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

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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 paper proposes to use a System Dynamics (SD) modelling 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 will double in the horizon 2036 under the actual birth and death rates; (2) the highest summer electricity demand in the year 2015 was 217 MW; (3) electricity supply can be far higher than demand by implementing a 50 MW Renewable Energy Sources (RES) in conjunction with a 10 MW Energy Storage System (ESS); and (4) through a sensitive analysis, Niamey and neighboring vicinity would reach energy independence from 2017 to 2055, and even beyond.**

Keywords*— *System dynamics; Niamey; energy security; energy storage systems; policy implications

I. Introduction

Energy balance is a real issue for developing countries. However, most of these emerging countries have a huge renewable energy (RE) potential. The lack of adequate technology is the main reason this abundance of RE, such as solar and wind, cannot be geared to support the collective economic endeavors. 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) [1] and [2].

Niger is one such developing countries and its electricity supply is more than 80% based on fossil fuel resources and importation from Nigeria. 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 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 [3] and [4].

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. The lack of sufficient power supply in the capital city slows down any economic prosperity in the country. It is a fact that both reliable and cost effective energy sources are key factors to stimulating economic development in the major sectors. Some examples of the dominant sectors are the industry, commerce, agriculture, water availability, and the like. Hence, the fast growing population and the national efforts to implement new and sophisticated industrial infrastructures to boost the economy were the main reasons in looking for alternative power generation systems [3].

The impact of DG on the distribution system is investigated in this paper in order to improve the existing power quality. Various small renewable power sources (solar and wind energy) in conjunction with 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. Therefore, to achieve the study objectives, STELLA PROFESIONAL 1.4 software is utilized [5].

The approach in this paper is organized as follows: (1) Sec. I, briefly introduces the subject of the matter; (2) Sec. II exposes the methods and data collection schemes; (3) the findings and their implications are presented in Sec. III; and (4) finally, the conclusion and policy implications are addressed in Sec. IV.

II. Methodology

A. 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 [6]. A SD approach is used in this paper. SD link theories, procedures, and philosophies will be utilized to analyze the behavior of some complex feedback (FB) systems, such as power supply and demand trends [7]. 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. A detailed analysis can be found in Ref. [3]. The SD model of the system under study in shown in Fig 1.

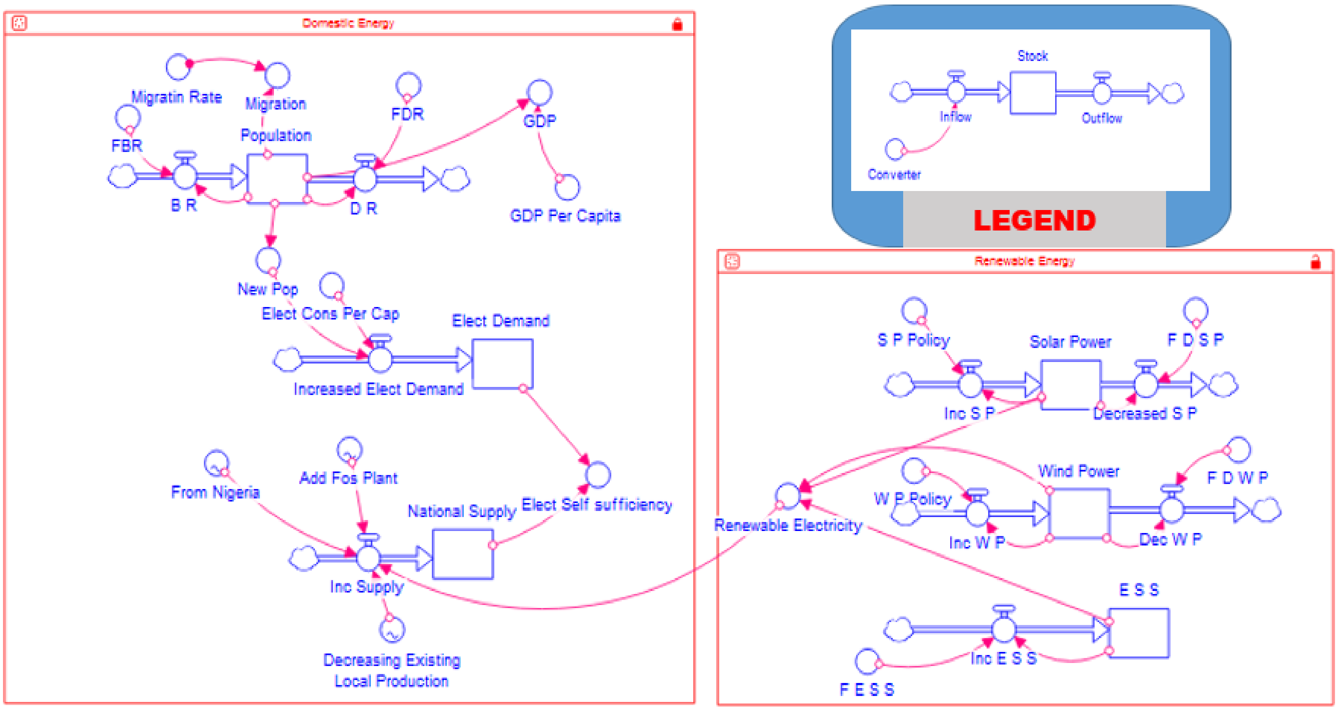

Figure 1. System Dynamics Stocks and Flows Model

This model is composed of two major parts. First, the National Electricity Supply, which is a combination of the (i) local electricity production by the national company NIGELEC, (ii) electricity import from Nigeria, (iii) future implementation of a 50 MW solar power plant and 5 wind turbines, and (iv) proposed 10 MW of Energy Storage System (ESS) around Niamey. The second aspect is based on social parameters, which have a strong impact on the national electricity production, knowing the population and the geographical boundaries of this study. Niamey is chosen, not only because of the its high energy potential, but also because 61.75% of the total electricity of Niger was consumed by its residents. The time horizon of this model is 40 years starting from 2015 through 2055.

B. 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 2015 the highest electricity demand in Niamey was estimated at 127 MW with an install capacity of 54.4 MW. Conversely, from the aforementioned installed capacity, only 27.3 MW were available because of inefficient plants built decades ago (before 2010) and aging generators installed thirty years ago (before 1990). Local peak electricity production in 2015 was 42.8 MW. An additional 58.5 MW were imported from Nigeria. In other words, the gap between electricity supply and demand was found to be 25.7 MW.

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

(1) the population of Niamey was 1126257 people in 2015;
(2) the Birth Rate (BR) and Death Rate (DR), respectively 44.8 and 12.1 per 1000 people per year; and
(3) the Gross Domestic Product (GDP) per capita in Niger in 2014 was $ 387.5 USD.

Moreover, 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. In the model, we also made use of 22 years (1995-2016) wind speed data from “La Direction de la Météorologie Nationale” (DMN) of Niger and [8]. Finally, 17 years (2005-2016) of stream flow data of the Niger river from the Hydrology Ministry was used to analyze the renewable energy potential of Niamey. This study covered three types of RE, including solar PV, hydropower, and wind energy.

Due to the difficulty 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.

C. Limitations

This model does not take into account the individual electricity demand of the three main sectors of the economy. Some of these sectors include, but not limited to industry, agriculture, and commerce. Most of the sectors lack of detailed energy consumption plans or possess their own generators.

III. 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.

A. 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 to 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 44.8 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 2 illustrates the simulation of future population trends. This figure shows that the population of the capital city will double in the horizon of the year 2036 under the current BR scenario. 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 the business men that there is a potential and urgent need to invest in the energy sector decades from today.

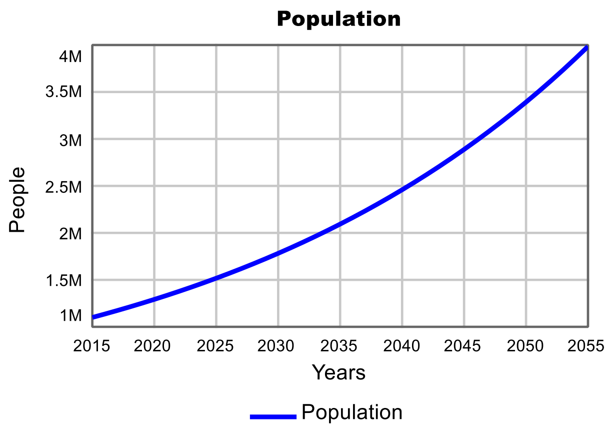

Figure 2. Population evolution of Niamey.

B. Electricity Supply and Demand in Niamey

Figure 3 shows a typical daily electric load patterns in Niamey during the month of June. Thus, after a close examination of the figure, it can be observed that the highest electricity demand, in that day of summer 2015, was 127 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.

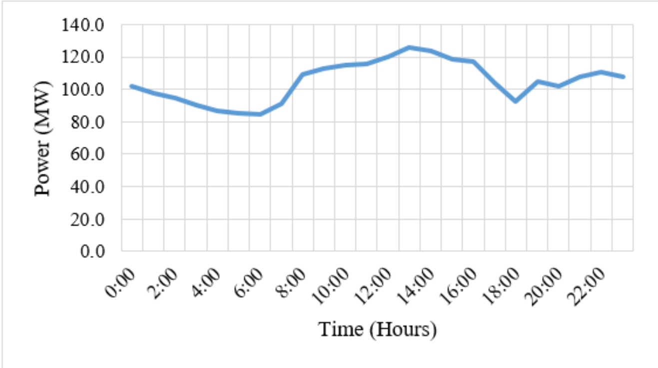

Figure 3. Daily Electricity Demand in Niamey

Moreover, Fig. 4 represents the long-term electricity supply and demand trends after a dynamic simulation of the model has been done to capture all the interdependencies between variables. It can be seen that Niamey has reached its energy production limits in early 2016 under this policy run. This rapid growth of electricity demand can be explained by the significant population growth rate. The latter itself is intimately 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. The proposed theoretical electricity capacity is far greater than the demand. In order to reach electricity independence in the capital city and vicinity, a 55 MW of RES and 10 MW of Energy Storage System were proposed to be added to the existing supply. Also, the electricity import from Nigeria was kept as an integral part of the national supply for the first four years of the model.

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 and thus put out a 50 MW on the distribution grid. The model then investigates the impacts of some small wind turbines at night in conjunction with energy storage systems. Together, they should generate a constant 15 MW to be added to the existing capacity.

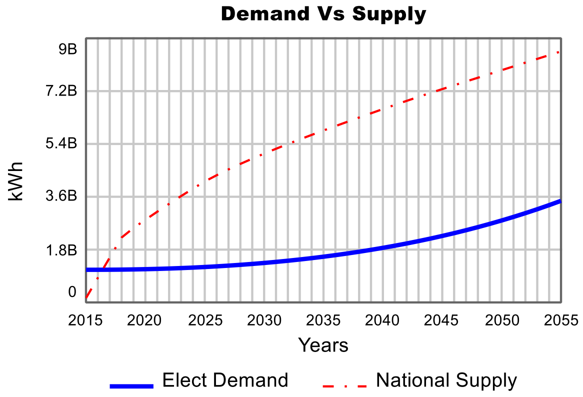

Figure 4. Electricity Supply and Demand

The diurnal electricity supply and demand patterns under the 44.8 per thousand inhabitants' scenario is shown in Fig. 5. The figure clearly depicts that the electricity supply is higher than demand from 2017 to 2040, as opposed to the scenario seen in Fig. 4. Under these conditions with the subsequent results exposed in Fig. 5, Niamey would attain its energy independence for twenty-three years. 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.

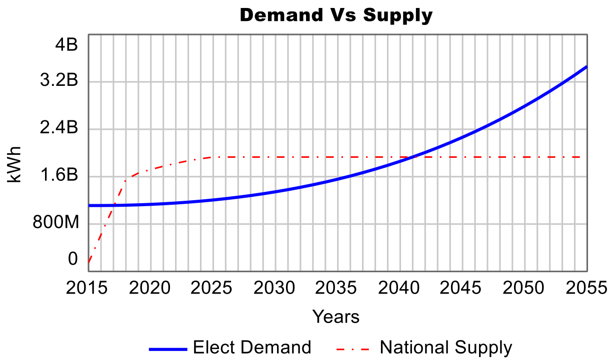

Figure 5. Nocturnal Electricity Supply and Demand (BR is 44.8)

A final scenario is portrayed in Fig. 6. A sensitivity analysis is proposed with a drastic reduction in BR (25/1000). 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.

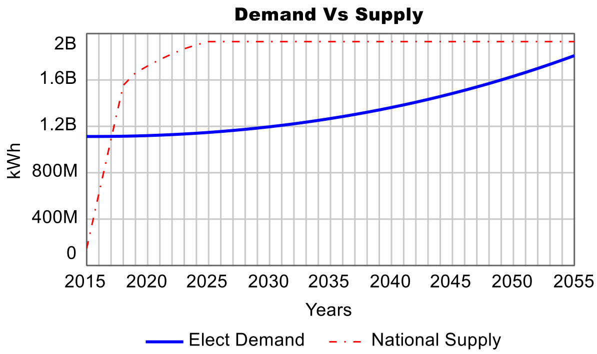

Figure 6. Nocturnal Electricity Supply and Demand (BR is 25)

C. Wind Energy Potential

Twenty-two years of diurnal wind data was obtained from a weather station located at the International Airport of Niamey. At 10m height, with given wind speeds of 3, 4, 5, 6, and 7 m/s, the frequency of distributions was respectively 32.8%, 31.3%, 17.8%, 5.0%, and 1.4%. Also, at 82m height, for the same cited wind speeds, the frequencies were 14.5%, 23.9%, 26.3%, 17.5%, and 9.8%, respectively. 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 wind turbine (Enercon E82/2000) in Niamey can give an annual energy throughput of 2,038,991.1 kWh in Niamey. The employment of 5 such of these wind turbines may yield 10.2 GWh on a yearly basis.

D. Solar Energy Potential

Solar energy is one of the most abundant and cleanest renewable sources in the universe and it is free from any GHG (greenhouse gas) and other harmful environmental pollutants [9]. 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 [10]. This model showed that the installation of 50 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. 7 shows that the implementation of the above-mentioned solar power plants can supply an annual energy of 219 GWh from 2015 to 2055.

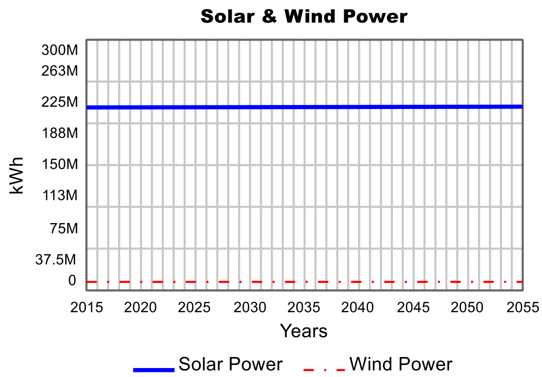

Figure 7. Solar and Wind Power Potential

E. 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.

IV. CONCLUSION

The main purpose of this study was to build policy scenarios for sustainable energy security in Niamey and vicinity using a System Dynamics modelling. 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, the: (1) transmission losses due aging infrastructure is cut down; (2) electricity distribution becomes cheap; and (3) availability, reliability, and accessibility of electric power is improved. The results of this SD model are more qualitative than quantitative and are 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.

The implementation of a 50 MW solar PV array, five wind turbines (Enercon E82/2000), and a 10 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 the birth rate (BR) to 25 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. These policies above could be used by the policy makers or private energy companies to sustain a long-term energy production with low GHG emissions.

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