firm. The external factors that influencing the productivity are: The product over-abundances, regulation laws, intermarket and trade competition as well as the flexible inputs market.

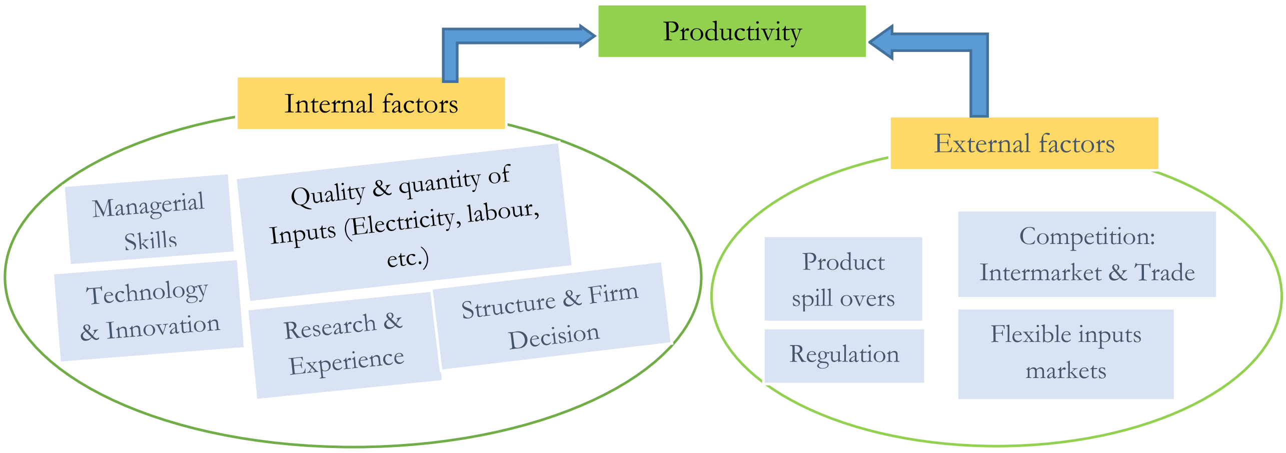


Figure 5: Internal and external factors influencing productivity.

Source: Author from literature

The performance in productivity of a country, secondary cities, industrial sector or a firm is determined by the way carried out the above factors though the extent to which each factor contributes to productivity is unknown. This thesis assesses the internal factors by analysing one input among many: "Electricity".

2.6. Quality of Electricity Needed for Manufacturing Industry Productivity

Energy, especially electricity, is an input among others for manufacturing industries. Its role of start-up of machines and equipment classify electricity among direct inputs as making part of the raw material. It is also an indirect input as a stimulus for other machines and equipment that lose their capacity when electricity is not properly supplied. Its abundance will increase the quantity of production while outage and voltage inconsistency will be a source of losses. Outages of electricity may have negative effects including no production for some industries. The lack of back-up system may be a source of big losses when the industry faces electricity outage. Voltage inconsistence (below or above the normal voltage) damages the machines and appliances. Repairing or rebuying create unplanned costs which reduce the industrial productivity. Unplanned outages create losses from 3% – 7% of total sales for African Countries (Pueyo & Hanna, 2015). For this reason, the cost is not a big barrier to consumption in manufacturing as it is low compared to its share in production cost.(Pueyo, González, Dent, & DeMartino, 2013).

If lack of electricity, low voltage and high voltage are problematic for industrial productivity, what will be the requirements for its enabling? Mindykowski (2003) found that electricity supply system should respond to the quality which he defined: "ability to transmit and deliver electrical energy to the consumers within the limits well defined". Quality problem is also defined as "an occurrence manifested as a non-standard voltage, current or frequency that results in a failure or a miss-operation of end user's equipment"(Singh & Sscet, 2013). Billinton at al (1998) and Mindykowski (2003) identified such requirements to be: reliability, providing information and quality of electricity supplied.

By defining access to energy as "the ability to avail energy that is adequate, available when needed, reliable, of good quality, affordable, legal, convenient, healthy and safe, for all required energy applications across households, productive enterprises, and community uses" ESMAP (2014) found that electricity supply system should meet the following attributes:

1. Capacity (satisfy peak demand),
2. Quality (assuring stable voltage),
3. Availability (having electricity without outage),
4. Reliability (with no unplanned cut-off),
5. Affordability: (electricity cost should not be a barrier to production),
6. Health and safety (free of electrocution),
7. Legality (with clear rules and laws) and
8. Convenience (facility to connect to the network)

If the first 4 elements are met, the manufacturing industries owners can trust the system and rely on it. This reliability increases their consumption without fearing the cost seen that the cost related to outage may be higher than the cost of electricity.

As per legality, illegal and poor institution are barriers to electricity access as they do not promote the use of electricity (Mulder & Tembe, 2008). Electricity distribution will follow the well-known, richer people and political leaders for their residence lighting ignoring the important productive use (Dijk & Clancy, 2010).

All the above 8 issues, if not well dressed in electricity supply system, will have a negative impact on individual firms especially on their productivity as demonstrated by several researchers including (Adenikinju, 2005; Lacommare & Eto, 2004). According to Billinton et al., (1998), any change if form, duration, quantity and phase alternation that disturb users are to be avoided in electricity supply.

2.7. Method to evaluate electricity supply

A number of countries, especially in developing countries, assess their electricity supply by looking whether electricity exist or not. They measure the level of electrification in the percentage of connection: less than 30% of the population connected for African countries or 70% for Asian and Latin America. This measure was used by UNDP (2012) in its survey on "Integrating Energy Access and Employment Creation to Accelerate Progress on the Millennium Development Goals in Sub-Saharan Africa" and classified countries according to their percentage of people without access to electricity. This percentage varies from more than 90% for African countries to less than 25% for Asian and Latin American countries 1. This measure of electricity supply based on the percentage of people connected lacks information about the system performance from suppliers that characterised most of the African grid (Karekezi & Kimani, 2002). To fill this void, access to electricity is used as metric to assess electricity supply.

There is no consensual meaning of "electricity access". Lack of consensual meaning creates a diversity in ways of assessing electricity access. Depending on orientation, countries define the term according to their target in service needed. For low income and middle countries, a need for grid expansion will guide their definition because of having a big number of the population deprived of electricity. They adopt to use the evaluation of the percentage of the connected population. An example is the East African Community who plan to expand their electricity network to reach 100% of the unconnected population to achieve millennium goals (MDGs)(EAC, 2006).

For developed countries with high income, they will define access according to the new performance need to meet technological change. For them, access to electricity means levels of satisfaction in service enabled by electricity. AGECC (2010) categorized levels of electricity services in three: 'The level 1 being for the basic need (lighting, health, education, communication and community services (50-100 KWh per person per year)), level 2 for productive use (Service to improve productivity) and level 3 for modern society needs (for many more domestic appliances, increased requirements for cooling and heating (space and water), private transportation (electricity usage is around 2000 KWh per person per year))'. These levels are not exclusive each other. They are complemental and have commonalities to be considered: Electricity should be available and reliable to ensure the use.

The above two methods do not meet the critics early presented by UNDESA (2001) of not clearly consider the multi-aspects of electricity supply. In this direction, Crousillat et.al (2010) suggested considering the type of network (on or off grid), average annual disruption, different losses, new transmission and distribution lines in assessing electricity access. Although Crousillat et.al (2010) method covers multiple aspects, it is lacking the major point: 'consideration of supply of and of demand for electricity.

To fill this gap, Scheepers et.al, (2007) proposed the assessment method that consists of two quantitative and one qualitative method. The quantitative methods are Crisis Capability (CC) index and Supply/Demand (S/D) Index/. The former assesses the supply disconnection risks and their mitigation capacity as part of the network system. The latter assesses the current supply and demand structure to make a medium and long term plan. The qualitative method consists of assessing the relations between electricity supplier and consumer. Scheepers et.al, (2007) method seems to be complicated as it requires a high expertise in electricity domain to weight electricity structure subdivisions such as source, generation capacity, transmission, distribution and use. To calculate S/D Index, each subdivision will be given a weight depending on expert appreciation.

Recently, ESMAP (2014) developed a measure that takes into account the level of service provided by electricity system "A Multi-tiers framework". This framework, which fills the gap presented by the previous method, consists of evaluating 8 attributes previously seen in section 2.5. Six tiers were elaborated and depending on the level of service provided, electricity supply system may fall into the tier 0, 1,2,3,4 or tier 5, tier 0 meaning where electricity services are very low or almost non-existing. The tier 5, recommended by ESMAP (2014) for industrial services, represents the area well served.

The said framework was recommended by Bhatia & Angelou (2014) and Pueyo & Hanna (2015) because of additional information it gives compared to the habitual method. It shows the requirement to be met by electricity supply for industrial productivity: As shown in figure 6, the supply capacity should be at least 10 KW above the observed peak hour demand, electricity should be available more than 100% of the need working time, outage should not exceed 5 hours per month, they should not be any voltage fluctuation in grid power line nor the possible life damage due to electricity, electricity should have binding law and regulation governing the supplier and demand, the cost of electricity should not be a barrier to the production and sourcing electricity should take less time and effort.

Attributes of electricity supply	Tier-0	Tier-1	Tier-2	Tier-3	Tier-4	Tier-5
Relevant application needed but not used due to electricity issue	True	False	False	False	False	False
1. Capacity to supply in peak hour	<1W	1W- 50W	50W-200W	200W-2KW	2KW-10KW	>10Kw
2. Availability (duration of electricity/ Needed time)	>25%	25%- 50%	50%- 75%	75% - 100%		>100%: No constraints in extending operating hour
3. Reliability (Time for unscheduled outage)	>5hours/month with severe impact			>5hours/month with moderate impact		<5hours per month or no/ little impact
4. Quality (Level and stability of voltage)	Quality issues reported with severe impact			Quality issue with moderate impact		No quality issue reported or No/little impact
5. Health and safety (electrocution, air pollution, drop & fluctuation)	No indoor smoke extraction + unhealthy with severe impact		No indoor smoke extraction with moderate impact		No damage are likely to happen that can cause any medical treatment, or reduce lifespan	
6. Legality (Electricity is obtained legally)	Illegal			Legal		
7. Affordability (No production reduction due to electricity cost)	Significant and frequent reduction			Sight/occasional reduction		Electricity cost do not generally cause reduction in production
8. Convenience (time &effort sourcing electricity)	Not convenient				Convenient	

Figure 6: Electricity access multi-tier framework for productive use.

Source: ESMAP (2014).

2.8. Measurements of Production and Method to Evaluate Manufacturing industries productivity

Depending on the kind of industry, the products are different among industries sectors, firms and within one firm the products may differ because a firm can produce several kind of products. For this reason, finding a common unit to measure the production for manufacturing industries requires standardised measurements. Among them are physical and nonphysical measurements.

The physical measurements of the production include a number of units, the volume and weight (Fenoaltea, 1976). Each of these measurements can be used to measure homogeneous products making impossible the inter-sectors or inter-firm comparison unless they produce the same products. Even internal in a firm, it will be difficult to compare different products by physical measurements.

The non-physical measurements for production include the total income, input-output and real value added (BEA, 2011). Income refers to the entries in the firm or in the sector in monetary value which can also be measured in term of turnover or annual sales. Input-output refer to exchange between industrial sectors (Miller & Blair, 2008).The real value added refers to the real wealth generated by using an input (Fenoaltea, 1976).

Other non-physic methods to measure industrial production are Industrial production Index and Industrial Turnover Index. The former measures ups and downs of industrial monthly production. The later consist of measuring progressively the sales (Conduto, 2001). It is a collection of billed exchange from different buyers and give the total sales within a given period.

As per evaluating the industrial productivity, two methods are used: Total Factor Productivity ratio (TFP) and Single Factor Productivity ratio (SFP) (Syverson, 2011; OECD, 2001). The TPF considers multiple or all inputs used in a production line for a given industry while SFP is used to evaluate the productivity for one given input in manufacturing industries: electricity, Single-Factor productivity ratio (Han et al., 2014); Lieberman & Kang, 2008).

2.9. Assessing electricity network.

To safeguard the quality of electricity supply, the powerlines should meet a reasonable distance to avoid the distribution losses. This distance should be calculated in accordance with the voltage in the power line. Seen that urban areas are high density populated, this distance should be within the radius (in km) equal to 1/3 voltage (in KV) and ½ for rural area (SIEMENS, 2015). For example, a powerline of 30KV can serve in 10 Km of radius for the urban area while it can serve in 15Km in rural areas. This is because more connection to the grid may be a source of blackout and other voltage inconsistency.

The distance from the source of electricity generation to the area to be served can also be used to evaluate the possible transmission or transportation losses that low the supply capacity (Ziari, 2011). The longer the distance from the source to the area to be served, the high the losses.

Other researchers such as Shengwei et al., (2015) use the graph theory topology analyse the node and edges as the connection point and the grid inter-distance from the one connection point to another or from the transformer to another, etc.

All the above researchers have one common point to analyse: The distance. This shows the role played by the distance in electricity network analysis.

3. RESEARCH METHODOLOGY

In order to respond to our research question, I have grouped our methodology in three major parts: The supply of electricity, the demand for electricity and the electricity productivity. This sequence is used for data collection and for data processing. The same sequences will be later used for presenting the results discussion and conclusion.
This chapter presents the methodological framework used, the study area in general in term of electricity supply and in term of manufacturing production in particular. In this chapter, I also describe how data was collected, organised and processed toward achieving our objectives. Figure 7 summarise the methodology framework used in this research.

3.1. Methodological framework

For electricity supply, I collected data from Rwanda Energy Group (REG). This data contained the monthly reports for 5 years (2009-2014). Useful data extracted from this monthly report are: electricity generation, importation and exportation, disturbance statistics (Overload, work, load shedding and blackout) in a number of occurrences and their durations.

For electricity demand, a list of manufacturing industries operating in the study area was issued from the ministry of infrastructure (MININFRA). Their electricity consumption was issued from REG as well as the monthly peak (electricity demand) for the national grid. For industrial productivity, the firm's annual turnovers were obtained from Rwanda Revenue Authority and from District accountant offices. After data collection, data collected were organised and processed.

The method used to collect and to process are described in the following paragraph. The results were analysed and results about electricity capacity, availability and reliability as well as firm electricity productivity were found. Based on the results found, a general assessment was done to conclude on electricity needed for manufacturing industry productivity.

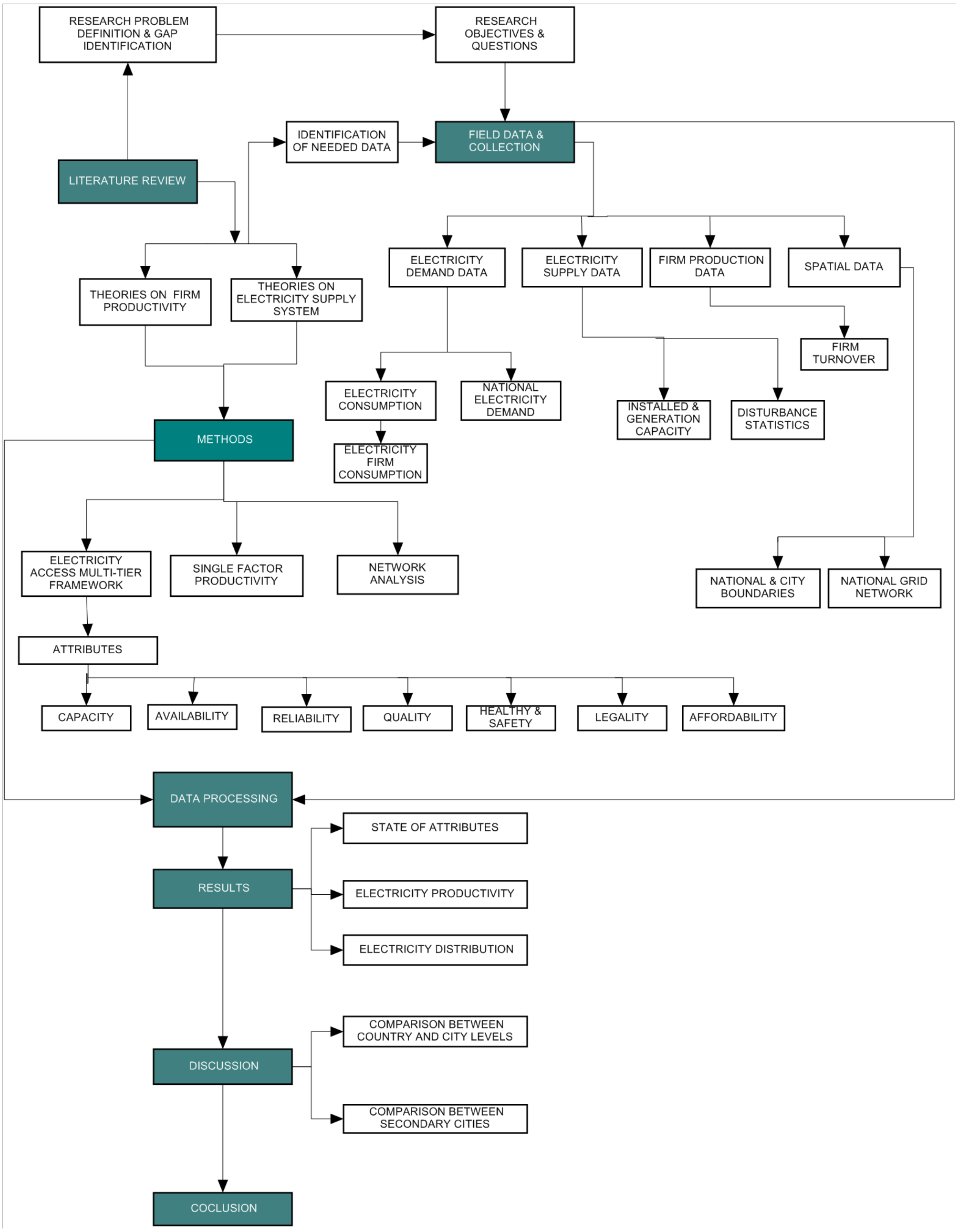


Figure 7: Methodological framework

Source: Author.

3.2. Study area

This study was conducted in Rwanda, a landlocked country with 26,338km² and around 12million of inhabitants. It is a poor country with Gross National Income (GNI) per capital is 560US$ (GNI is 3,795 and 37,653 for developing and developed countries, respectively) (NISR, 2014). Rwanda is high density populated with 415.5 inhabitants/Km².

In term of economy, Rwanda wants to move from low income to middle-income country by 2020. It has a target to increase its economy and productivity by increasing its growth rate from 8.3 (2014) percent to 11.5 percent in 2018, where energy is considered to be enabling factor (MINECOFIN, 2015). This target will be achieved by reducing agriculture contribution to GDP from 43% to 33% by 2020, increasing service from 37% to 42% and industrial contribution to GDP from 20% to 26%, during the period of 2010 to 2020 (EDPRS 2, 2013). In this perspective, six secondary cities (Huye, Muhanga, Rusizi, Nyagatare, Musanze, Rubavu), were chosen to be the pole of growth and centres of non-agriculture economic activities.

Regarding urbanisation in Rwanda, it grew very rapidly from 3% in 1970 to 5.6% in 1991 and from 16.7 in 2002 to 19.3% in 2012 (Manirakiza, 2012). Rwanda wants to move from 19.2% of people living in the urban area to reach 35% by 2020 (MININFRA, 2015b). In his study, Goodfellow (2013) found that rapid urbanisation in developing countries does not always go in pair with economic growth. The first challenge for Rwanda is to meet electricity demand that contributes more to the cost of economic transformation according to the EDPRS2, as shown in appendix 1. Therefore, the ambitious vision 2020 needs much effort in infrastructure supply, especially in electricity to support the manufacturing industries.

Assessing the status of electricity supply and manufacturing industries electricity productivity in these secondary cities would give the clear trend and better understanding. But constrained by time, data availability and budget related this research, I have only selected two secondary cities (Musanze and Rubavu) in our study due to their similarities in revenue generating projection as shown in appendix 2. Moreover, Musanze and Rubavu are the following cities in company establishments according to the establishment census 2014 as shown in appendix 3. The study area can be seen in figure 8.

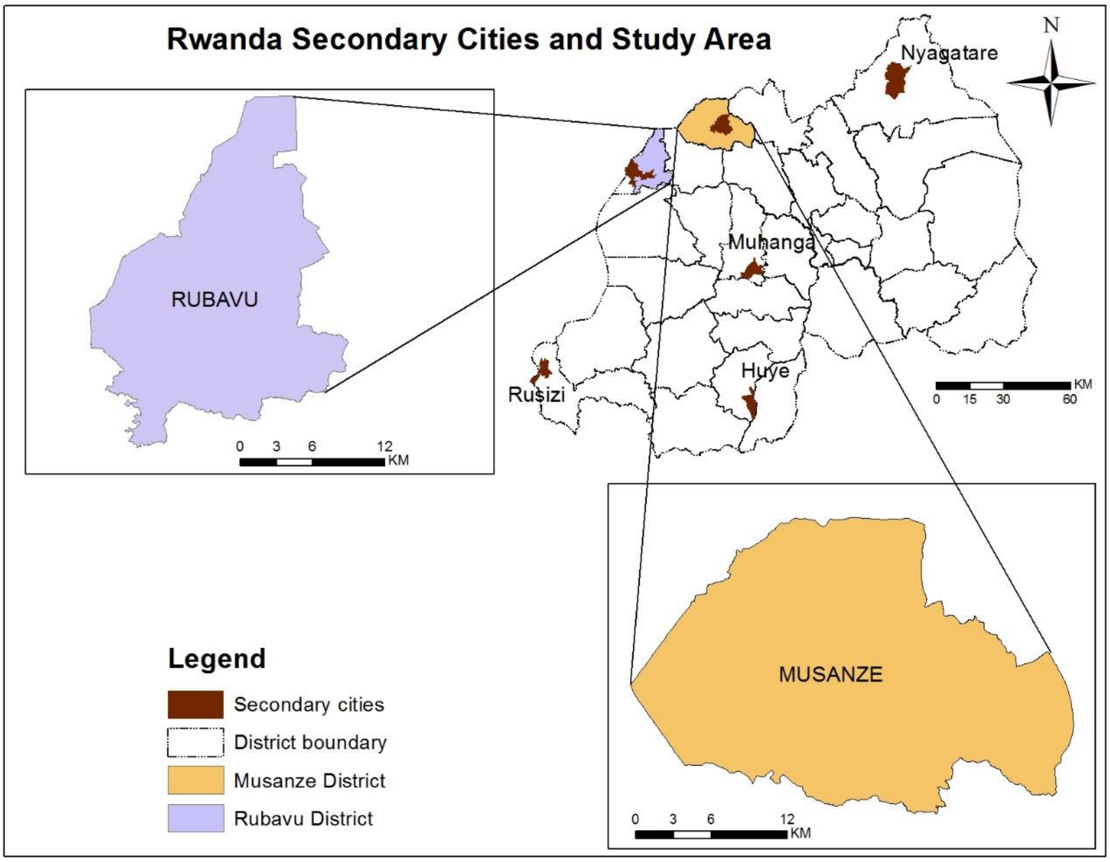


Figure 8: Study area (Musanze and Rubavu).

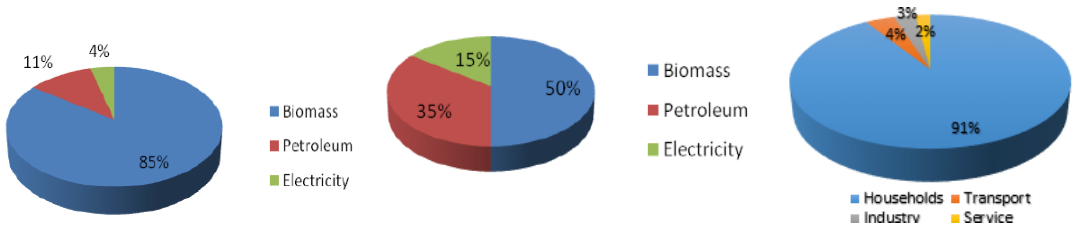
Source: Author from NISR data.

3.3. Overview of energy sector in Rwanda

The energy sector in Rwanda is under Ministry of Infrastructure (MININFRA). As shown in figure (9, a), most energy sources were biomass in 2011 (85% of total national energy offer) with only 4% of electricity contribution to national energy offer (total electricity available = national generation + importation - exportation). The goal is to reduce the biomass contribution to 50% at least and increase electricity contribution to 15% by 2018 (Figure 9, b). This requires the optimum use of all available sources both renewable (hydro, geothermal, solar and biogas) and non-renewable (peat, methane gas and fuel energy). Rwanda is said to have more electricity potentialities (RDB, 2012).

Despite these potentialities, access to and affordability of energy are considered to be major barriers for business investors. This issue is added to the foreign policy and trade dependency on energy source management where some energy sources are shared with neighbouring countries and require 'how to use' exploitation memorandum.

On the consumption side, the major part of the energy, composed mostly by biomass, is consumed by household (91%) as shown in figure (9, C) where industry sector uses only 3% of the total available energy. The industrial demand is expected to increase ten times by 2018 (MININFRA, 2014).



a. Energy source (2011) b. Projected energy source (2020) c. energy consumption by sector

Figure 9. The situation of energy in Rwanda presented by **(a)** its current sources; **(b)** projected proportion between different sources of energy and **(c)** the proportion of energy consumption by sector.

Source: MININFRA (2014).

The low level of industrial consumption compared to household shows the low industrial development. Stern (2000) proved that energy is a limiting production factor without which the production would impossible. He also found that disturbance in energy supply may lead to production reduction. The low percentage of electricity share in energy is also a challenge because electricity is the most promising to deliver required energy for industrial production (Patterson, 1999).

3.4. Electricity in Rwanda

The Rwandan electricity supply system includes an on-grid system and off-grid system. The former is operated by Rwanda Energy Group (REG), a public company, created in 2013. The customer base of REG was 450,000 in 2013 including 170 from industrial sector (MININFRA, 2014). The latter is generally operated by private companies, individuals or public-private partners. With reference to household electricity supply, only 20% had access (as defined by the government) by June 2014. However, the target is to reach 70% with 48% to be on-grid and 22% off-grid (MININFRA, 2014).

On-grid electricity in Rwanda is a property REG through it sub-company EUCL. It manages the power generation, transportation, transmission and distribution. It belongs to the regional East Africa Power Poor (EAPP) where regional countries benefit from each other by buying/selling agreements. The current installed electricity capacity is 119MW (June 2015 with estimated losses averaging 23 %). The most part comes from hydropower (60%) and diesel generators contribute for the rest (40%). This hydropower contribution will be increased by the year 2018 to reduce the cost related to diesel generators: Six American dollar per kilowatt hour (6US$/KWh), a very high cost in Rwanda, compared to hydropower and solar-power costing 1.1US$/KWh and 1.2US$/KWh, respectively (Meier & Fischer, 2011).

As shown in table 1, apart Burundi having 32MW, Rwanda has low installed capacity compared to neighbouring countries in the region: 767MW for Kenya, 692 MW for Uganda and 566 for Tanzania (EAC, 2014). The projection capacity is to be 563 MW by 2018. This will come mostly from hydropower, peat, methane, geothermal and solar electricity that will increase the connectivity from 16% in 2013 to 70% in

2018 (The World Bank, 2014; Infrastructure, 2004). The neighbouring countries will contribute by 176MW (137MW from DRC, 35MW from Burundi and 4MW from Uganda) (Gebrehiwot, 2013).

Table 1. Comparison of electricity installed capacity in EAC

Country	Burundi	Rwanda	Tanzania	Uganda	Kenya
Installed capacity in MW	32	119	566	692	767

Source: (EAC, 2014).

As shown in figure 10 showing the trend in electricity generation, demand, supply and consumption from 2001 to 2013 proves that demand for electricity increased exponentially from 2008 to 2013. It was 87.9MW in 2013 and is projected to be 470MW by 2018. It also shows that the total hourly electricity supply was 502GWh (2013) in which 408GWh was domestic generated and 94GWh imported while the consumption was 391GWh.

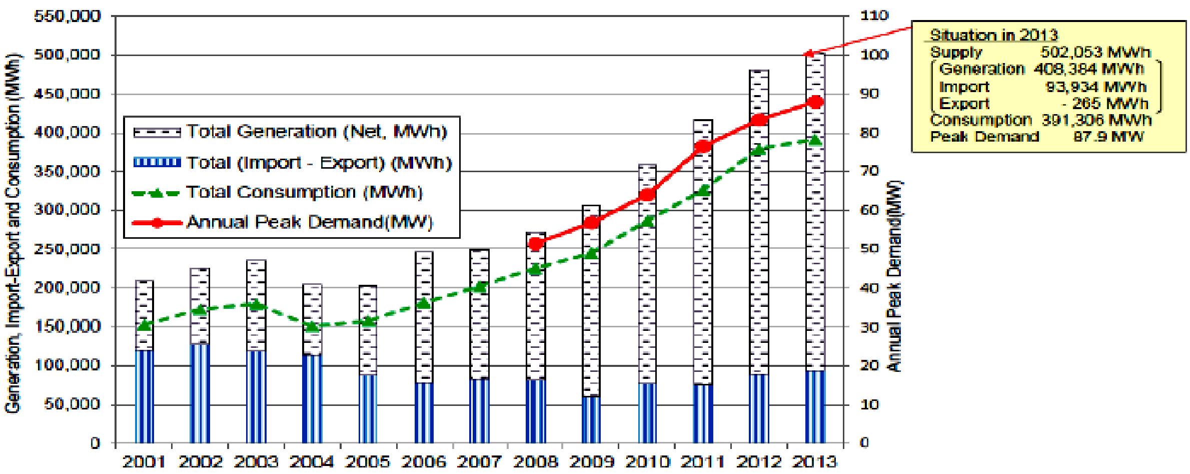


Figure 10. Rwanda yearly electricity supply and demand (2001-2013).

Source: (MININFRA, 2014).

3.5. Off-grid electricity system in Rwanda

The off-grid electricity in Rwanda is the only option for people in remote areas not reached by the national grid. It is also an option for firms and individuals who find themselves affected by the frequent electricity outage from the existing grid and prefer either to use their own generators, create their own mini-grid if near the river that can let them do so or install their own solar power. The off-grid electricity is also used by the public institution (like schools and health centres) which are not able to connect to the grid or need permanent electricity supply for technical or health reasons like a hospital.

Despite the multiple uses of off-grid electricity, its documentation still very poor what makes difficult to understand its share in electricity supply and uses in Rwanda.

3.6. Data collection, source and description.

To conduct this study on electricity supply for manufacturing industries and electricity productivity of manufacturing industries, three kinds of data were needed:

a. For electricity supply, data needed include electricity installed capacity, generation capacity and electricity disturbance record.
b. For the electricity demand, data such as electricity peak demand and electricity consumption (per firm) were needed.
c. To calculate electricity productivity for manufacturing, data about industries production were required. For uniformity of unit, I have used the turnover data (the total annual sales) for industries in the study area. This is because it is in monetary term (Rwandan currency) while the production in product units would complicate the industrial production comparison, seen that products are different from industry to another and sometimes within one industry (an industry can produce different products);
d. To locate source of electricity and analyse the grid network, the spatial data were needed including electricity network data and country administrative boundaries data

In order to get the above data, a field work was organised and the data were acquired. A general overview of some economic characteristics in the two secondary cities under study (Musanze and Rubavu) are presented in appendix 4. Following is a description of data collected and their source.

3.6.1. Data description and source for electricity supply and demand

For on-grid electricity data, information about electricity supply and demand are recorded by Rwanda Energy Group (REG). Hence, electricity data were obtained from REG's departments in twofold dataset:

The first dataset, obtained from Electricity Utility Company Ltd (EUCL) a REG sub-company, contained a five years (2010-July, 2015) 'monthly report' about national grid electricity. It is a compilation of information gathered from different power stations, sub-stations and grid lines. This folder contains: energy (production, importation and exportation of electric energy in KWh), peak demand of Rwanda electricity network, electricity consumption and disturbance statistics (Overload, cut off due to work (reparation or maintenance), load shedding and blackout) in numbers of occurrences and their durations.

The second dataset, obtained from REG commercial department at its headquarters, contained the firms annually consumption for the year 2014. These firms' electricity consumption were obtained in two ways:
For the big electricity consumers for which electricity consumption are monitored and sent the monthly bill to be paid (post-paid system), getting their electricity consumption data was easily accessible through the commercial monthly report.
For the medium and small firms, they use electricity bought from REG electricity sellers dispatched through the country where on-grid electricity connection exists. For these medium and small firms, they buy a number of units of KWh before use (pre-paid system). After buying electricity units, they activate the bought units using their cash-power machine (a device connected between the grid and the consumer installed at the client connection point). When activation code is recognised, the units bought will appear in the cash-power machine. The bought units will be recorded in electricity supply system. The clients can buy as much as they want but can't use unbought electricity. Obtaining these data requires to know ID (Identity) of client cash-power. These ids were obtained from REG district level (REG substation) and were used by REG

commercial department at its headquarters to serve as ID that allowed us to extract the firms' consumption records. Then, their cumulative electricity consumptions were printed out.

Regarding off-grid data, no information record was found. This made us to only consider on-grid electricity.

3.6.2. Data description and source for manufacturing industries' production

According to National Institute of Statistics of Rwanda, manufacturing industrial activities are sub-classified in seven sub-sectors. The activities for each sub-sector are shown in table 2.

Table 2. Manufacturing industries' classifications

Sector	Sub-sectors	Activities
Manufacturing		
	Food	Processing and preserving of meat, fish, crustaceans, mollusks, fruit and vegetables. Manufacture of vegetable and animal oils, fats, dairy products, grain mill products, starches and starch products, grain mill products.
	Beverages, & tobacco	Distilling, rectifying and blending of spirits; ethyl alcohol production from fermented materials. Manufacture of wines, malt liquors and malt, soft drinks; production of mineral waters and other bottled waters. Manufacture of tobacco products.
	Textiles and clothing	Spinning, weaving and finishing of textiles. Manufacture of other textiles, wearing apparel, leather and related products, footwear.
	Wood paper and printing	Sawmilling and planning of wood. Manufacture of products of wood, cork, straw and plaiting materials. Manufacture of paper and paper products. Printing and service activities related to printing.
	Chemicals & plastics	Manufacture of basic chemicals, fertiliser, pesticides and other agrochemical products and nitrogen compounds, plastics and synthetic rubber in primary forms and man-made fibres.
	Non-metallic	Manufacture of glass and glass products, clay building materials, porcelain and ceramic products, cement, lime and plaster. Cutting, shaping and finishing of stone
	Furniture & other	Other manufacturing: jewellery, music instruments, sports goods, toys and games, etc.

Source: (NISR, 2012)

To get firms production data, a list of classified manufacturing industries operating in Rwanda secondary cities was issued from a World Bank officer in MININFRA. It contains 64 firms in manufacturing industry sector across six secondary cities by July 2015 among which 11 were located in Musanze and 8 in Rubavu. It gives information on some firms that were operating in 2014 but which are closed or not operating in 2015, including 2 firms in Musanze and 1 firm in Rubavu. A cross check was made with a list obtained from Rwanda Private Sector federation (RPSF) as most of them are registered as private companies.

The firms' production in the monetary term (turnover) were requested from Rwanda Revenue Authority (RRA), its tax department and only 6 of 11 in Musanze and 4 of 8 in Rubavu were found in this system. Their turnovers for the year 2014 were obtained. For the rest of firms, which are local cooperatives, their data were collected from the District accountant office where the 2014 record were found based on 6% District taxes that the cooperative have to pay every four months. From the termly tax report, their annual turnovers were calculated.

Electricity network data were obtained from REG, its GIS department while national boundaries data were issued from NISR. The first contained the shape files of some source of electricity and their location. It also had different grid lines (high, medium and low voltage), the location of sub-station and transformers.
The last gives the cities, districts, sectors and cells boundaries. It also includes the limit of secondary cities

3.7. Data organisation and data processing

The data collected were organised in different excel sheets for electricity supply and demand as well as data for production depending on the need for objective to be met. The spatial data were organised in the shape file. After data organisation, an electricity access multi-tier framework was used, based on 8 attributes as seen in figure 6, to assess electricity supply system. The Single-Factor productivity ratio was used for calculating the electricity productivity. Following are details of the methods used.

Before assessing the access to electricity by, the electricity coverage was analysed for the grid line distribution in order to know whether the electricity network can serve the urban area. To achieve this, knowledge of power line voltage was needed. Then I have identified the type of grid, the type of network and the coverage area that can be served by these power lines. For assessing the coverage distance, a radius was determined using the following formula:

$$\mathrm{R(km)} = \frac{1}{3}\ \mathrm{supply\ voltage(in\ KV)} \qquad (4)$$

3.7.1. Multi-tier framework

Based on the level of service provided by electricity supplier, the electricity supply system can be classified in tier 0 to tier 5 ranging from the low level of service provided to the high level. As a matter of assessing electricity supply for productive use, electricity system should fall into tier 3 to tier 5. Tier 5 is the best for manufacturing industries. For this tier, the attribute for electricity supplied should be:

Capacity: Enough to meet peak demand,
Availability: Available beyond working hour so that the firm can extend their working hours with no constraints,
Reliability: Unscheduled outage should not exceed 5hours per months,
Quality: There should not be any poor quality of voltage,
Health and safety: Electricity should not be susceptible to cause any life danger,
Legality: Electricity should be legally obtained and governed by law,
Affordability: Electricity should be affordable and its price should not cause reduction in production,
Convenience: The client should not spend much time to get connection service.

The methods used to evaluate the above attribute are explained in the following paragraph expect the convenience where information about time to get connected to on-grid electricity was not found.

For the capacity, electricity supply system in Rwanda is not decentralised. Hence, it is not informative to analyse only the demand for electricity in the two secondary cities under study. It is good to compare the city capacity to supply in peak hour to the whole network capacity.
The capacity at peak hour is given by the ratio between (installed electricity –electricity losses) and peak demand.

$$Ct = ((Gt - Lt))/Pt \tag{5}$$

With Ct is the capacity to meet the peak hour in percentage (of peak demand); Gt, the installed capacity; Lt, the electricity losses (23% of total generated) and Pt, the peak demand

Regarding the availability, electricity should be available during the working hours for productive use. Working hours are between 8 to 12 hours per day and 72 hours of overtime limit per month (4 hours per day) as recognised by International Labour Organisation (ILO, 2011). Assuming one hour of work preparation I find that an industry needs at least 17 hours of electricity service (16 working hours plus 1-hour preparation). Hence, I considered 17 as minimum hours needed hours per day for industrial production. Then I calculated the availability as the ratio between time duration for having electricity to the working hours (17hours). Seen that I have outage duration rather than available duration, the last is day time minus outage time. Availability was calculated as follow:

$$Av = (Dt - Ot)/Wt \tag{6}$$

With Av, the availability in percentage (of working hours); Dt, annual time in hours (24* 360), assuming the year to have 360 days of 24 hours each day; Ot, the total electricity outage duration per year (A sum of all outages: work outage + load shedding outage + blackout outage) and Wt, the working hour per year (17*360 assuming the need for at least 16 hours per day of electricity service in manufacturing industries)

Concerning the reliability of electricity supply system, it depends on three parameters: frequency of outage, its duration and customer (un)served. Several measurements exist in the literature (Layton, 2004). I have used the Customer Average Interruption Duration Index (CAIDI), as the ratio between the total customer outage duration and the total number of customer interrupted. It is the most used because it consider all the above-stated parameters (Agalgaonkar & Battelle, 2015). This index represents the number of time duration in minutes that a customer will be out of work because of electricity outages. The calculation of this index was done using the following equation:

$$CAIDI = (\sum UiNi)/(\sum Ni\ \beta i) \ ; \tag{7}$$

Where βi is the frequency of outage in area i; Ni the total number of customers in the area and Ui the annual outage duration in the same area.

In regard to the quality of electricity, the over or under loading affect the normality of the supplied electricity. The increase in frequency and duration may increase the effects. For this reason, I have analysed the overloading data of the grid line for two secondary cities and compared them with other lines in term of overloading frequencies and durations.

About health and safety of Rwanda electricity supply system, there are no data available as per author's knowledge. Hence, this attribute was assessed by comparing this sector to construction sector where information may be found.

Examining the legality of electricity, since the REG as electricity supplier in Rwanda under the MININFRA, is legally known, with RURA as a regulator agency, I assume that electricity supply system is legal on the supply side. Nevertheless, I cannot have a say on the demand side since there is no illegal connected record in our hand.

As per affordability, analysing the impact of electricity cost on the production need extra data on the demand side. Hence, this analysis was not done. However, a comparison of electricity cost within East African Countries may give information about the possible market competition. In this perspective, I assume that less competitive capacity affects negatively the production. Based on this assumption, I have analysed the affordability.

The convenience was not analysed due to lack of data about the duration between the demand for connection by the client and the connection by the supplier.

3.7.2. Single Factor Productivity ratio and Network Analysis

To evaluate the electricity productivity for manufacturing industries in the cities of study, I have used the Single-Factor productivity ratio (Han et al., 2014; Lieberman & Kang, 2008). This is because I have only one factor to take into consideration in our input estimation. Another method would be a Multiple or Total-Factor productivity ratio which considers multiple or all inputs used in a production line for a given industry. For our study, I have only taken the electricity consumption as input.

The manufacturing industry productivity as ratio of output (production translated in monetary term or annual turnover) and inputs (electricity consumed to make this production) was calculated using the following equation:

$$Electricity\ productivity = \frac{Firm\ total\ Annual\ turnover\ (RwF)}{Total\ annual\ electricity\ consumption\ \ (kWh)} \tag{8}$$

4. RESULTS

In this chapter, the result obtained on electricity supply, electricity demand and electricity productivity are presented. For electricity supply, I first present the findings of Rwanda electricity supply system for a better understand of the general context of electricity supply system. This is because Rwandan on-grid electricity is a centralised and interconnected system. After presenting the situation at national level, I present the results for the secondary city level.
I start by presenting the result of electricity demand, electricity supply and electricity productivity to end by a comparison of results found.

4.1. Electricity supply

In this part, I present the general information on Rwanda electricity network starting by the source of electricity and the network, installed and supply capacity, generated capacity (National production, importation and exportation) and the national electricity demand.

4.1.1. Source of Electricity, Installed and Generation Capacity, Demand and Rwanda National Balance

Rwanda electricity network is composed of high voltage (70 KV and 110 KV) lines covering 383.6 km, medium voltage (30 KV, 15 KV and 6.6 KV) covering almost 4900 km and low voltage (380 v and 220 v) mostly used to connect the clients (RDB, 2014). The main source of this electricity is hydropower (59%) supported by diesel generator (40%) and ongoing methane gas project which contributes to 1%. Rwanda on-grid electricity is an interconnected-centralised network. The control centre is based in Kigali, the capital of Rwanda. The mains supply sources of this network are located in Rusizi (southern western province), Musanze (Nothern province) and in Rubavu (northwestern province). Other cities are connected, benefiting from this network as shown in figure 11 which shows the location of all secondary cities in the country and the electricity powerline reaching there.

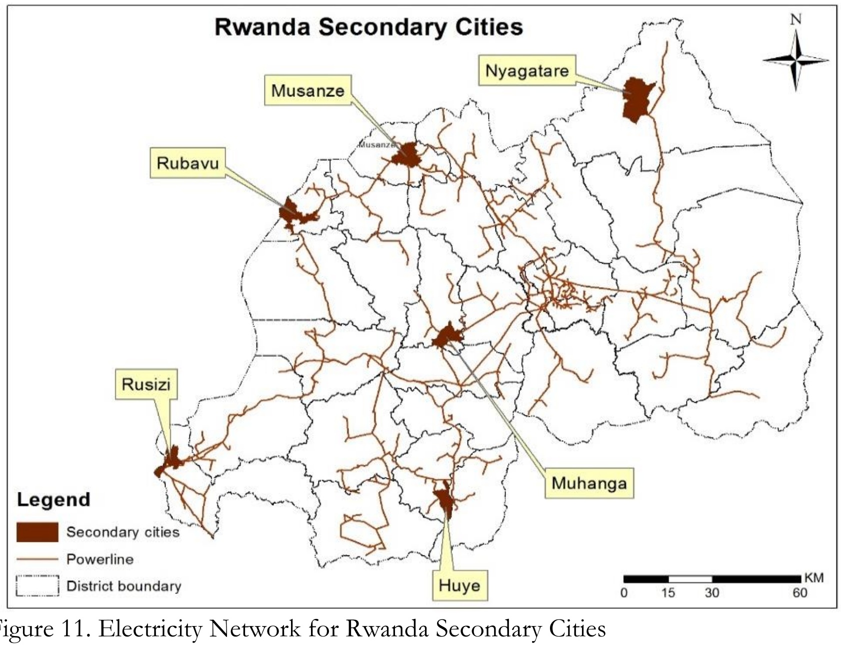


Figure 11. Electricity Network for Rwanda Secondary Cities

Source: Author using NISR data.

Although Rwanda uses diesel generators to support its low generation capacity, it has electricity potentialities for both renewable and non-renewable energy as shown table 3. The peat itself can produce more than tenfold the current installed capacity, the methane gas can produce around 7 times as well as hydropower (micro and macro). Musanze and Rubave both have the high potentiality in hydro-power and geothermal with the particularity for Rubave of having methane gas as an additional source.

Table 3. Energy source and source potentiality in Rwanda

	Resource Type	Capacity	Location
Non-Renewable potentialitie	Peat	1200MW	Akanyaru, Nyabarongo, Rwabusoro, Rugezi and other places
	Methane gas	700MW to be shared with DRC (350MW per each)	Lake Kivu
Current Installed	Hydro-power	65MW: Current	North and West
	Heavy -Fuel Oil	45MW: Current	North/Musanze
Renewable Potentialities	Pico-Micro hydro	400MW (different place available capacity vary from 50KW to 1MW)	Many places in the country special in North
	Hydro-power	313MW: 130MW domestic and 183MW regional	In country and EAC region
	Geothermal	170 to 740 MW	Karisimbi, Kinigi, Gisenyi and Bugarama
	Wind	-	Eastern province, Gisenyi, Kigali, Butare and Kamembe
	Solar	4.3 to 5.2KWh/m^2per day Variation of radiation	Most suitable from Eastern province to western

Sources: Peat (RDB, 2012), Methane gas (MININFRA, 2014), Hydro-power (MININFRA, 2014), Pico-Micro hydro (Meier & Fischer, 2011), Geothermal (Rutagarama, 2013), Wind (Safari, 2011), Solar (MININFRA, 2015).

In regard to the supply capacity, REG monthly report data (installed capacity, total generation, total import and total export) from 2010 to 2014 were used. Considering the average losses of 23%, the evolution of the installed capacity and the demand during this period is shown in figure 12. It shows that the installed capacity rose from 84 MW in 2010 to 110 MW in 2014. However, considering the losses of 23%, this capacity was reduced from 84 MW to 65MW in 2010 and from 110MW to 85 MW in 2014 as the real capacity. The peak demand was 65MW in 2010 and 99 MW in 2014. Comparing the real capacity and the peak demand, it can be found that peak demand has never been met during the period of 2010 to 2014 except in 2010.

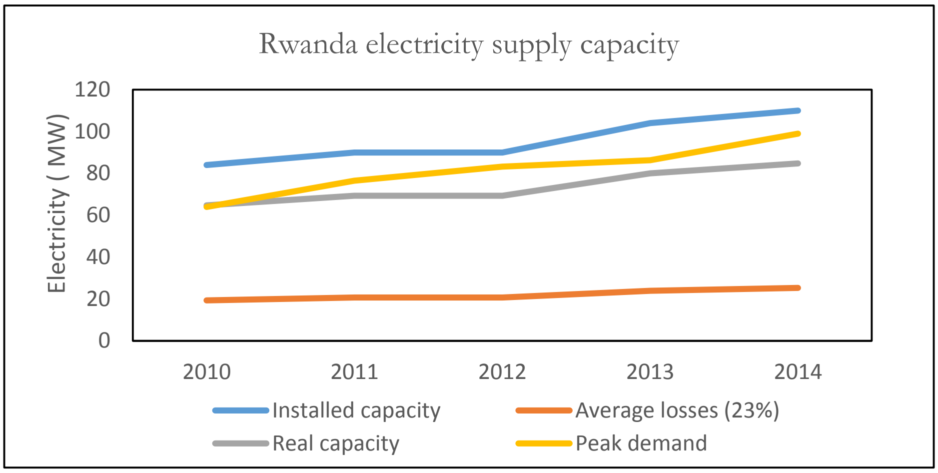


Figure 12. Plot showing Rwanda electricity capacity, real capacity, average losses and peak demand.

Source: Author using data from REG

The Rwandan grid is connected to Burundi, Uganda and Democratic republic of Congo (DRC) electricity network, where the imported electricity is used to support the national capacity. The total available electricity, called "national offer" by REG as a sum of the produced in the country and imported electricity with exported electricity deducted, increased by an increase in generation capacity. The last increased from 281GW in 2010 to 467GW in 2014 as shown in table 4.

The share of national production, as well as import-export of electricity, is shown in figure 13. It shows a slight increase in national production and a slight decrease of imported electricity from 2010 to 2014 within the same period. Exportation is very limited.

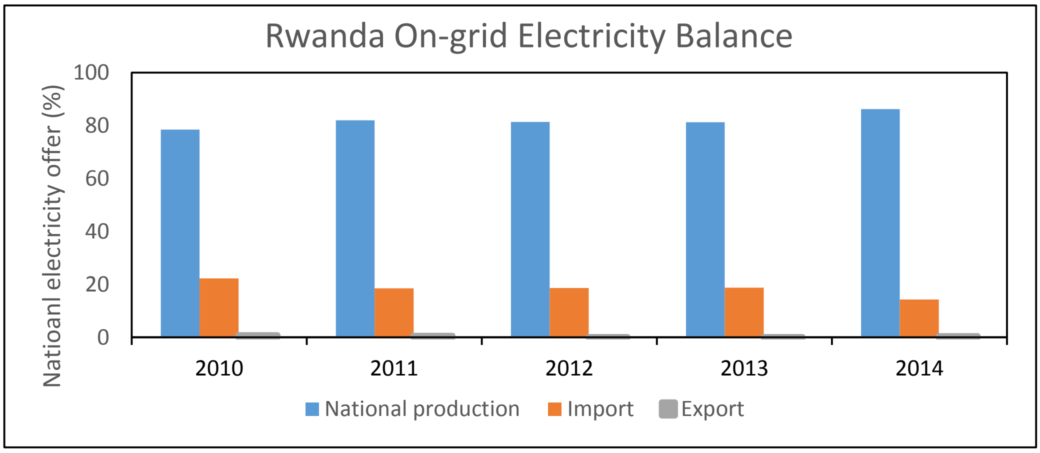


Figure 13. Rwanda relative on-grid electricity balance: National production, Import and export (2010-2014).

Source: Author calculation using data from REG.

Table 4. Rwanda National electricity generation from 2010 to 2014

Year	2010	2011	2012	2013	2014
National Production(GWh)	281	341	391	408	467

Source: Data from REG.

Despite the increase in generation capacity, the demand for electricity continues to increase as shown in figure 14. Considering a business as usual (BAU) situation, the demand will continue to increase as can be seen in figure 15. This increase may be much more with industrial development.

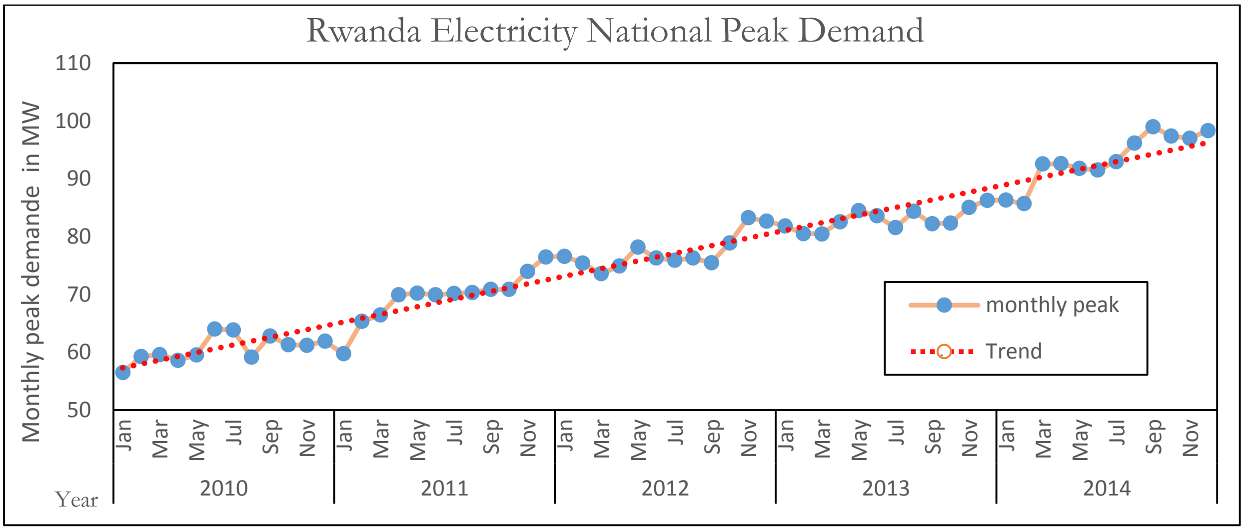


Figure 14. Rwanda electricity national peak demand: 2010-2014.

Source: Author calculation using data from REG.

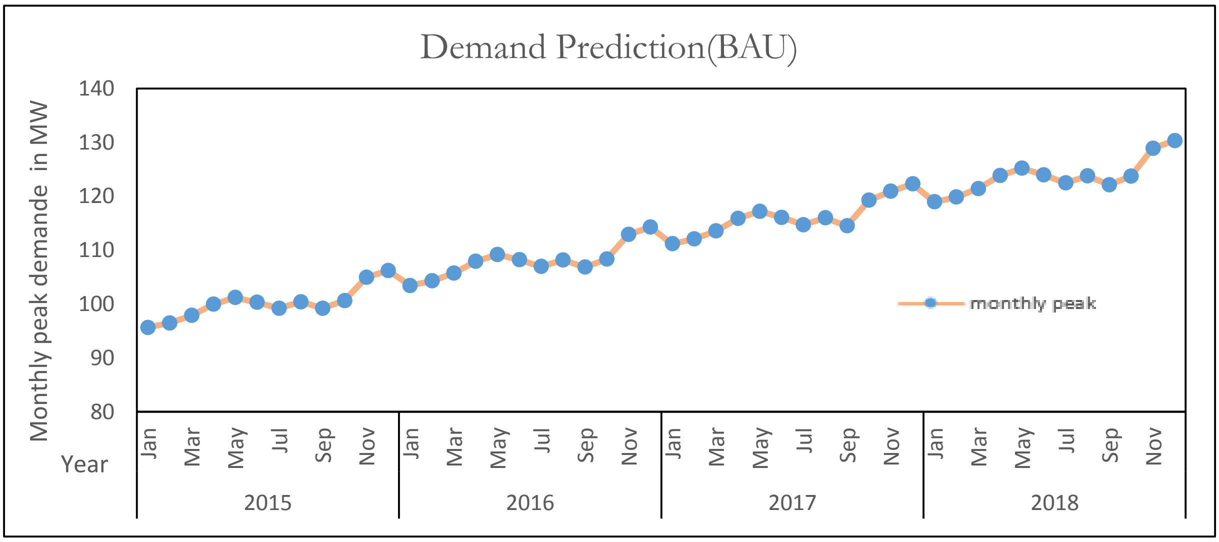


Figure 15. Demand prediction 2015 - 2018 based on 2010-2014 trend
Source: Author calculation using data from REG.

4.1.2. The state of Electricity in Musanze and Rubavu

In this part, I analyse the electricity network in Musanze and Rubavu as well as their situation in regards to the attribute as defined by the electricity access multi-tier framework.

4.1.2.1. The electricity network

Figure 16 shows Musanze electricity network and figure 17 shows the one for Rubavu.
Musanze secondary city, in the Northern Province of Rwanda, close to Ugandan boarder, has two hydropower plants, Ntaruka and Mukungwa, connected to the national grid and one identified geothermal source which is not yet exploited. Their annual generated electricity, in 2014, was 40GWh and 70GWh respectively. Mukungwa power plant has a derived power plant named Mukungwa II generating near 3GWh per year. It is also supported by diesel generators producing more than 58GWh per year. The total connection on the grid is 26299customers (NISR, 2015). As connected to the national grid, Musanze electricity network shares the same technical problems with the national grid.

Rubavu at the North-Kivu DRC boarder, in Rwanda Western Province, possesses also two hydropower plants: Gihira and Gisenyi. They are connected to the national grid as well. This city has Kivuwatt project of extracting methane gas to support current power supply. The phase I of 25MW is currently connected to the national grid and the phase II of 27MW is expected to be on-grid by 2017. Rubavu has also the potentiality of geothermal resource that may be later used to source the electricity network in Rwanda. The 2014 production for Gihira and Gisenyi was 8.6GWh and 5GWh, respectively. 20275 customers were connected consuming 5680620KWh the whole year (NISR, 2015).

To evaluate the distribution network, I used a buffer distance of 5km taken as a radius of the area that can be served by a medium voltage grid line. This distance was obtained using equation 4 by considering powerline voltage of 15KV, the medium voltage lines used for electricity supply in Musanze and Rubavu (Meier & Fischer, 2011). In Musanze and Rubavu, it is found that electricity grid could serve the entire urban area (secondary city boundary) for both Musanze and Rubavu as can be seen in figure 16 and 17.

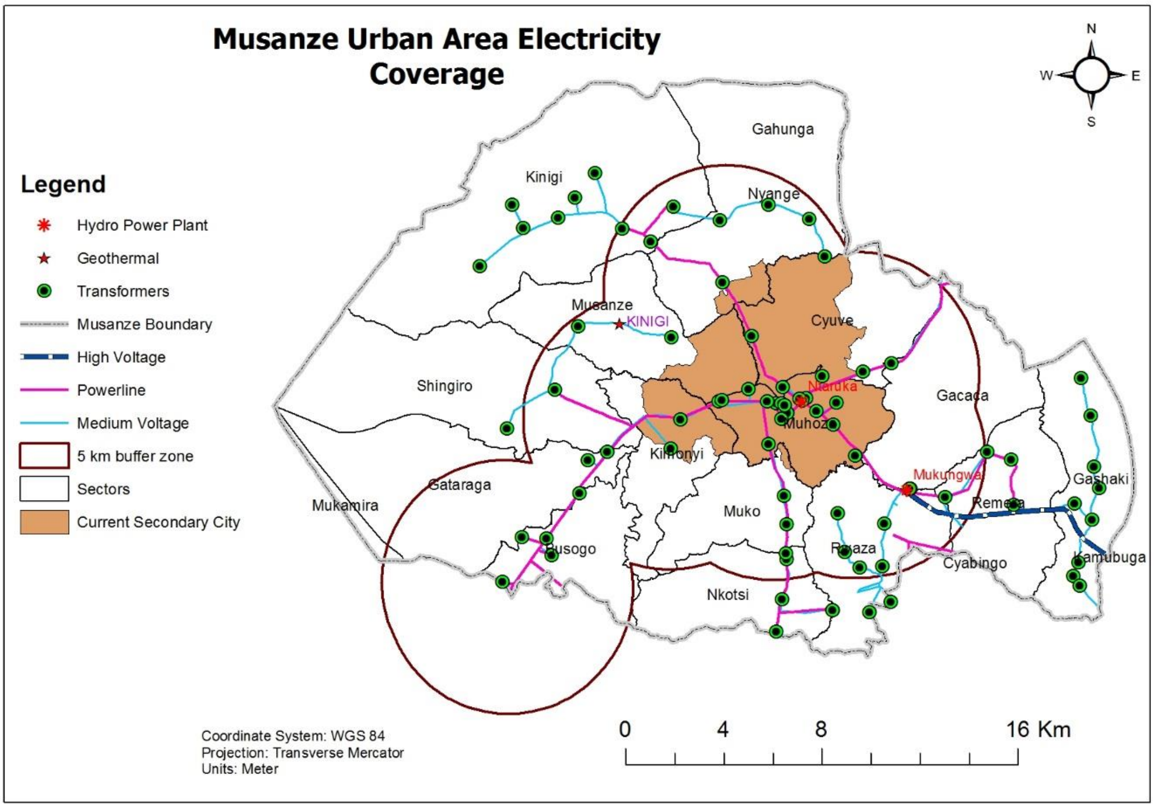


Figure 16. Electricity network service coverage: Musanze

Source: Author using data from REG and NISR.

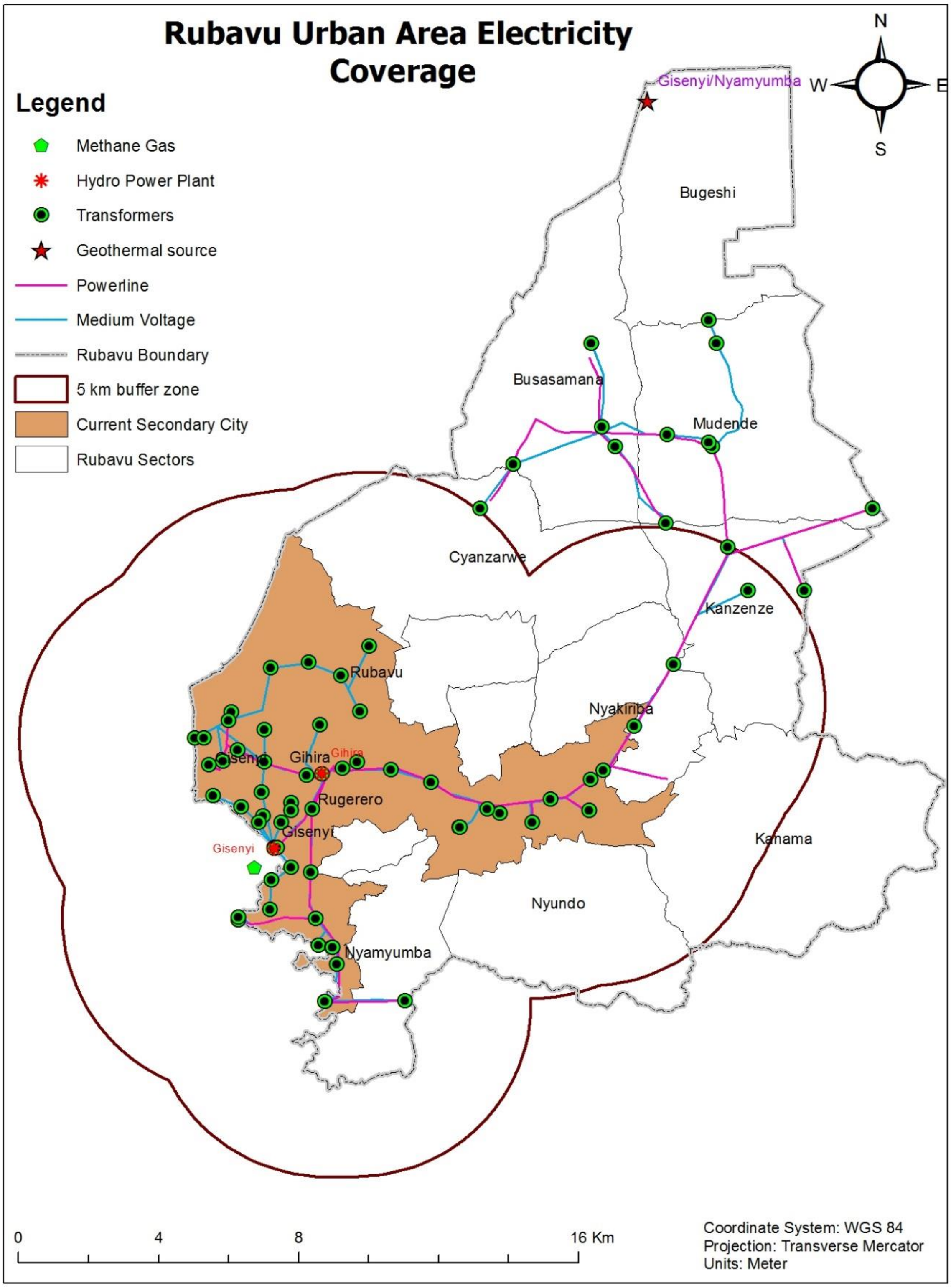


Figure 17. Electricity network service coverage: Rubavu.

Source: Author using data from REG and NISR.

4.1.2.2. The state of electricity access multi-tiers attributes

Table 5 shows that the electricity supply in Rubavu and Musanze does not meet most of the requirements to be supportive for industrial productivity. Apart for affordability (where I cannot prove clearly the impact on increase or decrease of production due to the cost and the convenience that was not analysed in this study), the electricity supply system meets only one of 8 requirements: the legality. The details for the state of each attribute can be found in the following paragraphs.

Table 5. Summary of findings for Access to Electricity multi-tier framework

Attribute	Requirements	Findings	Status: Yes (√) or No (×)
Capacity	>10 KV of peak demand	14MW of peak demands unmet	×
Availability	>100% of needed time for work	68% of needed working time for manufacturing industries	×
Reliability	<5 hour per month of outage	More than 8 hours of outages per month for Rubavu More than 24 hours of outages per month for Musanze	×
Quality	No quality issue reported	839 inconsistency frequency reported for Rubavu 125 inconsistency reported for Musanze	×
Health & Safety	No electricity issue possible to cause medical treatment	At least 3.5% of country accidents may have been caused by electricity	×
Legality	Legal	Legal	✓
Affordability	Electricity cannot be a cause of reduction in production	Electricity in Rwanda is expensive in comparison with the neighbouring countries. It is almost 3 times its cost in Burundi	×
Convenience	Convenient	No data	Not analysed

Source: Author comparison to (ESMAP, 2014).

The table above shows that the unmet peak demand was 14MW in 2014 for the grid network capacity. It is far higher than the required capacity. Instead of having, at least, 10kV above the peak demand, this grid network capacity is below the peak demand. Moreover, using the equation 5, it can be seen that the capacity to supply electricity during the peak hours has been decreasing during the period 2010 to 2014 from 101% in 2010 to 86% of the peak demand as shown in table 6.

Table 6. Electricity supply for peak demand (2010-2014).

Year	2010	2011	2012	2013	2014
Installed capacity in MW	84	90	90	104	110
Average losses (23%) in MW	19	21	21	24	25
Capacity after losses in MW	65	69	69	80	85
Peak demand in MW	64	76	83	86	99
Capacity to meet the peak demand (%)	**101**	**91**	**83**	**93**	**86**

Source: Data from REG and author calculation using data from REG.

Regarding availability, the disturbance statistics data (REG monthly report, 2014) was used. The total disturbances from January to December 2014 was calculated. The total number of outages of 4,357 outages total making up 185 days during the year. These outages resulted from blackout (35 days), load shedding (107 days) and work related outage (43 days). Using equation 6, it is found that electricity is only available for 68% of 17 hours taken as the needed time for electricity to be available for manufacturing industries operability. For Musanze secondary city, 1,117 outages due to load shedding were observed with total duration of 16 days while Rubavu registered 391 outages with a total duration of 3 days.

As per reliability, the Customer Average Interruption Duration Index (CAIDI) was calculated for the national grid using equation 7. The data used was also the disturbance statistics (REG monthly report, 2014). CAIDI was found to be 0.6. This means that an average of 0.6 minutes per hour or 14 minutes per day can be observed as average outage per each REG customer. Using the same equation for Musanze and Rubavu, CAIDI was found to be equal to 23 minutes per hour for Musanze secondary city and 7 minutes per hour for Rubavu secondary city. This means that a REG customer, using electricity, would expect to stop the work for 23 minutes per hour in Musanze, interruption working time would be expected to be 7 minutes per hour in Rubavu.

The quality of electricity supply was assessed using overvoltage and under voltage data from REG monthly report in its disturbance statistics data (REG monthly report, 2014). In total, 4,370 frequencies were reported voltage inconsistency with a total duration of 46,077 minutes for the national grid. During the year 2014, Rubavu had 839 frequency of observed voltage inconsistencies with the total duration of 3 days while Musanze registered a frequency of 125 with 1.6 days.

Considering health and safety issues, Rwanda electricity supply is not easy to assess. The data regarding health issues caused by electricity in the country are not reported. According to MIFOTRA (2013), the manufacturing industry has the highest rate of accidents. The third in rank of the rate of accidents is the construction sectors. For the last, electricity caused 3.5% of total accidents in the country (Cokeham & Tutesigensi, 2013). This means that electricity in the industrial sector caused much more than 3.5% of accidents in the country.

In view of legality, electricity in Rwanda is governed by a law No 21/2011 of 23/06/2011 published in Official Gazette n° Special of 12/07/2011 (Rwanda Parliament, 2011). This law describes the technical (production, transmission, distribution and purchase), licenses and rights of customers. REG is also under RURA control which regulates the uses, users and suppliers of electricity playing an intermediate role for regulation issues.

In regard to affordability, the cost of electricity in Rwanda is US$0.23 per KWh. In a country where the household income is less than US$1.25 per day, this cost is relatively high (ESMAP, 2012). In comparison to other EAC countries, Rwanda has a relatively high electricity cost especially for industrial use as shown in table 7.

Table 7. Electricity cost in East African Community countries (2011-2013)

Electricity cost ($/KWh) in East African Countries (EAC)				
	Country	2011	2012	2013
	Burundi	0.08	0.08	0.08
	Tanzania	0.09	0.10	0.10
	Uganda		0.18	0.18
	Kenya	0.15	0.15	0.14
Medium Industries	Rwanda	0.23	0.23	0.23
	Burundi	0.08	0.08	0.08
	Tanzania	0.07	0.08	0.08
	Uganda		0.12	0.12
	Kenya	0.15	0.14	0.13
Large Industries	Rwanda	0.23	0.23	0.23

Source: (EAC, 2014)

4.2. Electricity demand

Using data of installed capacity, electricity generated and electricity consumed (sold) from REG monthly report, 2014 and after discounting the electricity losses; it is found that almost all electricity supplied is consumed. However, the consumption of generated electricity decreased from 98% in 2010 to 94% in 2014 as can be seen in table 8. This decrease in electricity consumption may be a result of the unreliability of electricity where customers may decide to but their own generator to cope with electricity outages.

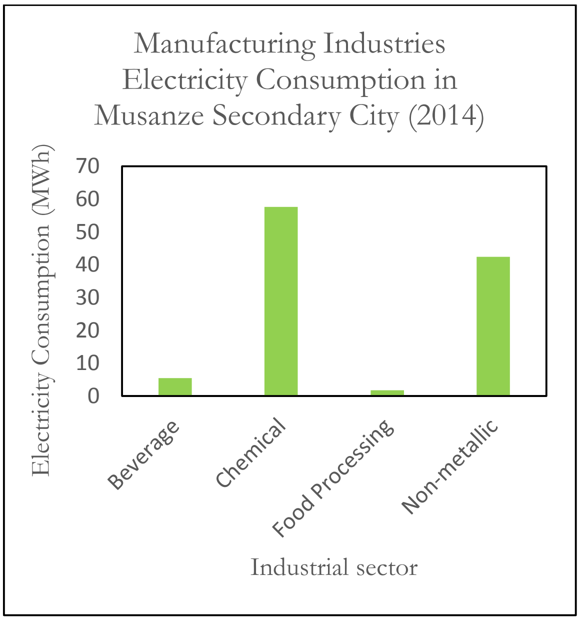
Table 8. Comparison between Rwanda electricity supply and consumption (demand) during (2010-2014).

Electricity (GWh)	**2010**	**2011**	**2012**	**2013**	**2014**
(A)Total Generation	281	341	391	408	467
(B)Total Import	80	77	90	94	77
(C)Total Export	3	2	0	0	2
(D)Total consumed	287	326	379	391	407
(E)Total losses (23% of A)	65	78	90	94	108
(F)Available electricity (A+B-C-E)	294	337	391	408	435
Ratio between available and consumed (%)	98	97	97	96	94

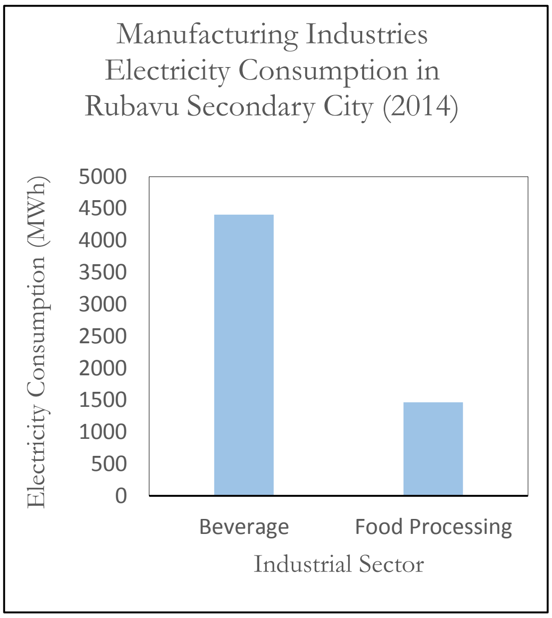
Source: Author calculation using data from REG.

4.2.1. Electricity consumption for manufacturing industries

As can be seen in figure (18, A), manufacturing industries annual electricity consumption in 2014 for Musanze secondary city was 57 MWh consumed in the chemical industrial sector, 43MWh in non-metallic, 5 MWh in beverage and 2MWh in food processing. The total manufacturing industries' electricity consumption in Musanze was 107 MWh. In Rubavu secondary city (figure 18, B), it was 4402MWh consumed in beverage sector and 1468MWh in food processing sector making a total of 5870MWh. This means that manufacturing industries in Rubavu consume almost 55 times more than in Musanze.



a.



b.

Figure 18. Manufacturing Industries' electricity consumption in (**a**) Musanze and (**b**) Rubavu.

Source: Author using data from REG.

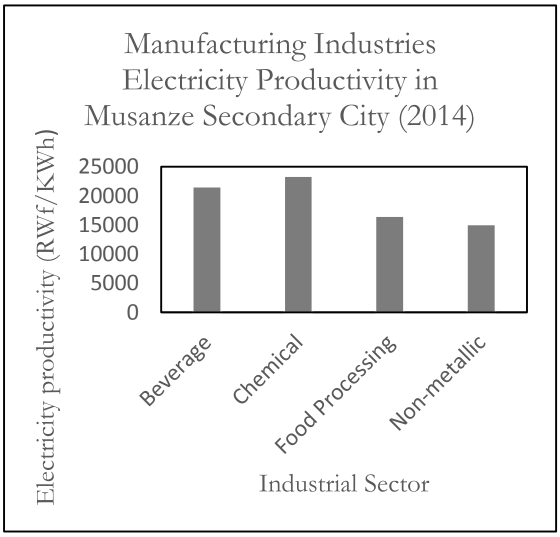
4.3. Electricity productivity

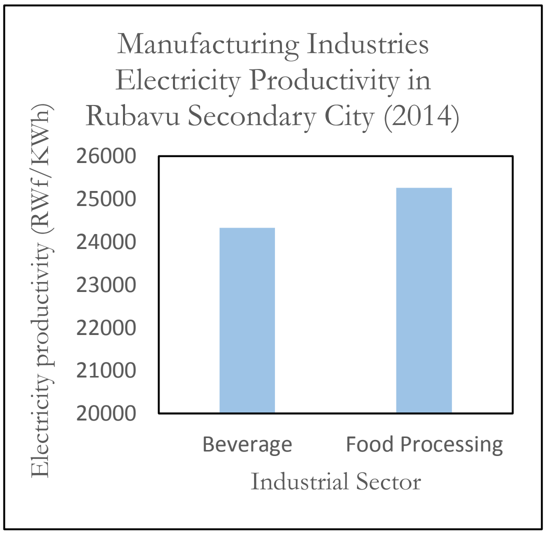
To calculate the electricity productivity, the annual electricity consumption during the year 2014 as well as the annual turnover in Rwandan currency were processed using equation 8, as shown in table 9. This table shows that the firms which consume higher electricity are higher in annual turnover. However, they are not the better in electricity productivity. The result obtained from equation 8 were used to calculate the average of electricity productivity for manufacturing industries' sectors. The figure (19, A) shows that chemical industries, in Musanze, are high electricity productive followed by industries in beverage sector while non-metallic industries are less electricity productive. Food processing sector has a high electricity productivity in Rubavu (see figure 19, B) (25264RWf/KWh) in contrast to Musanze where the same sector is less productive (16536RWf/KWh). The difference is relatively high (150% of food processing electricity productivity in Musanze). The beverage sector is also more productive in Rubavu than in Musanze though scoring the second place in Musanze.

Table 9. Firms' annual electricity consumption, turnover and electricity productivity (2014)

Firm name	Products	Sector	Electricity consumption in KWh	Turnover in millions of RWf	Productivity in thousands of RWf/KWh
RUBAVU SECONDARY CITY					
R1	Beer and soft drinks	Beverage	4400947	107095	24
R2	Black tea	Food	1452065	36850	25
R3	Maize flower	Food	11847	173	15
R4	Bakery Products	Food	2370	35	15
R5	Maize, Cassava and Sorghums	Food	2117	33	16
R6	Local beer	Beverage	783	15	19
R7	Green coffee	Food	290	8	28
MUSANZE SECONDARY CITY					
M1	Pyrethrum	Chemical	53260	1273	24
M2	Cement	Non-metallic	41461	615	15
M3	local wine	Beverage	3320	71	21
M4	Insecticides	Chemical	3754	64	17
M5	Bakery Products	Food	1760	29	17
M6	Bricks	Non-metallic	1003	27	27
M7	local beer	Beverage	1092	26	24
M8	Local wine	Beverage	1050	21	20
M9	Soaps and Detergents	Chemical	635	13	20

Source: REG and RRA. The firms are given codes instead of their names to keep firms' confidentiality.





a. b.

Figure 19. Manufacturing Industries' electricity productivity in (**a**) Musanze and (**b**) Rubavu.

Source: Author calculation using data from REG and RRA.

4.4. Comparisons between two secondary cities: Musanze and Rubavu

Table 10 shows that Musanze secondary city has a very high annual electricity production (168.5GWh) compared to Rubavu (13.78GWh). It also doubles Rubavu in overall electricity consumption: 21.84GWh for Musanze against 10.63 GWh for Rubavu. In contrast to the production and overall electricity consumption, Musanze has a very low industrial electricity consumption. The industrial consumption in Rubavu is more than a hundredfold the one for Musanze.

Table 10. Comparison of Electricity generated, city consumption and industrial consumption (2014)

Secondary city)	Electricity Generated (GWh)	Total Electricity Consumption in the City (GWh)	Total Industrial Consumption (GWh)
Rubavu	13.78	10.63	5.87
Musanze	168.50	21.84	0.06

Source: Data from REG.

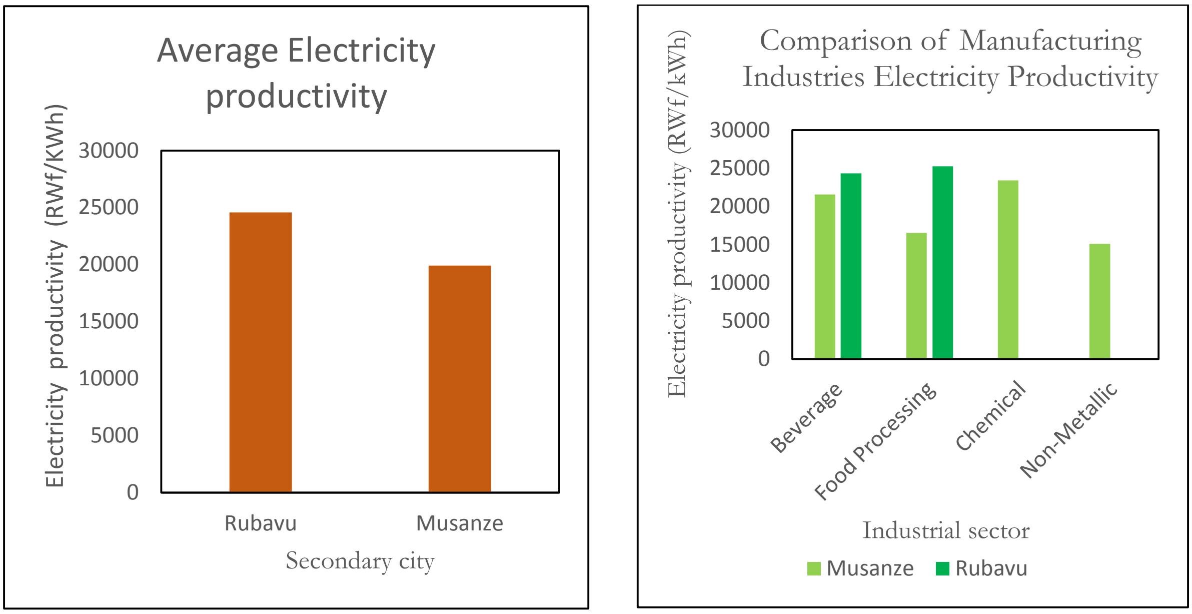
Regarding electricity consumption per sector, the sectoral comparison is surprisingly incomparable as can be observed in table 11: The beverage sector electricity consumption in Rubavu is more than eight hundred fiftyfold the consumption for the same sector in Musanze (4402MWh against 5MWh). For the food processing sector, Rubavu makes more than 20 times of Musanze electricity consumption for the same sector (1468MWh against 58MWh).

Table 11. Comparison of Electricity Consumption per Manufacturing Industries 'Sectors (2014)

Manufacturing Industries Electricity Consumption in MWh		
Industrial sector	**Musanze**	**Rubavu**
Beverage	5	4402
Food Processing	58	1468
Chemical	2	-
Non-Metallic	42	-

Source: Author calculation using data from REG.

In general, manufacturing industries in Rubavu (24566RWf/KWh) presents the high electricity productivity than in Musanze (19925RWf/KWh) as seen in figure 20 (A). For only two manufacturing sector (beverage and food processing) present in both secondary cities, Ruvabu also perform better than Musanze in terms of electricity productivity with a reverse trend: In Musanze beverage is more productive than food processing while the latter is more productive than beverage in Rubavu as shown in figure 20 (B).



a. b.

Figure 20. Comparison of average electricity productivity for Musanze and Rubavu secondary cities' manufacturing industries: (a) in general and (b) by sectors.

Source: Author calculation using data from REG and from RRA.

5. DISCUSSION

In this chapter, the major findings of this research work are discussed. The discussion follows the research questions: i) What are available sources of electricity in or near Musanze and Rubavu secondary cities? ii) How is electricity supply system in Musanze and Rubavu? What is the manufacturing industries' electricity consumption in Musanze and Rubavu secondary cities? What is the manufacturing industries' production in Musanze and Rubavu Secondary cities? What is the electricity productivity of manufacturing industries in the Musanze and Rubavu secondary cities? Where are problems and opportunities between secondary cities and between manufacturing sectors?

After the discussion in regards to the research questions, the summary of this research, in view of others secondary cities, is presented ending by the limitation in this research.

5.1. Available Sources of electricity in Musanze and Rubavu

With electricity network, I have identified the current source of electricity as well as the electricity potentialities. As belonging to an interconnected centralised network, this network benefits from national and regional support as seen in figure 11. Regarding current source, both secondary cities have two sources of electricity. Musanze has Mukungwa and Ntaruka while Rubavu has Gihira and Gisenyi. The generation capacity for Musanze source is higher than Rubavu, as can be seen, is figure 19. However, Rubavu has more electricity potentialities than Musanze: It is near Kivu Lake which is a source of methane gas. In addition to being located in Northern part of the country where the hydropower potentialities are high, they both belong to volcanic zone benefiting from geothermal source: Kalisimbi for Musanze and Gisenyi for Rubavu as seen in table 2.

5.2. State of Electricity supply in Musanze and Rubavu

As can be seen in figure 16, the electricity network in Rubavu is a one-directional network while Musanze has a branched electricity network can be seen in figure 15. More connection on one power line may cause an overload that will result in voltage fluctuation. In contrast, the branched network facilitates a proper distribution of connection which reduces the overloading. Furthermore, the voltage in powerline plays an important role as seen in literature. This means that in the same condition, high voltage line will support a high load than a medium voltage power line. This is the case for Rubavu and Musanze where Musanze has a high voltage power line in its network while Rubave does not. More quality issues were reported for Rubavu network than for Musanze network. In total, a number of 125 frequencies and 839 frequencies were reported to be under or over the normal voltage in Musanze and Rubavu, respectively.

Furthermore, the availability of electricity is problematic. Electricity can only be available for 68% of estimated working time per day. This is calculated based on 17 hours assumed to be needed working hours for industrial operations. Ideally, the availability of electricity should be calculated based on 24 hours of service. This would allow industries to make their choice on working time and increasing working time may be possible by working in different shifts. For example, a firm can choose to work with one team in the day time and with another in the night to satisfy the demand or to increase its production. This is not possible if the availability is a constraint.

5.3. Electricity Generation and Consumption in Musanze and Rubavu

Musanze secondary city has a very high annual electricity production (169 GWh) compared to Rubavu (14GWh). In terms of overall electricity consumption, Musanze is double that of Rubavu (22GWh for Musanze against 11 GWh for Rubavu) as can be seen in figure 19. In contrast to the production and overall electricity consumption, Musanze has a very low industrial consumption. The industrial consumption in Rubavu is more than a hundred times the one for Musanze. The sectoral comparison is incomparable in electricity consumption: The beverage sector electricity consumption is more than 850 times the consumption for the same sector in Musanze while the food processing sector for Rubavu makes more than 20 times of Musanze electricity consumption for the same sector. This shows how firms are high electricity intensive in Rubavu than in Musanze. However, the consumption may depend on availability and reliability of electricity. Expecting electricity outage of 6 hours per day, as observed in Musanze, may be an obstacle for high electricity consumers firms to choose this secondary city as their location. Using data of 2125 industrial firms from 23 countries, Badri (2007) found electricity to be among the critical factor for industrial location choice. It may be also a reason to find fewer electricity consumers firms in Musanze resulting to the less overall electricity consumption for manufacturing industries in Musanze than in Rubavu. The high cost of electricity may also be constraints on electricity consumption especially for small firms (Nijkamp & Perrels, 1988).

5.4. Manufacturing industries' production in Musanze and Rubavu

For both secondary cities, the firms which have higher production in terms of annual turnovers are also the ones to consume high electricity. For this reason, Rubavu, as having higher electricity intensive firms, is the higher in production. However, the big share in this production results from only two large firms (R1 and R2). Apart, these two, the rest are in the same range of production with a small difference that may be a result of electricity availability that differs from these two cities. The medium firms observed in Musanze present also a high production, even though they cannot be compared with the large firm in Rubavu. Their production might increase if the electricity availability was not an issue in Musanze.

5.5. Manufacturing Industries' Electricity productivity in Musanze and Rubavu

Regarding the electricity productivity, industries in Rubavu secondary city demonstrated an overall higher productivity than in Musanze as seen in figure 18. By comparing two manufacturing industrial sector present in both secondary cities: Beverage and food processing as seen in figure 17 and 19, I found that both sectors are more electricity productive in Rubavu than in Musanze. I also realised the same trend in electricity consumption as seen in figure 15. This means that the issue electricity may be a source of these differences in productivity. However, other factors as seen in figure 4 can also be a source of these disparities. Furthermore, electricity backup capacity for these industries is different. Large firms may easily find private electricity generators which will be a big problem for medium and small firms.

5.6. Problem/Opportunities in Musanze and Rubavu

The high electricity productivity industries exhibited a high electricity consumption as seen in figure 19. This increase the high demand with an increase in industrial development. Hence, by increasing industrial electricity consumption, the demand made on the interconnected national grid will increase, as seen in figure 12 and 13, reducing the supply capacity as seen in figure 14.

The current electricity supply is highly saturated. The results in table 4 have shown that the electricity generated was consumed at a rate of more than 90%. This is a challenge to this electricity supply system. The study conducted by Royal Academy of Engineering (2013) demonstrated that a minimum of 20% of the total capacity should be observed for the system security reason. Failure to this may cause system blackout due to load oversaturation.

Although the generation capacity is higher in Musanze than in Rubavu, both secondary cities generation capacity are higher than their total electricity consumption. Yet, the peak demand is unmet. At least, 14MW at peak was unmet. The unmet capacity is observed while Musanze generates more than 8 times its overall consumption. This explains that the problem found in electricity as shown in table 5 could not be justified by low generation capacity. Rather, it may result from the deliberate cut-off of electricity or poor maintenance. It can also result from priority given to other regions as this network is interconnected and managed from a centralised control point. For instance, voltage quality issue was reported to be 125 frequencies for Musanze and 839 frequencies for Rubavu. This means that electricity supply system in Musanze is more qualitative than in Rubavu. However, Musanze had more outages and less reliable electricity than Rubavu. Hence, working in these two secondary cities, especially in Musanze, using electricity may be accompanied by several losses. The losses due to unsupplied electricity can be very high depending on the duration of the outage. For instance, it was observed to be between 118$ and 149$ per 1KWh unserved in Japan (Matsukawa & Fujii, 1994).

Despite the high electricity generation in Musanze and relatively fewer quality issues, the access to electricity multi-tier framework shows that electricity is more unreliable in Musanze than in Rubavu which generates more than 10 times less than the generation capacity in Musanze. CAIDI of 6 hours per day is too high compared to 2 hours per day for Rubavu and compared to the limit stated in the framework (5 hours per month). The typical value for CAIDI is 1.26 hours per day with less implying reliable electricity while above this limit implies unreliability (Pacific Northwest SMART GRID, 2015). Both secondary cities, Musanze and Rubavu, present unreliable electricity. This may be the reason why high electricity-intensive manufacturing industries are not found in Musanze. Investors may fear the losses that can be caused by outages which can rise up to $1.477 per second (Lineweber & Mcnulty, 2001). An example is that, during the year 1998, a study conducted in Nigerian revealed that an outage of 792 hours caused 35% of manufacturing industries to close their production (Adenikinju, 2005).

As per price, it is found that electricity in Rwanda cost 0.23$/KWh, a relatively high cost in the region. Abeberese (2013) found for the case of Indian manufacturing industries a reduction of 1% of the electricity price would increase 2% the industrial production. Hence, a high cost of electricity may be a barrier to the competitive advantage of manufacturing industries in the region.

5.7. Summary

Before drawing a conclusion in the last chapter, main findings of this research are presented. It is also shown that these research findings are not a particularity for Rwanda, rather they can be observed in most developing countries:

i) Rwanda emphasizes more on increasing the number of households connected to the national grid than considering the quality of electricity supply.

Most developing countries make a target to reach a higher percentage of household connected within a fixed horizon year. For instance, Southeast Asian wants to connect 22% of its region's population that are not connected by 2035 (IEA, 2013). It becomes more a concern for Sub-Saharan Africa which was lagging behind other developing countries with less than 30% of the connected household in the year 2005 against 65% for South Asia (Eberhard et al., 2011). It can also explain a high target for some Sub-Saharan Africa's countries such as Rwanda who's target is to reach 70% of its households by 2017 (EDPRS 2, 2013). As shown in appendix 5, this measurement is also used to evaluate a level of achievement in terms of electrification improvement by international agencies such as (UNDP/WHO, 2009). For instance, IEA (2011) found that during the year 2009, 45% of Sub-Saharan Africa were not connected to electricity while it only represents 12% of the world population. The same report stated that the people lacking electricity connectivity will reduce from 19% in 2009 to 12% by 2030 while it will increase to 10% for Sub-Saharan Africa during the same period. However, the quality issue seems to be given less importance. This is reflected in the investments distribution for the electricity sector in developing countries: 70% in electricity generation, 14% in distribution, 8% in a mixed system (generation, distribution and transmission) and only 3% in transmission(Covindassamy et al., 2005). Moreover, poor quality of electricity was proven to be a barrier to industrial productivity. For instance, Dollar et al.,(2005) using firms' data of four countries (China, Bangladesh, India and Pakistan) for the year 1999 attribute the China's high growth rate of 7% to the fewer electricity outages. In the same year, the growth rate was 2.7%, 4.1% and 1.3% for Bangladesh, India and Pakistan, respectively with the cost of outage reaching 3.3%, 5.4% and 5.5% of the total sales while it was only 2% for China. In the same perspective, Iimi (2008), using data from 26 countries found that removing electricity outage would increase growth rate from 0.5% to 6%.

ii) Secondary cities in Rwanda face much more deliberated electricity outages

This contradicts the willing to promote the secondary cities in term of economic development. Better electricity supply in the secondary city can attract investor especially in the industrial sector (Martin & Carol, 1995). In addition, covering the disparities observed in production between secondary cities can be reduced by providing good quality of electricity. Martin (1999) proved that proper infrastructure provision can be a spatial equaliser in growth distribution, by decongesting from high industrial concentrated to less concentrated cities.

iii) Electricity in Rwanda secondary cities is unreliability.

The unreliability of electricity in Rwanda Secondary cities is not uniqueness for Rwanda. For Sub-Saharan African countries, only an average of 85% of installed capacity was operational in 2010 with some countries having a very less such as Benin with 36.4% of operational installed capacity(Eberhard et al., 2011). The average outage for this region was 34 days per year during 2008 with Burundi having the highest outage of 144 days per year, 75 days for Eritrea, 63 days for Malawi and Tanzania while South Africa had 5.5 days of outage per year(Foster & Cecilia, 2009). It was found that unreliability affects more developing countries than developed countries I term of firm productivity (Escribano et al., 2009).

iv) More importance is given to large firms which consume a high amount of electricity than to small and medium firm that consume less electricity.

Large firms are recognized to have a high productivity. But this is not only justified by electricity reliability, rather, they benefit from technology and many privileges given to them such as tax break, access to credit and priority in infrastructure provision including electricity (Little et al., 1987; Gauthier & Mark, 1995). However, the small and medium constitute a great number of firms in developing and developed countries. For instance, firms with less than 5 employees make more than 97% of manufacturing firms in Thailand and Mexico while firms with less than 50 workers make 96% of the whole number of employment (George et al., 2004). In addition, the share for informal small and medium firms in GDP is 32.2% and 11.7% for low-income and high-income countries respectively while job creation is 41.67% for the informal sector in low-income countries against 17.9% for high-income countries (Ayyagari et al., 2007).
Hence, in regards to economic development, emphasizing on large firms, with less importance to the small and medium firms would cause a big loss to the economic growth as well as a big handicap for secondary cities development. Moreover, these small and medium firms are the ones facing high effects of unserved electricity due to lack of electricity backup system (Ado & Josiah, 2015).

5.8. Limitation and Best Industrial Choice

The two electricity datasets (electricity consumption and monthly report) and electricity network collected from REG were sufficiently detailed to allow the understanding of electricity supply system. However, electricity network does not give precision on the connection point that would be taken as a reference to calculate the buffer zone of power lines service coverage. Hence, service is considered along the whole powerline distance which may give a different result if the connection points were known.

The data for firms' turnover are based on reported annual sale value of production. This is easier for large companies to keep records and report regularly to the tax office. They have to pay value added tax (VAT). For them, monthly VAT report is an obligation. However, the small firms or cooperatives are not obliged to register for VAT. Only firms that make an annual turnover of 20,000,000RWf are obliged to register (PwCIL, 2015). For those small firms and cooperative, the reliability of data may be questionable. This makes it also difficult to compare companies that make an annual turnover of less than twenty million with those making hundreds of million or even billions.

These large firms are also high electricity consumers creating a high disparity between electricity consumption in Rubavu and Musanze as seen in figure 19. Manufacturing industries in Rubavu consume much higher electricity than in Musanze (around 100 times). This is because of two large manufacturing industries (R1 in beverage and R2 in food processing sector) located in Rubavu. In Musanze, all manufacturing industries are small firms and cooperative except two companies (M1 in chemical and M2 in the non-metallic sector) which are medium industries.

Based on the electricity productivity, food processing and beverage can be given a priority in Rubavu secondary city. These sectors are also the best in electricity production in this city. For Musanze secondary city, the best qualified for annual production turnover are chemical and non-metallic industries. However, the beverage sector performs better than non-metallic in terms of electricity productivity. Since these two secondary cities are neighbours, developing non-metallic and chemical industrial sectors would be the best option for Musanze secondary city.

6. CONCLUSION

The combination of electricity network analysis, electricity access multi-tier framework and a single factor productivity ratio proved the evidence to draw a conclusion on the manufacturing industries electricity productivity. With electricity network, the physical state of the electricity network is assessed. The multi-tier framework helps to identify the condition in which is the electricity supply system to draw conclusions on supply and demand concerns for electricity productive use. The single factor productivity ratio measures the results and informs the users about the performance. This can guide the decision maker to decide the proper distribution of electricity, in both quantity and quality, to support the economic growth. For our case study, the research questions' answers were found and objectives achieved. However, a study of the cost of outages for manufacturing industries operating in the study area would complement this study. Analysing the share for others production factors, using a multiple factor productivity ration could give more insight on others production factors that contribute to decrease or increase in manufacturing industries' productivity.

The general conclusion of this research is that electricity supply in the secondary cities under study is not supportive for industrial productivity due to the poor quality and several outages observed during the year 2014 although, the connectivity is not an issue. Hence, high-intensity electricity consumers industries are not favoured to be located in these secondary cities, especially in Musanze, unless electricity issues are solved. This constitutes a handicap for secondary cities development as growth pole. The poor quality observed is not due to less electricity production in these secondary cities, nor the less network coverage. For both secondary cities under study, Musanze and Rubavu, the urban areas are covered by the network. The electricity generated in these secondary cities is higher than the electricity consumed, still, the generated electricity is distributed to other regions within the country, leaving these cities in a poor electricity state. This is a result of a deliberated cut-off of electricity to give priorities to others cities where the capital city can be thought of. In this condition, cities' competition in terms of industrial development and then in terms of economic growth become impossible.

The unreliability of electricity constitutes a very big challenge for secondary cities' development. Most attention given to major cities in despite to secondary cities keeps industries concentrated in major cities. Deconcentrating the major cities needs a proper distribution of electricity and other infrastructure to enable industrial operation. Lack of electricity will make industrial productivity handicapped. The observation of high electricity productivity that goes together with high electricity consumption is a proof of a very high need for electricity to increase industrial productivity and economic growth. Without reliable electricity, manufacturing industries cannot maximise their production. Consequently, their share in economic development can be lowered. Hence, decision makers who intend to increase industries developments in secondary cities should first solve the problem of electricity availability.

As observed in this research, the large company are given priority in electricity provision. However, in developing as well as in developed countries, small and medium firms constitute a large number than large firms. Hence, prioritising large firms, as high-intensity electricity consumers, in spite of low and medium electricity consumers, minimises the possibility to make a great impact in terms of productivity as well as job creation.

Finally, this research revealed that developing countries are targeting to increase the number of people connected to the electricity as reflected in their policy documents. However, the quality issue seems to be forgotten. An increase of the percentage of connected people without considering the services enabled by electricity can even lead to a decrease of electricity use when the users find electricity unreliable.

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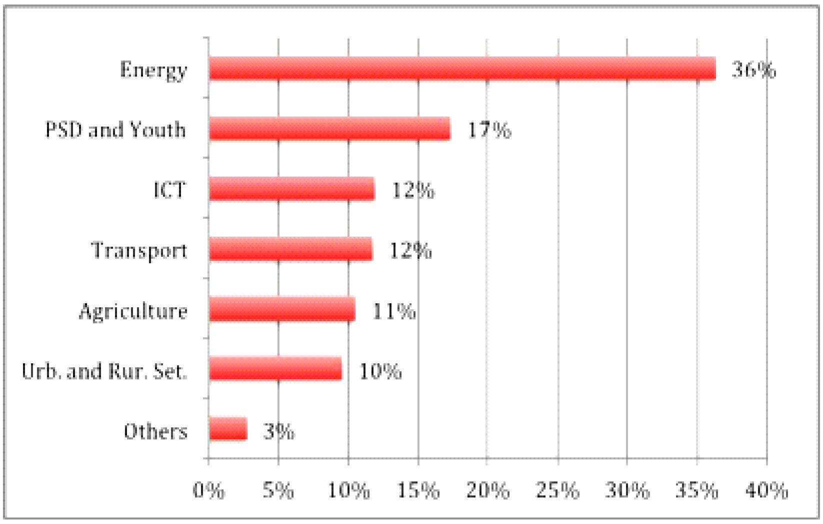
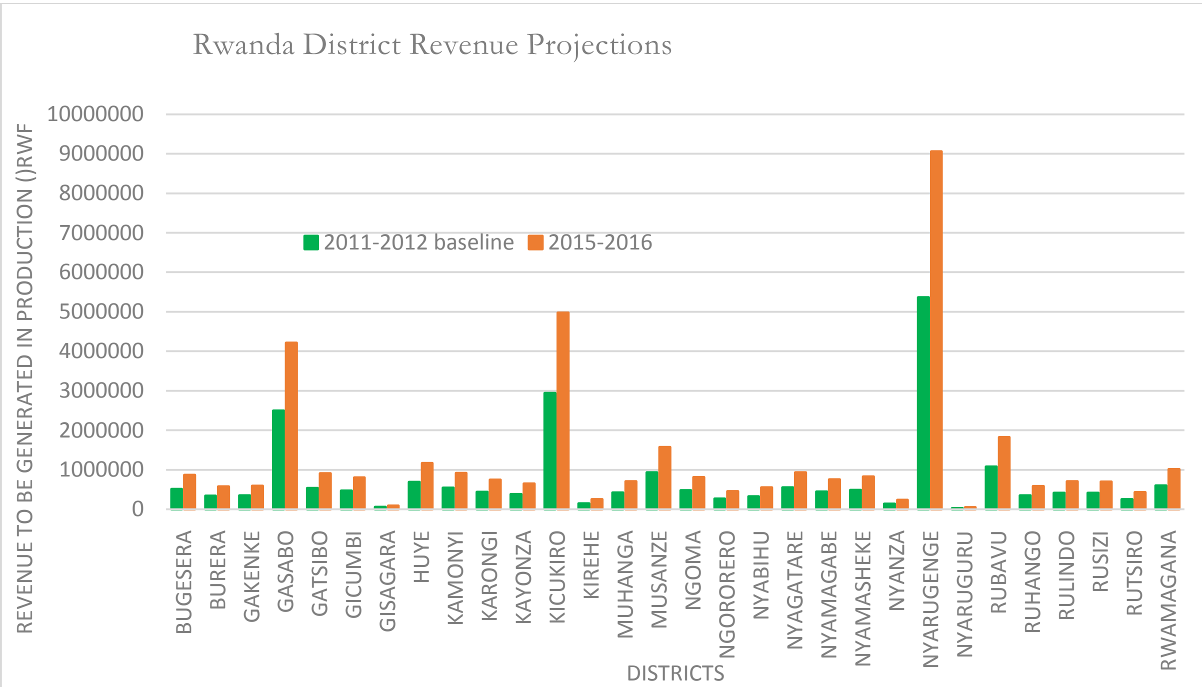
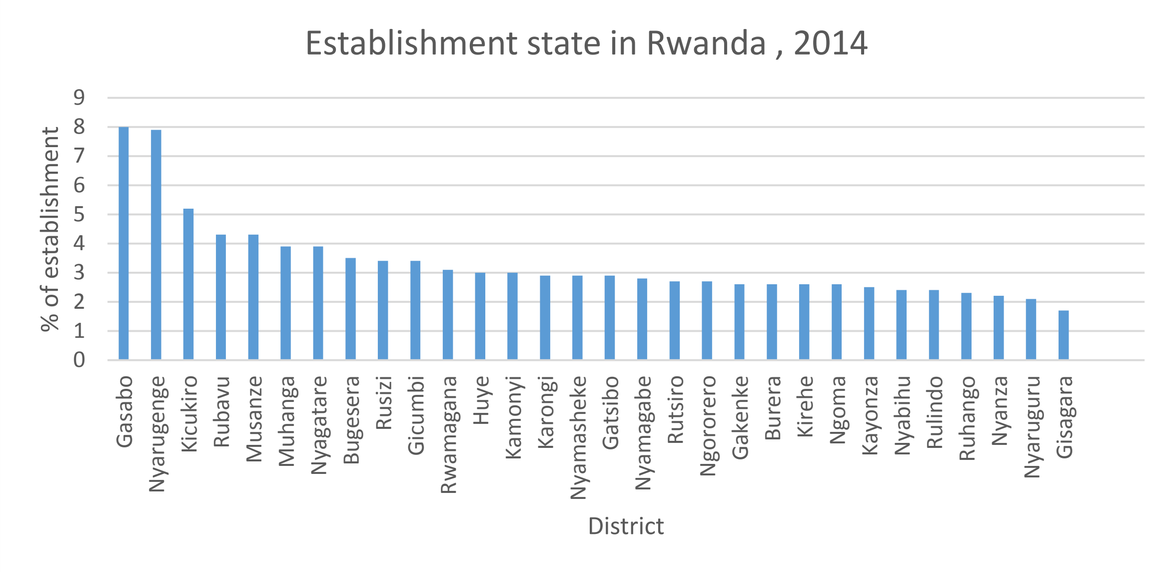
8. APPENDIX



Appendix 1: Percentage of contribution to the cost of economic transformation by sectors. Source: MINECOFIN



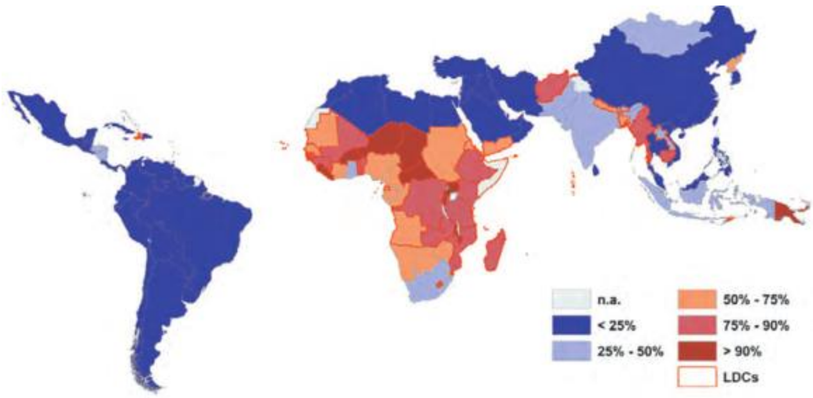
Appendix 2: District revenue projections. Source: Author using data from Local Government Revenue Potential in Rwanda, (LGRPS Nov 2013)



Appendix 3: Rwanda Establishment State for the year 2014

Some Economic and Electricity Characteristics for Musanze and Rubacu			
Characteristics	**Subdivision**	**Rubavu**	**Musanze**
Number of enterprises	Total number	6383	6406
	Formal	403	340
	Informal	5980	6066
Distribution of establishment by size	Total	6587	6616
	Micro	6054	6000
	Small	459	538
	Medium	67	68
	Large	7	10
Number of manufacturing enterprises		7	9
% of increase in private and business establishment from 2011 to 2014		20.8	1.3
Number of employments (Workers)		19095	18531
Distribution of employments	**Total**	**13001**	**14104**
	Formal	4416	4693
	Informal	8585	9411
Electricity generated in KWh	Ntaruka	-	40104000
	Mukungwa	-	70157090
	Mukungwa II	-	1950688
	Mukungwa diesel generators	-	56291710
	Gisenyi	5171248	-
	Gihira	8610040	-
	Total	**13781288**	**168503488**
Number of connections/Customers		20275	26299
Electricity consumption in KWh	Gisenyi	5680620	-
	Gihira	4947158	
	Ruhengeri(from Mukungwa)	-	10147200
	Ruhengeri (from Ntaruka)	-	3580720
	Kinigi	-	4491500
	Cyanika	-	3624310
	Total	**10627778**	**21843730**

Appendix 4: Some economic and electricity supply characteristics



Appendix 5: Share of people without access to electricity in developing countries

Source: UNDP/WHO, 2009.