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Title of thesis: A System Dynamic Model of a Distributed Generation for Energy Security in Niamey

Presented by **Modou Pouye on 09, March 2018**

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ABSTRACT

Economic development is based on a reliable and cost effective energy supply. To sustain their economic growth, emerging countries need a dependable Distributed Generation (DG). DG is an efficient way to reach energy security by minimizing power losses in long and aging transmission lines. Due to the inherent Complexity of electricity systems, this study proposes to use System Dynamics (SD) modeling approach to investigate the links between electricity supply and demand, population growth, and real climatic parameters in Niamey, Niger. Some of the variables utilized in this study were the local solar radiation and wind speed. Results proved that: (1) the current population would reach 4,500,000 people in the horizon of 2050 under the actual birth and death rates; (2) the highest summer electricity demand in the year 2012 was 97.3 MW; (3) electricity supply can be far higher than demand by implementing a 72.3 MW Renewable Energy Sources (RES) in conjunction with 15 MW Energy Storage System (ESS); and (4) through sensitive analysis, Niamey and neighboring vicinity would reach energy independence from now to 2050, and even beyond. Finally, this study proposes some policy guidelines and recommendations.

Keywords—System dynamics, Niamey, energy security, Renewable Energy Sources (RES), energy storage systems, policy implications.

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ABBREVIATIONS

BR	Birth Rate
CLD	Causal Loop Diagram
CNES	Centre National d'Energie Solaire
CSP	Concentrated Solar Power
DG	Distributed Generation
DMN	La Direction de la Météorologie du Niger
DR	Death Rate
ESS	Energy Storage System
FB	Feedback
Fig.	Figure
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GW	Global Warming
GWh	Giga Watt hour
INS	Institut National de la Statistique
kV	kilo-Volt
kW	kilo-Watt
kWh	kilo-Watt-hour
m/s	meter per second
MW	Mega-Watt
NIGELEC	La Société Nigerienne d'Electricité
PHNC	Power Holding Company of Nigeria
PV	Photovoltaic
RE	Renewable Energy
Ref.	Reference
RER	Renewable Energy Resources
RES	Renewable Energy Source

SD	System Dynamics
SONICHAR	Société Nigerienne du Charbon d'Anou Araren
T&D	Transmission and Distribution
USD	United States Dollar

CHAPTER 1

GENERAL INTRODUCTION

Introduction

Electricity accessibility in Africa has a low share because of generally weak electricity supply system, especially in rural areas. For example, some regions in Africa, such as the Central, the East, and the West have respectively 75%, 77% and 53% of their population not having access to electricity (IRENA, 2015, Remap 2030). It is widely known that a large share of the people accessing electricity is needed to improve some sectors, such as health, education, telecommunication, agriculture and commerce. Emerging countries are facing several issues, including food insecurity, weak education and health system, and clean water scarcity. Nevertheless, these emerging countries have an important natural resources potential. Most of these resources are fossil fuels, biomass, water bodies, arable lands, but unawareness of the inhabitants of the importance of the resources and sometimes bad management of the policy makers enhance poverty in those region.

Traditionally, weakness of the energy system may be the source of the pronounced imbalance between power supply and demand. It is widely known that power demand has some drivers, such as economic development and population growth. Conversely, the inability of some African nations to provide enough power to their population slows down any economy improvement. That leads to the trade deficit of the emerging countries, in terms of energy exchange and common goods. It is clear that energy deficit has a major impact on the whole economy, it is a barrier to industry implementation which leads to a low goods productivity. Also, the importation of goods from neighboring countries leads to a weaker economy. A low industrialization level of a nation means a large unemployment rate, which is a big challenge in this 21st century because the wellbeing of the ever growing population is hindered by an abusive use of machines.

Currently, energy balance is a real issue for developing nations. However, most of these emerging countries have a huge renewable energy (RE) potential. Some instance of RE potentials are abundant solar radiations, flowing River, biomass, and enough wind for power production. Thus, the lack of adequate technology is the main reason why this abundance of RE cited above, cannot be geared to support the collective economic endeavors. Renewable power production technology, such as photovoltaic system, Concentrated Solar Power, wind turbine, and Bio-digester are in the state-of-mature technology. However, multiple weakness within the economy, as a whole of the developing regions, are barriers to integrating those technologies to their electricity production mix. There are also some issues emerging from the local climatic situation in Africa. In the Sahel, specifically, dust and high temperature have negative impact on the lifetime of solar panel imported in that region (BONKANEY and Madougou, 2015).

Moreover, most of the electricity generation capacity of these countries is from fossil fuels, including oil, coal, and natural gas, although they do not usually produce such resources. Additionally, a significant part of the electricity produced is lost through the aging infrastructure during the transmission and distribution (T&D) (Al-Khalidi *et al.*, 2011 and Priyangika *et al.*, 2016). Niger is one of such developing countries and its electricity supply is more than 80% based on fossil fuel resources and electricity imported from Nigeria. Electricity production, transmission and distribution in Niger is ensure by "La Société Nigérienne d'Electricité" (NIGELEC) (Yacouba Moumouni *et al.*, 2014), the main electricity supply is based on fossil fuel energy sources, such as, coal, and oil. Nonetheless, because of the moderately fast economic growth of the city Niamey, NIGELEC is unable to supply 100% of the electricity demand of Niger. This is the reason why electricity imported from Nigeria is used to fill this energy gap.

Niger has a huge renewable energy potential, but few research has been done in this area. Since electricity demand is higher than supply in Niger, an additional renewable generation capacity is needed for the improvement of economic activities and quality of life of the population. Renewable energy technologies provide an excellent opportunity for mitigating greenhouse gas emission and reducing global warming through substituting conventional energy sources (Priyangika *et al.*, 2016). The share of RE generation in Niger needs to be increased because of its high Renewable Energy Resources (RER) potential. Renewable energy is the only viable alternative that has the potential, when properly managed, to improve quality of life on a national and continental scale (Priyangika *et al.*, 2016).

The position and the hot weather of Niger is the main reason of the high electricity demand in the summer. Energy is vital for the day-to-day comfort of the population and to develop the industry sector in order to cut down the country's huge dependence on importation. This situation is not favorable for the national economy, thus ways need to be found to resolve this vicious problem.

Some research works were done in the balance of power supply and demand, but the current work adds another dimension to the issue at hand. The impact of DG on the distribution system is investigated in this study in order to improve the existing power quality. Various small renewable power sources (solar and wind energy) in conjunction with Energy Storage System (ESS) are proposed to be implemented in the vicinity of the consumers. A thorough investigation based on System Dynamics (SD) approach of various power supply and demand scenarios is suggested and conducted.

This study is divided into five chapters and is organized as follows:

(1) Chapter 1 introduces the topic with a general Introduction of the subject of the matter, it displays problem statement, the research question, and objectives of the research;
(2) Chapter 2 explains the background literature of balancing power supply with demand and assesses the renewable power potentials;
(3) Chapter 3 exposes the methods used and the data collection schemes;
(4) the findings and their implications are presented in Chapter 4; and

(5) finally, chapter5 deals with the conclusion and recommendations.

1.1 Purpose of the study

1.1.1 General Objectives

The ultimate aim of the thesis as the development of a system dynamics model of a distributed generation for energy security in Niamey to achieve this goal the following points are analyzed:

1) Build a model using System Dynamics approach and simulate the inputs which are some new small power plants in order to meet effectively and reliably the national power needs;

2) implement Distributed Generation (DG) in Niamey, which is, on the current knowledge, the first town in West Africa to apply DG energy model;

3) balance power supply and demand in Niamey at a lower electricity price and at a significant reduction of the GHG emissions for the benefits of the inhabitants.

1.1.2 Specific objectives

1) resolve summer energy crisis in Niamey and vicinity, and

2) display the impacts of the socio-economic and climatic parameters on the bulk energy system in Niger.

The focus of this study is to investigate the impact of additional small power plants from different sources, like solar and wind energy on the national grid.

1.2 Research question

The primary objective of this report is to answer this research question:

What are the future dynamic of the energy in Niamey after the implementation of Distributed Generation and how the socio-economic and climatic parameters affect the electricity supply and demand trends?

1.3 Limitations

This model does not take into account the individual electricity demand patterns of the following three main sectors of the economy, *viz.*, industry, agriculture, and commerce. The reason is that, most of these sectors lack a detailed energy consumption plans or possess their own generators. Also, the renewable energy supply of this model does not look into PV systems and wind turbines installed in some private homes in Niamey.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

2.1 Background

2.1.1 Definition of keys terms

A range of definition is given to **energy security**, but in this study it simply means availability and local production of electricity either from fossil fuel or renewable resources.

Using natural power resources to generate electricity in the premises of the consumers is called **Distributed Generation** (DG). It also means the implementation of small solar power plants or dispersed wind farms on the vicinity of the consumers, DG can be utilized to achieve power self-sufficiency in big towns and rural areas.

A dynamics analysis of the impact of DG on the socio-economic factors, electricity supply and demand system, climatic parameters, and their interactions is called **System Dynamics (SD)**.

2.1.2 Energy Situation of Niger

Niger is a West African country located at longitude 0°- 17.5° and latitude 11°- 24°. Its population in 2016 is 19,865,068 people in a surface area of 1,267,000 km^2. Therefore, the population density is about 16 people/ km^2. A huge energy potential in both fossil fuels and renewable resources are available in this country. Recent renewable energy assessment has been done by IRENA, its results proved that Niger has a potential of:

- 8,829 TWh/year of Concentrated Solar Power (CSP), taking into account all suitable areas;
- 15,669 TWh/year of PV, taking into account all suitable areas;
- 14,628 TWh/year of wind energy, if all areas have turbines with a capacity factor greater than 20%,
- 1,262 TWh/year of wind energy, if all areas have turbines with a capacity factor greater than 30%, and
- 55.8 TWh/year of wind energy, if all areas have turbines with a capacity factor greater than 40% (IRENA, 2014)

However, energy consumption per capita is still low. It was only 54.17 kWh per capita in 2016 and the level of energy insecurity is high because 72.4% of the electricity consumption in Niger comes from Nigeria (NIGELEC, 2016).

2.1.3 Existing Electricity Production System

La Société Nigérienne d'Electricité (NIGELEC), is the main company in charge of the production, the transmission, and the distribution of electricity in Niger (Yacouba Moumouni *et al.*, 2014). Its install capacity is about 174 MW with 134 MW in the capital city, Niamey. Table 1 shows the install capacity of fossil fuels power production in the capital city of Niger.

Table 2.1: *Install capacity of the capital city of Niger, Niamey (Source: NIGELEC)*

Location	Generator	Install Power (MW)	Available Power (MW)	Capacity factor
Goudel	PC4 V12	12	9	0.75
Goudel	MTU / 20V 4000G63	2.2	1.8	0.81
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Goudel	MTU / 20V 4000G63	2.2	1.8	0.81
Goudel	V12	1.6	0.3	0.18
Niamey II	B0188	12	9	0.75
Gorou Banda	-	20	-	-
Gorou Banda	-	20	-	-
Gorou Banda	-	20	-	-
Gorou Banda	-	20	-	-

NIGELEC has three power stations in Niamey: (1) Goudel with 7 working generators (NIGELEC, 2015) of a total installed power of 24.6 MW, but due to decreasing efficiency they can produce only 18.3 MW; (2) Niamey II with only one working generator, but with a 12 MW of installed capacity, only 9 MW are available due to the same reason cited above; (3) Gorou Banda with 80 MW generators installed in 2016. The latter, according to the general opinion, is an environmental disaster because it runs on heavy fueled oil.

Table 2.2 *: Electricity availability and sold in Niger (Source: NIGELEC)*

Year	2011	2012	2013	2014	2015	2016
Electricity Available (GWh)	753.50	789.79	815.86	936.14	1024.33	1076.19
Electricity Import (GWh)	615.50	636.99	602.38	726.97	782.34	779.11

SONICHAR Production (GWh)	75.80	39.80	43.84	47.57	51.11	53.85
NIGELEC Production (GWh)	62.10	113.00	169.64	161.6	71.17	107.06
Electricity Sold	479.50	636.08	665.45	756.05	824.31	850.454
Total Losses (GWh)		146.53	148.41	177.86	201.14	221.98
Electric Power Consumption (kWh per Capita)	47.52	49.51	48.46	51.44	53.15	54.81
Population	-	17,138,707	17,679,760	18,389,164	19,124,383	19,865,068
Elec Av / Pop	-	46.08	46.15	51.00	53.56	54.17

Niger is electricity supply dependent on Nigeria, because of the total electricity consumed in the past two years in Niger, 76.37% in 2015 and 72.39% in 2016 came from Nigeria. It can be seen that there is a huge gap between the electricity produced in Niger and that sold to the consumers and the causes are: (1) inefficient transmission and distribution line with 201.14 GWh of loss in 2015; and (2) rotten customers who stole electricity or refuse to pay their electricity bills. Low local electricity production is a sign of high risk on Niger's energy sector. NIGELEC and SONICHAR have produced 160.91 GWh which is 15% of total electricity available in 2016. This risk is related to the dependence of Niger on three factors: (1) the social stability of Nigeria, for example if a major instability happens, the power may not be available; (2) the safety of the transmission line between Nigeria and Niger in case of severe weather events; and (3) the good relationship between the two countries.

The bonds between the main factors of the electricity supply system in Niger is displayed in Fig. 1. The analysis of 6 years' data from NIGELEC made clear the links between electricity available in Niger from the two suppliers: 1) the local production by two state-owned, companies, *i.e.*, NIGELEC and SONICHAR; and 2) the Power Holding Company of Nigeria (PHCN). Hence, it is clear that the local electricity production is far lower than the power imported due to a low installed capacity, inefficiency of the existing generators, aging transmission and distribution lines with more than 0.2% electricity loss (NIGELEC, 2016).

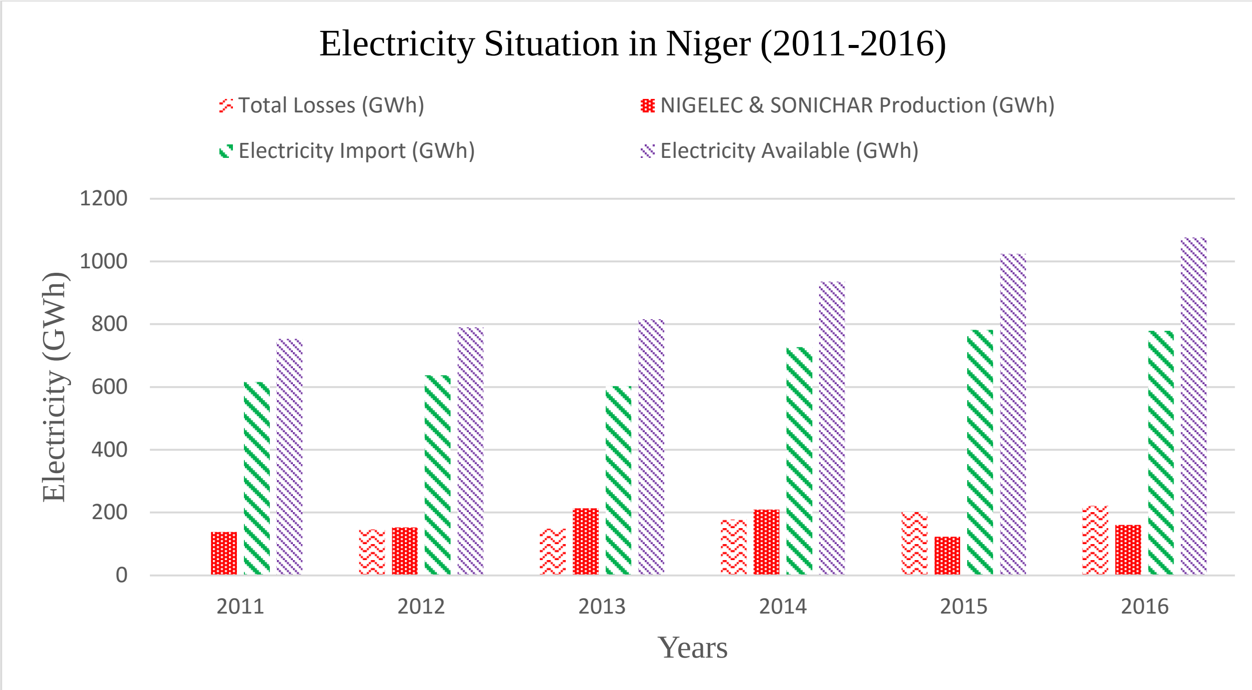

Figure 2.1 : Electricity Situation in Niger (2011-2016) (NIGELEC)

Like other West African emerging countries, electricity consumption per capita is growing slowly. Electricity coverage and access is one of the core human development indexes of a country.

2.1.4 Interaction of social, climatic and consumption factors

The electricity system of Niger has been experiencing since its existence a strong correlation between some social variables, temperature and electricity consumption drivers. It can be seen in Fig. 1 and 2 that electricity consumption in Niger follows population growth trends. Electricity consumption growth rate was estimated at 14.74%, 9.42%, and 5.06% in 2014, 2015 and 2016 respectively (NIGELEC). Population growth rate was constant in 2014, 2015 and 2016 with a value of 4% Institut National de la Statistique (INS). Electricity production is dependent on power demand, which has population growth as the main driver. Both electricity consumption and population growth have positive trend, this in fact proves that they are strictly interlinked.

Niger is legendary known for its hot summer months with an average temperature above 35°C in April and May. This rising temperature leads to more usage of electric appliances, such as fans, air conditioners, and refrigerators to keep the residents in their comfort zones. This climatic impact in the electricity consumption is further illustrated in Fig. 4. The peak temperature periods (April, May, June, October and November) perfectly match with the peak power consumed in Niamey. An opposite scenario is shown for the low temperature months of January, February, July, August, and September with low electricity sold. It can be concluded that the electricity consumption and seasonal temperature in Niamey follow the same variations.

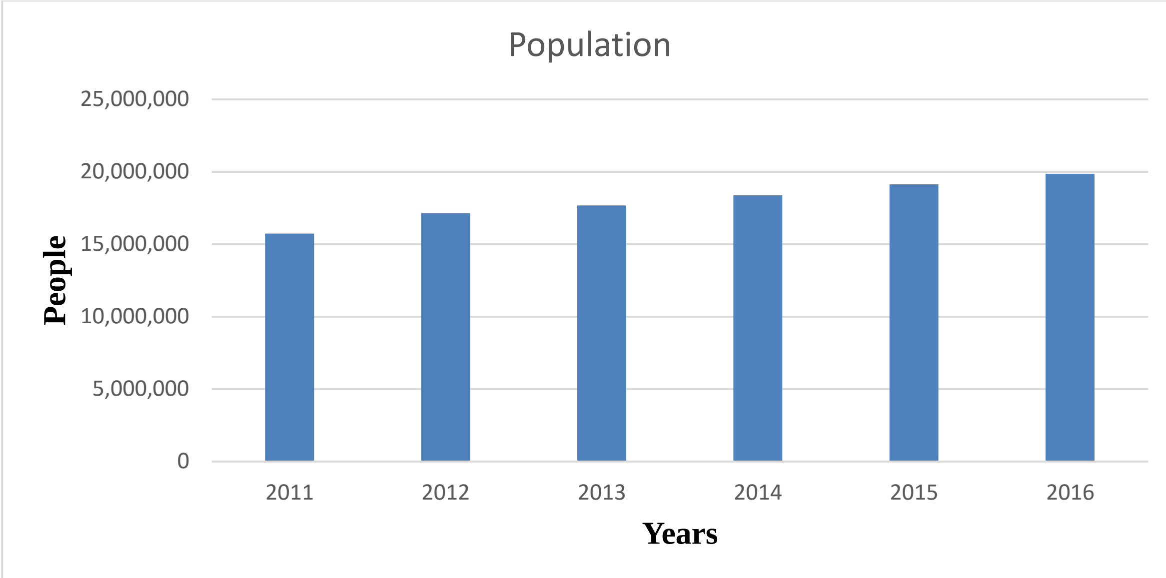

Figure 2.2 : Population growth in Niger (2011-2016)

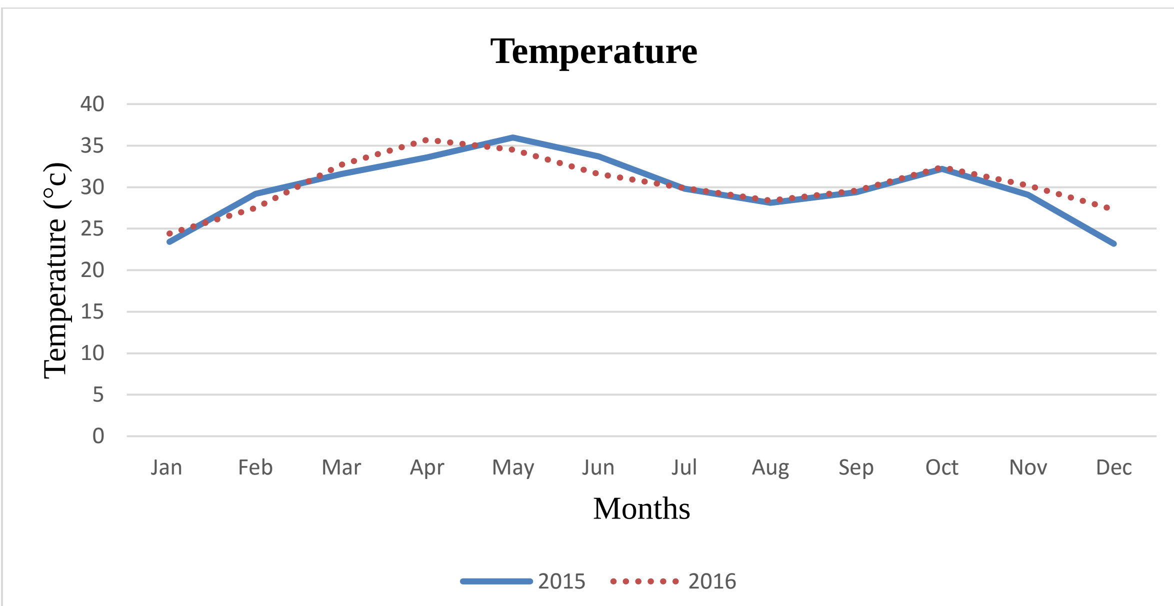

Figure 2.3 : Temperature variability in Niamey for 2015 and 2016

Table 2.3 : Electricity sold in Niamey (Source: NIGELEC)

Month	2015	2016
January	26,770,426	27,525,840
February	33,279,800	30,687,002
March	42,384,229	47,125,433
April	47,149,506	50,928,493
May	47,038,530	52,429,394
June	50,928,989	44,619,395
July	47,408,073	47,971,100
August	45,061,948	47,611,493
September	42,421,804	45,230,035
October	52,312,273	50,713,206
November	54,848,621	44,098,351
December	32,368,646	NA

For clarity purposes, the electricity data shown Table 3 are graphically presented in Fig. 4.

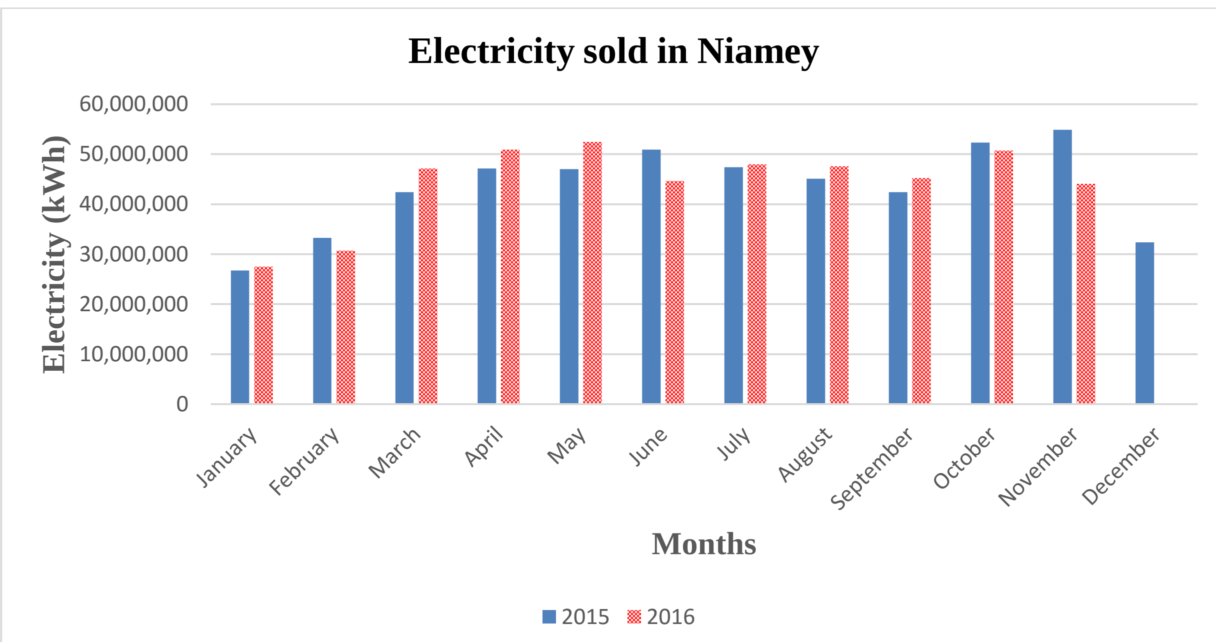

Figure 2.4 : Electricity sold in Niamey in 2015 and 2016

2.1.5 5 Solar and Wind Energy Potential

Niger has a large and diverse renewable energy potential across different regions of the country. Fig. 6 illustrates the horizontal solar radiation in four different cities in Niger. Solar irradiation is abundant everywhere in Niger. It is between 4 to 7.5 kWh/m²/day, with five low radiation months, such as January, February, October, November and December (IRENA, 2013). Niamey and Zinder (this city is about 900 km distant from Niamey) receive the highest irradiation in that low radiation months. Nonetheless, almost all the cities receive an irradiation of 6 to 7.5 kWh/m²/day from March to September. The use of modern renewable energy technologies, such as efficient PV system or Concentrated Solar Power (CSP) to convert solar irradiation into electricity will strengthen the national power supply. It is widely known that the costs of renewable technologies are decreasing rapidly. This technological breakthrough makes all recent African renewable energy projects among the most competitive in the world.

Wind resources can be harnessed for electricity generation using wind turbines. The theoretical potential for wind in Niger has yet to be considered by the National power production company, NIGELEC. Results of recent studies done in Africa proved that Niger has the highest wind resources in West Africa (Africa Roadmap 2030). Figure 6 shows the average monthly wind speed in four different cities in Niger at 10 m above ground. Zinder, Agadez (North) and Arlit (Far North) have almost the same values of wind speed variations throughout the year. These regions have their highest average wind speed occurring from November to February and from March to September, *i.e.*, 5 m/s to 7 m/s, 4 m/s to 6 m/s, respectively. Agadez, which is in the Sahara has the highest average wind speed. Niamey, with the lowest wind resources, experiences an average wind velocity from 3 m/s to 4 m/s on a yearly basis. However, for an investment in the wind energy sector to be worth economically, the wind speed has to be a minimum of 5 m/s.

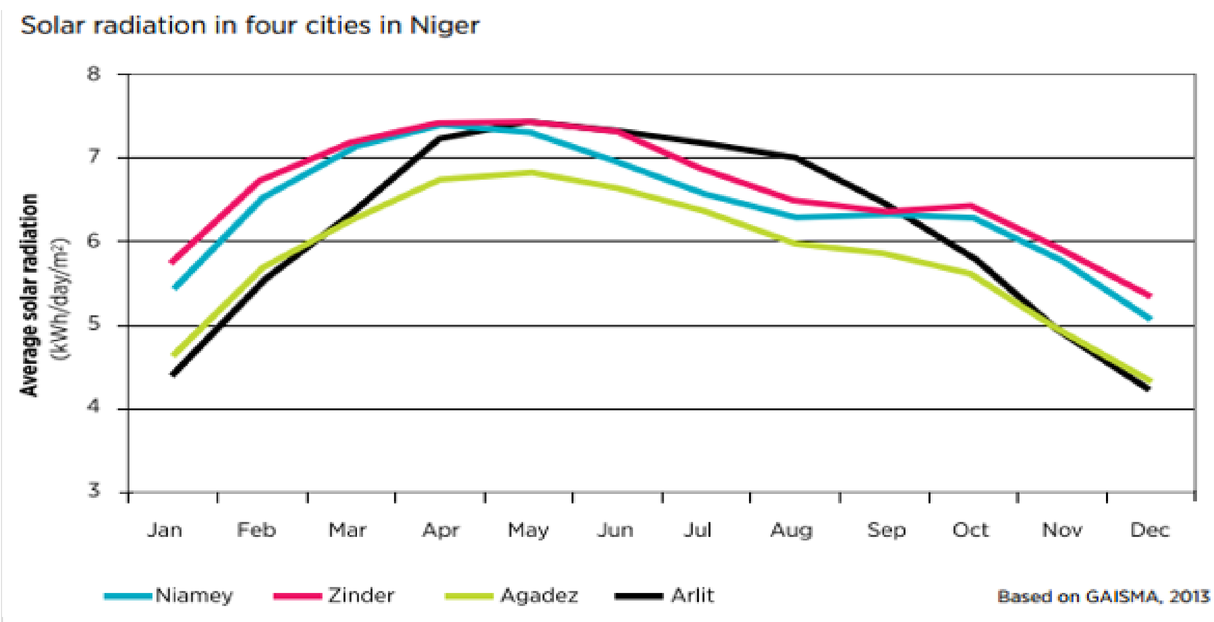

Figure 2.5 : Solar Radiation in Niger (IRENA, 2013)

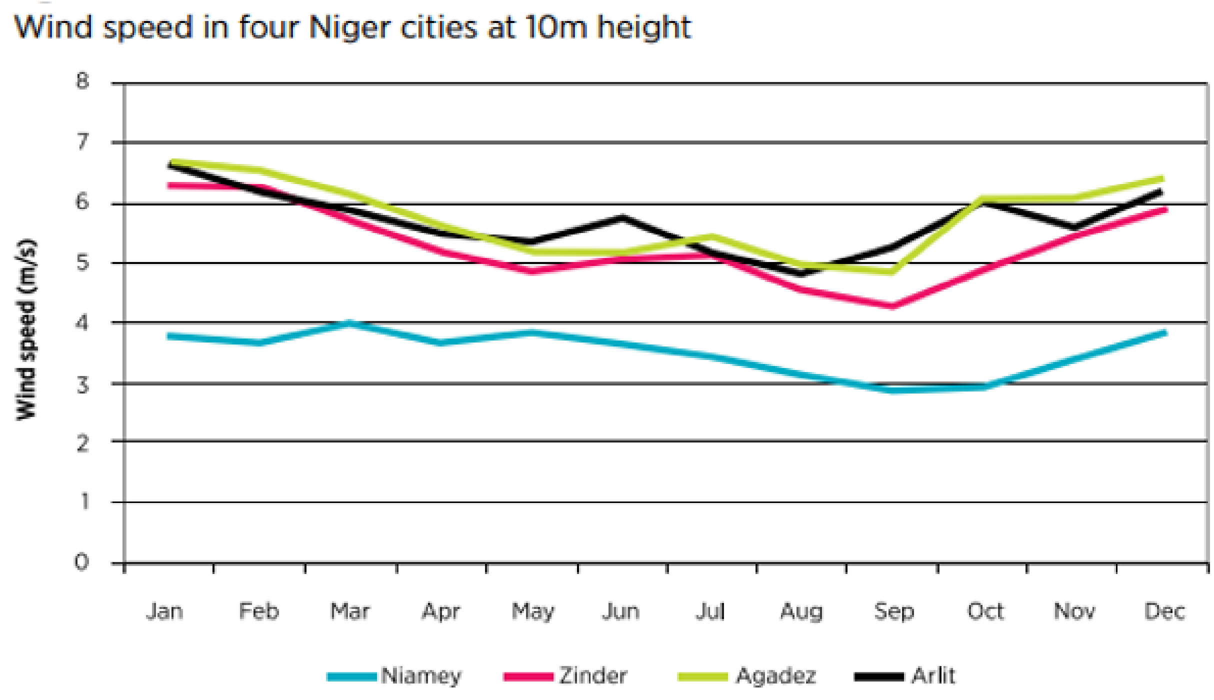

Figure 2.6 : Diurnal wind speed from Synoptic Station of Niamey Airport (IRENA, 2013)

2.1.6 I.6 Hydro-Energy Potential

Hydropower engineering refers to the processes and technology applied in converting the energy of the stream flow of a river into electrical energy. Thus, Niger has a river where this technique can be applied. Figure 7 displays the flow rate of Niger River recorded in 2015. It is comprised by two periods: (1) a period of high flow rate from August to January and (2) a period of low flow rate from February to July. These flow rates are dependent on the rainfall that usually lasts 3 months (June, July, and August) and the West Africa sub-regional precipitation because the River runs from Guinea Conakry to Nigeria. Niger's electricity supply system can be strengthened by the potential of 400 MW in seven suitable sites along the River (ECOWAS, 2006). This potential can increase the electricity per capita of Niger, which is a requirement for the national economic to take off. These suitable sites are listed in Table 4.

***Table 2.4 :** Niger's hydropower potential (IRENA, 2013)*

Sites	Capacity (MW)	Size
Kandadji	130	Large hydropower
Gambou	112.5	Large hydropower
Dyodyonga	26	Medium hydropower
Mekrou, Tapoa, Gorouol and Sirba	8	Small hydropower

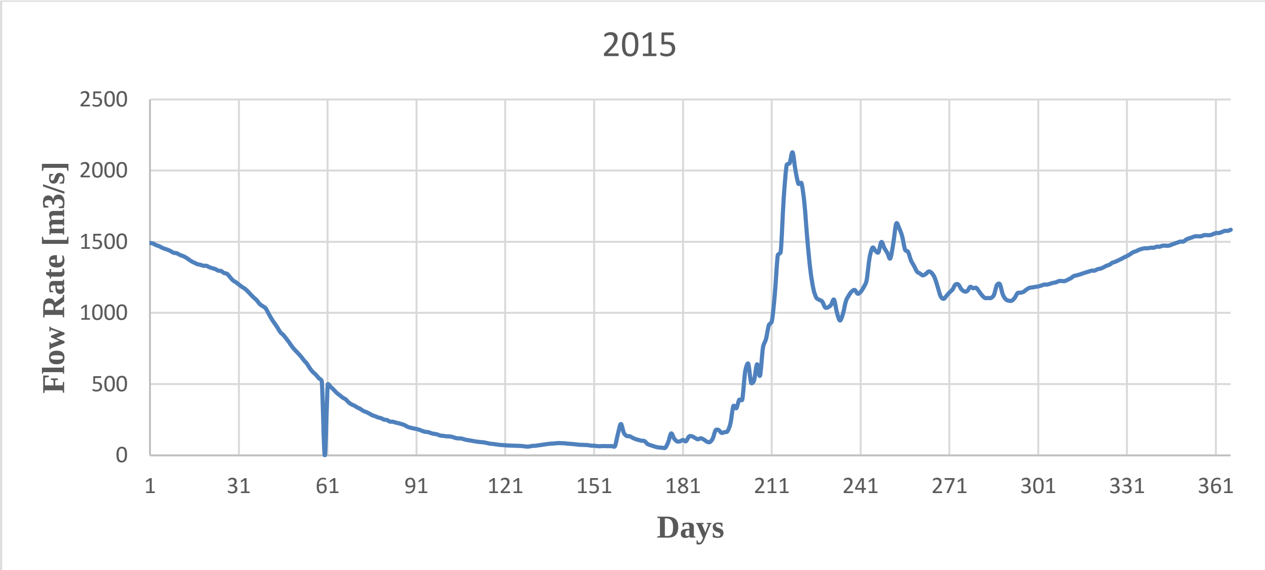

Figure 2.7 : Flow rate of Niger River (2015)

2.2 Literature review on System Dynamics Approach

System Dynamics is a modeling complex system tool. It has been used since the mid twentieth century (Alsani *et al.*, 2014). SD can be used to demonstrate the interaction between a system and its factors, it helps modelers to know the sensitivity of those factors on the dynamics of the system's environment (Xiao *et al.*, 2017). Recently SD has been used to analyze several sustainable development factors, such as electricity demand-supply balance, agriculture, natural resources, transportation, and the atmosphere environment.

2.2.1 Transportation, education, industry, atmosphere and environment

Some recent studies have used SD modeling on transportation system. Armah *et al.* (2010) have identified the policy resistant and their effects on the Ghanaian transportation system. They have provided some policies as solutions about traffic congestion and air pollution in the capital city, Accra. SD modeling approach has been used to model the climate change-road safety-economy nexus (Alirezaei *et al.*, 2017). Guo *et al.* have built a SD model for three scenarios of air-pollution control policies simulation in order to predict China's PV power development from 2015 to 2025 (Guo *et al.*, 2016). SD approach was used in many research of causal-effect link of a system. A SD model has been used by Li *et al.* to forecast the Sustainable Development of Green Space (SDGS) in Beijing, taking into account some policies (Li *et al.*, 2016). Pavlov *et al.* have used

SD approach to design undergraduate and graduate programs at Worcester Polytechnic Institute (WPI) (Pavlov *et al.*, 2014). Wu *et al.* have analyzed employee's work-family conflict in the construction industry using a SD model (Wu *et al.*, 2016).

2.2.2 Energy

System Dynamics was used in many research works on energy consumption, production, and energy impacts on the atmosphere. This method is widely used in the field of energy research. Naill, as precursor of System Dynamics (SD) in the field of energy, has built SD model of the process of Natural Gas (NG) discovery and production in the United States gas industry (Naill, 1972). Based on the three main factors of electricity demand of Niger, such as population, economic and per capita consumption of electricity, Yacouba Moumouni *et al.* presented a SD model to show the links and interactions of the socio-economic parameters and electricity demand and supply trends in emerging economies: A case study of Niger; this study provided policies for long term energy solutions in Niger (Yacouba Moumouni *et al.*, 2014). To clarify the link between energy consumption and air pollution, Chen *et al.* used a SD model to show the dynamics of CO_2 emission from household energy consumption under different conditions in China (Chen *et al.*, 2016). Research work was done by Xiao *et al.*, they investigated the dynamics on natural gas companies in China taking into account reserve exploration and well construction (Xiao *et al.*, 2017). Cimren *et al.* have developed a SD model to elucidate the social, economic and environmental impacts of electricity generation from waste and biofuel production in Ohio (Cimren *et al.* 2010). Also, a SD approach has been used to analyze the influencing factors of efficient and optimized distributed photovoltaic in China (Song *et al.*, 2016). Finally, BenDor has displayed the relationship between increased fuel economy standards and potential changes to gas tax policies by utilizing a system dynamics computer simulation model of American automobile fuel economy (BenDor 2012).

2.2.3 Water, agriculture and food security

System Dynamics approach has been used for the understanding of complex system in hydrology research. The hydrologic, ecologic, economic and social links of the dynamics on the acequia community in Mexico were done by Turner *et al.* using SD methodology (Turner *et al.*, 2016). Dynamics between water quality and water quantity were investigated by Yang *et al.* using SD method (Yang *et al.*, 2016). Beall *et al.* have used SD approach to describe the ground water dynamics in a confined aquifer system in the Palouse basin (Beall *et al.*, 2011). Dhungel *et al.* have developed a hydrologic model of the aquifers in the Palouse region of Washington and Idaho, USA, based on SD approach and a water balance that considered the entire hydrologic cycle (Dhungel *et al.* 2016). Additionally, a SD model was used in underground water modeling. For example Niazi *et al.* developed a SD model in aquifer storage and recovery (ASR) using a surface water reservoir. (Niazi *et al.*, 2014). SD approach has been used by Balili and Viaggi to develop a model on the dynamics of groundwater depletion, taking into account climate change and different economic policies, in Hamedan-Bahar plain (Balili and Viaggi, 2015).

Previous research activities on agriculture and food security fields have built policies on resilience of food production on vulnerabilities, such as climate change and its effects. Brzezina *et al.* investigated the vulnerability of the European food system; they provided evidence that there was potential of organic farming to create resilience (Brzezina *et al.*, 2016). Monasterolo *et al.* have done a bibliographic review of food system articles from 1970 to 2016 using SD analysis (Monasterolo *et al.*, 2016). System Thinking and SD approach were used by Armendáriz *et al.* for a systemic analysis of Food Supply and Distribution Systems (FSDS) taking into account biophysical boundaries and social targets. The focus of this study was the integration of urban and rural structures (Armendáriz *et al.*, 2016). Finally, Olabisi *et al.* used SD modeling methodology to display the dynamics of forest cover on Negros Island, Philippines based on perception gap between researchers and local community (Olabisi *et al.*, 2010)).

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 Study Area

The geographical positions of the country are: (1) longitude 0°- 17.5° and (2) latitude 11°- 24°. These coordinates make the country close to the equator where the year-round insolation is tremendous. As a consequence, it is not only hot during summer months, such as March, April, May, and October, but also the days are long. Thus, cooling load remains a big issue until today. In other words, electricity demand in Niamey, is far higher than the supply during the hot season, although it represents only 2% of the total annual energy needs (Yacouba Moumouni *et al.*, 2014) and (Ministry of Mines and Energy, 2007). Strong RE policies are needed in the city of Niamey and neighboring vicinity in order to sustainably find and/or keep the balance between electricity supply and demand.

Add a map of Niger zooming on Niamey

3.2 System Dynamics Approach

The safe and reliable provision of electric power to people promote several social components. In turn, these components build a complex, modern, and well-organized system. However, complex systems are difficult to be fully understood especially by an internal beholder (Sterman, 2000). A SD approach is used in this study. SD link theories, procedures and philosophies that will be utilized to analyze the behavior of some complex feedback (FB) systems, such as power supply and demand trends (Hollmann, 2006). SD is composed of stocks, flows, converters, and connectors. The stock represents an accumulation or depletion of either tangible or non-tangible variables, such as population or belief. Stocks can only change through flows into or out of a stock. Converters are used to house data or mathematical relations. In addition, connectors are used to link stocks, flows, and converters. Fig. 1 shows an example of stock, inflow, outflow, and convertor.

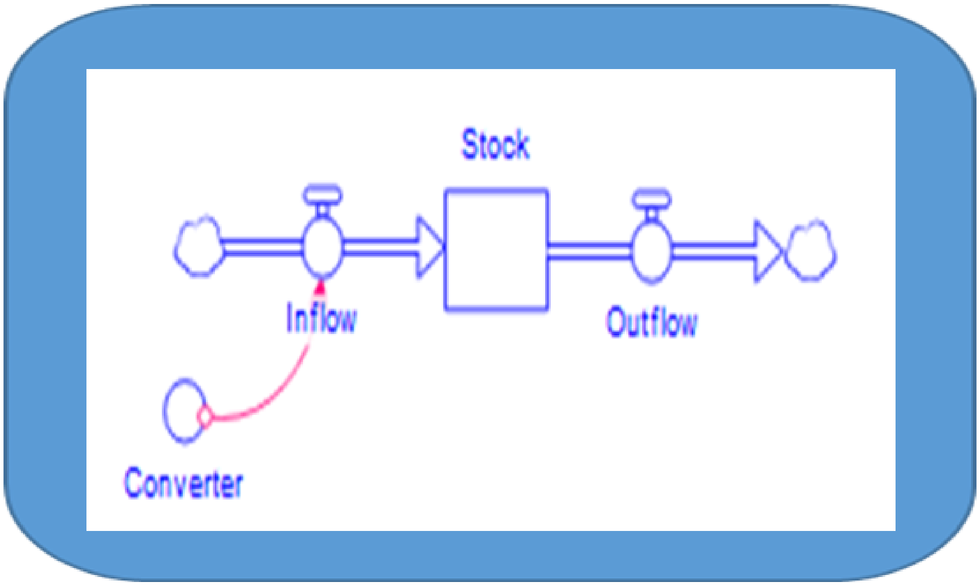

Figure 3.1 : Main components of System Dynamics stock and flow model

3.3 Model development

To better cope with power supply-demand gap, policy makers need a clear view on sensitive factors of electricity supply system. That overview helps them to understand the behavior of the components of the system and, at the same time, analyze the factors which are affecting electricity demand growth. In this study, a System Dynamics (SD) model for sustainable and renewable power production to reduce energy dependence of the capital city of Niger is proposed.

System Dynamics modeling follows some principles: (1) problem articulation, (2) formulation of dynamic hypothesis, (3) formulation of a simulation model, (4) model testing, (5) policy design and evaluation, and (6) implementation (Sterman, 2000).

3.3.1 Problem articulation

The purpose of this model is to build policies for a sustainable balance between electricity supply and demand. Its simulations are tests of different scenarios to find the best way to reach electricity supply security in Niamey, at the same time, reducing negative power production impacts on the atmosphere. For this purpose, a stock and flow diagram is presented in this study in order to identify the parameters of four sub-systems, listed in Table 1, which are drivers of dynamics in Niamey's electricity system.

3.3.1.1 Theme selection

Power supply in emerging countries is a real issue for policy makers. Niger is struggling to balance electricity demand and supply since its sovereignty as an independent country based on local electricity production and power imported from Nigeria (Yacouba Moumouni *et al.*, 2014). Its electricity demand is higher than supply from both sources, this is a real burden for national economic growth and well-being of its citizens. The gap between power demand and supply causes several shortages which can prevent people to practice their daily economic activities and as consequence lower their income.

3.3.1.2 Key variables

Table 5 represents the key variables of the system dynamics model. It is composed of model's sub-systems, such as (1) **social variables** composed by inhabitants of Niamey and its growth rate. The latter means the difference between birth rate, number of birth per year, and death rate which is the number of death per year. Additional variable, which can have a positive or negative feedback on Niamey's population growth, is immigration and emigration. Their difference is called migration in this study; (2) **social variables** composed of Niger's GDP growth, its positive impact on electricity consumption is widely known; (3) **domestic energy variables**, which hold electricity demand and supply and their growth rate; and finally, **renewable energy variables,** such as power production from renewable energy resources (solar and wind).

Table 3.1 *: Model parameters*

Sub-System	Variables	Description
Social	Population	Inhabitants of Niamey
	Birth Rate (BR)	Number of birth per year
	Fraction Birth Rate (FBR)	Number of birth per 1000 people
	Death Rate (DR)	Number of death per year
	Fraction Death Rate (FDR)	Number of death per 1000 people
	Migration	Sum of immigration and emigration of Niamey
	Fraction Migration Rate (FMR)	Fraction in a population composed of migrants
Economic	Gross Domestic Product Per Capita (GDP PC)	Monetary value of finished goods and services in Niger per person

	Increased GDP (Inc GDP)	Increased GDP rate
	Niamey’s GDP	GDP of Niamey
	Population Growth Versus GDP Growth (PG Vs GDPG)	Yearly ratio between GDP and population
	Fraction GDP Per Capita (FGDP PC)	Fraction increased GDP rate
Domestic Energy	Electricity Demand (Demand)	Electricity demand in Niamey
	Increased Electricity Demand (Inc Demand)	Increased electricity demand in Niamey
	Electricity Consumption Per Capita (Elect Cons PC)	Electricity Consumption per person in Niger
	GDP Growth on Electricity Consumption (GDPG on Elect Cons)	Impact of GDP growth on electricity consumption
	Electricity Supply (Supply)	Electricity supply in Niamey
	Existing Power Plants (Existing Plants)	Existing power plants in Niamey
	Electricity Import From Nigeria (From Nigeria)	Electricity import from Nigeria to supply Niamey
	Additional Power Plants (Add Fos Plants)	Future implementation of power plants based on fossil fuel resources
	Increased Electricity Supply (Inc Supply)	Increased electricity supply in Niamey
Renewable Electricity Production	Solar Power (Solar Pow)	Electricity from conversion of solar radiations
	Increased Solar Power (Inc SP)	Increased electricity from conversion of solar radiations
	Solar Power Policy (SP Policy)	Policy enhancing solar power production
	Decreased Solar Power (Dec SP)	Decreased electricity from conversion of solar radiations
	Fraction Decreased Solar Power (FDSP)	Fraction decreased electricity from conversion of solar radiations

	Wind Power (WP)	Electricity from conversion of wind velocity
	Increased Wind Power (Inc SP)	Increased electricity from conversion of wind velocity
	Wind Power Policy (WP Power)	Policy enhancing wind power production
	decreased Wind Power (Dec WP)	Decreased electricity from conversion of wind velocity
	Fraction Decreased Wind Power (FDWP)	Fraction decreased electricity from conversion of wind velocity
	Energy Storage System (ESS)	Electricity conservation in case of excess production
	Increased Energy Storage System (Inc ESS)	Increased Energy Storage System capacity
	Fraction Increased Energy Storage System (FIESS)	Fraction increased Energy Storage System capacity

3.3.1.3 Time horizon

To produce policies for long term and sustainable balance between power demand and supply, a good understanding of dynamics of the Niger's electricity system for decades is needed. The time horizon of this model is 40 years, starting from 2012 through 2050. The first part of the model's time span is from 2012 to 2017, it will be used to structurally check the system; then 2017 to 2050 is considered as future dynamics of the system.

3.3.1.4 Dynamic problem definition

The historical behavior of the Nigerien electricity system is a tiny fraction of the electricity produced by the local power plants based on fossil fuels resources. In the past 6 years, 22.9% of the national electricity supply was produced locally. This local power quota represents a high risk on the power supply system because, as stated earlier, 71.1% of national electricity was supplied by the Nigerian power company (NIGELEC). Therefore, any major event affecting Nigeria's electricity production sector, will surely shake Niger's power system.

To reach electricity supply security, Niger needs additional power plants based on both fossil fuels (coal and natural gas) and renewable resources. For national security, health, and environmental concerns, electricity production from renewable have to be higher than both generation from fossil fuels and power imported from Nigeria. Based on renewable resources assessment, *i.e.*, solar, wind and hydro energy, this target is reachable by investing on renewable power technologies. In the future, national electricity supply may come from renewable energy and local power generation based on fossil fuels.

3.3.2 Formulation of Dynamic Hypothesis

3.3.2.1 Initial hypothesis generation

Currently the local electricity production from NIGELEC and SONICHAR is about 152.8 GWh/year. The imported energy from Nigeria through the PHCN (Power Holding Company of Nigeria) is 636.99 GWh/year. The population of Niamey in 2012 was estimated at 1,026,848 inhabitants. Also, the GDP and electricity per capita were $405 USD and 46.08 kWh, in that order. This model does not take into account renewable electricity production from the base year.

3.3.2.2 Endogenous focus

The main motivations of this study are:

(1) to evaluate the power generation form renewable sources, which can potentially replace electricity imported from Nigeria,
(2) to know how population growth can affect electricity demand in Niamey,
(3) to display the dynamics between GDP per capita and electricity demand,
(4) to evaluate local power production growth rate,
(5) to investigate the share of solar power, wind power and the subsequent Energy Storage System in Niamey and vicinity, and
(6) to display the impact of Energy Storage System on Niamey's electricity supply system.

3.3.2.3 Mapping

In this section a stock and flow diagram is developed based on the sub-systems in Table 1. This enable us to draw good policies based on sensitive energy system's variables, such as: 1) birth rate, which is the main driver of population growth; 2) GDP growth, to evaluate the impact of economic factors on Niamey's electricity demand; and 3) renewable energy potential of Niamey (solar and wind energy). Hence, Fig. 9 shows the real world system dynamics model under study; it symbolizes the current electricity situation. The model is composed of four sub-systems, *viz.*, Social, Economy, Renewable Energy, and Domestic Energy. However, it does not include the contribution of renewable energy, as mentioned above. Domestic energy sub-system is met by local power production and electricity import (Nigeria).

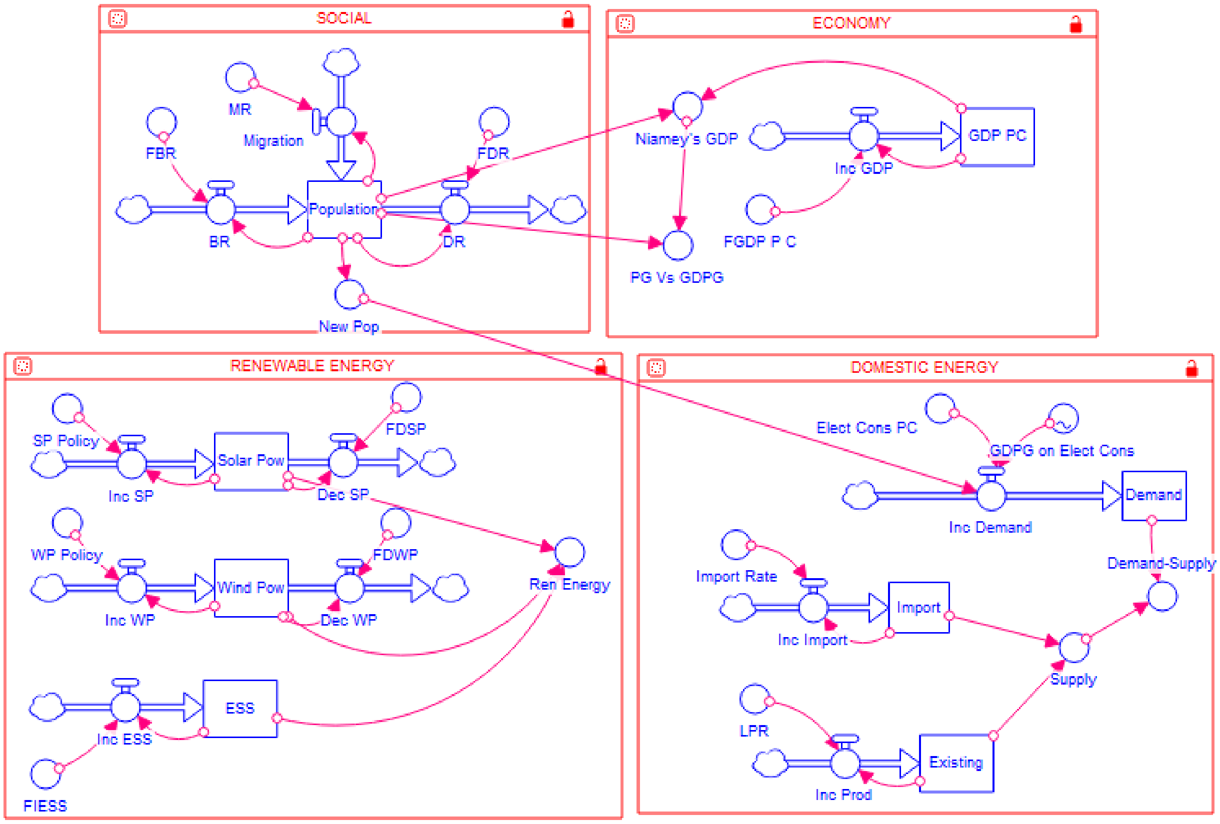

Figure 3.2 : Real world System Dynamic stock and flow model

Fig. 10 displays the Distributed Generation (DG) system dynamic model. It depicts the future electricity system's behavior after implementation of small power plants based on solar and wind turbines in Niamey and vicinity. It is composed of four sub-systems with the contribution of renewable energy sources and local electricity production to feed the national power supply.

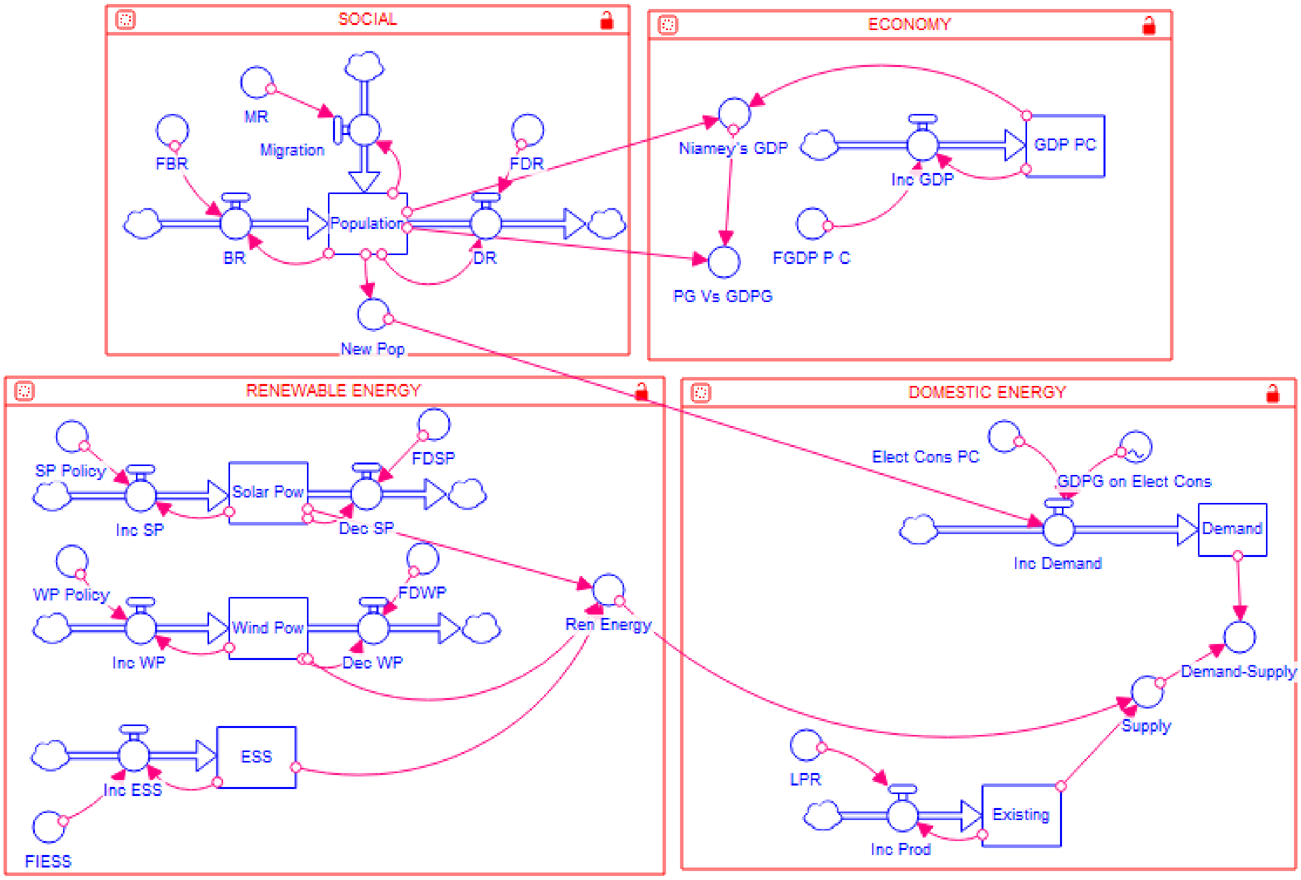

Figure 3.3 : Distributed Generation System Dynamic stock and flow model

3.3.3 Formulation of a Simulation Model

3.3.3.1 Specification

The focus of this study is to display the dynamics of the electricity system's behavior after applying Distributed Generation in Niamey. This System Dynamic (SD) model is composed of four major parts.

- ✓ First, the National Electricity Supply, which is a combination of the:
    - local electricity production by the national company NIGELEC in three different locations around Niamey: Goudel (North), Niamey II (South), and Gorou Banda (South-West), with an overall installed capacity of 116.6 MW. These power plants run on polluting fossil fuels, such as heavy fuel oil, coal, and natural gas.
    - electricity imported from Nigeria through the 132 kV interconnection line from BirninKebbi (Nigeria) to Niamey (IRENA, NIGER Renewables Readiness Assessment 2013).

- ✓ The second aspect is based on future implementation of renewable power production; it is composed of:
  - a 70 MW solar power plant─PV and Concentrated Solar Power (CSP),
  - 2.3 MW wind turbines, and
  - a proposed 15 MW of Energy Storage System (ESS) around Niamey in order to increase reliability, resilience, and to practically shave demand peaks when electricity is mostly needed. It is recently a requisite that in developed countries, a power station must have a significant ESS capacity to enhance any fluctuations in the distribution side.
- ✓ The third part is based on social parameters, which have a strong impact on the national electricity production, it is the combination of the:
  - Birth rate, which is the number of birth per year in Niamey. It is an important variable because it evaluates the number of people added to the population per year.
  - Death rate, which is the number of death per year in Niamey. It is an outflow, which characterizes a decreasing population.
  - Migration, which is the difference between immigration and emigration to/from Niamey

Therefore, paying a close attention aforementioned three social variables, it can be seen that population growth rate turned out to be the major drivers of electricity demand.

- ✓ The fourth aspect is based on economic parameters, such as:
  - GDP per capita, known as monetary value of finished goods and services in Niger per person, and
  - Electricity per capita.

This SD model has 8 main stocks, such as:

1) **Population** which holds people living in Niamey with fluctuate variables, including the births and migration as inflows and an outflow symbolized by deaths;
2) **GDP** holds initial GDP per capita (2012) and its yearly increasing value which is based on GDP growth rate;
3) **Electricity Demand**, known as the power needed in Niamey by households, industries, agriculture, commerce, administration and other sectors. It holds initial power demand known as yearly base load and its growth rate based on electricity consumption per person and the ratio of Niamey's GDP growth on population growth;
4) **Electricity Import** holds initial power provided by Nigeria and the increasing power imported rate based on the difference between power demand and local electricity production;

5) **Existing Supply** which holds local electricity production in Niamey based on fossil fuels by NIGELEC, and increasing local power production based on the strengthening of the three power stations in Niamey or implementation of new power plants in this area;
6) **Solar Power** holds power produced after implementation of small solar power plants in Niamey and vicinity and its increasing rate based on national policy in the solar energy sector;
7) **Wind Power** holds electricity produced by wind turbines implanted in Niamey and increased wind turbine implementation in Niamey based on investment in wind energy sector; and finally,
8) **Energy Storage System** (ESS) used to store the electricity produced by the solar power plants and wind turbines in case of excess renewable productions.

Knowing the population and the geographical boundaries of this study, Niamey is chosen, not only because of its high energy potential, but also because 68.9% of the total electricity sold in Niger in 2015 was consumed by its residents which constituted 6% of the country's population.

This System Dynamics (SD) model displays relationships between the model's sub-systems. It can be seen from the model that social variables and domestic energy variables are directly connected. This link has been shown by the arrow from new population to the increased electricity demand. It means that power demand depends on new population, *i.e.*, the additional people on the base-population. Then connection between social and economic sub-systems is shown by the link between population and Niamey's GDP. This economic variable comes from the population stock times GDP per capita. GDP Growth on electricity consumption (GDPG on Elec Cons) shows the relationship between the economic and domestic energy sub-systems, it comes from the ratio of the Population Growth Versus GDP Growth (PG Vs GDPG). It is assumed in this model that the initial ratio GDP growth on population is equal to initial electricity consumption, if that ratio is equal to 20 power consumption per capita will double in the time horizon 2046. Finally, the link between domestic energy and renewable energy is shown by the arrow from Ren Energy to Supply, which means power from conversion of solar radiations, wind, and energy storage systems can be used to strengthen the national power supply.

The tests for the model's consistency with clear purposes are: (1) the balance between power supply and demand; (2) the matching growth between population, GDP and power demand; and (3) to fill the gap between electricity demand and supply. Tests for model's consistency with the boundary are based on additional power for strengthening electricity supply. It is limited on power generation based on solar and wind resources.

3.3.3.2 Mathematical formulation

There are three major dynamics, namely socio-economic, domestic energy known as power demand, and renewable energy. These dynamics are results of other sub-dynamics explained as follows:

3.3.3.2.1 Socio-economic dynamics

Socio-economic dynamics are the result of two changing phenomena, *viz.*, population and economic growth in Niger. Mathematically these dynamics are given by Eqs. (1), (2), and (3). (STELLA):

- ✓ **Social dynamics**

$$\text{Population}(t) = \text{Population}(t - dt) + (BR + \text{Migration} - DR) \cdot dt \qquad (3.1)$$

Where,

Population (t) is population at time t,

Population (t - dt) is population at previous time step,

BR is Birth Rate known as the number of births in an incremental time dt,

Migration is the difference between immigration and emigration in Niamey in an incremental time dt, and

DR is Death Rate known as the number of deaths in an incremental time, dt.

- ✓ **Economic dynamics**

$$GDP\_PC(t) = GDP\_PC(t - dt) + (Inc\_GDP) \cdot dt \qquad (3.2)$$

$$Niamey's\_GDP(t) = GDP\_PC(t) \cdot \text{Population}(t) \qquad (3.3)$$

Where,

GDP_PC (t) is the Gross Domestic Product per capita in Niger at time t,

GDP_PC (t - dt) is the Gross Domestic Product per capita in Niger at previous time step,

(Inc_GDP) · dt is the additional value on initial Gross Domestic Product per capita in Niger in an incremental time, dt due to its growth, and

Niamey's_GDP (t) is the Gross Domestic Product in Niamey.

3.3.3.2.2 Renewable energy dynamics

Renewable energy dynamics have three major components, such as solar power, wind power, and Energy Storage System (ESS). They are modeled as in Eqs. (4) through (7).

- **Solar power**

$$Solar\_Pow(t) = Solar\_Pow(t - dt) + (Inc\_SP - Dec\_SP) \cdot dt \quad (3.4)$$

Where,

Solar_Pow (t) is the future solar power from Distributed Generation in time t,

Solar_Pow (t - dt) is the future solar power from Distributed Generation at previous time step,

Inc_SP is the additional value on solar power plant in time dt due to its growth, and

Dec_SP is the decreasing value on solar power plant in time dt due to damage or maintenance.

- **Wind power**

$$Wind\_Pow(t) = Wind\_Pow(t - dt) + (Inc\_WP - Dec\_WP) \cdot dt \quad (3.5)$$

Where,

Wind_Pow (t) is the future wind power from Distributed Generation in time t,

Wind_Pow (t - dt) is the future wind power from Distributed Generation at previous time step,

Inc_WP is the additional value on wind power in an incremental time dt due to its growth, and

Dec_WP is the decreasing value on wind power plant in an incremental time dt due to damage or maintenance.

- **Energy Storage System (ESS)**

$$ESS(t) = ESS(t - dt) + (Inc\_ESS) \cdot dt \quad (3.6)$$

Where,

ESS (t) is the future ESS from Distributed Generation in time t,

ESS (t - dt) is the future ESS from Distributed Generation at previous time step, and

(Inc_ESS) · dt is the additional value on ESS in an incremental time dt due to its growth.

- **Renewable energy**

$$Ren\_Energy(t) = Solar\_Pow(t) + Wind\_Pow(t) + ESS(t) \quad (3.7)$$

Where,

Ren_Energy(t) is the future renewable implementation in Niamey in time t.

The meaning of Solar_Pow (t), Wind_Pow (t), and ESS (t) were explained above.

3.3.3.2.3 Domestic energy dynamics

The domestic energy dynamics is composed of two distinct components, which are dynamical sub-systems, such as electricity supply and demand. These dynamics are illustrated by Eqs. (8) through (12):

- ✓ **Electricity demand:**

$$\text{Demand}(t) = \text{Demand}(t - dt) + (\text{Inc\_Demand}) \cdot dt \quad (3.8)$$

$$\text{Inc\_Demand} = \text{Elect\_Cons\_PC} \cdot \text{GDPG\_on\_Elect\_Cons} \cdot \text{New\_Pop} \quad (3.9)$$

$$\text{New\_Pop} = \text{Population} - \text{initial Population} \quad (3.10)$$

Where,

Demand (t) is electricity demand in Niamey in time t,

Demand (t - dt) is electricity demand in Niamey at previous time step,

(Inc_Demand) · dt is the additional value on initial electricity demand in an incremental time dt due to its growth,

Elect_Cons_PC is electricity consumed per capita in Niger in time t,

GDPG_on_Elect_Cons is the impact of Gross Domestic Product growth on electricity demand per capita, and

New_Pop is the additional people on initial population in Niamey in time t,

- ✓ **Electricity supply :**

$$\text{Supply} = \text{Existing} + \text{Ren\_Energy} \quad (3.11)$$

$$\text{Existing}(t) = \text{Existing}(t - dt) + (\text{Inc\_Prod}) \cdot dt \quad (3.12)$$

Where,

Supply is electricity supply in Niamey in time t,

Existing is local electricity production in time t,

Ren_Energy is future renewable energy generation,

Existing (t - dt) is local electricity production at previous time step, and

(Inc_Prod) · dt is the additional value on initial local electricity production in an incremental time dt due to its growth.

3.3.3.3 Reference mode

Time horizon of this model is, again, from 2012 to 2050. The initial conditions of this system dynamics model were data from the base year of 2012. Table 6 shows the base year data and Fig. 11 displays the framework model of this study.

Table 3.2 : *Base year data (INS)*

Variables	**Type**	**Unit**	**Value**
Population	Social	People	1,026,848
GDP per capita	Economic	USD	405
Electricity Demand	Domestic energy	GWh	438
Electricity Supply	Domestic energy	GWh	444.8
Electricity Import	Domestic energy	GWh	354.35
Local electricity Production	Domestic energy	GWh	90.45
Electricity consumption per capita	Domestic energy	kWh	46.08

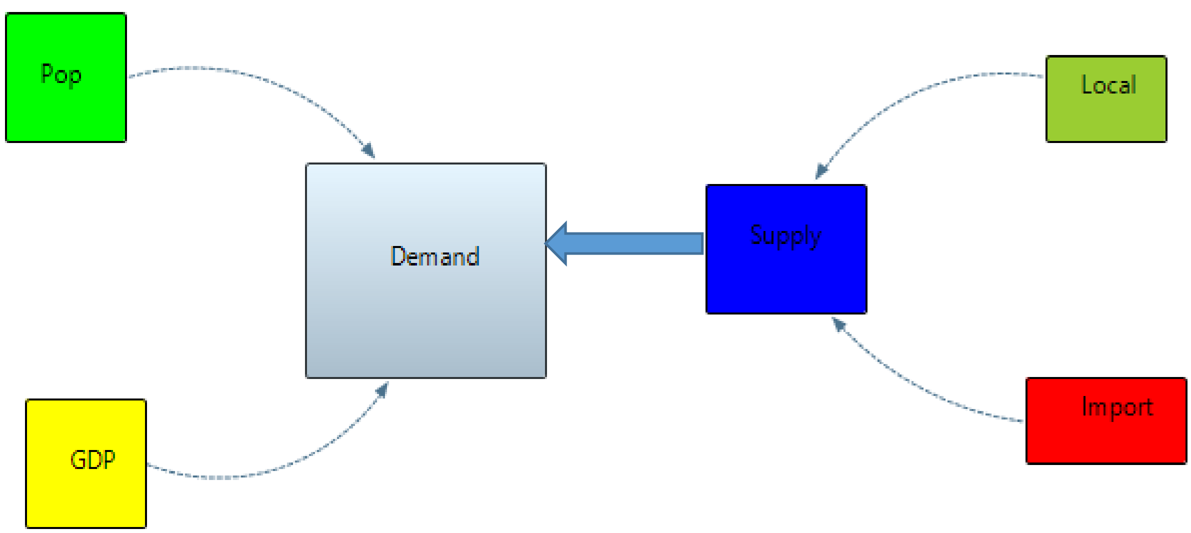

Figure 3.4 : System Dynamics reference frame model

The reference mode is based on power generation from local power generation by the national utility company, NIGELEC and electricity imported from Nigeria (PHCN). It is worth mentioning that the power demand was higher than supply as shown in Fig. 11. On one hand, the socio-economic parameters (population and GDP) have positive feedback on electricity demand. In the other hand, the local power generation and electricity import fed the national supply, which was still lower to the demand, thus energy shortage is inevitable.

3.3.3.4 Comparison to reference modes

The target of this model is to balance electricity supply and demand without resorting to electricity import from Nigeria. Therefore, Fig. 12 shows the final model's framework.

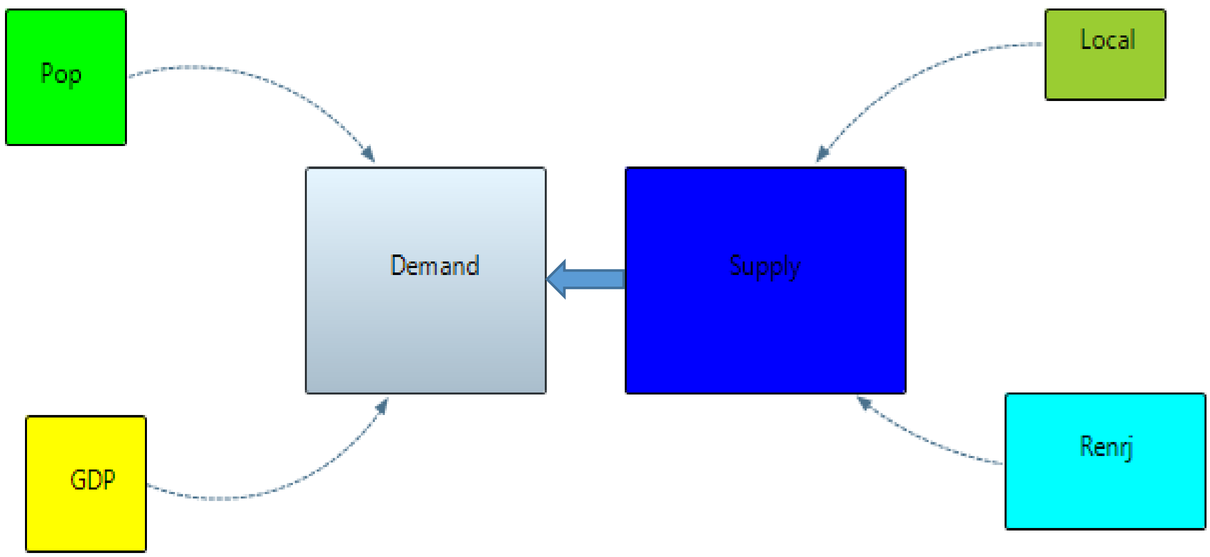

Figure 3.5 : Final System Dynamics frame model

This model framework displays the strengths of the national power supply based on additional power generation from renewable energy resources. It also has to significantly lower or totally wipe out the amount of electricity imported to Niger by the power utility company before 2050. The difference between the reference mode and this SD model is the contribution of clean energy in the national power supply. In addition, the ratio of electricity supply to demand is greater than unity. It means that Niamey has enough solar and wind energy potential to bring power supply above electricity demand.

3.3.3.5 Robustness under extreme conditions

The extreme or sensitive conditions of this model are emerging from the social aspects, known as birth rate, which is the main driver of population growth. They can also emerge from domestic energy parameters, such as the number of households. This sensitive analysis can also be linked to the variations of electricity import from Nigeria. Based on the solar and wind energy potential of Niamey, it is proved by simulation that the model has a strong ability to provide policies, which can rise power supply above the demand. But the model might fail if the power import factor is totally removed from the power supply system without any renewable power generation and an increase of the birth rate above 50.

3.3.3.6 Sensitivity

To build policies for a sustainable energy security in Niamey, an accurate model was generated with real social, weather, and energy data from some sensitive parameters, such as:

1) The social parameters: initial population, birth rate, and death rate;
2) The domestic energy parameters: Initial power demand, initial local power production, and the initial power import; and
3) The renewable energy parameters: solar and wind power potential.

Any uncertainty in these parameters cited above may lead to tremendous inaccuracies in the model; hence, this will surely result in inefficient policies that can hinder the local prosperity.

3.3.3.7 Scenario specification

The design of Niamey's electricity management scenarios was based on three sub-systems, which are quite similar to the aforementioned sensitive parameters. These three components are:

- ✓ Social parameters: Birth Rate
- ✓ Economic Parameters: GDP per Capita
- ✓ Renewable Energy parameters: Solar Power, Wind Power, and Energy Storage System.

Table 7 presents five (5) different policy scenarios. Each of these scenarios has a unique and special meaning for Niger in particular and all the emerging economies in general, as they all share the same birth rate and economic growth characteristics.

Table 3.3 : *Niamey's electricity system scenario*

Scenario	Population Growth (BR)	Economic Growth Rate	Renewable Energy Implementation					
			Solar Power	**Solar Policy**	**Wind Power**	**Wind Policy**	**ESS**	**ESS Policy**
Baseline	0.049	0.01	0 MW	0	0 Wind Turbines	0	0 MW	0%
1	0.049	0.01	70 MW	0.02%	10 Wind Turbines	0.1%	15 MW	0.0001%
2	0.04	0.01	70 MW	0.02%	10 Wind Turbines	0.1%	20 MW	0.0001%
3	0.035	0.01	60 MW	0.003%	5 Wind Turbines	0.06%	20 MW	0.0001%
4	0.03	0.01	65 MW	0.001%	5 Wind Turbines	0.001%	15 MW	0.0001%

3.3.3.7.1 Baseline Scenario

Under the baseline, population and economic growth are the main drivers of the electricity demand in this model. In this scenario, the birth rate was set as 49 per 1000 people per year and the economic growth rate was 0.01% of national GDP. There was no power production from renewable energy resources. The entire electricity supply was ensured by the local power production and electricity import from Nigeria.

3.3.3.7.2 Scenario 1

The power production from renewable energy resources has three components, such as: (1) initial solar power generation of 70 MW, with a yearly policy of additional installed capacity of 0.2% power output; (2) implementation of 10 wind turbines, type Enercon E82/2000, with an increasing rate of 0.1% and a 15 MW capacity of energy storage system, following an annual growth rate of 0.0001%.

3.3.3.7.3 Scenario 2

Based on the population growth rate variations, this scenario was obtained by decreasing the Birth Rate to 0.04 in order to slow down electricity demand from scenario 1. It is worth mentioning that this type of scenario, in real life, is highly likely impossible. To strengthen the power supply system, a 5 MW has added on the electricity storage system as a backup capacity.

3.3.3.7.4 Scenario 3

If the population growth is slowed down, this will surely have a negative feedback or balancing effect on the power generation. In this scenario, Birth Rate was reduced to 35/1000, the initial solar power was set to 60 MW with 0.003% growth rate, and the initial wind power was maintained at 5 wind turbines with 0.06% growth rate.

3.3.3.7.5 Scenario 4

In the last scenario, the model's sensitivity to population growth and Energy Storage System was investigated. The birth rate was assumed to be 30/1000 and the initial ESS was reduced to 15 MW compared to the previous scenarios. But the initial solar power was increased to 65 MW from scenario 3.

3.4 Data Collection

It is noteworthy to assert that the main energy data source of the country is "La Société Nigérienne d'Electricité, NIGELEC," *viz.* the National Electric Company. Hence, in 2012 the highest electricity demand in Niamey was estimated at 97.3 MW with an installed capacity of 41.5 MW in Niamey, distributed among Goudel (15.4 MW) and Niamey II (26.1 MW) (NIGELEC, 2012). Conversely, from the aforementioned installed capacity, only 30 MW was available because of inefficient plants built decades ago (before 2010) and aging generators installed thirty years ago (before 1990). The local peak electricity production, 2012 in Niamey, was 50.9 MW provided by NIGELEC through Goudel and Niamey II (30.9 MW) and a private company AGGRECO (20 MW).

In the base year of this study, the electricity demand was between 30 MW to 100 MW. It is the reason why the initial power demand is assumed to be 50 MW. The local electricity production, the power import from Nigeria, and the electricity consumption per capita are given by NIGELEC, respectively were 90.45 GWh, 354.35 GWh, and 46.08 kWh (NIGELEC, 2012).

In addition, the following socio-economic data were utilized in the model:

(1) the population of Niamey, 1,026,848 people in 2012;

(2) the Birth Rate (BR) and Death Rate (DR), respectively 49.4 and 10.9 per 1000 people per year; and
(3) the Gross Domestic Product (GDP) per capita in Niger, $ 405 USD of 2012.

Moreover, the daily solar insolation data from the last 10 years (2007-2016) were mined from "Le Centre National d'Energie Solaire, (CNES)," meaning the National Center for Solar Energy of Niger. Also, in the model, 22 years (1995-2016) daily wind speed data extracted from "La

Direction de la Météorologie Nationale" (DMN) of Niger and (https://en.tutiempo.net/climate/africa.html, 2017) were utilized. These data cited above were used to analyze the renewable energy potential of Niamey.

Due to the difficulties in getting some data, some assumptions were carried on in order to facilitate the completion of this study within the 6 months allocated time frame. An example of such assumptions was the seasonal migration rate to Niamey. It was estimated that 1000 migrants come each year in Niamey.

3.5 Dynamic Analysis of Renewable Energy Implementation in Niamey

The difference between electricity supply and demand showed that Niamey has a low level of electricity security. To overcome this issue, the capital city of Niger needs to invest more in electricity alternatives. Fig 13 is a Causal Loop Diagram (CLD) of the energy status in Niamey. The main importance is its ability to make a clear dynamic interaction of all the influencing factors of the system. The arrows represent the positive or negative influence between the component of the system. Thus, the components of the system are: (1) **Renewable Energy**, a combination of **Solar** and **Wind Power** based on the conversion of daily **Solar Radiation** and the kinetic energy of **Wind** into electricity. Its implementation depends on the level of **RE Policy** in Niamey; (2) **Install Capacity,** which is currently based on fossil fuel resources (Goudel, Gorou Banda, and Niamey II) that will be strengthened by the implementation of small solar power plants and wind turbines; (3) **Electricity From Nigeria,** which is the electricity import to fill-in the gap between electricity supply and demand;(4) **Electricity Supply** based on the current supply from the national utility company, NIGELEC, and electricity import from Nigeria, which will be reinforced by RE; (5) **Electricity Demand** depends mainly on **Population Growth**.

As stated earlier, the population component is the main driver of any **Economic Activities** through industries, urbanization, trade, education services etc. This, in turn, leads to more electricity demand. Also, **Increasing Temperature** increases electricity demand because of the intense fans and air conditioning appliances; and (6) **Dependency** based on electricity import from Nigeria is a barrier to **Sustainable Development**, which depends mainly on **Energy Security.**

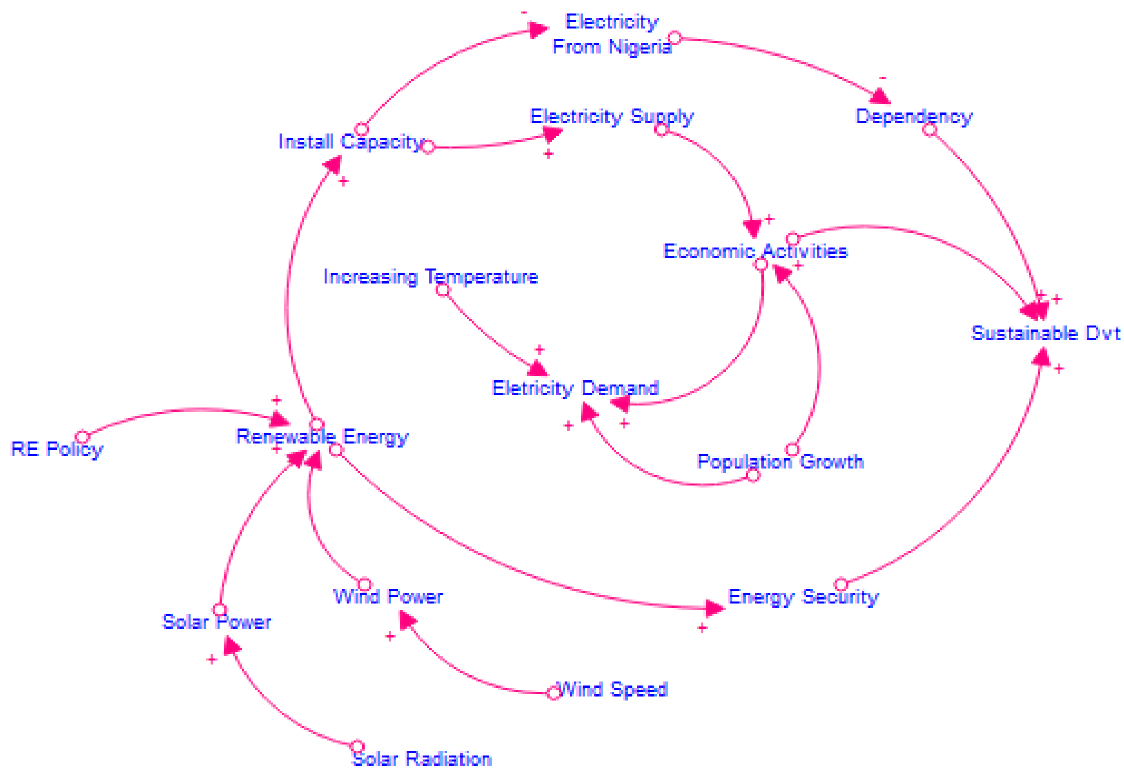

Figure 3.6 : Causal loop diagram

Therefore, to achieve the study objectives, STELLA PROFESIONAL 1.4 software, from ISEE SYSTEM, is utilized (isee system, 2017). This software has the ability to display the interactions between components in complex system, and predict with accuracy future system's variables such as population, electricity supply and demand and so on.

3.5.1 Potential of wind energy

22 years of wind speed data, recorded at a height of 82 meters, were evaluated. Some extrapolations based on the 10 meters' data were carried on, for the synoptic station of Niamey Airport provided by the DMN, using the power law, as in (13).

$$\frac{v}{v_0} = \left(\frac{h}{h_0}\right)^n \qquad \text{III.(13)}$$

Where, v is wind velocity at the reference height h; v_0 is the wind velocity at height h_0, and n is the Hellman exponent, in this study general accepted value of 1/7 or 0.143 was chosen.

The extractable theoretical power from the kinetic energy of wind is given in Eq. (14)

$$\mathbf{P}\ (v) = \frac{1}{2}\rho A v^3 \qquad \text{III.(14)}$$

Where, **P(v)** is the wind power (kW), ρ is the air density at the meteorological station, A is the sweep area of the rotor blades (m^2), and v is the average mean wind speed.

CHAPTER 4

RESULTS AND DISCUSSIONS

This section presents in a concise manner all the research findings. Additionally, all the demographic, economic, and environmental policy implications are addressed.

4.1 Population

As already stated, the population which is a stock, is allowed to fluctuate. It is primarily dependent on the BR, DR, and the seasonal migration of people in and/or out of Niamey. This population is the main driver of economic activities through industries, urbanization, trade, education, and other tertiary services. This in turn leads to more electricity demand. Currently, the rapid population growth experience by Niger is the major barrier that impedes the balance between electricity supply and demand in Niamey. This fact may be treated as common to all the emerging countries. Therefore, fast population growth in Niamey and vicinity may be explained by the high BR of 49.4 per 1000 inhabitants per year, driven by the need to renew the workforce because the primary sector's share of the national economy is around 80%. Figure 14 illustrates the simulation of the future population trends under four policy scenarios.

The blue line shows the population trend under the baseline which is scenario 1. With the highest birth rate, it depicts the fastest population growth over the simulation period. The curve soars from 1,026,848 people in the base year 2012 to 4,500,000 people at the end of the model's period, 2050. Also, this same simulation shows 4 yearly different population growth rates: 1) 0.04% from 2012 to 2031; 2) 0.047% from 2031 to 2040; 3) 0.049% from 2040 to 2047; and finally, 4) 0.05% from 2047 to 2050.

The dash-dotted red line represents the population evolution over the simulation period under scenario 2. It basically indicates the model's sensitivity to Birth Rate. Hence, the reduction of the birth rate to 40/1000 has reduced population from 4,500,000 people in 2050 (baseline) to 3,200,000 people, thus a growth rate of 0.03%. The same effect is shown in the dotted pink line, which is the population evolution under scenario 3 with a yearly growth rate of 0.025%. in the fourth scenario where the lowest birth rate policy was applied, represented by the dashed green line, the average yearly population growth was 0.02%.

Consequently, the results showed that population growth was slowed down by a reduction of birth rate. It is noteworthy that this is not realistic. After the simulations, it can be concluded that the birth rate is one of the most sensitive variables on Niamey's electricity supply and demand patterns. Additionally, the SD model's output displayed that population of the capital city of Niger, will double in the horizon of the following years under the conditions stated earlier:

- ✓ 2030 under the baseline or scenario 1
- ✓ 2036 under scenario 2
- ✓ 2040 under scenario 3
- ✓ 2047 under scenario 4

More details on how the combined effect of birth, death and migration affect population growth can be found in annexes 1, 6, 10, and 14.

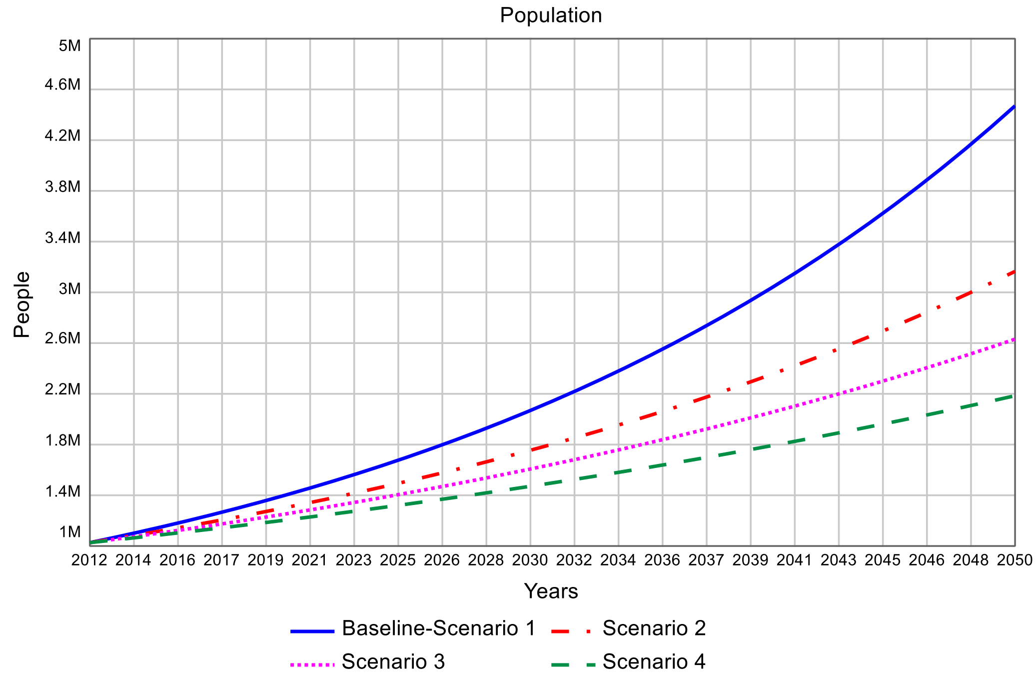

Figure 4.1 : Population evolution of Niamey

4.2 Impact of population growth on electricity demand

A System Dynamic model was proposed to analyze the interactions between social, economic, and climatic factors in Niger's electricity supply system under different policy scenarios. The future changes in electricity demand were modeled based on birth rate variations. Thus, the results of this simulation-based research revealed that the actual power generation growth in Niamey is intimately related to the population growth. These dynamics between the social variables, *i.e.*, population and BR, and the domestic energy variables, such as solar, wind power, and Energy Storage System (ESS), can be explained by the fact that electricity is generated to satisfy the current and future consumers in the following sectors: household, industry, commerce, agriculture, just to mention few. These consumers are widely known as the constituents of population, and its growth will lead surely an increased power production in order to balance electricity demand and supply.

Figure 15 illustrates electricity demand in Niamey under the four different scenario. The highest BR (49.4/1000) scenario, which is the actual, gives the fastest electricity demand growth represented by the blue line with a value of 438 GWh in 2012 and 3,700 GWh at end of the simulation period, 2050. Power demand evolution under the second scenario (BR = 40/1000) is shown by the dash-dotted red line; this growth rate is slowed down as compared to the first scenario. Hence, the reduction in power demand evolution is proved by its value of 3,100 GWh in 2050, which means 600 GWh could be saved under this scenario. In the third and fourth scenarios low electricity demand trends were predicted and represented by the dotted pink line and the dashed green line with, 2,200 GWh and 1,700 GWh in 2050, respectively.

The direct implication is that the electricity demand would increase even more, thus making the country more vulnerable to power shortages and frequent outages. Indirectly, this tells the decision makers and investors that there is a potential and urgent need to invest in the energy sector, decades from today.

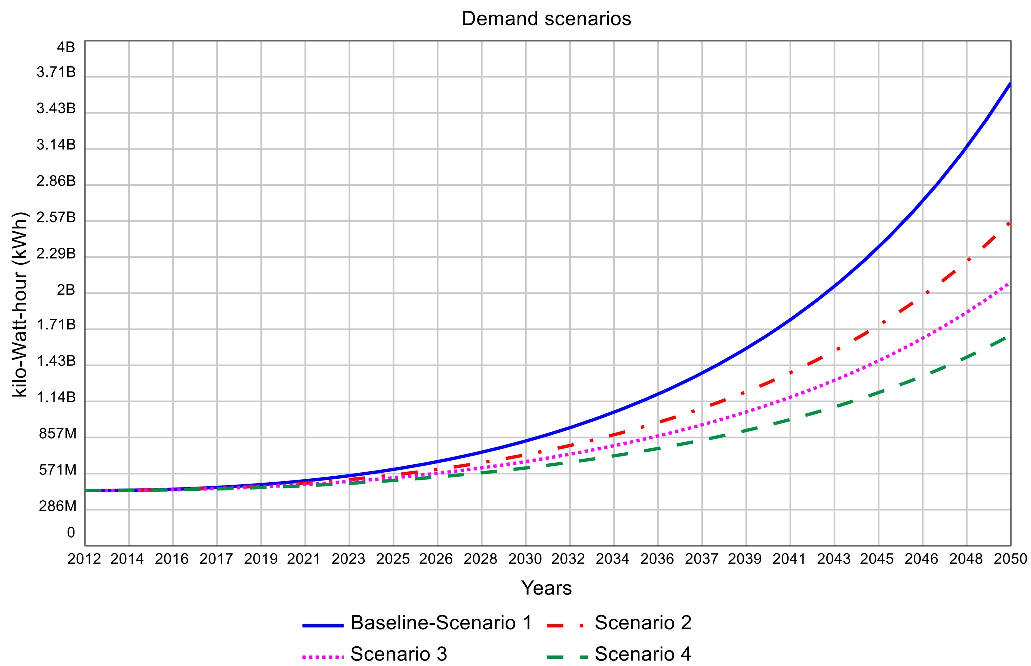

Figure 4.2 : Electricity Demand in Niamey

4.3 Electricity Supply and Demand in Niamey

Figure 16 shows a typical maximum and minimum daily electricity load patterns in Niamey during the months of January for minimum power demand and May for maximum power demand. Thus, after a close examination of the figure, the highest electricity demand (Red), in that day of summer 2012, was 97.3 MW. This is a typical summer day load curve in Niger. The true implication is that based on the existing infrastructure, on such a hot summer day, the national company often adopts electricity management strategies, such as load shedding, firing picker and expensive generators, or else the entire distribution system would collapse. Unfortunately, the latter eventuality is what to devoted customers have been struggling with for the last two decades to keep their businesses alive.

During summer months, the power supply has never been enough, although the country has a tremendous potential of both renewable and non-renewable resources that could be converted into useful energy via matured technologies.

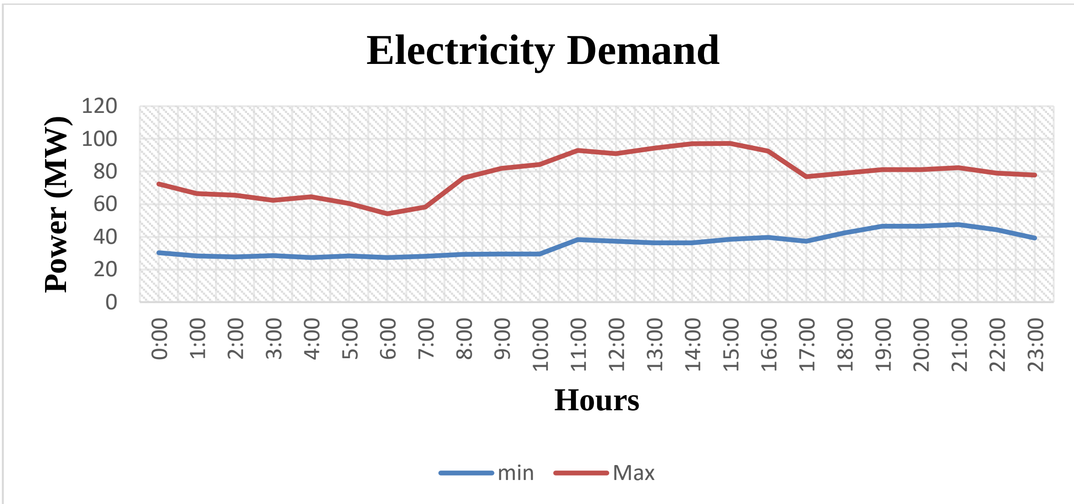

Figure 4.3 Daily Electricity Demand in Niamey in January 9 (min), and May 7 (Max), 2012 (NIGELEC)

Moreover, Fig. 17 represents the long-term electricity supply and demand trends through a dynamic simulation of the model under the baseline scenario. It meant to capture all the interdependencies between the major variables. It can be seen that Niamey might have reached its energy production limits in 2046 despite the fact that the local power production and electricity import from Nigeria were increased every year with a rate of, 0.08% and 0.05%, in that order. This rapid growth of electricity demand can be explained by the significant population growth rate under this policy run. The latter itself is closely linked to the dominant share of the primary (more than four fifth of the economy), thus this economic sector will probably rise under this policy. It means that there is a need to look for another power generation means in order to ensure the balance between electricity supply and demand beyond 2046.

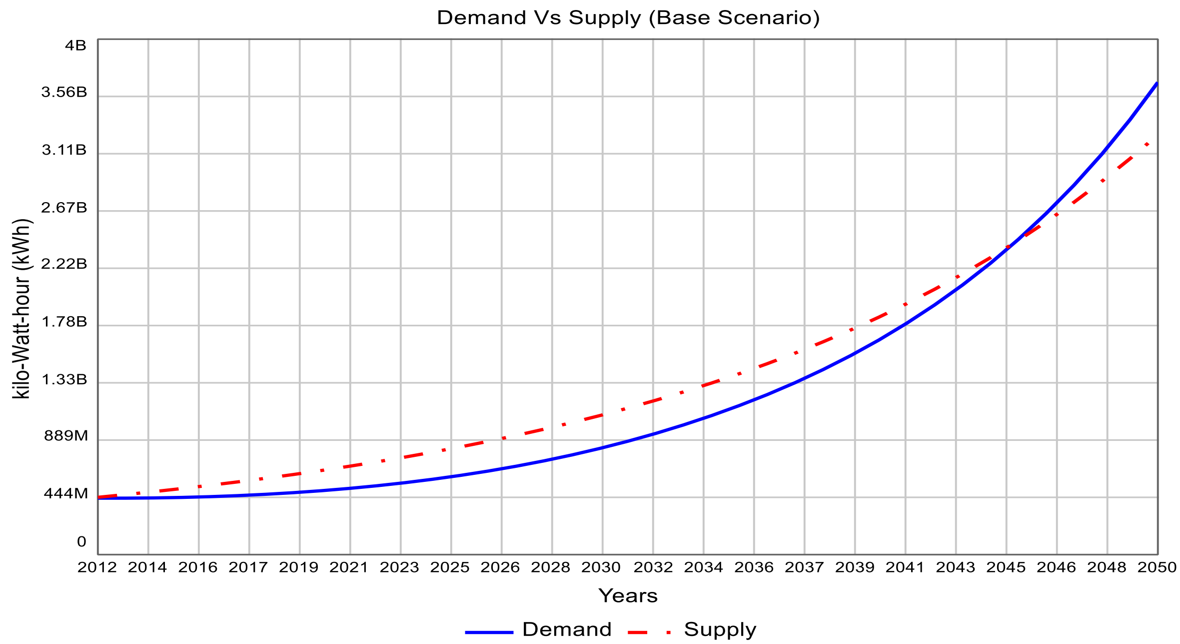

Figure 4.4 : Electricity Supply and Demand (Base scenario) (STELLA)

The proposed theoretical electricity capacity, based on the Distributed Generation model, is slightly greater than the demand. In the first scenario, in order to reach electricity independence in the capital city and its vicinity, a 72.3 MW of Renewable Energy Sources (RES), *i.e.*, 70 MW of small solar power plants and 10 Enercon E82/2000 wind turbines in conjunction with a 15 MW of Energy Storage System, were proposed to replace the existing electricity import from Nigeria. Figure 18 shows electricity demand and supply trends under scenario 1.

This model simulates a continuous 24h electricity production. It first takes into account the day time known for the abundant of sunshine in Niger with an average annual sun light hours of 8.5. As a result, the solar power plants would work at their full capacity, thus putting on the national distribution grid 70 MW of electrical power. As opposed to solar, wind energy is predominantly important night time. The model then investigates the impacts of some wind turbines running 24h in conjunction with energy storage systems at night only. Together, these turbines should generate a constant 17.3 MW to be added to the existing local generation capacity.

As shown in Fig. 18, scenario 1, the electricity supply slightly rises above the demand from the base year of the simulation period, 2012, to 2036. This power generation policy has succeeded to make Niamey electricity self-sufficiency for 24 years despite the high population growth rate discussed in section I. This policy's failure to meet the electricity demand throughout the simulation period means that another sensitive variable of the model need to be changed in the next scenarios.

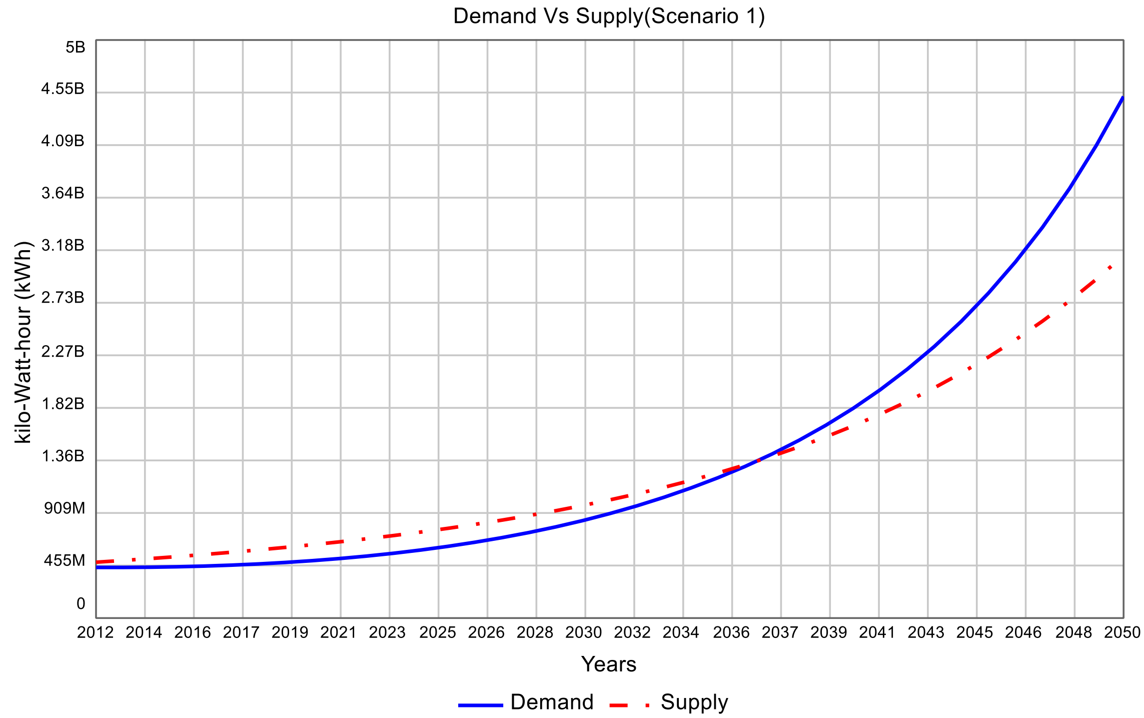

Figure 4.5 : Electricity Supply and Demand (Scenario 1) (STELLA)

Fig. 19 illustrates the electricity supply-demand trends under scenario 2. In this second scenario, the simulation results have showed that by slowing down the birth rate to 40/1000, the electricity supply can be far higher than demand on the whole simulation period, as opposed to the scenario 1. The national power supply was strengthened by the electricity generation from RES. The latter was not only comprised of the implementation of solar power plant and wind turbines like scenario 1, but also had an energy storage capacity increased from 15 MW to 20 MW.

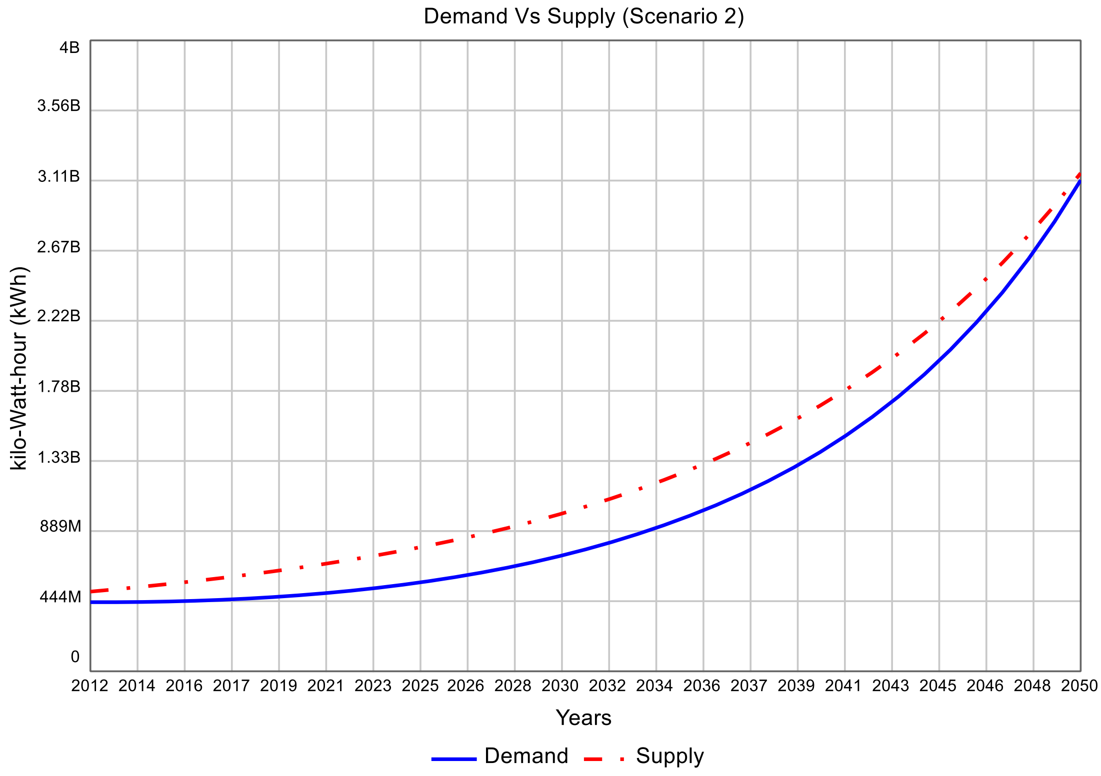

Figure 4.6: Electricity Supply and Demand (Scenario 2) (STELLA)

The diurnal electricity supply and demand patterns under the 35 per thousand inhabitants' scenario is shown in Fig. 20, scenario 3. Therefore, Fig. 20 clearly depicts that the electricity supply is higher than demand from 2012 to 2048. Under these conditions with the subsequent results exposed in here, Niamey would attain its energy independence for the entire simulation period. But electricity supply nearly coincides with demand in two last years, *viz.*, 2049 and 2050. Thus, this fact annunciates that an additional policy must take place just in 2050. The economic implication is that the constant availability of energy would, not only boost the national GDP by developing the secondary sector, but would also enhance the health conditions and the wellbeing of the residents.

With a clear knowledge of the good practices in the field of electrical power business and by taking a critical look at Fig. 20, it turned out that this is the best scenario among all taking into account the test criteria. The reason is that the supply trends closely match with demand without any major excess of power. This is a good thing because the country is yet to implement dispersed energy storage systems policies in order to store any excess of power for either a later usage or to smooth out any power fluctuations coming from RE.

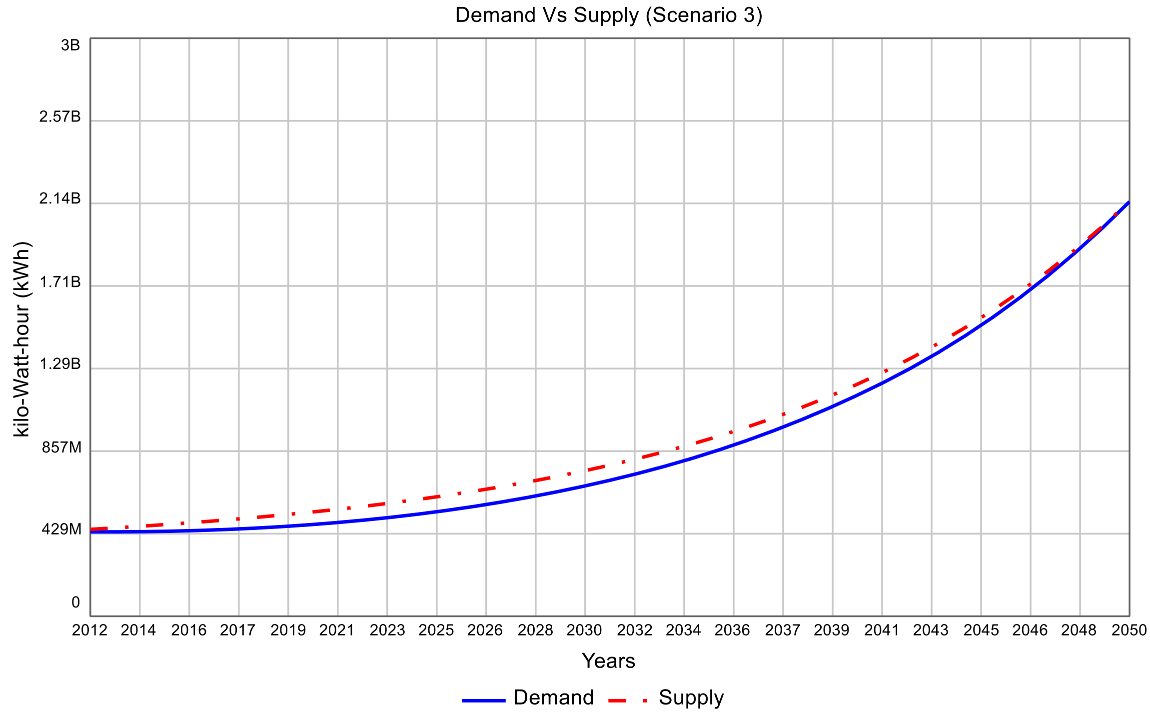

Figure 4.7 : Electricity Supply and Demand (Scenario 3)

A final scenario is portrayed in Fig. 21. A sensitivity analysis was proposed with a drastic reduction in BR (30/1000) although this is not realistic. Consequently, this is only meant to show that the quest for energy independence, under the current birth policy in Niger, is a pure utopia. However, acting on this sensible variable could lead the way to self-sufficiency in energy, but again caution must be exercised. Consequently, it can be seen that supply is way bigger than demand over the entire run time. The key ingredient for Niamey to reaching its energy security is undoubtedly renewable energy, including solar and wind, and Energy Storage System.

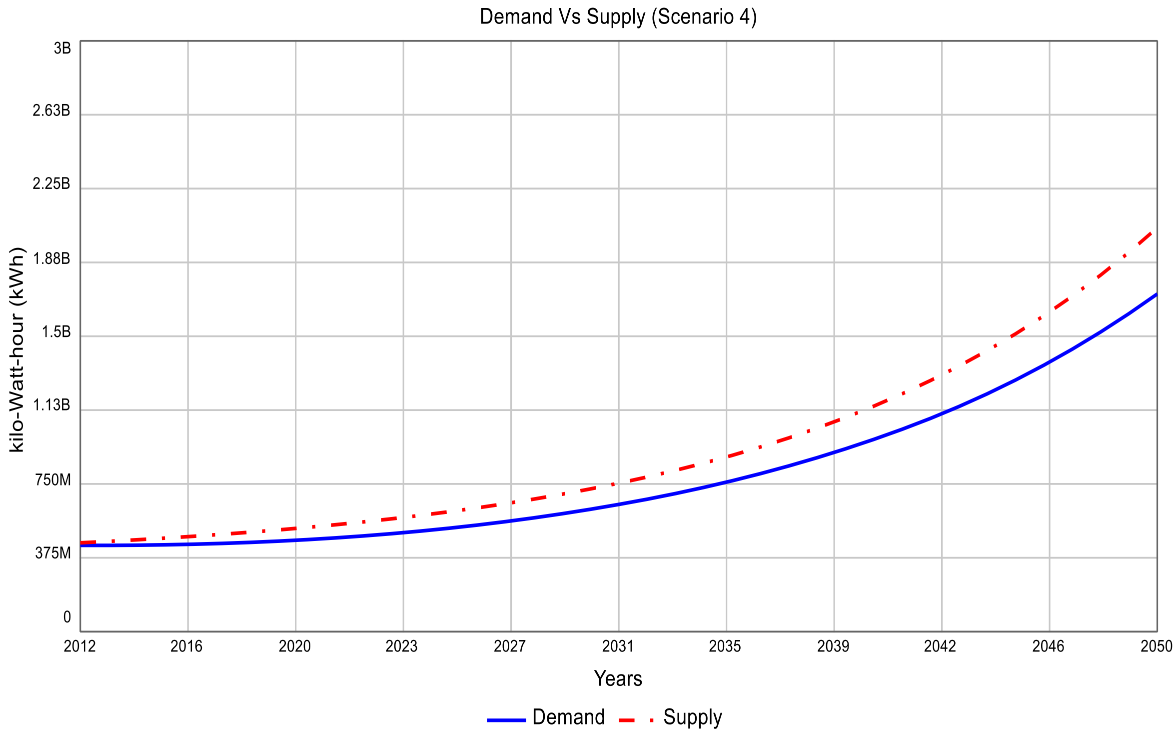

Figure 4.8 : Electricity Supply and Demand (Scenario 4)

4.4 Policy Evaluation

Evaluation of the scenarios are based on the sustainable management criteria of the electricity supply system of Niamey. The first criterion has to do with power supply security in Niamey, meaning to balance of electricity supply and demand at all times. The second criterion deals with the sustainability of electricity generation. This can be accomplished through a sustained power generation from Renewable Energy Resources (RES). The third criterion is the electricity supply independency, meaning the balance of power supply and demand without importing power from Nigeria. Lastly, the final criterion is the economic analysis, this takes into account the total power generation cost of the four scenarios.

The simulation model under the first scenario has proved to balance power supply and demand for 25 years. It showed the highest initial renewable power generation (87.3 MW). For a continuous and secured power supply, the electricity import from Nigeria need to be included in this scenario from 2037 to 2050. However, this fact will escalate the dependence of the national power supply. The three last scenarios provided a sustainable power supply based on RES with different initial electricity production costs. However, scenario 4 had the lowest power generation cost compared to the second and the third scenarios.

4.5 Testing

This System Dynamic (SD) model has four sub-sectors, in which the social sector was the most delicate because of the model sensitivity to Birth Rate (BR). To verify the model, the error between real and simulated data from the base year 2012 to 2016 was calculated and portrayed in Fig. 22. The results illustrated that the population average error was 2.5%, which was far lower than the allowable range of 10%. Thus, this SD model is accurate enough to simulate the actual electricity supply and demand trends in Niamey with a minimum error percentage.

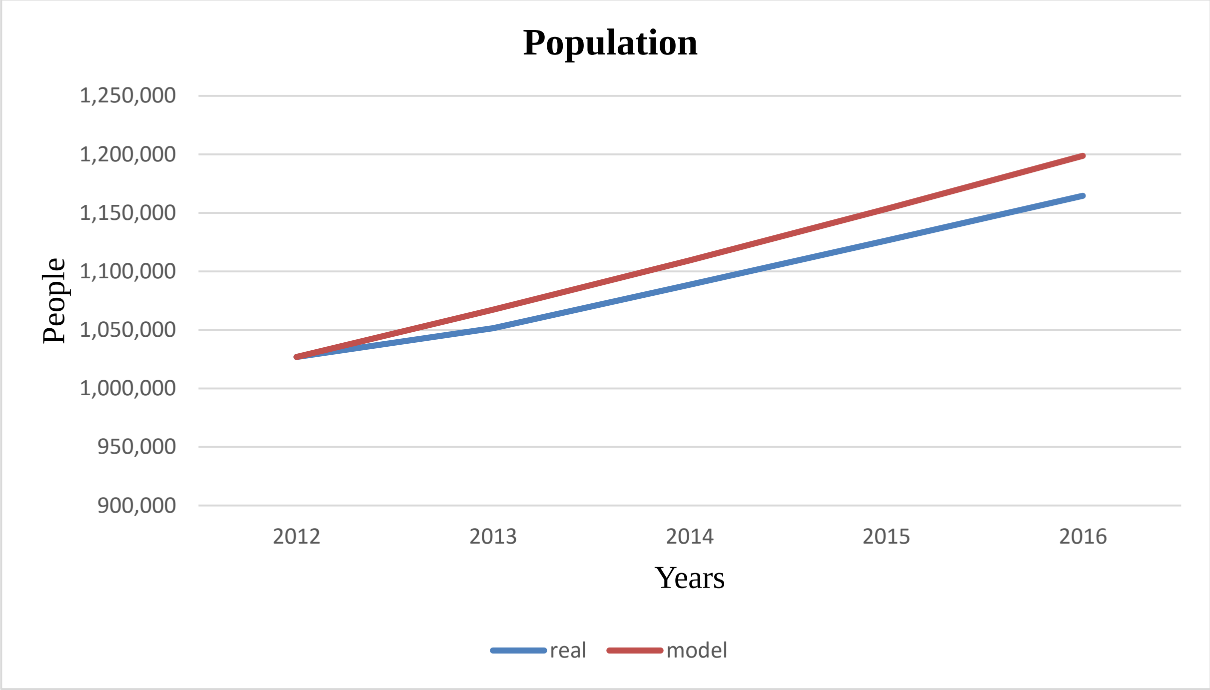

Figure 4.9 : Actual and simulation population data (INS)

4.6 Wind Energy Potential

Twenty-two years of diurnal wind data were obtained from the weather station located at the International Airport of Niamey. At a height of 10 m, with given wind speeds of 3, 4, 5, 6, and 7 m/s, the frequencies of distributions were, respectively 32.8%, 31.3%, 17.8%, 5.0%, and 1.4% as shown in Fig. 23. Also, at a height of 82 m, for the same cited wind speeds, the frequencies were 14.5%, 23.9%, 26.3%, 17.5%, and 9.8%, respectively as illustrated by Fig. 24. From the same source, Niamey has an enormous potential of high wind, ranging from 8 to 14 m/s with an average frequency of 5.6%. Therefore, the implementation of an “Enercon E82/2000” wind turbine in Niamey can give an annual energy throughput of 2.10 GWh. The employment of 10 such wind turbines may yield 20.76 GWh on a yearly basis.

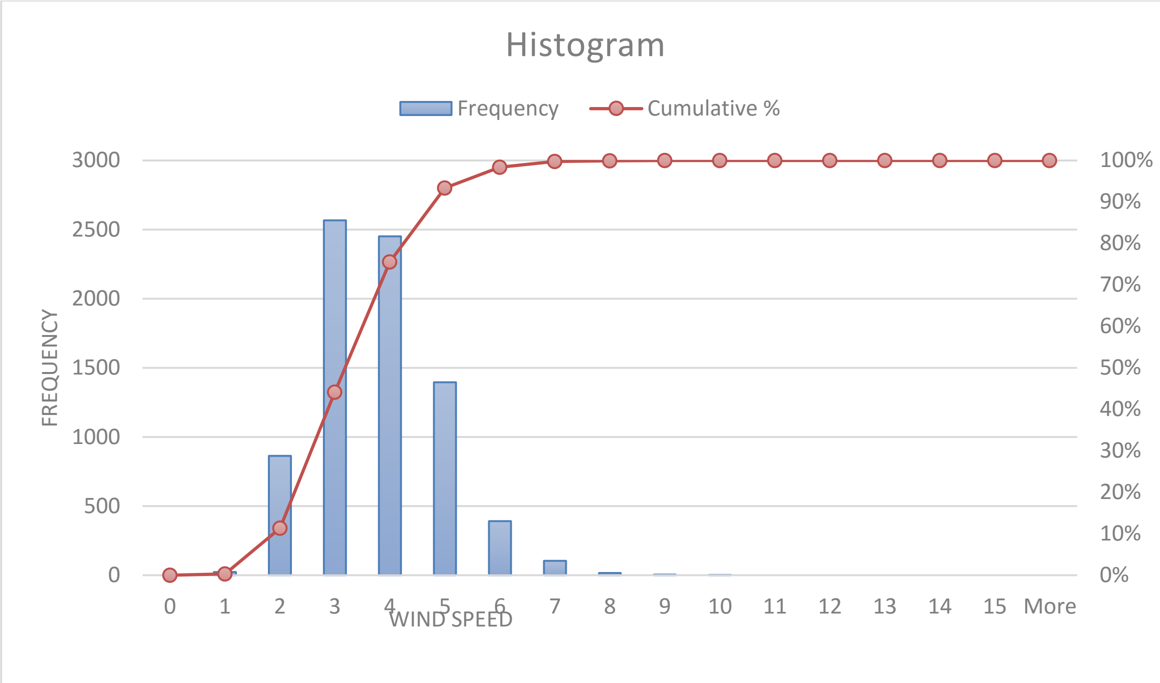

Figure 4.10 : Wind Speed distribution in Niamey at 10 m height

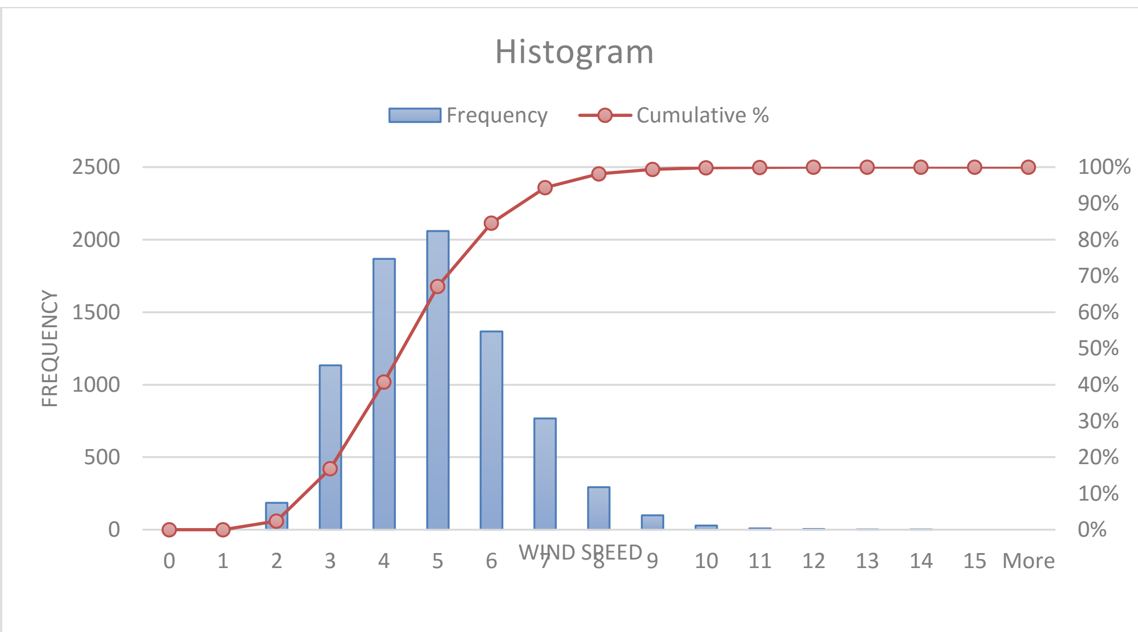

Figure 4.11 : Wind Speed distribution in Niamey at 82 m height

The Enercon E82/2000 was the wind turbine selected for the purpose of this study. The choice of this wind turbine was solely based on its compatibility with the wind speed characteristics of Niamey. For example the cut-in wind speed of the wind machine represents 2.4% of 22 years' data used in this study. Table 8 gives the wind characteristics: 1) the maximum power kW, 2) sweep area in m², 3) cut-in wind speed in m/s, 4) cut-out wind speed in m/s, and 5) maximum power coefficient. As a results, Fig. 25 shows the power output curve of the Enercon.

***Table 4.1** : Characteristics of Enercon E82/2000*

Manufacturer	Model	Rated power manufacturer (kW)	Maximum power (kW)	Area (m2)	Cut-in wind speed (m/s)	Cut-out wind speed (m/s)	Estimated vr	Maximum power coefficient
Enercon	E82/2000	NaN	2050	5281	2.0	28.0	1	0.500

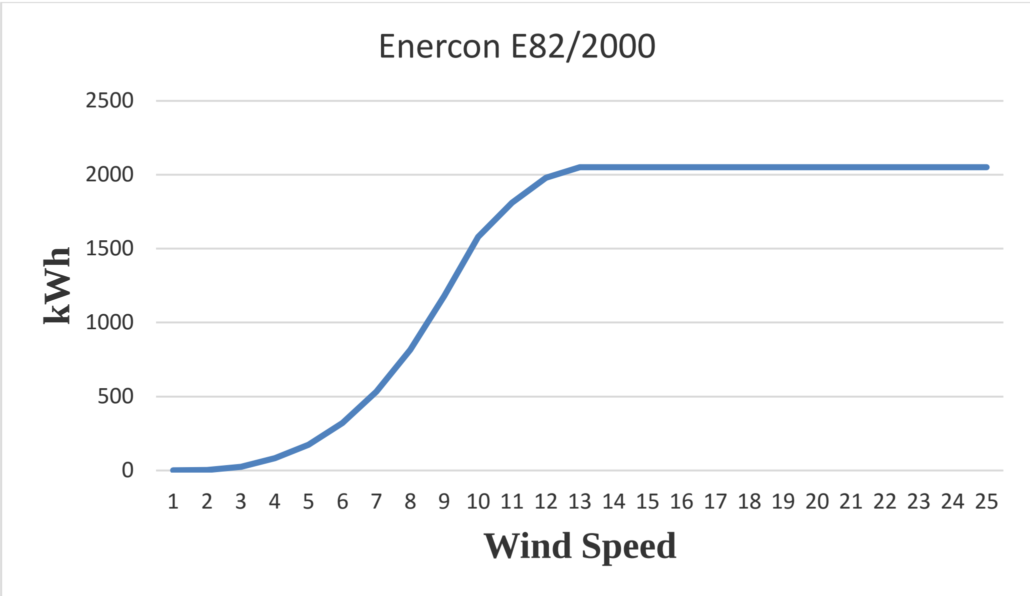

Figure 4.12 : Power Output of Enercon E82/2000

Fig. 26 shows the curve of wind speed Weibull distribution patterns over the course of 22 years. The percentage of wind speed ranging from 2 to 4, 5 to 7, and 8 to 13 m/s are, respectively 40.8%, 53.6%, and 5.6% over periods of wind availability from 1995 to 2016 at 82 meters' hub height. The peak correspond to V = 5 m/s occurred 26.3% of the considered data. In 2016, the minimum wind speed was noticed in November to be 1.8 m/s, the maximum occurred in January, 8.8 m/s; and the average was 4.4 m/s.

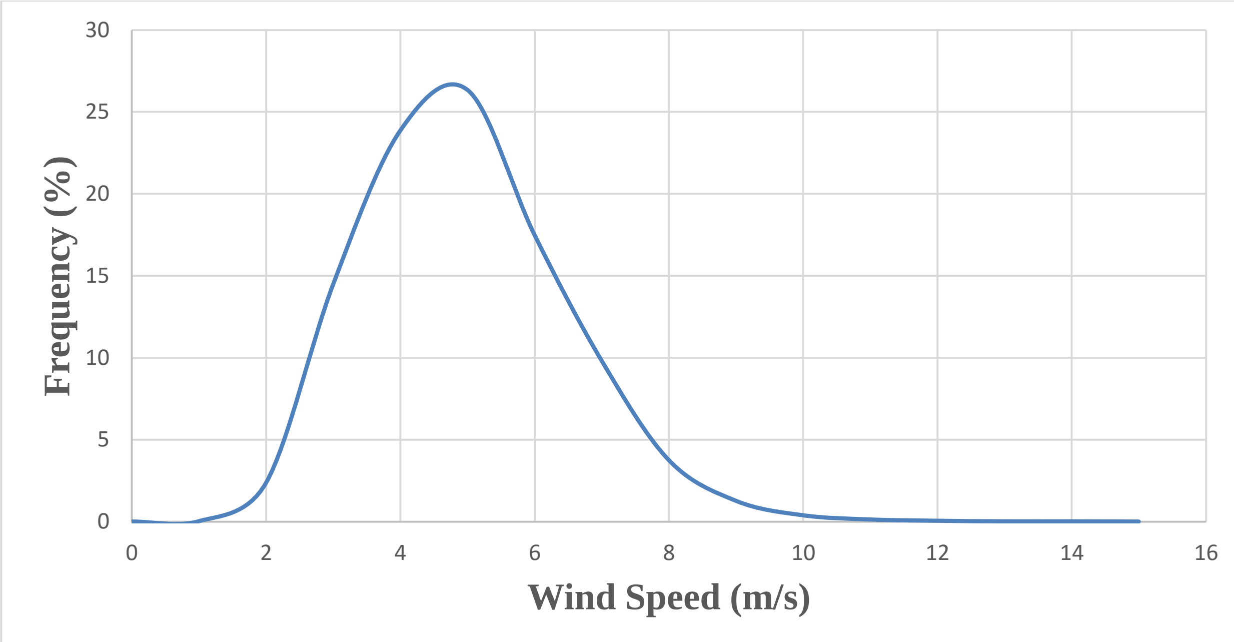

Figure 4.13 : Wind Speed Weibull distribution in Niamey at 82 m height

In addition, it can be observed in Fig. 27 that the highest energy output from the wind turbine, Enercon E82/2000, was given at the wind speeds of 6 m/s. Thus, the average wind speed data from 1995 to 2016 gave an annual power output of 2,10 GWh. Consequently, it means that Niamey needs 215 Enercon E82/2000 to supply its yearly electricity demand with 100% wind energy. The implementation of 10 wind machines cited above can only supply 1.8% Niamey's electricity demand.

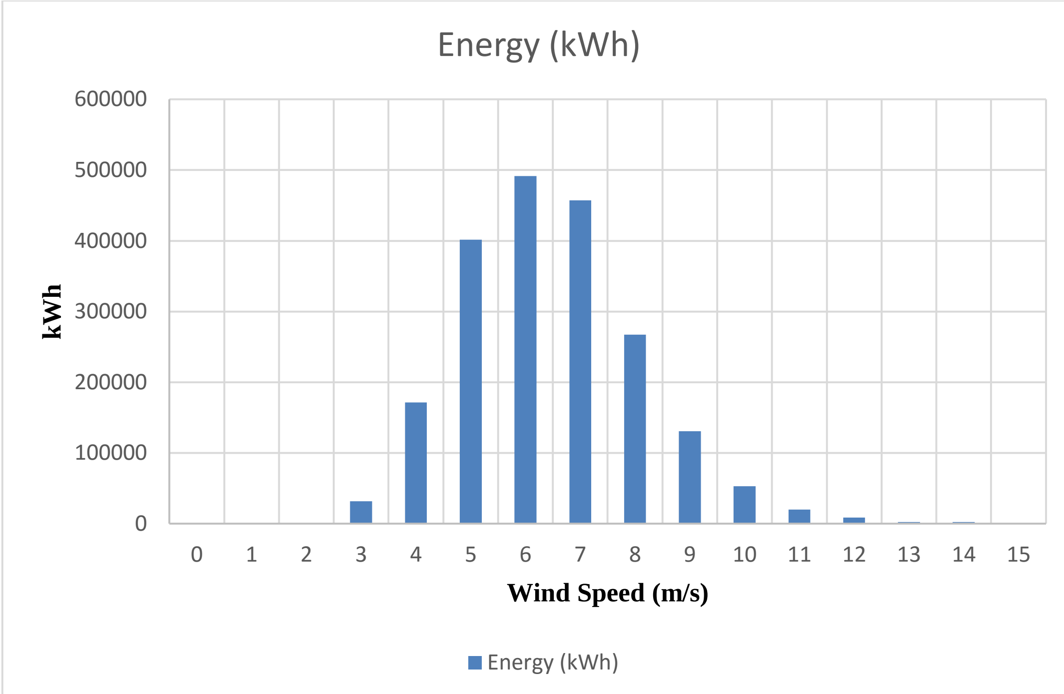

Figure 4.14 : Yearly Energy Output

4.7 Solar Energy Potential

Solar energy is one of the most abundant and cleanest renewable sources in the universe and it is free from any greenhouse gas (GHG) and other harmful environmental pollutants (Yacouba Moumouni and Baker, 2016). Among all the renewable energy resources available in Niger, solar energy is the best option to balance electricity demand and supply. In addition, Niamey receives an average daily solar energy of 5.22 kWh/m²/day. This model showed that the installation of 70 MW small solar power plants and a 10 MW wind turbine with ESS in Niamey could pave the way to a sustainable energy security. Furthermore, Fig. 28 shows that the implementation of the above-mentioned solar power plants can supply an average annual energy of 450 GWh from 2012 to 2050.

The critical energy situation of Niger requires that a big city like Niamey has to make efforts on solar energy production, such as photovoltaic and concentrated solar power. The sun provides the energy to sustain life in the solar system. In one hour, the earth receives enough energy from the sun to meet its energy needs for nearly a year (Yacouba Moumouni *et al.*, 2014). With a yearly solar energy of 1,905.3 kWh/m²/day in Niamey, 583,908 m² is enough to supply 100% of its electricity demand. Solar power potential cannot be exploited 100% taking into account of economic, technical and topographical considerations. The maximum power extracted from a solar power plant is determined by its efficiency and the number of solar panels. Also, the quality of other equipment, such as cables, inverters, batteries etc. can significantly impact on the harvested power. The intensity of the sunlight that reaches the earth varies with the time of the day, season, location, and the weather conditions (Yacouba Moumouni *et al.*, 2014). In 2016 the minimum average daily irradiation was recorded in December (5.1 kWh) and the maximum in April (6.3 kWh). In the rainy season, Niamey usually receives low irradiation from 1 to 2 kWh/m²/day. This low insolation, *i.e.*, low generation, has to be compensated by another renewable energy sources or with an Energy Storage System (ESS). Table 9 illustrated the average monthly and daily insolation in Niamey.

Table 4.2 *: Solar irradiation in Niamey in 2015 (CNES)*

Months	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Monthly Irradiation (kWh)	164	163	175	189	183	170	174	159	168	178	165	158
Mean Daily Irradiation (kWh)	5.3	5.8	5.6	6.3	5.9	5.7	5.6	5.1	5.6	5.7	5.5	5.1

4.8 Energy Storage System

Renewable energy sources are the way out to meeting the ever-growing energy demand for both developed and emerging countries. Unfortunately, the main drawback of these abundant and cheap renewable sources, such as solar and wind, is that they are intermittent in nature. Consequently, the implementation of RES goes most of the time hand-in-hand with energy storage systems for a constant and reliable supply. The dynamic analysis of renewable energy system proved that solar and wind power depend on climate variables, such as solar radiations and wind speed. It can be seen from Fig. 20 that sustainable energy sufficiency in Niamey will be given by electricity production based on RE and a likely reduction of population growth in order to slow down electricity demand in the near future. The rate of climate change in the Sahel is changing the cycle of the climate variables, such as temperature, rainfall, irradiation, wind speed and so on. Thus, the reason is obvious why policy makers have to implement clean electricity production. Recent research study proved that electricity production form fossil fuel sources is emitting a huge amount of Greenhouse Gases (GHGs) in the atmosphere. Increasing GHGs in the atmosphere leads to Global Warming, which is one key aspect of climate change. The challenge is to make a West African brand local RE technologies, for example use sand to produce silicon, and make solar panel with a long lifetime with respect to the local weather conditions.

4.9 Renewable energy role on future electricity supply in Niamey

Simulation results under scenario 1 proved that 392.7 GWh in 2012 and 1,500 GWh in 2050 were the minimum and maximum, in that order, of renewable power contribution to the national power supply in order to balance power supply and demand in Niamey over the entire period. This share in the electricity supply is comprised of three power contributions: (1) 78.07% and 42.58% of solar energy at the starting and the end of the scenario period; (2) 5.19% and 49.8% of wind energy; and finally, (3) 16.73% and 4.4% of Energy Storage System (ESS) as shown in Fig. 28. Investment in this sector will reduce the Nigerien power dependency on Nigeria in one hand. In the other hand, the national supply will be resilient to extreme events, accidents and climate change. Vulnerability of the Nigerien power sector to extreme events is contingent to various calamities on the transmission lines. For example storm or floods can damage some vital components of the transmission lines. Road accidents are also a threat to the lines, but climate change affects directly the power source of electricity imported from Nigeria, which is Kandji Dam. This vulnerability is due to climate change effects on precipitations, which can further reduce the Niger river stream flow used by that Dam for power generation.

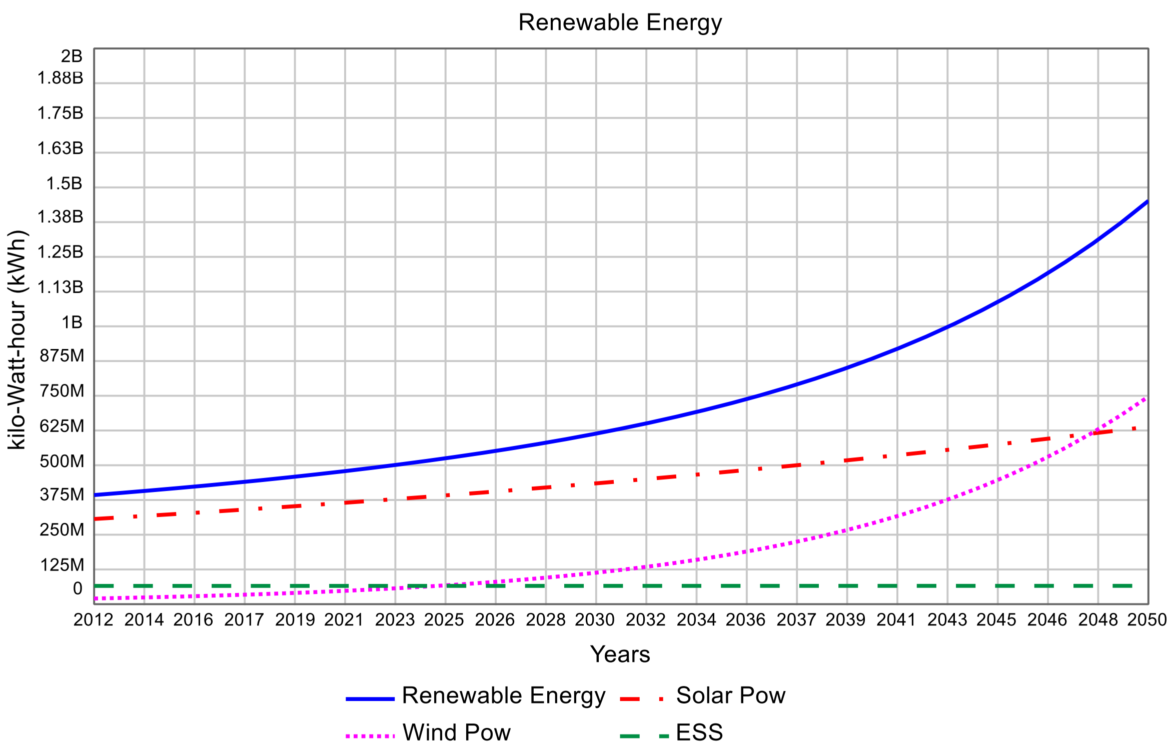

Figure 4.15 : Nocturnal Electricity Supply and Demand (BR is 44.8) (STELLA)

CHAPTER5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The main purpose of this study was to build policy scenarios for sustainable energy security in Niamey and vicinity. These scenarios were based on criteria, such as: 1) secure power supply; 2) sustainable power generation; and finally, 3) power supply independency of Niamey. As proposed to be introduced, Distributed Generations (DG) can help an emerging country like Niger not only to meet its increasing power demand with a cheap and reliable supply, but also to decrease its overall greenhouse gas emissions. Thus, some of the DG advantages are: 1) cutting down transmission losses due to ageing infrastructure; 2) reducing electricity distribution cost; 3) improving the availability, reliability, and accessibility of electric power; 4) reduce greenhouse gas emissions; and 5) helping developing countries to reaching energy independence.

System Dynamic (SD) approach was used in this study. Two stock and flow models were built known as real world and DG model. The first one displayed clearly interactions between socio-economic and power demand factors, and how Niamey's power supply was dependent on electricity import from Nigeria. The second gave renewable energy quantity needed to reach power self-sufficiency in Niamey and vicinity from the status quo to the time horizon of 2050.

With regards to statistical analysis of 6 years of solar radiation and 22 years of wind speed measured, respectively at CNES (Centre National d'Energie Solaire) and synoptic station of Niamey Airport, it can be concluded that Niamey has enough renewable energy potential to supply its own electricity demand. The annual energy output of 10 wind machines, type Enercon E82/2000 represents 1.8% of Niamey's electricity demand, but economic analysis should be done to estimate the renewable power profitability. However, it can be concluded that renewable power potential in Niamey is far higher than electricity import from Nigeria.

Moreover, results proved that the implementation of a 70 MW solar PV array, 10 wind turbines (Enercon E82/2000), and a 15 MW ESS, are proved to be more than enough to completely eliminating both electricity shortage and dependency of Niamey. In addition, results showed that any likely reduction of Birth Rate (BR) to 30/1000 will significantly lower electricity demand, and consequently enabling Niamey to produce 100% of its electricity supply from renewable energy such as, solar and wind energy. The results of this SD model were more qualitative than quantitative and were mainly policy-oriented. The qualitative aspect may serve as policies which may allow Niamey and vicinity to be energy self-sufficient. The implementation of small RE solar power plants and wind turbines in the vicinity of load centers, taking into account both socio-economic and climatic parameters, would be the paramount factor in paving the way to energy independence in Niger.

5.2 Recommendations

To fight against climate change, countries across the world need to abide by the international climate agreement at the United Nation Framework Convention on Climate Change (UNFCCC) Conference of the parties (COP21) held in Paris in December 2015. In anticipation of this moment, countries publicly outlined what post 2020 climate actions they intended to take under the new international agreement, known as their Intended Nationally Determined Contributions (INDCs). The climate actions communicated in these INDCs, largely determine whether the world would achieve the long-term goals of the Paris Agreement: 1) hold the increase in global average temperature to well below 2°C, 2) pursue efforts to limit the increase to 1.5°C, and 3) achieve net zero emissions in the second half of this century (WRI, 2017).

Niger is one of the countries, which have taken the engagement to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten sustainable development. To achieve the INDCs' targets, Niger has to implement some policies before the time 2030 horizon:

- Promoting solar photovoltaic for pumping and electrification;
- Reduction of power losses from 12% to less than 10%;
- Finalizing the 130 MW Kandadji hydroelectric plant by 2030;
- Constructing gas power plants;
- Erecting 20 MW wind energy plants;
- Reaching -25% in GDP energy intensity through energy efficiency improvement; and
- Exceeding a capacity of 250 MW in 2030; thus reaching 30% share.

Policies from this study could be used by the Nigerien government to achieve these engagements above. Policy makers or private energy companies can also use them to sustain a long-term energy production with low GHG emissions.

Personal effort can be done by inhabitants of Niamey to help the government for balancing power supply and demand in a sustainable way by:

- Utilizing more energy efficiency appliances,
- Saving electricity (switch off light and electronic appliances before leaving a room, home or office)
- If possible, installing a PV system at home or office as a contribution to national power generation efforts.

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Annexes

Annexe 1: Result Output for Scenario 1

A.1. Social output data of the baseline scenario and scenario 1

Social Output Data

	Population	BR	DR	Migration	New Pop
2012	1.0M	50.7k	11.2k	996.0	0.0
2013	1.1M	52.7k	11.6k	1.0k	40.5k
2014	1.1M	54.8k	12.1k	1.1k	82.7k
2015	1.2M	57.0k	12.6k	1.1k	126.5k
2016	1.2M	59.2k	13.1k	1.2k	172.0k
2017	1.2M	61.6k	13.6k	1.2k	219.3k
2018	1.3M	64.0k	14.1k	1.3k	268.5k
2019	1.3M	66.5k	14.7k	1.3k	319.6k
2020	1.4M	69.1k	15.3k	1.4k	372.7k
2021	1.5M	71.9k	15.9k	1.4k	428.0k
2022	1.5M	74.7k	16.5k	1.5k	485.4k
2023	1.6M	77.7k	17.1k	1.5k	545.1k
2024	1.6M	80.7k	17.8k	1.6k	607.1k
2025	1.7M	83.9k	18.5k	1.6k	671.6k
2026	1.8M	87.2k	19.2k	1.7k	738.7k
2027	1.8M	90.7k	20.0k	1.8k	808.4k
2028	1.9M	94.2k	20.8k	1.9k	880.8k
2029	2.0M	98.0k	21.6k	1.9k	956.1k
2030	2.1M	101.8k	22.5k	2.0k	1.0M
2031	2.1M	105.8k	23.4k	2.1k	1.1M

Social Output Data

	Population	BR	DR	Migration	New Pop
2031	2.1M	105.8k	23.4k	2.1k	1.1M
2032	2.2M	110.0k	24.3k	2.2k	1.2M
2033	2.3M	114.4k	25.2k	2.2k	1.3M
2034	2.4M	118.9k	26.2k	2.3k	1.4M
2035	2.5M	123.6k	27.3k	2.4k	1.5M
2036	2.6M	128.4k	28.3k	2.5k	1.6M
2037	2.7M	133.5k	29.5k	2.6k	1.7M
2038	2.8M	138.8k	30.6k	2.7k	1.8M
2039	2.9M	144.3k	31.8k	2.8k	1.9M
2040	3.0M	150.0k	33.1k	2.9k	2.0M
2041	3.2M	155.9k	34.4k	3.1k	2.1M
2042	3.3M	162.0k	35.8k	3.2k	2.3M
2043	3.4M	168.4k	37.2k	3.3k	2.4M
2044	3.5M	175.1k	38.6k	3.4k	2.5M
2045	3.7M	182.0k	40.2k	3.6k	2.7M
2046	3.8M	189.2k	41.7k	3.7k	2.8M
2047	4.0M	196.6k	43.4k	3.9k	3.0M
2048	4.1M	204.4k	45.1k	4.0k	3.1M
2049	4.3M	212.5k	46.9k	4.2k	3.3M
Final	4.5M				3.4M

A.2. Economic output data of the baseline scenario and scenario 1

Economic Output Data

	GDP PC	Inc GDP	Niamey's GDP	PG Vs GDPG
2012	405.0	4.0	415.9M	1.1T
2013	409.1	4.1	436.6M	1.2T
2014	413.1	4.1	458.4M	1.3T
2015	417.3	4.2	481.2M	1.4T
2016	421.4	4.2	505.2M	1.5T
2017	425.7	4.3	530.4M	1.6T
2018	429.9	4.3	556.9M	1.8T
2019	434.2	4.3	584.6M	1.9T
2020	438.6	4.4	613.8M	2.1T
2021	442.9	4.4	644.4M	2.3T
2022	447.4	4.5	676.5M	2.5T
2023	451.8	4.5	710.3M	2.8T
2024	456.4	4.6	745.7M	3.0T
2025	460.9	4.6	782.9M	3.3T
2026	465.5	4.7	821.9M	3.6T
2027	470.2	4.7	862.9M	3.9T
2028	474.9	4.7	905.9M	4.3T
2029	479.6	4.8	951.1M	4.7T
2030	484.4	4.8	998.5M	5.1T
2031	489.3	4.9	1.0B	5.5T

Economic Output Data

	GDP PC	Inc GDP	Niamey's GDP	PG Vs GDPG
2031	489.3	4.9	1.0B	5.5T
2032	494.2	4.9	1.1B	6.1T
2033	499.1	5.0	1.2B	6.6T
2034	504.1	5.0	1.2B	7.2T
2035	509.2	5.1	1.3B	7.9T
2036	514.2	5.1	1.3B	8.6T
2037	519.4	5.2	1.4B	9.4T
2038	524.6	5.2	1.5B	10.2T
2039	529.8	5.3	1.5B	11.2T
2040	535.1	5.4	1.6B	12.2T
2041	540.5	5.4	1.7B	13.3T
2042	545.9	5.5	1.8B	14.5T
2043	551.3	5.5	1.9B	15.8T
2044	556.9	5.6	2.0B	17.3T
2045	562.4	5.6	2.1B	18.8T
2046	568.0	5.7	2.2B	20.6T
2047	573.7	5.7	2.3B	22.4T
2048	579.5	5.8	2.4B	24.5T
2049	585.3	5.9	2.5B	26.7T
Final	591.1		2.6B	29.2T

A.3. Domestic energy output data of the baseline scenario

Domestic Energy Output

	Demand	Supply	Existing	Import	Inc Demand	Inc Prod	Inc Import	Elect Cons PC	Demand-Supply
2012	438.0M	444.8M	90.5M	354.4M	0.0	7.2M	14.2M	46.1	-6.8M
2013	438.0M	466.2M	97.7M	368.5M	1.9M	7.8M	14.7M	46.1	-28.2M
2014	439.9M	488.8M	105.5M	383.3M	3.8M	8.4M	15.3M	46.1	-48.9M
2015	443.7M	512.5M	113.9M	398.6M	5.9M	9.1M	15.9M	46.1	-68.8M
2016	449.6M	537.6M	123.1M	414.5M	8.0M	9.8M	16.6M	46.1	-88.0M
2017	457.6M	564.0M	132.9M	431.1M	10.3M	10.6M	17.2M	46.1	-106.4M
2018	467.9M	591.9M	143.5M	448.4M	12.7M	11.5M	17.9M	46.1	-124.0M
2019	480.5M	621.3M	155.0M	466.3M	15.2M	12.4M	18.7M	46.1	-140.8M
2020	495.7M	652.4M	167.4M	485.0M	17.8M	13.4M	19.4M	46.1	-156.6M
2021	513.6M	685.2M	180.8M	504.4M	20.7M	14.5M	20.2M	46.1	-171.6M
2022	534.2M	719.8M	195.3M	524.5M	23.6M	15.6M	21.0M	46.1	-185.6M
2023	557.9M	756.4M	210.9M	545.5M	26.8M	16.9M	21.8M	46.1	-198.5M
2024	584.7M	795.1M	227.8M	567.3M	30.2M	18.2M	22.7M	46.1	-210.4M
2025	614.8M	836.0M	246.0M	590.0M	33.8M	19.7M	23.6M	46.1	-221.2M
2026	648.6M	879.3M	265.7M	613.6M	37.6M	21.3M	24.5M	46.1	-230.7M
2027	686.2M	925.1M	286.9M	638.2M	41.6M	23.0M	25.5M	46.1	-238.9M
2028	727.8M	973.6M	309.9M	663.7M	46.0M	24.8M	26.5M	46.1	-245.8M
2029	773.8M	1.0B	334.7M	690.2M	50.6M	26.8M	27.6M	46.1	-251.1M
2030	824.4M	1.1B	361.4M	717.9M	55.5M	28.9M	28.7M	46.1	-254.9M
2031	879.9M	1.1B	390.4M	746.6M	60.7M	31.2M	29.9M	46.1	-257.1M

Domestic Energy Output									
	Demand	Supply	Existing	Import	Inc Demand	Inc Prod	Inc Import	Elect Cons PC	Demand-Supply
2031	879.9M	1.1B	390.4M	746.6M	60.7M	31.2M	29.9M	46.1	-257.1M
2032	940.5M	1.2B	421.6M	776.4M	66.2M	33.7M	31.1M	46.1	-257.5M
2033	1.0B	1.3B	455.3M	807.5M	72.1M	36.4M	32.3M	46.1	-256.1M
2034	1.1B	1.3B	491.7M	839.8M	78.3M	39.3M	33.6M	46.1	-252.7M
2035	1.2B	1.4B	531.1M	873.4M	85.0M	42.5M	34.9M	46.1	-247.4M
2036	1.2B	1.5B	573.6M	908.3M	92.8M	45.9M	36.3M	46.1	-239.8M
2037	1.3B	1.6B	619.5M	944.6M	101.1M	49.6M	37.8M	46.1	-229.3M
2038	1.4B	1.7B	669.0M	982.4M	109.9M	53.5M	39.3M	46.1	-215.5M
2039	1.5B	1.7B	722.5M	1.0B	119.6M	57.8M	40.9M	46.1	-198.5M
2040	1.7B	1.8B	780.3M	1.1B	130.5M	62.4M	42.5M	46.1	-177.5M
2041	1.8B	1.9B	842.8M	1.1B	142.2M	67.4M	44.2M	46.1	-151.9M
2042	1.9B	2.1B	910.2M	1.1B	154.6M	72.8M	46.0M	46.1	-121.4M
2043	2.1B	2.2B	983.0M	1.2B	168.9M	78.6M	47.8M	46.1	-85.5M
2044	2.3B	2.3B	1.1B	1.2B	184.8M	84.9M	49.7M	46.1	-43.1M
2045	2.4B	2.4B	1.1B	1.3B	201.9M	91.7M	51.7M	46.1	7.0M
2046	2.6B	2.6B	1.2B	1.3B	220.0M	99.1M	53.8M	46.1	65.5M
2047	2.9B	2.7B	1.3B	1.4B	241.6M	107.0M	55.9M	46.1	132.7M
2048	3.1B	2.9B	1.4B	1.5B	265.2M	115.5M	58.2M	46.1	211.3M
2049	3.4B	3.1B	1.6B	1.5B	290.4M	124.8M	60.5M	46.1	302.8M
Final	3.7B	3.3B	1.7B	1.6B				46.1	407.9M

A.4. Domestic energy output data of scenario 1

Domestic Energy Output

	Demand	Supply	Existing	Inc Demand	Inc Prod	Elect Cons PC	Demand-Supply
2012	438.0M	483.1M	90.5M	0.0	7.2M	46.1	-45.1M
2013	438.0M	498.4M	97.7M	1.9M	7.8M	46.1	-60.4M
2014	439.9M	514.5M	105.5M	3.8M	8.4M	46.1	-74.7M
2015	443.7M	531.6M	113.9M	5.9M	9.1M	46.1	-87.9M
2016	449.6M	549.8M	123.1M	8.1M	9.8M	46.1	-100.1M
2017	457.7M	569.1M	132.9M	10.4M	10.6M	46.1	-111.3M
2018	468.2M	589.5M	143.5M	12.9M	11.5M	46.1	-121.4M
2019	481.0M	611.3M	155.0M	15.5M	12.4M	46.1	-130.3M
2020	496.5M	634.5M	167.4M	18.2M	13.4M	46.1	-138.0M
2021	514.7M	659.2M	180.8M	21.3M	14.5M	46.1	-144.5M
2022	536.0M	685.6M	195.3M	24.5M	15.6M	46.1	-149.6M
2023	560.5M	713.7M	210.9M	27.9M	16.9M	46.1	-153.2M
2024	588.3M	743.7M	227.8M	31.6M	18.2M	46.1	-155.3M
2025	619.9M	775.8M	246.0M	35.5M	19.7M	46.1	-155.9M
2026	655.4M	810.1M	265.7M	39.7M	21.3M	46.1	-154.7M
2027	695.2M	846.8M	286.9M	44.2M	23.0M	46.1	-151.7M
2028	739.3M	886.2M	309.9M	49.2M	24.8M	46.1	-146.8M
2029	788.6M	928.3M	334.7M	54.7M	26.8M	46.1	-139.8M
2030	843.3M	973.6M	361.4M	60.6M	28.9M	46.1	-130.3M
2031	903.9M	1.0B	390.4M	66.8M	31.2M	46.1	-118.2M

Domestic Energy Output							
	Demand	Supply	Existing	Inc Demand	Inc Prod	Elect Cons PC	Demand-Supply
2031	903.9M	1.0B	390.4M	66.8M	31.2M	46.1	-118.2M
2032	970.7M	1.1B	421.6M	73.6M	33.7M	46.1	-103.5M
2033	1.0B	1.1B	455.3M	80.9M	36.4M	46.1	-85.9M
2034	1.1B	1.2B	491.7M	88.7M	39.3M	46.1	-65.2M
2035	1.2B	1.3B	531.1M	97.2M	42.5M	46.1	-41.3M
2036	1.3B	1.3B	573.6M	107.8M	45.9M	46.1	-13.8M
2037	1.4B	1.4B	619.5M	119.0M	49.6M	46.1	18.8M
2038	1.5B	1.5B	669.0M	131.2M	53.5M	46.1	57.0M
2039	1.7B	1.6B	722.5M	144.9M	57.8M	46.1	100.9M
2040	1.8B	1.7B	780.3M	160.8M	62.4M	46.1	151.7M
2041	2.0B	1.8B	842.8M	177.8M	67.4M	46.1	211.0M
2042	2.2B	1.9B	910.2M	196.2M	72.8M	46.1	279.3M
2043	2.3B	2.0B	983.0M	218.1M	78.6M	46.1	357.2M
2044	2.6B	2.1B	1.1B	243.2M	84.9M	46.1	447.5M
2045	2.8B	2.3B	1.1B	270.3M	91.7M	46.1	552.6M
2046	3.1B	2.4B	1.2B	299.3M	99.1M	46.1	673.6M
2047	3.4B	2.6B	1.3B	335.7M	107.0M	46.1	811.5M
2048	3.7B	2.7B	1.4B	376.1M	115.5M	46.1	972.5M
2049	4.1B	2.9B	1.6B	419.7M	124.8M	46.1	1.2B
Final	4.5B	3.1B	1.7B			46.1	1.4B

A.5. Renewable energy output data of scenario 1

Renewable Energy Output

	Solar Pow	Wind Pow	ESS	Inc SP	Inc WP	Inc ESS	Ren Energy	Dec SP	Dec WP
2012	306.6M	20.4M	65.7M	6.1M	2.0M	6.6k	392.7M	153.3k	12.2k
2013	312.6M	22.4M	65.7M	6.3M	2.2M	6.6k	400.7M	156.3k	13.5k
2014	318.7M	24.6M	65.7M	6.4M	2.5M	6.6k	409.0M	159.3k	14.8k
2015	324.9M	27.1M	65.7M	6.5M	2.7M	6.6k	417.7M	162.4k	16.3k
2016	331.2M	29.8M	65.7M	6.6M	3.0M	6.6k	426.7M	165.6k	17.9k
2017	337.7M	32.7M	65.7M	6.8M	3.3M	6.6k	436.2M	168.8k	19.6k
2018	344.3M	36.0M	65.7M	6.9M	3.6M	6.6k	446.0M	172.1k	21.6k
2019	351.0M	39.6M	65.7M	7.0M	4.0M	6.6k	456.3M	175.5k	23.7k
2020	357.8M	43.5M	65.8M	7.2M	4.4M	6.6k	467.1M	178.9k	26.1k
2021	364.8M	47.8M	65.8M	7.3M	4.8M	6.6k	478.4M	182.4k	28.7k
2022	371.9M	52.6M	65.8M	7.4M	5.3M	6.6k	490.3M	186.0k	31.6k
2023	379.2M	57.8M	65.8M	7.6M	5.8M	6.6k	502.8M	189.6k	34.7k
2024	386.6M	63.6M	65.8M	7.7M	6.4M	6.6k	515.9M	193.3k	38.1k
2025	394.1M	69.9M	65.8M	7.9M	7.0M	6.6k	529.8M	197.0k	41.9k
2026	401.8M	76.8M	65.8M	8.0M	7.7M	6.6k	544.4M	200.9k	46.1k
2027	409.6M	84.5M	65.8M	8.2M	8.4M	6.6k	559.9M	204.8k	50.7k
2028	417.6M	92.9M	65.8M	8.4M	9.3M	6.6k	576.3M	208.8k	55.7k
2029	425.8M	102.1M	65.8M	8.5M	10.2M	6.6k	593.7M	212.9k	61.3k
2030	434.1M	112.3M	65.8M	8.7M	11.2M	6.6k	612.1M	217.0k	67.4k
2031	442.5M	123.4M	65.8M	8.9M	12.3M	6.6k	631.8M	221.3k	74.1k

Renewable Energy Output									
	Solar Pow	Wind Pow	ESS	Inc SP	Inc WP	Inc ESS	Ren Energy	Dec SP	Dec WP
2031	442.5M	123.4M	65.8M	8.9M	12.3M	6.6k	631.8M	221.3k	74.1k
2032	451.1M	135.7M	65.8M	9.0M	13.6M	6.6k	652.7M	225.6k	81.4k
2033	459.9M	149.2M	65.8M	9.2M	14.9M	6.6k	675.0M	230.0k	89.5k
2034	468.9M	164.0M	65.8M	9.4M	16.4M	6.6k	698.8M	234.5k	98.4k
2035	478.1M	180.3M	65.9M	9.6M	18.0M	6.6k	724.2M	239.0k	108.2k
2036	487.4M	198.2M	65.9M	9.7M	19.8M	6.6k	751.5M	243.7k	118.9k
2037	496.9M	217.9M	65.9M	9.9M	21.8M	6.6k	780.7M	248.4k	130.8k
2038	506.6M	239.6M	65.9M	10.1M	24.0M	6.6k	812.0M	253.3k	143.8k
2039	516.4M	263.4M	65.9M	10.3M	26.3M	6.6k	845.7M	258.2k	158.0k
2040	526.5M	289.6M	65.9M	10.5M	29.0M	6.6k	882.0M	263.3k	173.8k
2041	536.8M	318.4M	65.9M	10.7M	31.8M	6.6k	921.0M	268.4k	191.0k
2042	547.3M	350.0M	65.9M	10.9M	35.0M	6.6k	963.2M	273.6k	210.0k
2043	557.9M	384.8M	65.9M	11.2M	38.5M	6.6k	1.0B	279.0k	230.9k
2044	568.8M	423.1M	65.9M	11.4M	42.3M	6.6k	1.1B	284.4k	253.8k
2045	579.9M	465.1M	65.9M	11.6M	46.5M	6.6k	1.1B	289.9k	279.1k
2046	591.2M	511.3M	65.9M	11.8M	51.1M	6.6k	1.2B	295.6k	306.8k
2047	602.7M	562.2M	65.9M	12.1M	56.2M	6.6k	1.2B	301.4k	337.3k
2048	614.5M	618.0M	65.9M	12.3M	61.8M	6.6k	1.3B	307.2k	370.8k
2049	626.5M	679.5M	65.9M	12.5M	67.9M	6.6k	1.4B	313.2k	407.7k
Final	638.7M	747.0M	66.0M				1.5B		

Annexe 2: Result Output for Scenario 2

B.1. Social output data of scenario 2

Social Output Data

	Population	BR	DR	Migration	New Pop
2012	1.0M	41.1k	11.2k	996.0	0.0
2013	1.1M	42.3k	11.5k	1.0k	30.9k
2014	1.1M	43.6k	11.9k	1.1k	62.7k
2015	1.1M	44.9k	12.2k	1.1k	95.4k
2016	1.2M	46.2k	12.6k	1.1k	129.2k
2017	1.2M	47.6k	13.0k	1.2k	164.0k
2018	1.2M	49.1k	13.4k	1.2k	199.8k
2019	1.3M	50.5k	13.8k	1.2k	236.6k
2020	1.3M	52.1k	14.2k	1.3k	274.6k
2021	1.3M	53.6k	14.6k	1.3k	313.8k
2022	1.4M	55.2k	15.1k	1.3k	354.1k
2023	1.4M	56.9k	15.5k	1.4k	395.6k
2024	1.5M	58.6k	16.0k	1.4k	438.4k
2025	1.5M	60.4k	16.5k	1.5k	482.4k
2026	1.6M	62.2k	16.9k	1.5k	527.8k
2027	1.6M	64.1k	17.5k	1.6k	574.6k
2028	1.6M	66.0k	18.0k	1.6k	622.7k
2029	1.7M	68.0k	18.5k	1.6k	672.3k
2030	1.8M	70.0k	19.1k	1.7k	723.4k
2031	1.8M	72.1k	19.7k	1.7k	776.1k

Social Output Data

	Population	BR	DR	Migration	New Pop
2031	1.8M	72.1k	19.7k	1.7k	776.1k
2032	1.9M	74.3k	20.2k	1.8k	830.3k
2033	1.9M	76.5k	20.9k	1.9k	886.1k
2034	2.0M	78.8k	21.5k	1.9k	943.6k
2035	2.0M	81.2k	22.1k	2.0k	1.0M
2036	2.1M	83.6k	22.8k	2.0k	1.1M
2037	2.2M	86.1k	23.5k	2.1k	1.1M
2038	2.2M	88.7k	24.2k	2.2k	1.2M
2039	2.3M	91.4k	24.9k	2.2k	1.3M
2040	2.4M	94.2k	25.7k	2.3k	1.3M
2041	2.4M	97.0k	26.4k	2.4k	1.4M
2042	2.5M	99.9k	27.2k	2.4k	1.5M
2043	2.6M	102.9k	28.0k	2.5k	1.5M
2044	2.6M	106.0k	28.9k	2.6k	1.6M
2045	2.7M	109.2k	29.8k	2.6k	1.7M
2046	2.8M	112.5k	30.6k	2.7k	1.8M
2047	2.9M	115.9k	31.6k	2.8k	1.9M
2048	3.0M	119.3k	32.5k	2.9k	2.0M
2049	3.1M	122.9k	33.5k	3.0k	2.0M
Final	3.2M				2.1M

B.2. Economic output data of scenario 2

Economic output data

	GDP PC	Inc GDP	Niamey's GDP	PG Vs GDPG
2012	405.0	4.0	415.9M	1.1T
2013	409.1	4.1	432.7M	1.1T
2014	413.1	4.1	450.1M	1.2T
2015	417.3	4.2	468.3M	1.3T
2016	421.4	4.2	487.2M	1.4T
2017	425.7	4.3	506.9M	1.5T
2018	429.9	4.3	527.3M	1.6T
2019	434.2	4.3	548.6M	1.7T
2020	438.6	4.4	570.8M	1.8T
2021	442.9	4.4	593.8M	2.0T
2022	447.4	4.5	617.8M	2.1T
2023	451.8	4.5	642.7M	2.3T
2024	456.4	4.6	668.7M	2.4T
2025	460.9	4.6	695.7M	2.6T
2026	465.5	4.7	723.8M	2.8T
2027	470.2	4.7	753.0M	3.0T
2028	474.9	4.7	783.4M	3.2T
2029	479.6	4.8	815.0M	3.4T
2030	484.4	4.8	847.9M	3.7T
2031	489.3	4.9	882.1M	3.9T

Economic output data				
	GDP PC	Inc GDP	Niamey's GDP	PG Vs GDPG
2031	489.3	4.9	882.1M	3.9T
2032	494.2	4.9	917.7M	4.2T
2033	499.1	5.0	954.8M	4.5T
2034	504.1	5.0	993.3M	4.8T
2035	509.2	5.1	1.0B	5.2T
2036	514.2	5.1	1.1B	5.6T
2037	519.4	5.2	1.1B	5.9T
2038	524.6	5.2	1.2B	6.4T
2039	529.8	5.3	1.2B	6.8T
2040	535.1	5.4	1.3B	7.3T
2041	540.5	5.4	1.3B	7.8T
2042	545.9	5.5	1.4B	8.4T
2043	551.3	5.5	1.4B	9.0T
2044	556.9	5.6	1.5B	9.7T
2045	562.4	5.6	1.5B	10.3T
2046	568.0	5.7	1.6B	11.1T
2047	573.7	5.7	1.7B	11.9T
2048	579.5	5.8	1.7B	12.7T
2049	585.3	5.9	1.8B	13.6T
Final	591.1		1.9B	14.6T

B.3. Domestic Energy output data of scenario 2

Domestic energy output

	Demand	Supply	Existing	Inc Demand	Inc Prod	Elect Cons PC	Demand-Supply
2012	438.0M	505.0M	90.5M	0.0	7.2M	46.1	-67.0M
2013	438.0M	520.3M	97.7M	1.4M	7.8M	46.1	-82.3M
2014	439.4M	536.4M	105.5M	2.9M	8.4M	46.1	-97.0M
2015	442.3M	553.6M	113.9M	4.5M	9.1M	46.1	-111.2M
2016	446.8M	571.7M	123.1M	6.1M	9.8M	46.1	-124.9M
2017	452.9M	591.0M	132.9M	7.8M	10.6M	46.1	-138.1M
2018	460.7M	611.5M	143.5M	9.6M	11.5M	46.1	-150.8M
2019	470.3M	633.2M	155.0M	11.4M	12.4M	46.1	-163.0M
2020	481.7M	656.4M	167.4M	13.4M	13.4M	46.1	-174.7M
2021	495.1M	681.1M	180.8M	15.6M	14.5M	46.1	-186.0M
2022	510.7M	707.5M	195.3M	17.9M	15.6M	46.1	-196.8M
2023	528.6M	735.6M	210.9M	20.2M	16.9M	46.1	-207.0M
2024	548.8M	765.6M	227.8M	22.8M	18.2M	46.1	-216.8M
2025	571.6M	797.7M	246.0M	25.5M	19.7M	46.1	-226.1M
2026	597.1M	832.0M	265.7M	28.4M	21.3M	46.1	-234.9M
2027	625.5M	868.8M	286.9M	31.4M	23.0M	46.1	-243.2M
2028	656.9M	908.1M	309.9M	34.8M	24.8M	46.1	-251.2M
2029	691.7M	950.3M	334.7M	38.5M	26.8M	46.1	-258.5M
2030	730.2M	995.5M	361.4M	42.4M	28.9M	46.1	-265.3M
2031	772.6M	1.0B	390.4M	46.5M	31.2M	46.1	-271.5M

Domestic energy output							
	Demand	Supply	Existing	Inc Demand	Inc Prod	Elect Cons PC	Demand-Supply
2031	772.6M	1.0B	390.4M	46.5M	31.2M	46.1	-271.5M
2032	819.1M	1.1B	421.6M	50.9M	33.7M	46.1	-277.1M
2033	870.0M	1.2B	455.3M	55.7M	36.4M	46.1	-282.2M
2034	925.7M	1.2B	491.7M	60.6M	39.3M	46.1	-286.8M
2035	986.3M	1.3B	531.1M	66.1M	42.5M	46.1	-290.9M
2036	1.1B	1.3B	573.6M	72.9M	45.9M	46.1	-294.5M
2037	1.1B	1.4B	619.5M	80.0M	49.6M	46.1	-296.7M
2038	1.2B	1.5B	669.0M	87.7M	53.5M	46.1	-297.6M
2039	1.3B	1.6B	722.5M	96.3M	57.8M	46.1	-297.2M
2040	1.4B	1.7B	780.3M	106.2M	62.4M	46.1	-294.9M
2041	1.5B	1.8B	842.8M	116.8M	67.4M	46.1	-290.2M
2042	1.6B	1.9B	910.2M	128.0M	72.8M	46.1	-283.0M
2043	1.7B	2.0B	983.0M	141.5M	78.6M	46.1	-273.2M
2044	1.9B	2.1B	1.1B	156.8M	84.9M	46.1	-259.5M
2045	2.0B	2.3B	1.1B	173.2M	91.7M	46.1	-240.8M
2046	2.2B	2.4B	1.2B	190.6M	99.1M	46.1	-216.8M
2047	2.4B	2.6B	1.3B	212.5M	107.0M	46.1	-187.6M
2048	2.6B	2.8B	1.4B	236.6M	115.5M	46.1	-149.8M
2049	2.9B	3.0B	1.6B	262.3M	124.8M	46.1	-102.2M
Final	3.1B	3.2B	1.7B			46.1	-44.4M

B.4. Renewable Energy output data of scenario 2

Renewable energy output

	Ren Energy	Solar Pow	Wind Pow	ESS	Inc SP	Inc WP	Inc ESS	Dec SP	Dec WP
2012	414.6M	306.6M	20.4M	87.6M	6.1M	2.0M	8.8k	153.3k	12.2k
2013	422.6M	312.6M	22.4M	87.6M	6.3M	2.2M	8.8k	156.3k	13.5k
2014	430.9M	318.7M	24.6M	87.6M	6.4M	2.5M	8.8k	159.3k	14.8k
2015	439.6M	324.9M	27.1M	87.6M	6.5M	2.7M	8.8k	162.4k	16.3k
2016	448.6M	331.2M	29.8M	87.6M	6.6M	3.0M	8.8k	165.6k	17.9k
2017	458.1M	337.7M	32.7M	87.6M	6.8M	3.3M	8.8k	168.8k	19.6k
2018	467.9M	344.3M	36.0M	87.7M	6.9M	3.6M	8.8k	172.1k	21.6k
2019	478.2M	351.0M	39.6M	87.7M	7.0M	4.0M	8.8k	175.5k	23.7k
2020	489.0M	357.8M	43.5M	87.7M	7.2M	4.4M	8.8k	178.9k	26.1k
2021	500.3M	364.8M	47.8M	87.7M	7.3M	4.8M	8.8k	182.4k	28.7k
2022	512.2M	371.9M	52.6M	87.7M	7.4M	5.3M	8.8k	186.0k	31.6k
2023	524.7M	379.2M	57.8M	87.7M	7.6M	5.8M	8.8k	189.6k	34.7k
2024	537.8M	386.6M	63.6M	87.7M	7.7M	6.4M	8.8k	193.3k	38.1k
2025	551.7M	394.1M	69.9M	87.7M	7.9M	7.0M	8.8k	197.0k	41.9k
2026	566.3M	401.8M	76.8M	87.7M	8.0M	7.7M	8.8k	200.9k	46.1k
2027	581.8M	409.6M	84.5M	87.7M	8.2M	8.4M	8.8k	204.8k	50.7k
2028	598.2M	417.6M	92.9M	87.7M	8.4M	9.3M	8.8k	208.8k	55.7k
2029	615.6M	425.8M	102.1M	87.7M	8.5M	10.2M	8.8k	212.9k	61.3k
2030	634.1M	434.1M	112.3M	87.8M	8.7M	11.2M	8.8k	217.0k	67.4k
2031	653.7M	442.5M	123.4M	87.8M	8.9M	12.3M	8.8k	221.3k	74.1k

Renewable energy output

	Ren Energy	Solar Pow	Wind Pow	ESS	Inc SP	Inc WP	Inc ESS	Dec SP	Dec WP
2031	653.7M	442.5M	123.4M	87.8M	8.9M	12.3M	8.8k	221.3k	74.1k
2032	674.6M	451.1M	135.7M	87.8M	9.0M	13.6M	8.8k	225.6k	81.4k
2033	696.9M	459.9M	149.2M	87.8M	9.2M	14.9M	8.8k	230.0k	89.5k
2034	720.7M	468.9M	164.0M	87.8M	9.4M	16.4M	8.8k	234.5k	98.4k
2035	746.2M	478.1M	180.3M	87.8M	9.6M	18.0M	8.8k	239.0k	108.2k
2036	773.4M	487.4M	198.2M	87.8M	9.7M	19.8M	8.8k	243.7k	118.9k
2037	802.6M	496.9M	217.9M	87.8M	9.9M	21.8M	8.8k	248.4k	130.8k
2038	834.0M	506.6M	239.6M	87.8M	10.1M	24.0M	8.8k	253.3k	143.8k
2039	867.7M	516.4M	263.4M	87.8M	10.3M	26.3M	8.8k	258.2k	158.0k
2040	904.0M	526.5M	289.6M	87.8M	10.5M	29.0M	8.8k	263.3k	173.8k
2041	943.0M	536.8M	318.4M	87.9M	10.7M	31.8M	8.8k	268.4k	191.0k
2042	985.1M	547.3M	350.0M	87.9M	10.9M	35.0M	8.8k	273.6k	210.0k
2043	1.0B	557.9M	384.8M	87.9M	11.2M	38.5M	8.8k	279.0k	230.9k
2044	1.1B	568.8M	423.1M	87.9M	11.4M	42.3M	8.8k	284.4k	253.8k
2045	1.1B	579.9M	465.1M	87.9M	11.6M	46.5M	8.8k	289.9k	279.1k
2046	1.2B	591.2M	511.3M	87.9M	11.8M	51.1M	8.8k	295.6k	306.8k
2047	1.3B	602.7M	562.2M	87.9M	12.1M	56.2M	8.8k	301.4k	337.3k
2048	1.3B	614.5M	618.0M	87.9M	12.3M	61.8M	8.8k	307.2k	370.8k
2049	1.4B	626.5M	679.5M	87.9M	12.5M	67.9M	8.8k	313.2k	407.7k
Final	1.5B	638.7M	747.0M	87.9M					

Annexe 3: Result Output for Scenario 3

C.1. Social output data of scenario 3

Social output data

	Population	BR	DR	Migration	New Pop
2012	1.0M	35.9k	11.2k	996.0	0.0
2013	1.1M	36.8k	11.5k	1.0k	25.7k
2014	1.1M	37.8k	11.8k	1.0k	52.1k
2015	1.1M	38.7k	12.1k	1.1k	79.2k
2016	1.1M	39.7k	12.4k	1.1k	106.9k
2017	1.2M	40.7k	12.7k	1.1k	135.3k
2018	1.2M	41.7k	13.0k	1.2k	164.5k
2019	1.2M	42.7k	13.3k	1.2k	194.3k
2020	1.3M	43.8k	13.6k	1.2k	225.0k
2021	1.3M	44.9k	14.0k	1.2k	256.3k
2022	1.3M	46.0k	14.3k	1.3k	288.5k
2023	1.3M	47.2k	14.7k	1.3k	321.5k
2024	1.4M	48.4k	15.1k	1.3k	355.3k
2025	1.4M	49.6k	15.4k	1.4k	389.9k
2026	1.5M	50.8k	15.8k	1.4k	425.4k
2027	1.5M	52.1k	16.2k	1.4k	461.9k
2028	1.5M	53.4k	16.6k	1.5k	499.2k
2029	1.6M	54.7k	17.1k	1.5k	537.4k
2030	1.6M	56.1k	17.5k	1.6k	576.7k
2031	1.6M	57.5k	17.9k	1.6k	616.9k

Social output data

	Population	BR	DR	Migration	New Pop
2031	1.6M	57.5k	17.9k	1.6k	616.9k
2032	1.7M	59.0k	18.4k	1.6k	658.1k
2033	1.7M	60.5k	18.8k	1.7k	700.3k
2034	1.8M	62.0k	19.3k	1.7k	743.6k
2035	1.8M	63.5k	19.8k	1.8k	788.0k
2036	1.9M	65.1k	20.3k	1.8k	833.5k
2037	1.9M	66.7k	20.8k	1.8k	880.1k
2038	2.0M	68.4k	21.3k	1.9k	927.9k
2039	2.0M	70.1k	21.8k	1.9k	976.9k
2040	2.1M	71.9k	22.4k	2.0k	1.0M
2041	2.1M	73.7k	23.0k	2.0k	1.1M
2042	2.2M	75.5k	23.5k	2.1k	1.1M
2043	2.2M	77.4k	24.1k	2.1k	1.2M
2044	2.3M	79.4k	24.7k	2.2k	1.2M
2045	2.3M	81.4k	25.3k	2.3k	1.3M
2046	2.4M	83.4k	26.0k	2.3k	1.4M
2047	2.4M	85.5k	26.6k	2.4k	1.4M
2048	2.5M	87.6k	27.3k	2.4k	1.5M
2049	2.6M	89.8k	28.0k	2.5k	1.5M
Final	2.6M				1.6M

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C.2. Economic output data of scenario 3

Economic output data				
	GDP PC	Inc GDP	Niamey's GDP	PG Vs GDPG
2012	405.0	4.0	415.9M	1.1T
2013	409.1	4.1	430.6M	1.1T
2014	413.1	4.1	445.8M	1.2T
2015	417.3	4.2	461.5M	1.3T
2016	421.4	4.2	477.8M	1.3T
2017	425.7	4.3	494.7M	1.4T
2018	429.9	4.3	512.2M	1.5T
2019	434.2	4.3	530.3M	1.6T
2020	438.6	4.4	549.0M	1.7T
2021	442.9	4.4	568.4M	1.8T
2022	447.4	4.5	588.5M	1.9T
2023	451.8	4.5	609.2M	2.0T
2024	456.4	4.6	630.8M	2.2T
2025	460.9	4.6	653.0M	2.3T
2026	465.5	4.7	676.1M	2.4T
2027	470.2	4.7	700.0M	2.6T
2028	474.9	4.7	724.7M	2.7T
2029	479.6	4.8	750.3M	2.9T
2030	484.4	4.8	776.8M	3.1T
2031	489.3	4.9	804.2M	3.3T

Economic output data

	GDP PC	Inc GDP	Niamey's GDP	PG Vs GDPG
2031	489.3	4.9	804.2M	3.3T
2032	494.2	4.9	832.6M	3.5T
2033	499.1	5.0	862.1M	3.7T
2034	504.1	5.0	892.5M	3.9T
2035	509.2	5.1	924.0M	4.1T
2036	514.2	5.1	956.7M	4.4T
2037	519.4	5.2	990.5M	4.7T
2038	524.6	5.2	1.0B	4.9T
2039	529.8	5.3	1.1B	5.3T
2040	535.1	5.4	1.1B	5.6T
2041	540.5	5.4	1.1B	5.9T
2042	545.9	5.5	1.2B	6.3T
2043	551.3	5.5	1.2B	6.7T
2044	556.9	5.6	1.3B	7.1T
2045	562.4	5.6	1.3B	7.5T
2046	568.0	5.7	1.4B	8.0T
2047	573.7	5.7	1.4B	8.5T
2048	579.5	5.8	1.5B	9.0T
2049	585.3	5.9	1.5B	9.5T
Final	591.1		1.6B	10.1T

C.3. Domestic energy output data of scenario 3

Domestic Energy output								
	Demand	Supply	Existing	Inc Demand	Inc Prod	Elect Cons PC	Demand-Supply
2012	438.0M	451.0M	90.5M	0.0	7.2M	46.1	-13.0M
2013	438.0M	459.6M	97.7M	1.2M	7.8M	46.1	-21.6M
2014	439.2M	468.7M	105.5M	2.5M	8.4M	46.1	-29.5M
2015	441.7M	478.5M	113.9M	3.8M	9.1M	46.1	-36.8M
2016	445.4M	489.0M	123.1M	5.1M	9.8M	46.1	-43.6M
2017	450.5M	500.3M	132.9M	6.6M	10.6M	46.1	-49.7M
2018	457.1M	512.4M	143.5M	8.1M	11.5M	46.1	-55.3M
2019	465.2M	525.4M	155.0M	9.6M	12.4M	46.1	-60.2M
2020	474.8M	539.4M	167.4M	11.2M	13.4M	46.1	-64.6M
2021	486.0M	554.4M	180.8M	12.9M	14.5M	46.1	-68.4M
2022	499.0M	570.6M	195.3M	14.7M	15.6M	46.1	-71.6M
2023	513.7M	587.9M	210.9M	16.6M	16.9M	46.1	-74.3M
2024	530.2M	606.6M	227.8M	18.5M	18.2M	46.1	-76.4M
2025	548.8M	626.8M	246.0M	20.6M	19.7M	46.1	-78.0M
2026	569.3M	648.4M	265.7M	22.7M	21.3M	46.1	-79.1M
2027	592.0M	671.7M	286.9M	24.9M	23.0M	46.1	-79.7M
2028	616.9M	696.8M	309.9M	27.2M	24.8M	46.1	-79.9M
2029	644.1M	723.8M	334.7M	29.6M	26.8M	46.1	-79.7M
2030	673.7M	752.9M	361.4M	32.1M	28.9M	46.1	-79.2M
2031	705.8M	784.2M	390.4M	34.7M	31.2M	46.1	-78.5M

Domestic Energy output

	Demand	Supply	Existing	Inc Demand	Inc Prod	Elect Cons PC	Demand-Supply
2031	705.8M	784.2M	390.4M	34.7M	31.2M	46.1	-78.5M
2032	740.4M	817.9M	421.6M	37.8M	33.7M	46.1	-77.5M
2033	778.2M	854.3M	455.3M	41.1M	36.4M	46.1	-76.1M
2034	819.3M	893.5M	491.7M	44.5M	39.3M	46.1	-74.2M
2035	863.8M	935.7M	531.1M	48.1M	42.5M	46.1	-71.9M
2036	911.9M	981.1M	573.6M	51.9M	45.9M	46.1	-69.2M
2037	963.8M	1.0B	619.5M	55.9M	49.6M	46.1	-66.3M
2038	1.0B	1.1B	669.0M	60.0M	53.5M	46.1	-63.3M
2039	1.1B	1.1B	722.5M	64.4M	57.8M	46.1	-60.2M
2040	1.1B	1.2B	780.3M	69.0M	62.4M	46.1	-57.1M
2041	1.2B	1.3B	842.8M	74.5M	67.4M	46.1	-54.4M
2042	1.3B	1.3B	910.2M	81.0M	72.8M	46.1	-51.3M
2043	1.4B	1.4B	983.0M	87.9M	78.6M	46.1	-47.2M
2044	1.5B	1.5B	1.1B	95.2M	84.9M	46.1	-42.3M
2045	1.6B	1.6B	1.1B	102.9M	91.7M	46.1	-36.5M
2046	1.7B	1.7B	1.2B	111.0M	99.1M	46.1	-30.1M
2047	1.8B	1.8B	1.3B	119.6M	107.0M	46.1	-23.2M
2048	1.9B	1.9B	1.4B	128.5M	115.5M	46.1	-15.9M
2049	2.0B	2.0B	1.6B	138.0M	124.8M	46.1	-8.5M
Final	2.2B	2.2B	1.7B			46.1	-1.1M

C.4. Renewable energy output data of scenario 3

Renewable Energy output

	Ren Energy	Solar Pow	Wind Pow	ESS	Inc SP	Inc WP	Inc ESS	Dec SP	Dec WP
2012	360.6M	262.8M	10.2M	87.6M	788.4k	611.7k	8.8k	131.4k	6.1k
2013	361.9M	263.5M	10.8M	87.6M	790.4k	648.0k	8.8k	131.7k	6.5k
2014	363.2M	264.1M	11.4M	87.6M	792.3k	686.5k	8.8k	132.1k	6.9k
2015	364.5M	264.8M	12.1M	87.6M	794.3k	727.3k	8.8k	132.4k	7.3k
2016	365.9M	265.4M	12.8M	87.6M	796.3k	770.5k	8.8k	132.7k	7.7k
2017	367.3M	266.1M	13.6M	87.6M	798.3k	816.3k	8.8k	133.1k	8.2k
2018	368.8M	266.8M	14.4M	87.7M	800.3k	864.8k	8.8k	133.4k	8.6k
2019	370.4M	267.4M	15.3M	87.7M	802.3k	916.1k	8.8k	133.7k	9.2k
2020	371.9M	268.1M	16.2M	87.7M	804.3k	970.5k	8.8k	134.1k	9.7k
2021	373.6M	268.8M	17.1M	87.7M	806.3k	1.0M	8.8k	134.4k	10.3k
2022	375.3M	269.4M	18.2M	87.7M	808.3k	1.1M	8.8k	134.7k	10.9k
2023	377.0M	270.1M	19.2M	87.7M	810.4k	1.2M	8.8k	135.1k	11.5k
2024	378.9M	270.8M	20.4M	87.7M	812.4k	1.2M	8.8k	135.4k	12.2k
2025	380.8M	271.5M	21.6M	87.7M	814.4k	1.3M	8.8k	135.7k	13.0k
2026	382.7M	272.1M	22.9M	87.7M	816.4k	1.4M	8.8k	136.1k	13.7k
2027	384.8M	272.8M	24.2M	87.7M	818.5k	1.5M	8.8k	136.4k	14.5k
2028	386.9M	273.5M	25.7M	87.7M	820.5k	1.5M	8.8k	136.8k	15.4k
2029	389.1M	274.2M	27.2M	87.7M	822.6k	1.6M	8.8k	137.1k	16.3k
2030	391.4M	274.9M	28.8M	87.8M	824.6k	1.7M	8.8k	137.4k	17.3k
2031	393.9M	275.6M	30.5M	87.8M	826.7k	1.8M	8.8k	137.8k	18.3k

Renewable Energy output									
	Ren Energy	Solar Pow	Wind Pow	ESS	Inc SP	Inc WP	Inc ESS	Dec SP	Dec WP
2031	393.9M	275.6M	30.5M	87.8M	826.7k	1.8M	8.8k	137.8k	18.3k
2032	396.4M	276.3M	32.3M	87.8M	828.8k	1.9M	8.8k	138.1k	19.4k
2033	399.0M	276.9M	34.2M	87.8M	830.8k	2.1M	8.8k	138.5k	20.5k
2034	401.7M	277.6M	36.3M	87.8M	832.9k	2.2M	8.8k	138.8k	21.8k
2035	404.6M	278.3M	38.4M	87.8M	835.0k	2.3M	8.8k	139.2k	23.1k
2036	407.6M	279.0M	40.7M	87.8M	837.1k	2.4M	8.8k	139.5k	24.4k
2037	410.7M	279.7M	43.1M	87.8M	839.2k	2.6M	8.8k	139.9k	25.9k
2038	414.0M	280.4M	45.7M	87.8M	841.3k	2.7M	8.8k	140.2k	27.4k
2039	417.4M	281.1M	48.4M	87.8M	843.4k	2.9M	8.8k	140.6k	29.1k
2040	421.0M	281.8M	51.3M	87.8M	845.5k	3.1M	8.8k	140.9k	30.8k
2041	424.7M	282.5M	54.3M	87.9M	847.6k	3.3M	8.8k	141.3k	32.6k
2042	428.7M	283.2M	57.6M	87.9M	849.7k	3.5M	8.8k	141.6k	34.5k
2043	432.8M	283.9M	61.0M	87.9M	851.8k	3.7M	8.8k	142.0k	36.6k
2044	437.2M	284.7M	64.6M	87.9M	854.0k	3.9M	8.8k	142.3k	38.8k
2045	441.7M	285.4M	68.4M	87.9M	856.1k	4.1M	8.8k	142.7k	41.1k
2046	446.5M	286.1M	72.5M	87.9M	858.3k	4.4M	8.8k	143.0k	43.5k
2047	451.5M	286.8M	76.8M	87.9M	860.4k	4.6M	8.8k	143.4k	46.1k
2048	456.8M	287.5M	81.4M	87.9M	862.6k	4.9M	8.8k	143.8k	48.8k
2049	462.4M	288.2M	86.2M	87.9M	864.7k	5.2M	8.8k	144.1k	51.7k
Final	468.2M	289.0M	91.3M	87.9M					

Annexe 4: Result Output for Scenario 4

D.1. Social output data of scenario 4

Social output data

	Population	BR	DR	Migration	New Pop
2012	1.0M	30.8k	11.2k	996.0	0.0
2013	1.0M	31.4k	11.4k	1.0k	20.6k
2014	1.1M	32.1k	11.6k	1.0k	41.6k
2015	1.1M	32.7k	11.9k	1.1k	63.1k
2016	1.1M	33.4k	12.1k	1.1k	85.0k
2017	1.1M	34.0k	12.4k	1.1k	107.3k
2018	1.2M	34.7k	12.6k	1.1k	130.0k
2019	1.2M	35.4k	12.9k	1.1k	153.2k
2020	1.2M	36.1k	13.1k	1.2k	176.9k
2021	1.2M	36.8k	13.4k	1.2k	201.1k
2022	1.3M	37.6k	13.7k	1.2k	225.7k
2023	1.3M	38.3k	13.9k	1.2k	250.9k
2024	1.3M	39.1k	14.2k	1.3k	276.5k
2025	1.3M	39.9k	14.5k	1.3k	302.7k
2026	1.4M	40.7k	14.8k	1.3k	329.4k
2027	1.4M	41.5k	15.1k	1.3k	356.6k
2028	1.4M	42.3k	15.4k	1.4k	384.3k
2029	1.4M	43.2k	15.7k	1.4k	412.7k
2030	1.5M	44.1k	16.0k	1.4k	441.6k
2031	1.5M	44.9k	16.3k	1.5k	471.0k

Social output data

	Population	BR	DR	Migration	New Pop
2031	1.5M	44.9k	16.3k	1.5k	471.0k
2032	1.5M	45.8k	16.7k	1.5k	501.1k
2033	1.6M	46.8k	17.0k	1.5k	531.8k
2034	1.6M	47.7k	17.3k	1.5k	563.0k
2035	1.6M	48.7k	17.7k	1.6k	594.9k
2036	1.7M	49.6k	18.0k	1.6k	627.5k
2037	1.7M	50.6k	18.4k	1.6k	660.7k
2038	1.7M	51.6k	18.8k	1.7k	694.6k
2039	1.8M	52.7k	19.1k	1.7k	729.1k
2040	1.8M	53.7k	19.5k	1.7k	764.4k
2041	1.8M	54.8k	19.9k	1.8k	800.3k
2042	1.9M	55.9k	20.3k	1.8k	837.0k
2043	1.9M	57.0k	20.7k	1.8k	874.4k
2044	1.9M	58.2k	21.1k	1.9k	912.5k
2045	2.0M	59.3k	21.6k	1.9k	951.5k
2046	2.0M	60.5k	22.0k	2.0k	991.2k
2047	2.1M	61.8k	22.4k	2.0k	1.0M
2048	2.1M	63.0k	22.9k	2.0k	1.1M
2049	2.1M	64.3k	23.3k	2.1k	1.1M
Final	2.2M				1.2M

D.2. Economic output data of scenario 4

Economic output data

	GDP PC	Inc GDP	Niamey's GDP	PG Vs GDPG
2012	405.0	4.0	415.9M	1.1T
2013	409.1	4.1	428.5M	1.1T
2014	413.1	4.1	441.4M	1.2T
2015	417.3	4.2	454.8M	1.2T
2016	421.4	4.2	468.6M	1.3T
2017	425.7	4.3	482.7M	1.4T
2018	429.9	4.3	497.4M	1.4T
2019	434.2	4.3	512.4M	1.5T
2020	438.6	4.4	527.9M	1.6T
2021	442.9	4.4	543.9M	1.6T
2022	447.4	4.5	560.4M	1.7T
2023	451.8	4.5	577.3M	1.8T
2024	456.4	4.6	594.8M	1.9T
2025	460.9	4.6	612.8M	2.0T
2026	465.5	4.7	631.4M	2.1T
2027	470.2	4.7	650.5M	2.2T
2028	474.9	4.7	670.2M	2.3T
2029	479.6	4.8	690.5M	2.5T
2030	484.4	4.8	711.4M	2.6T
2031	489.3	4.9	732.9M	2.7T

	Economic output data			
	GDP PC	Inc GDP	Niamey's GDP	PG Vs GDPG
2031	489.3	4.9	732.9M	2.7T
2032	494.2	4.9	755.1M	2.8T
2033	499.1	5.0	777.9M	3.0T
2034	504.1	5.0	801.5M	3.1T
2035	509.2	5.1	825.7M	3.3T
2036	514.2	5.1	850.7M	3.5T
2037	519.4	5.2	876.5M	3.7T
2038	524.6	5.2	903.0M	3.8T
2039	529.8	5.3	930.4M	4.0T
2040	535.1	5.4	958.5M	4.2T
2041	540.5	5.4	987.5M	4.5T
2042	545.9	5.5	1.0B	4.7T
2043	551.3	5.5	1.0B	4.9T
2044	556.9	5.6	1.1B	5.2T
2045	562.4	5.6	1.1B	5.4T
2046	568.0	5.7	1.1B	5.7T
2047	573.7	5.7	1.2B	6.0T
2048	579.5	5.8	1.2B	6.3T
2049	585.3	5.9	1.3B	6.6T
Final	591.1		1.3B	7.0T

D.3. Domestic energy output data of scenario 4

Domestic energy output

	Demand	Supply	Existing	Inc Demand	Inc Prod	Elect Cons PC	Demand-Supply
2012	438.0M	451.0M	90.5M	0.0	7.2M	46.1	-13.0M
2013	438.0M	458.4M	97.7M	959.7k	7.8M	46.1	-20.4M
2014	439.0M	466.4M	105.5M	2.0M	8.4M	46.1	-27.4M
2015	440.9M	475.0M	113.9M	3.0M	9.1M	46.1	-34.1M
2016	443.9M	484.3M	123.1M	4.1M	9.8M	46.1	-40.3M
2017	448.0M	494.3M	132.9M	5.2M	10.6M	46.1	-46.3M
2018	453.2M	505.0M	143.5M	6.4M	11.5M	46.1	-51.8M
2019	459.6M	516.7M	155.0M	7.6M	12.4M	46.1	-57.1M
2020	467.2M	529.2M	167.4M	8.8M	13.4M	46.1	-62.1M
2021	476.0M	542.8M	180.8M	10.1M	14.5M	46.1	-66.8M
2022	486.1M	557.4M	195.3M	11.5M	15.6M	46.1	-71.3M
2023	497.6M	573.2M	210.9M	12.9M	16.9M	46.1	-75.5M
2024	510.6M	590.2M	227.8M	14.4M	18.2M	46.1	-79.6M
2025	525.0M	608.6M	246.0M	16.0M	19.7M	46.1	-83.6M
2026	541.0M	628.4M	265.7M	17.6M	21.3M	46.1	-87.5M
2027	558.5M	649.8M	286.9M	19.2M	23.0M	46.1	-91.3M
2028	577.7M	672.9M	309.9M	20.9M	24.8M	46.1	-95.2M
2029	598.7M	697.9M	334.7M	22.7M	26.8M	46.1	-99.2M
2030	621.4M	724.8M	361.4M	24.6M	28.9M	46.1	-103.4M
2031	645.9M	753.9M	390.4M	26.5M	31.2M	46.1	-107.9M

Domestic energy output

	Demand	Supply	Existing	Inc Demand	Inc Prod	Elect Cons PC	Demand-Supply
2031	645.9M	753.9M	390.4M	26.5M	31.2M	46.1	-107.9M
2032	672.4M	785.3M	421.6M	28.8M	33.7M	46.1	-112.8M
2033	701.2M	819.1M	455.3M	31.2M	36.4M	46.1	-117.9M
2034	732.4M	855.7M	491.7M	33.7M	39.3M	46.1	-123.3M
2035	766.1M	895.2M	531.1M	36.3M	42.5M	46.1	-129.1M
2036	802.4M	937.9M	573.6M	39.1M	45.9M	46.1	-135.4M
2037	841.5M	983.9M	619.5M	41.9M	49.6M	46.1	-142.4M
2038	883.5M	1.0B	669.0M	44.9M	53.5M	46.1	-150.2M
2039	928.4M	1.1B	722.5M	48.1M	57.8M	46.1	-158.9M
2040	976.5M	1.1B	780.3M	51.3M	62.4M	46.1	-168.8M
2041	1.0B	1.2B	842.8M	55.2M	67.4M	46.1	-180.0M
2042	1.1B	1.3B	910.2M	59.9M	72.8M	46.1	-192.4M
2043	1.1B	1.3B	983.0M	64.8M	78.6M	46.1	-205.4M
2044	1.2B	1.4B	1.1B	70.0M	84.9M	46.1	-219.4M
2045	1.3B	1.5B	1.1B	75.5M	91.7M	46.1	-234.4M
2046	1.4B	1.6B	1.2B	81.2M	99.1M	46.1	-250.9M
2047	1.4B	1.7B	1.3B	87.1M	107.0M	46.1	-268.9M
2048	1.5B	1.8B	1.4B	93.4M	115.5M	46.1	-288.9M
2049	1.6B	1.9B	1.6B	99.9M	124.8M	46.1	-311.3M
Final	1.7B	2.1B	1.7B			46.1	-336.3M

D.4. Renewable energy output data of scenario 4

Renewable energy output

	Ren Energy	Solar Pow	Wind Pow	ESS	Inc SP	Inc WP	Inc ESS	Dec SP	Dec WP
2012	360.6M	284.7M	10.2M	65.7M	284.7k	10.2k	6.6k	142.3k	6.1k
2013	360.7M	284.8M	10.2M	65.7M	284.8k	10.2k	6.6k	142.4k	6.1k
2014	360.9M	285.0M	10.2M	65.7M	285.0k	10.2k	6.6k	142.5k	6.1k
2015	361.1M	285.1M	10.2M	65.7M	285.1k	10.2k	6.6k	142.6k	6.1k
2016	361.2M	285.3M	10.2M	65.7M	285.3k	10.2k	6.6k	142.6k	6.1k
2017	361.4M	285.4M	10.2M	65.7M	285.4k	10.2k	6.6k	142.7k	6.1k
2018	361.5M	285.6M	10.2M	65.7M	285.6k	10.2k	6.6k	142.8k	6.1k
2019	361.7M	285.7M	10.2M	65.7M	285.7k	10.2k	6.6k	142.8k	6.1k
2020	361.8M	285.8M	10.2M	65.8M	285.8k	10.2k	6.6k	142.9k	6.1k
2021	362.0M	286.0M	10.2M	65.8M	286.0k	10.2k	6.6k	143.0k	6.1k
2022	362.1M	286.1M	10.2M	65.8M	286.1k	10.2k	6.6k	143.1k	6.1k
2023	362.3M	286.3M	10.2M	65.8M	286.3k	10.2k	6.6k	143.1k	6.1k
2024	362.4M	286.4M	10.2M	65.8M	286.4k	10.2k	6.6k	143.2k	6.1k
2025	362.6M	286.6M	10.2M	65.8M	286.6k	10.2k	6.6k	143.3k	6.1k
2026	362.7M	286.7M	10.3M	65.8M	286.7k	10.3k	6.6k	143.3k	6.2k
2027	362.9M	286.8M	10.3M	65.8M	286.8k	10.3k	6.6k	143.4k	6.2k
2028	363.1M	287.0M	10.3M	65.8M	287.0k	10.3k	6.6k	143.5k	6.2k
2029	363.2M	287.1M	10.3M	65.8M	287.1k	10.3k	6.6k	143.6k	6.2k
2030	363.4M	287.3M	10.3M	65.8M	287.3k	10.3k	6.6k	143.6k	6.2k
2031	363.5M	287.4M	10.3M	65.8M	287.4k	10.3k	6.6k	143.7k	6.2k

Renewable energy output

	Ren Energy	Solar Pow	Wind Pow	ESS	Inc SP	Inc WP	Inc ESS	Dec SP	Dec WP
2031	363.5M	287.4M	10.3M	65.8M	287.4k	10.3k	6.6k	143.7k	6.2k
2032	363.7M	287.6M	10.3M	65.8M	287.6k	10.3k	6.6k	143.8k	6.2k
2033	363.8M	287.7M	10.3M	65.8M	287.7k	10.3k	6.6k	143.9k	6.2k
2034	364.0M	287.8M	10.3M	65.8M	287.8k	10.3k	6.6k	143.9k	6.2k
2035	364.1M	288.0M	10.3M	65.9M	288.0k	10.3k	6.6k	144.0k	6.2k
2036	364.3M	288.1M	10.3M	65.9M	288.1k	10.3k	6.6k	144.1k	6.2k
2037	364.4M	288.3M	10.3M	65.9M	288.3k	10.3k	6.6k	144.1k	6.2k
2038	364.6M	288.4M	10.3M	65.9M	288.4k	10.3k	6.6k	144.2k	6.2k
2039	364.8M	288.6M	10.3M	65.9M	288.6k	10.3k	6.6k	144.3k	6.2k
2040	364.9M	288.7M	10.3M	65.9M	288.7k	10.3k	6.6k	144.4k	6.2k
2041	365.1M	288.9M	10.3M	65.9M	288.9k	10.3k	6.6k	144.4k	6.2k
2042	365.2M	289.0M	10.3M	65.9M	289.0k	10.3k	6.6k	144.5k	6.2k
2043	365.4M	289.1M	10.3M	65.9M	289.1k	10.3k	6.6k	144.6k	6.2k
2044	365.5M	289.3M	10.3M	65.9M	289.3k	10.3k	6.6k	144.6k	6.2k
2045	365.7M	289.4M	10.3M	65.9M	289.4k	10.3k	6.6k	144.7k	6.2k
2046	365.8M	289.6M	10.3M	65.9M	289.6k	10.3k	6.6k	144.8k	6.2k
2047	366.0M	289.7M	10.3M	65.9M	289.7k	10.3k	6.6k	144.9k	6.2k
2048	366.1M	289.9M	10.3M	65.9M	289.9k	10.3k	6.6k	144.9k	6.2k
2049	366.3M	290.0M	10.3M	65.9M	290.0k	10.3k	6.6k	145.0k	6.2k
Final	366.5M	290.2M	10.4M	66.0M					