Calibrating an Energy Planning Model for Niger: A System Dynamics Approach

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Abstract

Developing countries experience frequent power outages during the summer months. Load shedding becomes the norm for utilities to deal with these issues to avoid a total blackout. Due to greater demand, these power outages are generally more noticeable in the capital cities. This paper utilizes system dynamics to model energy planning in Niger. The analysis spans from 2003 to 2050. The model was tested on six policy scenarios, but only the base case is presented. This model can be utilized for policies in emerging countries. Population, household size, per-capita electricity, and the industrial sectors were input to predict the future electricity supply and demand patterns. Although Niger lacks detailed energy data, the method yields a concise energy model, which may assist utilities in planning. Results showed that the state-owned company (NIGELEC) emits 37 Mega-Tonnes of equivalent CO_2 into the environment via its fossil-fueled plants. Results also revealed that, even with the 80-100MW diesel plant installed at Gorou-Banda (2017), upcoming 20MW of PV system (2024), and full commissioning of the 130MW Kandadji dam (2025), Niger would only be energy self-sufficient for a decade. Consequently, imports continue to play significant roles in Niger's energy mix, thus hindering any noticeable long-term socio-economic development.

Keywords: System dynamics, Energy supply and demand, Per capita electricity, Carbon footprint, Niger, Population.

1. Introduction

A good understanding of a sovereign country's energy consumption is essential for its long-term economic prosperity. Consequently, a country must forecast its long-term electrical energy needs via an accurate method (Moumouni, Ahmad and Baker, 2015; Pouye and Moumouni, 2018). Proper energy planning and estimation provide a mechanism for balancing supply and demand at all times (Akhwanzada and Tahar, 2012). A dependable power supply is essential for economic attainment; it is needed for most aspects of social promotion, happiness, and security (Li, Zhang and Wei, 2011). Emerging nations, such as Niger, Nigeria, and Senegal, struggle to attain energy and food self-sufficiency. Thus, their respective inhabitants are passing by the numerous luxuries of modern life and lacking a high standard of living. A reliable energy supply remains critical for the sustainability and improvement of the well-being attained, thus far, in the aforementioned emerging nations. Therefore, a consistent power supply has become imperative to the communities in the developing countries at large because it positively impacts the economies of scale but has the potential to affect the environment in many ways (Koh and Lim, 2010) and (Moumouni, Ahmad and Baker, 2015). A hindering force to achieving energy independence in emerging countries is the particular prearranged treatment for the authorities regarding frequent load sheds. This status quo prevents the grid operators from shedding the supply of first-class citizens. The indirect consequence is creating a double standard, which does not call for any long-term solutions.

La Société Nigérienne d'Electricité, NIGELEC, is the utility company in charge of the generation, transport, and distribution of electricity in Niger. The state government controls up to 95% of NIGELEC. Furthermore, NIGELEC has a monopoly over all matters related to power management (Cigogne, 2009) in Niger. Unfortunately, it remains common knowledge that monopolistic competitions are more realistic than perfect because they are allocatively and productively inefficient in both the short and short-term (Recordon and Rudnick, 2002; Tarapaca, 2004; Hua-tao, 2007). This paradigm has typically been happening in Niger for decades now. Notwithstanding numerous benefits, monopolistic utilities have bumped into severe denunciation from NGOs, governments, and the public.

Therefore, the following are some of the harms of monopolistic markets:

(i) Monopolistic companies are price makers, i.e., they charge high prices to maintain maximum income. They often exploit customers. The consumers have no alternative but to pay the price fixed by the monopolist.

(ii) Monopolistic companies only care for their profit and have nothing to do with the market's elasticities. They only abuse lesser factors at their advantage than are economically essential.

(iii) Monopolistic companies are inherently inefficient and have to pressure to improve their services. Their prices are generally high compared to the quality of their products; thus, the consumers are stuck with no other options.

(iv) Monopolistic companies regularly apply discriminatory and cut-throat practices to remove competition. For instance, decades ago, the Nigerien government banned customers from owning generators and other dispersed resources at their premises.

(v) Monopolistic companies have the power to influence or bribe lawmakers and canal the economy to their advantage through their wealth and unfair manners. These practices typically happen in emerging countries because of capital formation. The lawmakers in such countries usually fall into the spiral trap of monopolists.

(vi) The re-distribution of the supply, in this case, electricity, is inefficient and biased under monopoly. This point has already been explained above.

(vii) Monopolistic companies tend to practice price discrimination. For instance, some countries only subsidize the tariffs, in this case, price/kWh, of their nationals, i.e., charging different prices for the same commodity.

The sub-Saharan countries are constantly struggling to meet their daily energy demand, and Niger is no exception. Electrical energy remains a challenge in Niger because a long-term energy solution has not been developed. Understanding this dynamic structure and the significant future investments to meet the present and future energy demands will undoubtedly resolve the issues of frequent power shortages in Niger, particularly in its Western part with the highest demand. To illustrate this point, the total number of customers in 2010 was estimated to be 137,714, and out of that, 87,927 customers, i.e., 63.85%, were located in the capital city, Niamey (CUN). In other words, of the over 449 GWh of energy sold in 2010, the town of Niamey purchased 331 GWh, thus making the electricity consumption in CUN roughly 74% of Niger's total energy usage (Idrissa, 2020). Further, in 2000, the Ministry in charge of housing (Ministère De l'Equipement De l'Habitat et De l'Aménagement Du Territoire) estimated that the number of additional homes to be developed in Niger at, around, 40,000 per annum (Finance and Africa, 2011). These additional houses will further drive the demand for electrical energy in Niger and are factored into the model developed in this work.

To better understand the extent of the electricity problem in Niger, it is vital to start with the current status and hindcast the historical aspects of energy supply and demand for the entire country. Henceforward, the main contributor to electricity supply in Niger is unquestionably Nigeria. The supply from Nigeria was approximately a constant 40 MW from 1976 to 2008. The transmission lines between Niger and Nigeria were then improved in 2008 to transmit up to 80 MW. This upgrading was needed to help supply the growing energy needs in the country. Unfortunately, the attempt to increase the transmission capacity failed. The renovated lines were only able to support 50 MW, falling short of 30 MW. In 2013, Niger imported more than 85% (NIGELEC, 2018; Bhandari *et al.*, 2021) of its energy from Nigeria. Fortunately, the import is decreasing due to the recent commissioning of an 80-100 MW diesel plant at Gorou-Banda (GB), although this choice poses huge environmental threats to the residents. This energy dependence limits the ability of Niger to grow, develop, and improve the well-being of its residents.

In addition to importing from Nigeria, there are, located at Gamkale (Southern part of CUN) and Goudel (Western part CUN) spinning reserve capacities. A Natural Gas (NG) turbine of 15.6 MW is located at Gamkalé, and a Heavy Fueled Oil (HFO) fired plant with 12 MW at Goudel. Together, these two-generation facilities added a capacity of 27.6 MW.

It is important to emphasize how the electricity sector is organized and subdivided in Niger. It would help better comprehend the current supply issues and, most importantly, possibly help solve them for the next three decades. The utility company divides its operations into Interconnected Zones, "Zone Inter-connectée," mainly the Northern Zone, Western Zone, and Central Zone. The Western Zone, which represents the focus of this study, had its demand estimated at 20 MW from 1976 up to 2004. In 2013, the electricity demand in this same Zone grew four times bigger (~80 MW). Since then, the demand for the study zone has grown tremendously. It was reported by the grid operators to be 215 MW in 2021 at its peak, i.e., April. In March 2022, the total demand in the Western Zone reached almost 117 MW. Around 68%, viz., 80 MW, is available to Niamey and vicinity via the transmission line (TL) from Birnin-Kebbi (BK). The utility company projects this electricity demand to reach 230 MW during the hot summer months in mid-2022. It is also worth mentioning that the supply from Kanji Dam in Nigeria is highly dependent on rainfall, and at least two minimum criteria have to be met consistently for Niger to benefit from the total capacity of the line BK-Niamey. These criteria are mainly a certain amount of rainfall per year within an acceptable range of 200 to 500 mm (UNDP, Niger) and that the entire TL should work perfectly with no failures. In addition, if all the base generators and peaker plants were "ON" simultaneously, only 127.6 MW would be produced. These capacities are equivalent to 109% and 55,47% in winter and summer, respectively. This potential summer shortage has been a problem for decades now and hinders any socio-economic development in the country. The utility company deals with having more demand than supply, especially during the summer months, by shedding loads to avoid a significant collapse of the entire grid. Notice that a self-reinforcing loop is automatically created in this scenario. The lesser the power supply, the higher the demand, and more load will be cut off to avoid a blackout.

A critical paradox worthy of note is that Niger has been exporting electricity to Malanville, Benin, immediately across the Southern border. The amount of Energy exported was estimated at 2.4 GWh/year in 2010 (Idrissa, 2020). Since then, the export has grown significantly.

The research objectives of this paper are to 1) identify the significant electricity consumption sectors in Niger and estimate how the consumptions evolve, 2) apply an SD methodology to understand the dynamism of the Nigerien electricity trends, 3) estimate the corresponding Carbon Footprint (CFPT) of all the generation plants, 4) identify the potential Nigerien dependence on energy import, 5) identify the major consumption driving forces, and finally 6) find how the residents of the CUN cope with the frequent summer power outages.

Conclusively, this study answers the following research questions: a) How does energy demand evolve (2003 to 2050) considering population growth, technology, and the number of newly electrified homes; b) How the 20 MW PV plant (2024), 80-100 MW Diesel plant at GB (2017), and Kandadji dam (2025) would change the demand-supply paradigm in Niamey and vicinity?; and c) Can Niger become energy self-sufficient in the long run if the supply from Nigeria is jeopardized?

The following section explains data collection and the methodology utilized in this study. Section 3 presents and discusses the theoretical results. Finally, Section 4 concludes the paper by giving a summary of the study's main findings and their policy implications.

2. Data and Methodology

2.1 An overview of SD

System dynamics, SD, is a feedback-based model invented by Forrester in 1958. Nowadays, SD is viewed as a computer-aided technique for designing strategic policies for both governments and corporates. Thus, dynamic and complex systems can be modeled with the tools and methods provided by the SD approach. With its complex modeling paradigms, SD has a few basic building blocks such as stocks, converters, flows, and connectors (Balnac *et al.*, 2009; Rehan *et al.*, 2011;

Adelino J.C. et al., 2013). SD examines quantitatively the impacts and interactions between the variables of a system. Additionally, system dynamics (SD) is a proven methodology for analyzing complex systems. Although the entities may be tangible or intangible, the SD approach highlights respective mental models via Causal Loop Diagram (CLD). With the appropriate CLDs, system thinking is better understood by utilizing mental models. As a result, the complexities, causalities, feedback, and delays among interacting variables are elaborated (Hossen and Hossain, 2021). More details on the building blocks and their subsequent meaning were detailed in previous work (Moumouni, Ahmad and Baker, 2015).

2.2 The big picture

A simple yet comprehensive CLD of the system at hand is presented in Fig. 1. This big picture serves not only as a perspective, but also as a quick means to view the addressed energy issues in Niger. The figure has four balancing loops and five re-enforcing ones. The CLD mentioned above clearly shows how the socio-economic factors, such as population, housing, technology, seasons, well-being, GHG emissions, etc., affect the present and future energy supply and demand patterns in the country.

For all the qualities mentioned above in ***2.1*** and ***2.2***, SD was chosen as the most appropriate method at hand to calibrate the current Nigerien Energy Model.

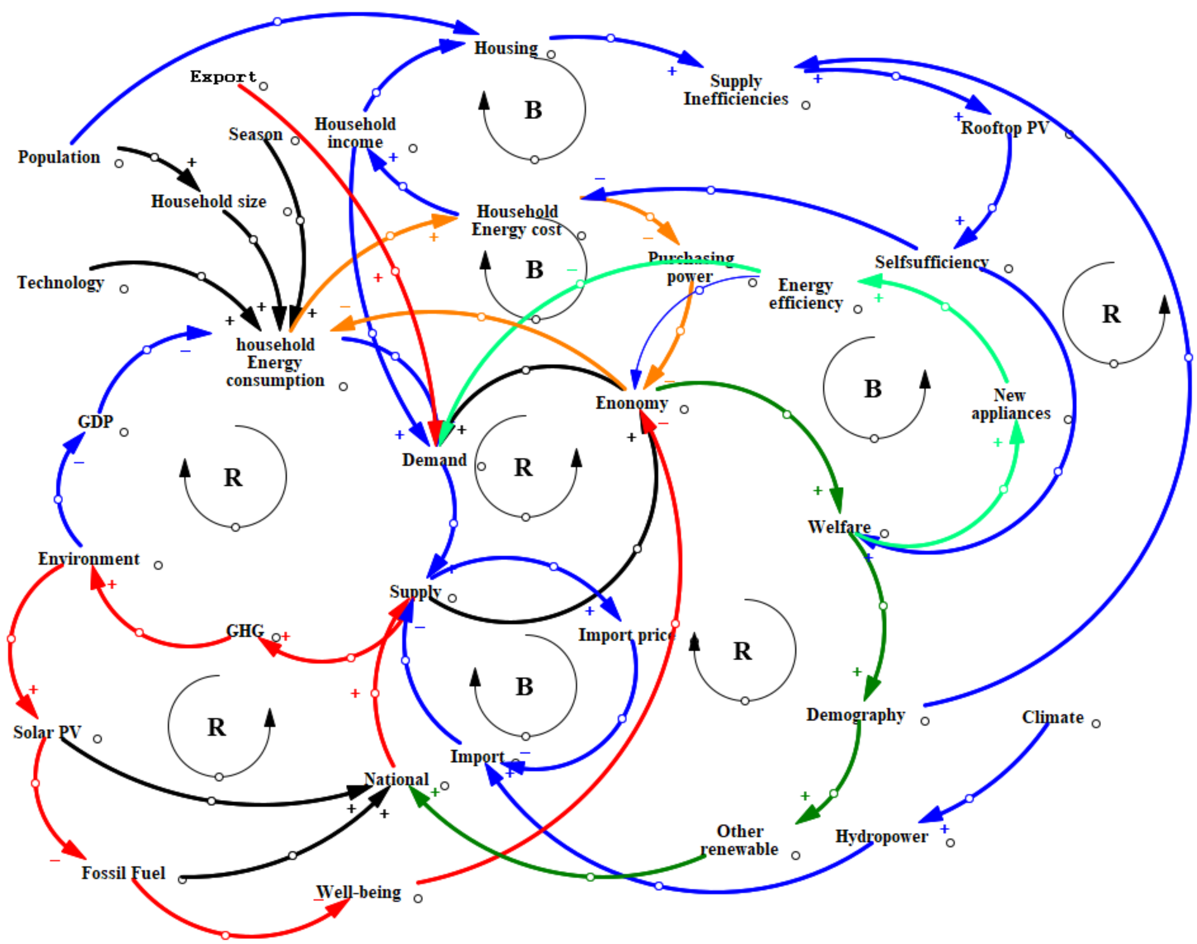

Figure 1. Causal loop diagram of the system

2.3 System dynamics interface

Figure 2 presents the graphical user interface (GUI) of the energy planning model. This GUI provides the user a friendly means for various policy testing scenarios and formulations using the ithink software. Ways to interactively utilize the GUI are included, where the user can input required data using sliders, tables, and switch input devices. This interface allows the user to quickly alter values of various parameters to conduct 'what if' analysis without making changes at the structural level. Finally, results are displayed graphically and/or stored in tabular format for analysis. The additional functionalities, such as run, pause, and resume, offer the user an augmented feature and privilege in performing the simulations.

For simplicity purposes, the authors omitted most of the equations and the policies. Rather, only Eq. (1) and the base case scenario (BCS) are presented. More details on the remaining equations, policies, and their implications were detailed in previous work (Moumouni, Ahmad and Baker, 2015).

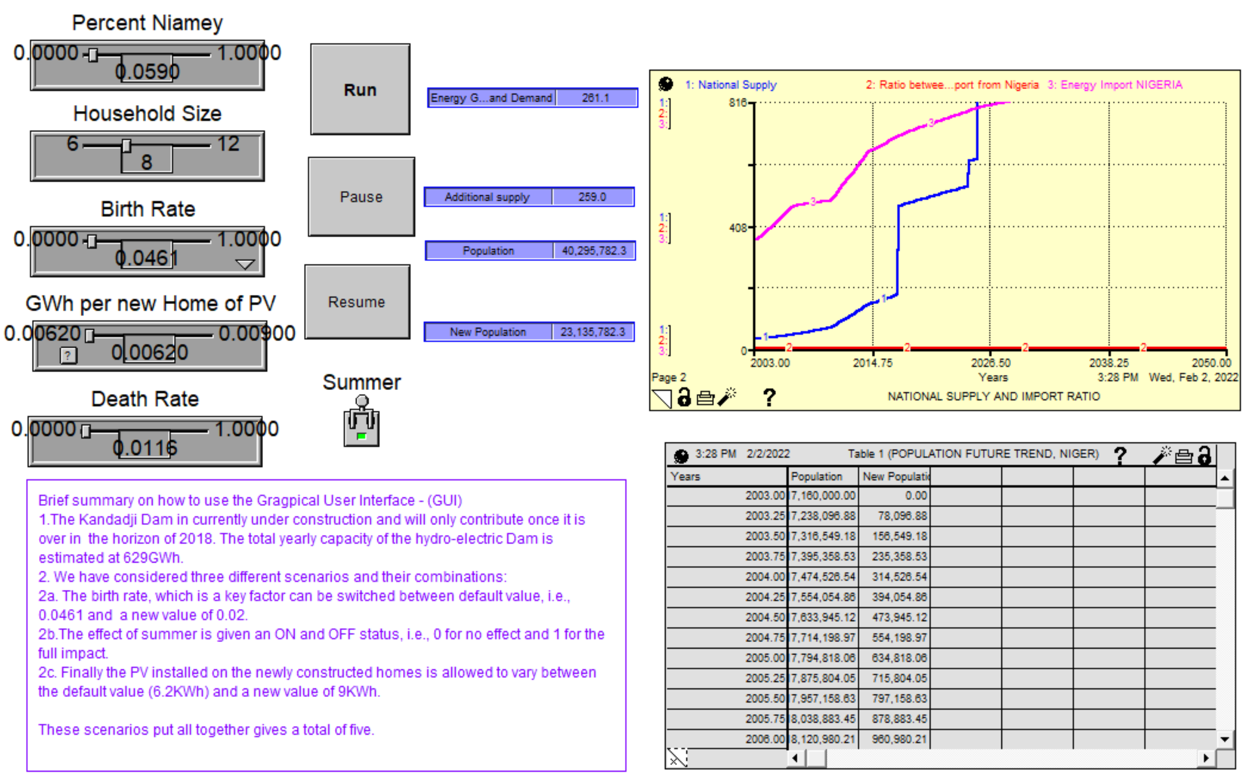

Figure 2: GUI of the model in ithink.

2.4 Data collection

The initial model (Moumouni, Ahmad and Baker, 2015), which was first developed in 2013, relied typically on the National Institute of Statistics (Idrissa, 2020). The latter institution remains one of the major and most reliable sources of energy information in the country. After almost a decade has passed, some parameters, such as BR, rate of electrification, Kandadji Dam, lost their consistency; thus, the need to revamp the model. As a result, the new data set ranges from 2003 to

2020. Other data were selected to follow the available energy data. For instance, it was noticed that the 2011 per capita consumption of electricity in Niger, estimated at 35 kWh, soared in 2019 to 51 kWh.

Similarly, the 2006 population access to electricity of 9 % (NIGELEC, 2018; Idrissa, 2020) has become obsolete for the new model. The sources mentioned above estimated the new access rate to be 13.86% in 2019. It is worth pointing out that this rate was not consistent over time because of the authorities' extensive rural and sub-urban electrification campaign from 2007 to 2011. As a result, the population having access to electrical energy was estimated at 22 % in 2013 (NIGELEC, 2018). Indeed, according to the utility company, the current access rate of ≈ 15% is less than 1% in rural areas and varies in small cities from 20% to 40%. This access rate was estimated at 59% for the capital city of Niger, Niamey, in 2015. The annual increase in people getting access to the electricity supply was estimated to be about 2.5% in 2013. This access rate has increased to 3.9% in 2019. An important factor that has a significant impact on this study's outcomes is the country's population, which jumped from 17 million inhabitants in the year 2012 to over 24.3 million in 2022. Hence, the associated birth and death rates fell from 46.1 and 11.6 in 2013 to 45.2 and 7.8 per thousand people in 2019, respectively. The former rate exhibited a counterintuitive behavior for a country with one of the highest BR records in the world. Figure 3 shows the birth rate trends over 10 years.

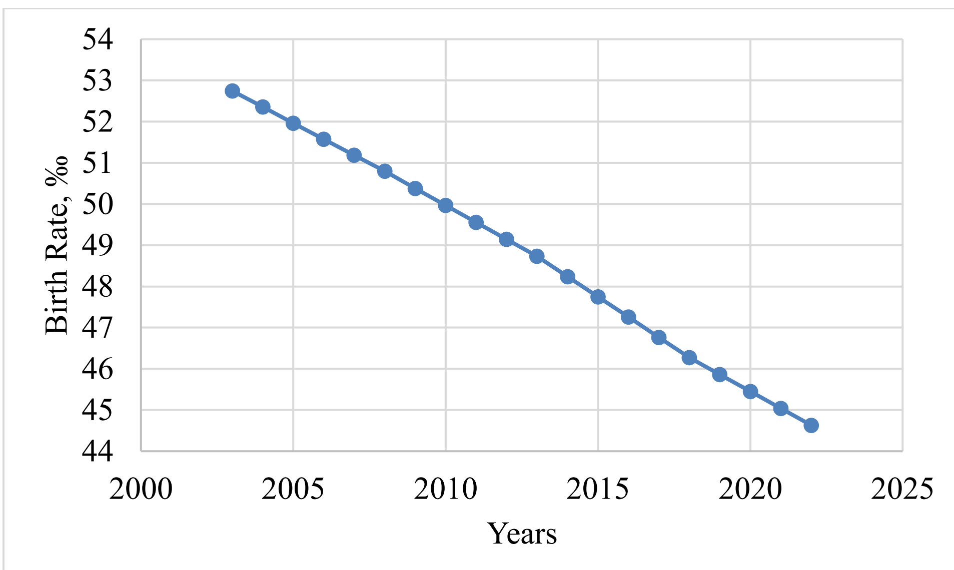

Figure 3. Evolution of Birth Rates, 2003-2022.

Likewise, the BR data show a significant decline over the decade. Thus, figure 4 presents the declines with a positive slope. The value of the R^2, somewhat deceiving, is very close to zero. The aforementioned value, $R^2 = 0.1522$, indicated an inordinate deviation from the linear curve fit. This fact was caused by the lowest decline in births recorded in 2014.

In 2013, the housing demand was estimated at 40,000 per annum in Niger. Since the recorded annual urbanization rate was 4.4%. In addition, Niger is experiencing a massive rural exodus to the cities, resulting in a yearly 500,000 new city dwellers by 2050, according to the Center for Affordable Housing Finance in Africa (CAHFA, 2021).

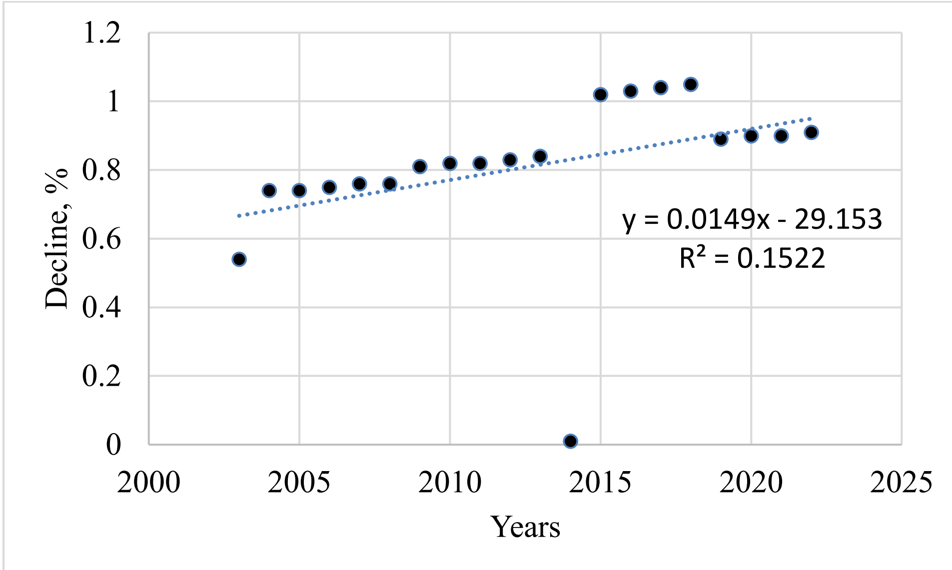

Figure 4. Percent Decline of BR, 2003-2022.

The urban population, estimated to double every 12 years (Finance and Africa, 2011), was 17% of the total population in 2020. One-third of the urban population lives in the capital city, Niamey. This percent has revealed an increase of 384 thousand inhabitants since 2013. Thus, as mentioned earlier in the CUN, the population is now 1.384 million inhabitants (2022), i.e., 5.8 % of Niger's total population (Idrissa, 2020), yet its energy demand is tremendously increasing. Also, most of the wealthiest people reside in Niamey, which implies a concentration of more electrical loads in the CUN. This concentration of electrical loads hurts the availability of the utility service in summer. Table 1 lists the most critical data sources utilized in this study.

Table 1: Data and sources

Variables	Values	References
Total population	17,129,076	(INS, Niger)
BR and DR	0.0461; 0.0116	(INS, Niger)
Population in Niamey	1,011,227	(INS, Niger)
Per capita Electricity	51 KWh	(INS, Niger), (Nigelec, Niger)
% of population having electricity in 2006	9%	(INS, Niger), (Nigelec, Niger)
% of population having electricity in 2013	22%	(INS, Niger), (Nigelec, Niger)
% of population having electricity in 2019	13.86%	(INS, Niger), (Nigelec, Niger)
Electricity per economic sector	(See Table 2)	(INS, Niger), (Nigelec, Niger)
% of electricity import	85%	(INS, Niger), (Nigelec, Niger)
% of electricity export	0.3%	(INS, Niger), (Nigelec, Niger)
Annual rate increase of electrification	2.5%	(Energy report, Niger)
Utility company's local power generation	27.2 MW	(Coddae, 2010), (Nigelec, Niger)
Solar thermal power capacity	10 MW	(RNI, 2008)
Dam Kandadji's annual capacity	125 GW	(Coddae, 2010), (Nigelec, Niger), (CNEDD, Niger)
Average fecundity rate	7.1 to 7.6	(INS, Niger), (CNEDD, Niger)
Gorou-Banda - HFO plant	80 – 100 GW	(Nigelec, Niger)

2.5 Methodology

The model was based on three factors: the economy, population, and per capita electricity consumption for both conventional power and renewable alternatives for the past two decades, starting from 2003 and the upcoming 27 years. It is worthy to note that we segregated the demands for the various economic sectors on the premise that a breakdown was required at a strategic level. Unlike the previous model (Moumouni, Ahmad and Baker, 2015), this updated model may serve demonstration purposes and assist utility management in making decisions.

Unfortunately, the country has been going through some socio-economic turmoil leading to the abandonment of the construction of Kandadji. However, according to official communication, the construction will resume by the end of 2025. The primary purpose of this study is to investigate the future trends of the national supply and demand for electricity after the completion of Kandadji. The second objective is to investigate the socio-economic benefits of the continuous electricity supply from Nigeria and how these impacts would evolve in the near and far future. Therefore, to achieve the aforementioned goals, an SD model is proposed. It is comprised of many stocks, flows, and auxiliary variables. Secs 3.4.1 through 3.4.4 describe the significant stocks, feedbacks, and other interconnections among the stocks and the model's variables. Some key sensitive strategies and assumptions are presented below as compelling policy scenarios to investigate ways to resolve the issues of electrical power outages in Niamey in the years to come. Figure 5 depicts the map of the study area (Source: West African Power Pool - WAPP). This area, known as “The Western Zone,” is presented in the blue square. This zone is solely chosen to investigate the Nigerien electricity supply and demand trends because it accounts for almost 70% of the country’s energy consumption.

Thus, the revised SD model explores the changes in the following social, environmental, and economic paradigms:

1. Changes in the national energy demand as the population intensely increase.
2. Impacts of the decline in birth rate on the national electricity demand.
3. Contributions of the 80 - 100 MW thermal power plant – GB – in the national energy mix and its subsequent environmental impacts.
4. How would the completion of the 20 MWp solar park improve the quality of the public electricity service for about 18,000 subscribers in the interconnected Western Zone, viz., Niger River area, which accounts for almost 70% of the country’s electricity demand?
5. Effects of Kandadji (Annual capacity is 629 GWh) in the national supply mix. The dam will be fully operational on the horizon of 2025.

Finally, the individual and the total CFP of the various sources of electricity in Niger.

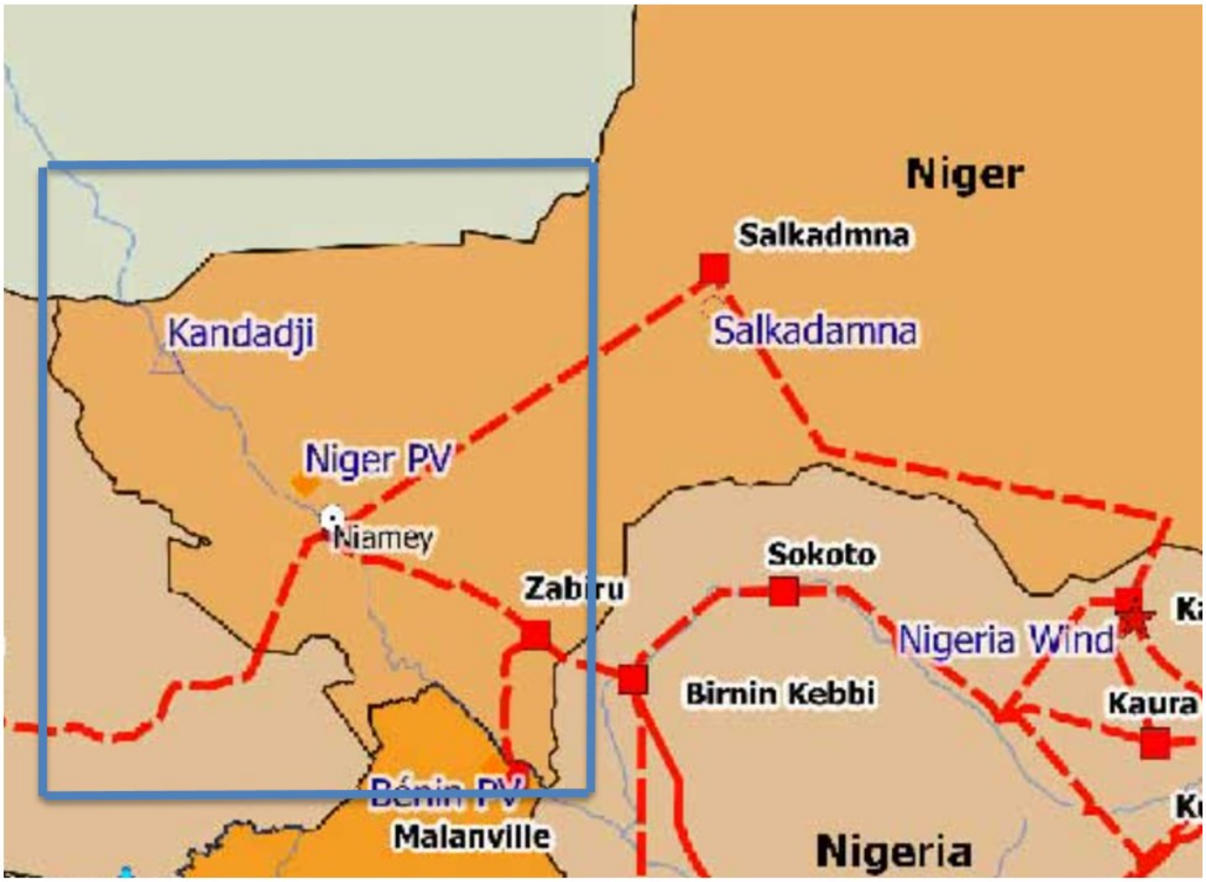

Figure 5. Map of the study area (WAPP).

2.5.1 Demand sector

Figure 6 shows the major stocks, feedbacks, and other variables – inflows and outflows – about the demand sector. This sector helps to estimate the electricity consumption over the simulation period. The average annual household consumption is determined using the per capita demand and the household size. In addition to the major economic sectors, such as industry, agriculture, transport, and government, electricity consumption is driven by population. The latter variable is the primary driving force behind the electricity demand in the country through domestic consumption.

Finally, to draw a more profound understanding of how the total electricity demand relates to the supply, a quantity called "Electricity Gap" was estimated. This quantity was computed by subtracting the total demand from the total supply. Accordingly, three different outcomes are identified. First, the gap is positive throughout the entire simulation period. Second, the gap is zero, i.e., the supply exactly matches the demand; thus, the system is balanced but marginally stable because it lacks a spinning capacity. Finally, the gap is negative. The system is unstable, and a comprehensive investigation is performed in the results and analysis section.

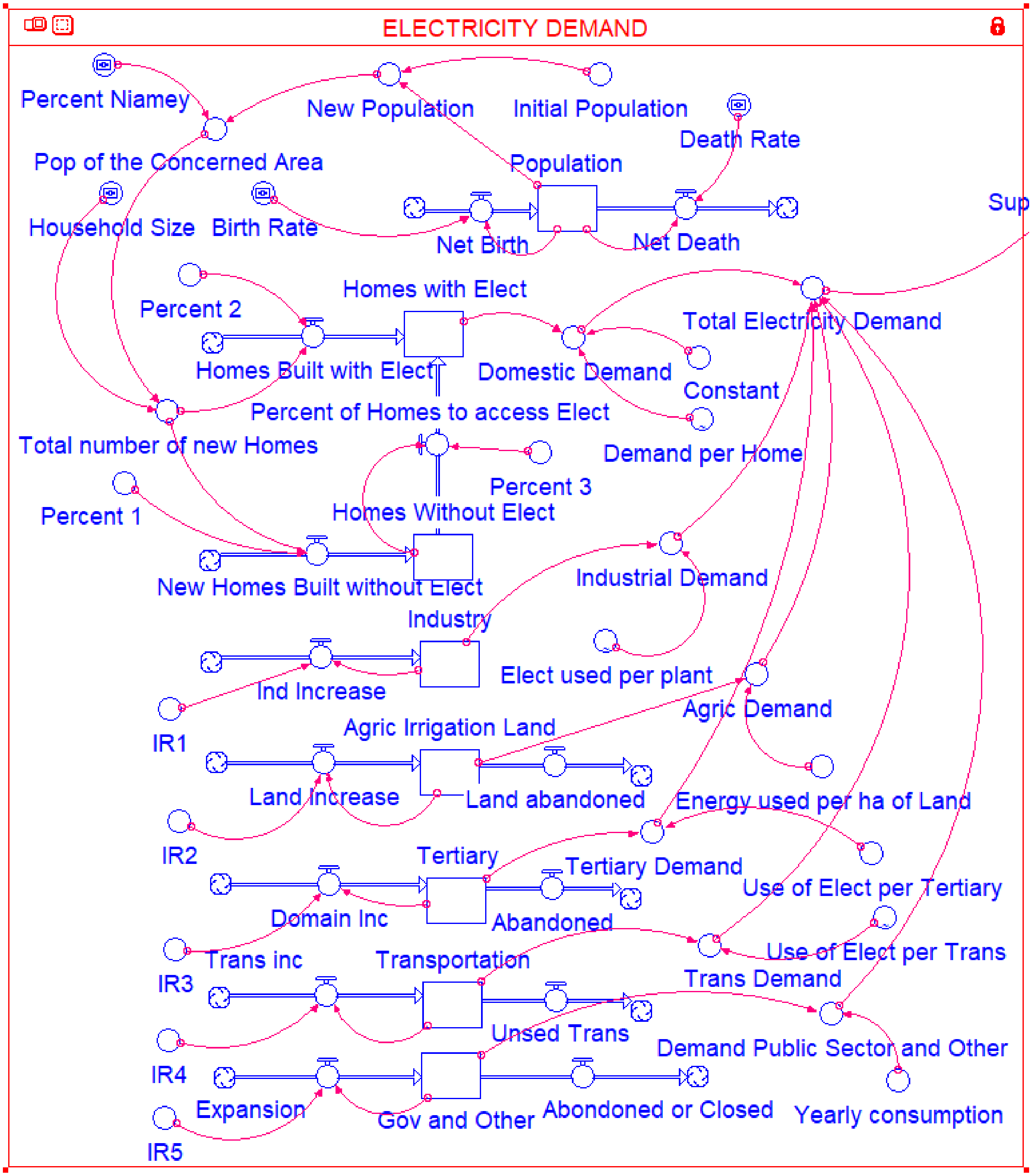

Figure 6. Electricity demand sector

2.5.2 *Supply sector*

Like most West-African nations, Niger is planning to invest in clean energy. Hence, both conventional and renewable energy sources are considered in this study. Figure 7 presents the Nigerien electricity supply sector developed on the Stella platform. It is worth pointing out that the contribution of renewable resources, mainly PV, at the national level is still insignificant, dispersed, and owned by individuals because the national supply is still unreliable in summer. Most of the issues related to reliability were addressed in a previous work (Moumouni and Pouye, 2020). However, the country is installing a 20 MWp grid-tied PV system on the horizon of 2024 at GB. Thus, the major contributors to the supply sector are the: 1) Kandadji (projected to finish in 2025), 2) Coal-fired plant of Anou Araren, 3) Heavy-fueled plant installed at GB (2017), and 4) Imported electrical energy (Nigeria).

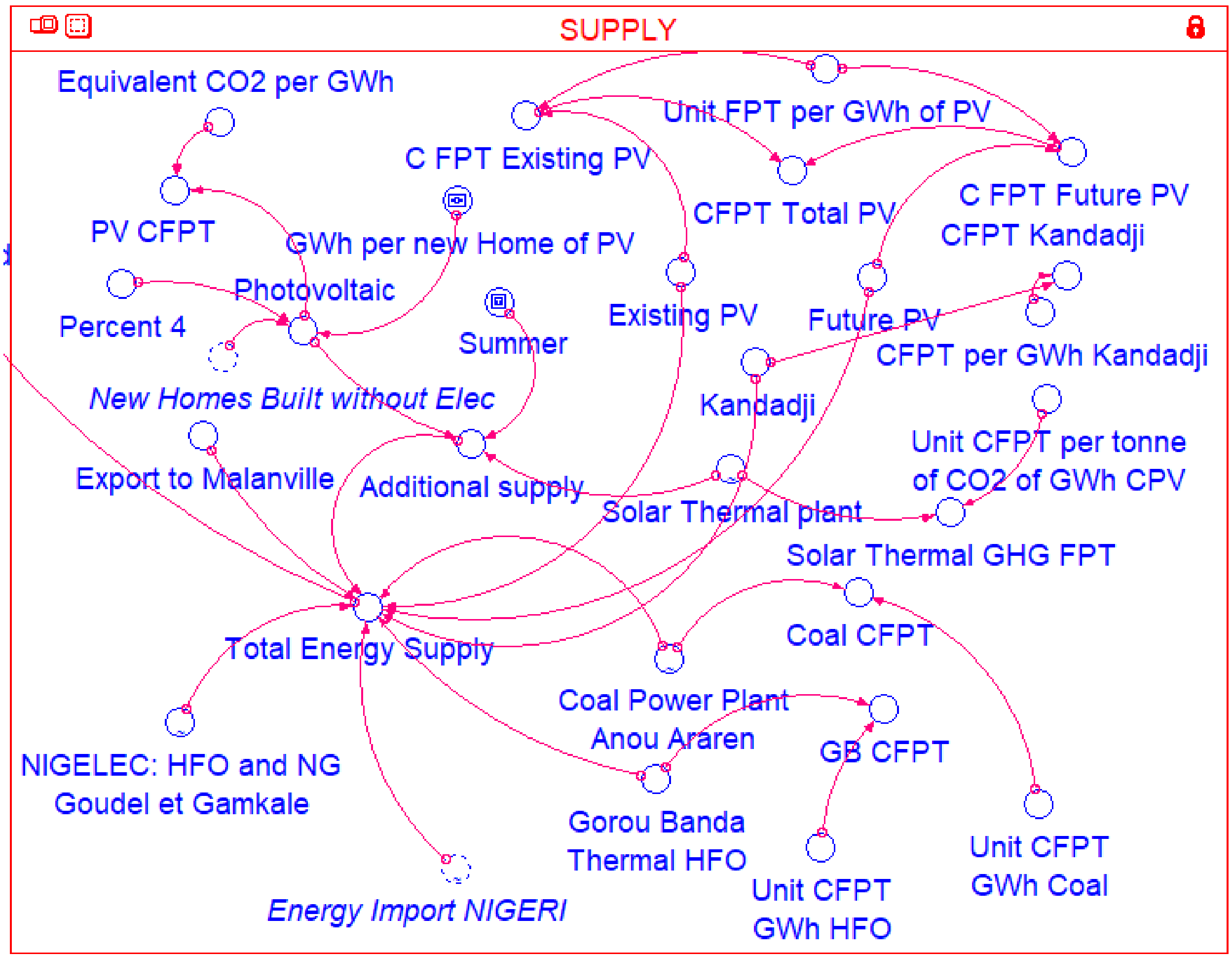

Figure 7. Electricity supply sector

2.5.3 Carbon footprint sector

The GHG emissions of the entire source are estimated through this sector. Carbon dioxide (CO_2) is one of the dominant GHGs leading to climatic change and global warming. CO_2 concentrations are increasing above preindustrial levels (Ali Kerem Saysel et al., 2013). CFPT is an all-encompassing term for pollutants. Therefore, the term is shorthand to describe understandably and the best estimable sense of what can be gotten off that pollutant's entire climate change impact. For instance, the term CFPT could range from simple activity, lifestyle, and company to a country (Dong *et al.*, 2013). Undoubtedly, fossil-fueled-based sources remain the most predominant in the Nigerien energy mix. It is worth pointing out that even the new and renewable technologies emit some pollutants during their manufacturing process. As a result, their individual and total lifecycle equivalent metric tonnes of CO_2 equivalent per GWh produced were estimated. For more details on the individual lifecycle GHG emissions per source, see (World Nuclear Association, 2011; Al-Wawadhi, Moumouni and Khodary, 2019). The utility company has a Natural Gas (NG) energy production capacity of 15.6 MW, an HFO power plant capacity of 12 MW, and an 80-100 MW Diesel power plant (NIGELEC, 2018). The major contributors in terms of CFPT at the national level are GB, Goudel, and the Coal-fired plant at Anou Araren.

2.5.4 National supply and import sector

This sector compares the national supply and the electricity import from Nigeria. It is mainly considered for comparison purposes. The essential factors to note in this sub-section are the total national energy supply, the supply without taking into consideration the import from Nigeria, and finally, their ratio.

2.6 Policy Scenarios

To better understand the dynamics of electricity supply and demand capacities of the Western part of Niger (La zone du fleuve), an SD model was first developed in 2013 (Moumouni, Ahmad and Baker, 2015). The model was validated using six policy scenarios, as presented in table 2. Four parameters turned out to be critical, decisive, and inevitably important for Niger to attain energy self-sufficiency. The first parameter is the birth rate (BR), which has declined since 2003, undoubtedly due to socio-economic hardship and persistent birth control campaigns (Fig. 2). The second factor is the need to invest in RE to cut-down GHG emissions; a 20 MW PV system is underway (2024). The third parameter, an ineffectual investment, is the 80-100 MW Diesel power plant installed at GB, in the vicinity of Niamey. Fifth, Niger must increase its spinning reserve capacity to meet unpredictable summertime peaks. Lastly, Kandadji, delayed for four years now, needs to be fully operational on the horizon of 2025 for Niger to reach energy self-sufficiency soon.

Table 2: Summary of the policy scenarios

Scenarios	BR(‰)	Additional Supply	Kandadji (2025)	Gorou Banda	Grid-tied PV (2024)	Standalone PV (kWh)
1	46.1 (BC)	OFF	629GWh	80 MW	20 MW	6.2
2	20.0 (New)	OFF	629GWh	80 MW	20 MW	0.0
3	46.1	ON	629GWh	80 MW	20 MW	6.2 (BC)
4	46.1	ON	629GWh	80 MW	20 MW	9.0 (New)
5	20.0	ON	629GWh	80 MW	20 MW	9.0
6	20.0	ON	629GWh	80 MW	20 MW	0.0

3. Results and Analysis

3.1 Supply and Demand

The updated SD model not only simulated various socio-economic data of the past two decades but also estimated their trends over the next 30 years. Figure 8 displays the simulation results of two scenarios for a better view and simplicity of comparisons. The dotted black line shows the total electricity demand under the base case (BC) scenario. In contrast, the blue and dotted red curves are the total supply with 9 kW renewable in the summer and the total supply without PV, in that order. The electricity supply and demand represent the variables in this figure. These variables intersected twice at two locations, i.e., 2012 and 2013 for the blue and the red-dotted curves, respectively. The former curve implicitly sheds light on the extensive and dispersed use of RE at homeowners' premises during the summer months from 2012 onward. Conversely, the last curve reveals the absence of PV panels at customers' premises due to some economic hardship.

Additionally, this same graph shows the contributions of the:

1. 80 - 100 MW diesel power plant installed at GB in early 2017,
2. 20 MWp PV system to be installed at GB in 2024, and
3. 130 MW Kandadji hydro-electric plant on the horizon of 2025.

With all things being equal, the long-term energy independence of Niger and specifically in the western region, which consumes more than two-thirds of the supply, would be hardly achievable without import. Consequently, imports from Nigeria will continue to play a significant role in the country's energy mix. In the meantime, for the next 25 years, the country may have an extra amount of energy that could be sold to neighboring countries or be re-directed to enhance both urban and rural electrification rates.

It was discovered earlier that the BR of the entire population is disclosing a counter-intuitive behavior than what usually happens in developing nations, a negative slope for the last two decades. Therefore, with the upcoming investment in this field, fewer people is a synonym of less demand, which in turn leads to a surplus in the supply resulting in a healthier economy.

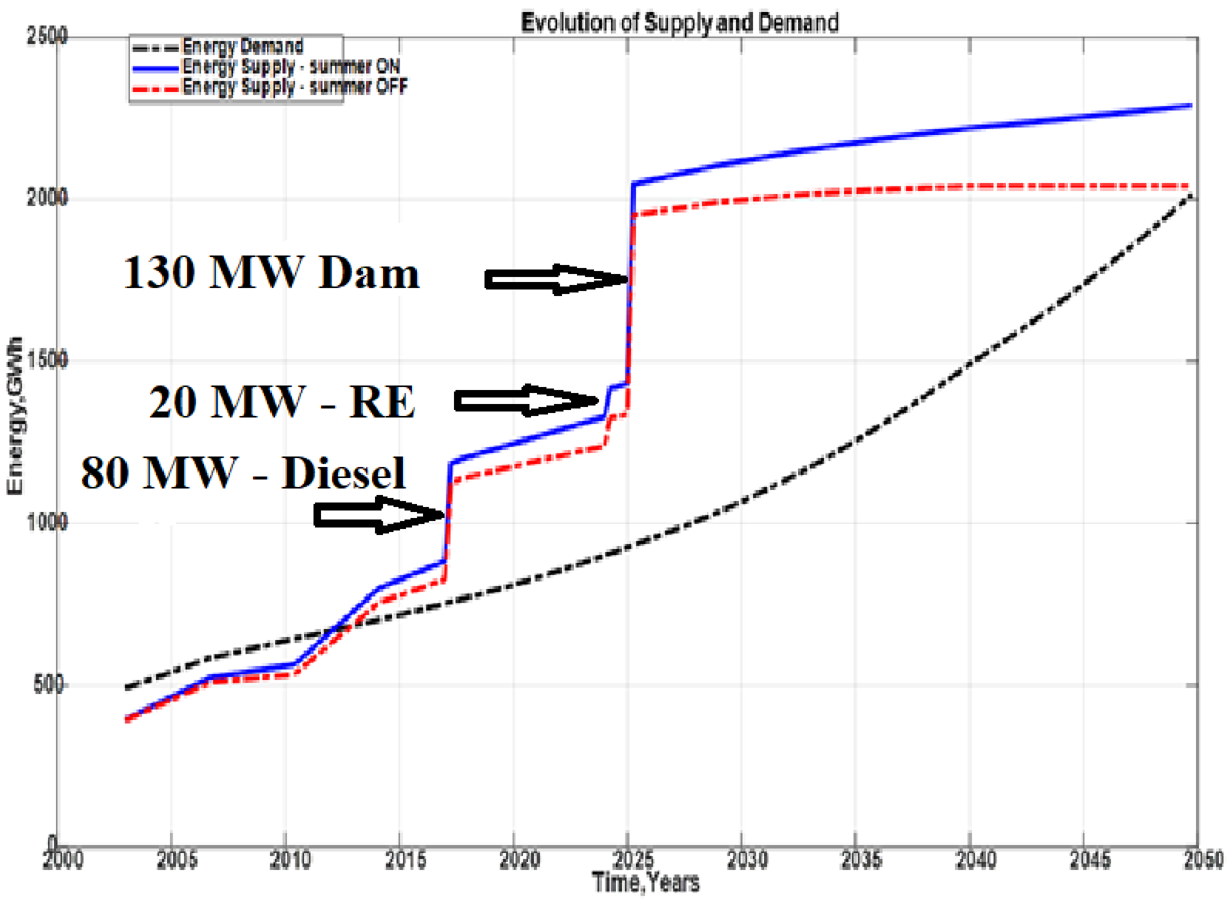

Figure 8: Demand and Supply projections

3.2 National Supply and Import

For simplicity in the approach, Figure 9 presents the BC scenario of the national supply without any dispersed RE and the electricity import from Nigeria over the 30 years. The import is shown in the red line, whereas the national supply is green. Hence, as can be seen from the two curves, the import dominated the national supply from 2003 until 2025. For this status quo to change, two conditions must be fulfilled as can be seen from the figure: 1) the installation of the 20 MW PV power system and 2) the construction of the Kandadji have to be fully completed and commissioned as planned, i.e., 2024 and 2025, respectively. The hidden economic implication is that Niger, under the business-as-usual scenario, would have a tremendous amount of electrical energy to either export or transmit in the other parts of the country.

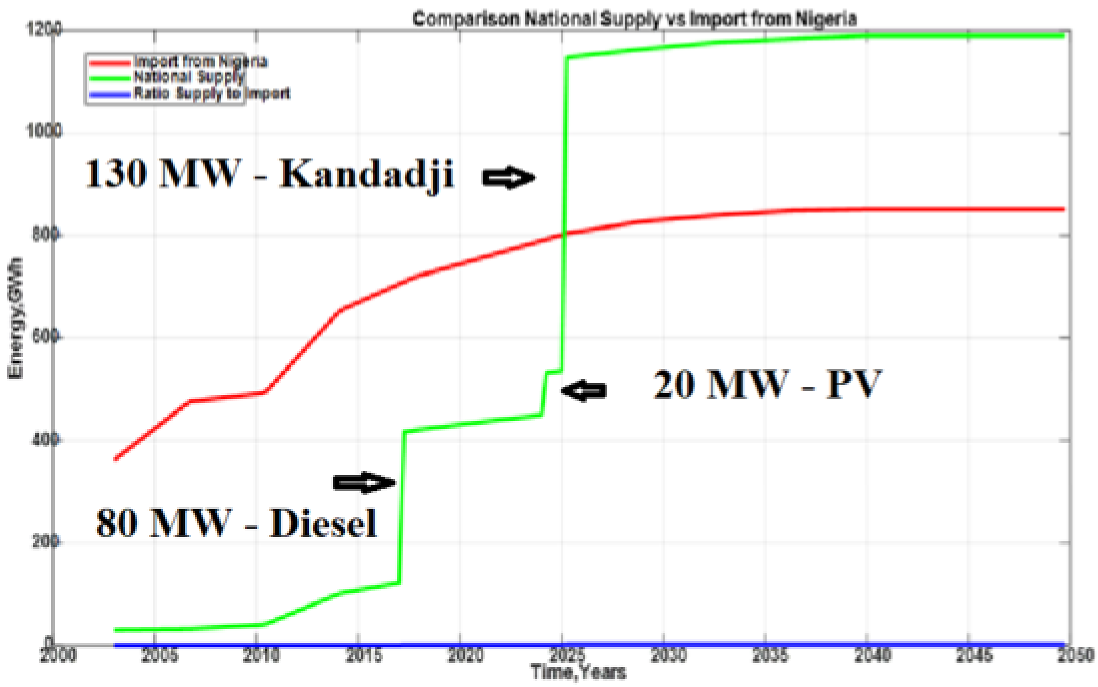

Figure 9: Projections of the National supply and Import

3.3. Gaps between supplies and demands

Figure 10 shows the gaps between supply and demand under four different scenarios: 1) BC with import and summer OFF (Red), 2) BC without import and summer ON (Blue), 3) BC with import and summer ON (Dash-dotted blue), and 4) BC without import and summer OFF (Dash-dotted green). The horizontal black line indicates the limit between the electrical energy surplus (+) and deficit (-) over the simulation time frame.

i) BC with import and summer OFF (Red).

Under this scenario, Niger has a net energy surplus from 2013 to 2049 because the ratio falls in the positive half-plane. The socio-economic implication is that Niger effortlessly could continue its rural electrification and/or even export some of the excess electricity to neighboring countries. Another option is to cut part of the budget allocated to energy imports from Nigeria.

ii) BC with import and summer ON (Blue).

Under this case, it is assumed that the Nigerien economy is booming, and the residents can afford to install PV panels in their premises – rooftop and backyard. As the best-case scenario, it can be seen that from 2012 to 2050, the supply-demand gap is positive. In other words, the supply exceeds the demand over the entire simulation period and even beyond. Therefore, one can conjecture that some socio-economic prosperities may result from the widespread use of electrical energy. Although optimistic, this scenario hides some downfalls of the state-owned utility company. Specifically, the electricity service has never been reliable, especially during the hot summer months. During this period, the Nigeriens witnessed frequent load sheds and power cuts to the extent that the economy was paralyzed. Thus, for the past two decades, the country has been struggling to satisfy its summer electrical loads despite the colossal investment measures.

iii) BC without import and summer ON (Dash-dotted blue).

From 2025 to 2037, a small portion of the ratio falls in the positive half-plane but stays negative before 2025 and above 2037. This scenario reveals the actual situation of the country without electricity imports. Again, the total import is more than 75% of the current electricity demand. It can be seen that Niger can only become self-sufficient if Kandadji is completed. In other words, with only the diesel and PV power plants, both located at GB, Niger would still experience a massive shortage of energy. This situation has the potential to delay any sustainable development in the country.

iv) BC without import and summer OFF (Dash-dotted green).

The gap is positive from 2025 to 2032 but stays negative before 2025 and above 2032. Similar to the above scenario, this scenario exposes the actual condition of the country without the import from Nigeria. As both nations are members of the Economic Community Of West African States (ECOWAS), it is assumed that their socio-economic and political ties are strong. However, for its residents' continuous social well-being and economic prosperity, Niger has the moral obligation to strengthen its relations with Nigeria. It is worth pointing out that most of the power outages and load sheds experienced in Niamey were attributable to inconsistencies in the import and some severe weather events.

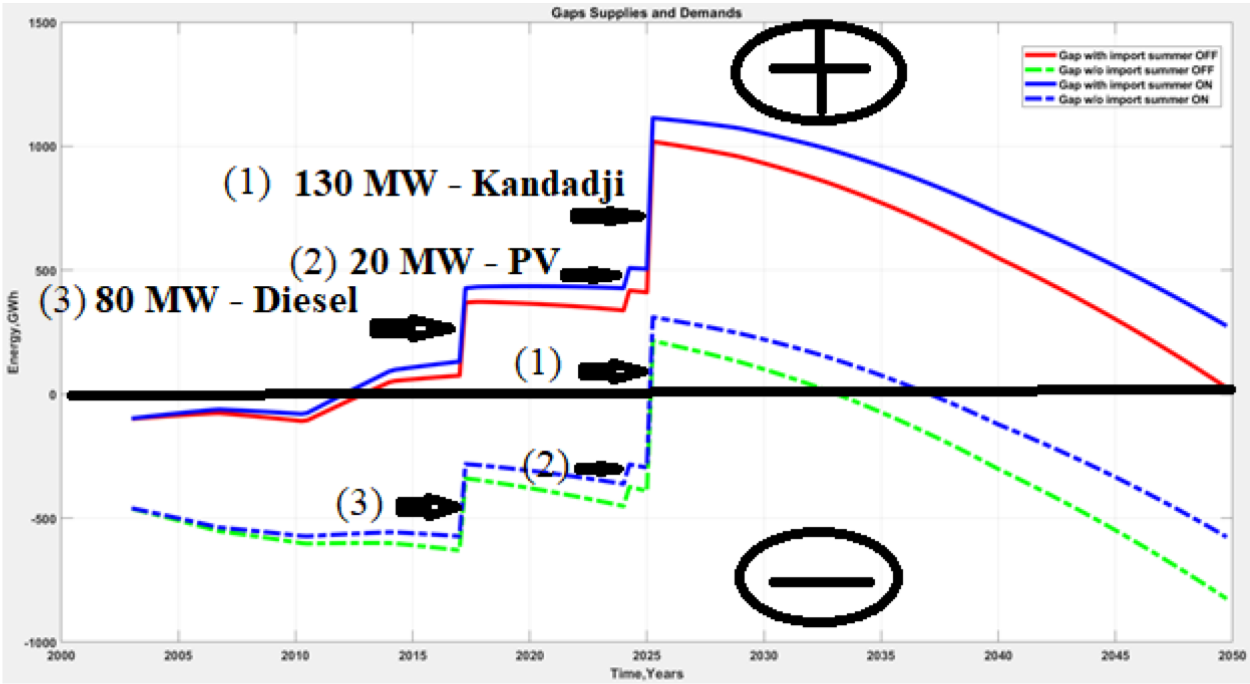

Figure 10: Projected gaps between supply and demand

3.4 Analysis of Carbon Footprints

Figure 11 presents the estimation of the life cycle CFPT of all the generation mix, including the imports. The period spans from 2003 to 2050. More details on how to estimate CFPT can be found in (Ansari and Seifi, 2013; Moumouni, Ahmad and Baker, 2015; Shari, Moumouni and Momodu, 2020). It is fascinating to note that although Niger has yet to enact any clear plan to cut down its GHG emissions although the CFPT of the utility company is quite humongous. Over the entire period, NIGELEC, through its 80-100 MW Diesel and HFO power plants, rejects 37 Mega-Tonnes of CO_2 equivalent into the atmosphere. These emissions are pretty significant to be ignored by lawmakers and the utility management. If nothing is done at present, this will hinder any social well-being in Niamey and the vicinity. These emissions will also affect the economy of the country in various ways.

The second most crucial emitter of GHG in Fig. 11 is the Coal-fired plant installed in the northern part of the country. This plant is estimated to produce 15 Mega-Tonnes of CO_2 equivalent over the period. Although far from Niamey, this plant can cause significant environmental issues unless something is done to reduce emissions. We suggest either of the following actions:

1. an early decommissioning of the plant (Anou Araren),
2. upgrading it to a clean-coal system, or
3. an increasing the RE shares in the region.

The various CFPTs of the renewable sources (Kandadji, Kanji, and PV) are also shown in this exact figure. Kandadji, Kanji, and PV emit, respectively, 1.6, 3.6, and 0.7 Mega-Tonnes of CO_2 equivalent by 2050.

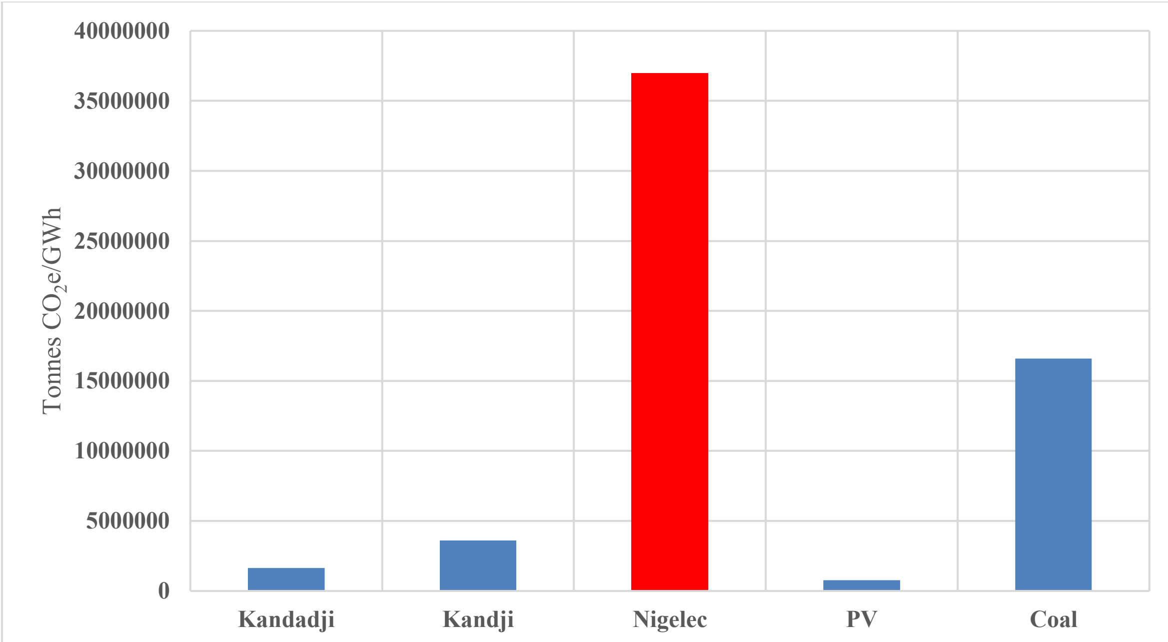

Figure 11. Lifecycle GHG emissions per energy source, Niger.

4. Conclusions

A long-term electricity supply and demand for Niger was estimated utilizing system dynamics', SD, approach. The period of the study spans from 2003 to 2050. The major variables were the 1) population, 2) household size, 3) major economic sectors, 4) birth and death rates, and 5) per capita electricity consumption. Under the various policy scenarios adopted in this study, not all are applicable in real life, such as halving the birth rate. This possibility confirms the quintessence and elasticity of simulation rather than experience. Consequently, the results of the study indicated that:

- The population in Niger, despite the relative decline in birth rate, will be close to 40 million in 2050. Through the increasing per capita energy consumption due to technology and prosperity, the population will fuel future energy demands at an alarming rate.
- Under the BC scenario, Niger will continue importing electricity from Nigeria after completing the 20 MWp PV plant and 130 MW Kandadji dam. These two plants are projected to be commissioned in the horizon of 2024 and 2025, in that order.
- The study reveals that Niamey, and the surrounding vicinity, will only be self-sufficient for a decade – 2025 to 2035 – after completing the PV plant and Kandadji.
- The results also showed that the various GHG emissions were exponentially compounding. Through its fossil-fueled plants, the utility company will emit more than 40 Mega-Tonnes CO_2 equivalent into the atmosphere. These emissions not only will they pose severe health issues to the residents of Niamey but will also continue to damage the fragile ecosystem.

Finally, this study may guide decision-makers in better planning the electricity supply and demand in Niger while strategically facilitating the management of the utility company.

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