International Journal of Energy and Power Engineering
2021; 10(6): 141-150
http://www.sciencepublishinggroup.com/j/ijepe
doi: 10.11648/j.ijepe.20211006.17
ISSN: 2326-957X (Print); ISSN: 2326-960X (Online)

A System Dynamics Modelling of a Long-term Residential Electricity Consumption in Lomé, Togo

Kokou Amega[1, *], Yacouba Moumouni[2], Yendoubé Lare[3]

[1]West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL), University Abdou Moumouni, Niamey, Niger
[2]Department of Electrical and Electronics Engineering, Higher Colleges of Technology, Ras Al Khaimah, UAE
[3]Physics' Department, University of Lomé, Lomé, Togo

Email address:
yenlare14@gmail.com (Y. Lare), ymoumouni@hct.ac.ae (Y. Moumouni), amega.k@edu.wascal.org (K. Amega)
[*]Corresponding author

To cite this article:
Kokou Amega, Yacouba Moumouni, Yendoubé Lare. A System Dynamics Modelling of a Long-term Residential Electricity Consumption in Lomé, Togo. *International Journal of Energy and Power Engineering*. Vol. 10, No. 6, 2021, pp. 141-150. doi: 10.11648/j.ijepe.20211006.17

Received: November 18, 2021; **Accepted**: December 7, 2021; **Published**: December 24, 2021

Abstract: According to the Togolese Policy and Regulatory Overviews on Clean Energy, the residential sector in Lomé accounts for nearly 60 percent of the total electricity consumption. This fact is especially due to the current nature of the economy. A system dynamics model was built using Stella software to estimate both the current and long-term household electricity consumptions. These near (2030) and far future (2050) energy forecasts were carried out for Lomé, the capital city of Togo. Two different models were not only built, but also calibrated utilizing data from the past sixteen years as a benchmark. The first model was built based on the: 1) population, 2) Gross Domestic Product (GDP) growth, and 3) per capita electricity consumption. The second model was solely based on the: 1) number of households with electricity and 2) households accessing electricity. Results revealed that the population of Lomé under the current birth rate will be close to 3 million in 2030 and 5 million in 2050, with corresponding electricity consumption close to 860 GWh and 3 TWh, respectively. Therefore, growth in population, economy, and number of households with electricity will continue to drive the future electricity consumption in Lomé. This study could help investors and policy-makers to set the necessary investments by ensuring a timely, reliable, and resilient electricity supply at the turning of 2050 in the city of Lomé and the country at large.

Keywords: Electricity Consumption, Long-Term, Residential Sector, System Dynamics, Stella, Urban

1. Introduction

Electricity is an essential component of the modern lifestyle and sustains the wellbeing of billions of people in various communities throughout the world. Electricity services are countless in homes and businesses, such as lighting, refrigeration, cooling, and heating. As population and economy are subjected to growth, the demand for energy continues to grow at an equal pace [21]. Therefore, it becomes necessary to manage supply and demand for both the short and long term in order to meet the rising residential electricity consumption in emerging economies. Electricity planning aims at determining objectively the details in energy demand in order to be able to achieve the growth and development targets of any nation. At the same time, by choosing the environmentally-friendly mix of energy sources, the future energy demand will be met in the cheapest and most sustainable ways [16].

It is important to better understand future electricity consumption trends in order, not only to help planning demand, but also to take earlier strategic measures to face growing energy demand. Hence, the expansion of energy supply needs years of intensive capital investments. Also, energy supplies should be both reliable and well-timed for the continuity of modern life [16]. Recently, the observed electricity consumption model of Lomé, the capital city of Togo, has been soaring at an alarming rate. The residential sector is the second major energy driver after the industry sector according to the national utility supply company and it is partly due to the nature of the economy. A system dynamics modelling was proposed to accurately model the long-term residential electricity consumption of Lomé in order to simulate its evolution under the growing population and economy. The total household electricity consumers along with their subsequent electricity consumption of the whole country represent 83.1% and 41%, respectively [20]. In addition, in 2016, 65.50% of the utility company's customers are residents of Lomé. Moreover, on average, 83.64% of the low voltage clients (220V - 400V) in Lomé represent the households that have access to electricity. Further, this corresponds to 80% of the total electricity consumption in the city of Lomé. To our knowledge, there was no study that had adequately model the consumption of electricity in the city. This study attempted to bridge the gap and could help policy-makers and investors to set the necessary investments by ensuring a timely, reliable, and resilient electricity supply at the turning of 2050 in the city of Lomé and the country at large.

The objectives of this paper are to: 1) assess the residential consumption patterns in Lomé; 2) model, via a system dynamics approach, the long-term electricity supply and demand trends (up to 2030 and 2050) in Lomé; and 3) suggest a sustainable energy consumption model, matching both national economic ambitions and environmental goals.

The rest of the paper is organized as follows: Section 2 discusses the literature, while Section 3 presents the methodology and the data collection. Section 4 presents the results and discussions. Finally, Section 5 concludes the paper with the main findings and some policy recommendations.

2. Literature Review

Energy supply and demand modelling emerged from the aftermath of the first energy crisis imposed on the OECD countries by the OPEC members in 1973. As a result, energy modelling, through numerous simulation platforms, was used to foresee the future energy trends based on population growth and economic prosperity. This helps nations, not only to make the best economic decisions in line with current and future environmental concerns, but also to plan decades ahead for efficient energy distribution patterns. In this order, several studies were carried out in the area of residential electricity demand in both developed and emerging countries utilizing diverse methods of modelling.

Previously, SD modelling studies have been carried out on the residential energy sector. P. Holtedahl and F. L. Joutz (2010) modeled the demand for residential electricity in Taiwan using an error correction model [12]. They found that the demand for electricity in the sector was a function of the gross household income, population growth, price of electricity, and the degree of urbanization. An Autoregressive Distributed Lag (ARDL) approach was utilized to predict residential and aggregate electricity demand in Namibia [27]. According to Vita et al., neither does an increase in income lead to a significant increase in households' electricity demand, nor does a price surge hinder residential electricity consumption. In 2011, another study was conducted in Nigeria using an economic model and SD to model the urban residential energy demand [16]. Results revealed that two main factors, *i.e.*, the power generation and real available income, affected the residential household electricity demand. In this same year, the Elasticities of Electricity Consumption for Rural and Urban Areas in Malaysia were assessed [1] using a non-linear model. It was found that the high sensitivity of electricity consumption in the urban population was primarily attributable to a high exposure to electricity appliances and facilities. Chen et al. (2009) modelled the residential energy demand in Tokyo utilizing multi-economic data [5]; this study was mainly based on a combination of both TD and BU approaches. Results showed that the per capita GDP strongly affected energy demand in households. Beijing urban energy consumption and CO_2 emissions were also adequately modelled using SD [8]. In this study, it was found that electricity used per capita was highly correlated with the stock of electrical appliances and GDP. Also, in 2011, S. Gyamfi et al. highlighted some behavioral issues related to the residential peak electricity demand response [10]. In 2015, the residential electricity demand in Ethiopia was investigated using different approaches [7]. Here, it was discovered that economic growth causes a subsequent increase in the residential electricity demand. From the above studies, it can be noted that households' electricity consumption was solely dependent on income, time-of-use tariff, and the household size.

3. Methods

3.1. Methods of Energy Demand Planning

Traditionally, three energy modelling approaches were utilized to plan energy system management and to predict the associated gas pollution and greenhouse gas emissions at cities level. These approaches can be classified as: 1) top-down (TD) [19], 2) bottom-up (BU) [20], and 3) hybrid model (HM) methods [2].

The TD approach is based on macroeconomic models developed in the late 1950s with the sole purpose to help energy suppliers and administrators to decide on the appropriate energy prospect schema. This method seeks to meet the growing energy demand of the rapidly rising OECD countries. The abovementioned macroeconomic models are, therefore, used to simulate the future energy supply and demand patterns of a specific sector, including its impacts on upcoming economic growth and potential employment. The TD approach encompasses various input/output models, econometric models, and computable general equilibrium models as described by Ref. [11]. Thus, fluctuations in energy prices and financial policies are factors on which the TD method chiefly relies. Consequently, financial uncertainties make this method unsuitable for any 1) specific technology development, 2) related technological breakthrough, and 3) investment at a sufficiently detailed level.

The BU approach is a detailed techno-economic model also known as a process-oriented model. This method is mainly used to simulate both penetration and cost changes of new energy technologies in to the market, thus its core approach relies heavily on sufficient technical details. Therefore, some of the most commonly used BU methods are: 1) partial equilibrium models, 2) optimization models, 3) simulation models, and 4) multi-agent models. Although these models have been proven to perform well in most of the sectors, they conversely failed to project the structure of the economy and the employment net impacts that may result from new policies.

The HM is a combination of the top-down and bottom-up approaches in order to overcome their weaknesses and limitations. As stated in [13], to have a high-quality HM, the following three properties must be inclusively integrated, *viz.*, 1) the technological explicitness, 2) the microeconomic realism, and 3) the macroeconomic completeness. The reason is that the TD approach provides energy modelers with a high degree of macroeconomic completeness with microeconomic realism. In contrast, a pure BU model offers a high level of technological explicitness at a low level of macroeconomic completeness. The aforementioned approaches use deterministic forecast under various assumptions and runs based on scenarios to predict the evolution of energy systems. However, it is difficult to precisely manage the complexities of urban energy systems [8].

As a comprehensive model, a system dynamics (SD) approach can be mentioned at this point. SD is an approach used to model and analyze the long-term behavior of complex systems, such as industrial entities, entire cities, whole energy systems, and urban energy system. SD came to existence in the mid-1950s, by Pr. Jay Forrester, at the Massachusetts Institute of Technology [9]. It helps corporate managers improve their understanding of industrial processes. Since then, SD has been widely used in various socio-economic studies as noted by Radsicki and Taylor in 1997 [24].

3.2. System Dynamics (SD)

System dynamics is a powerful method that exposes useful insights from systems of dynamic complexities and policy resistances. SD is increasingly used to design more successful policies in companies and public policy settings [16]. Modelling is inherently creative and iterative. All successful modelers follow a disciplined process that involves the following activities: 1) articulating the problem to be addressed, 2) formulating a dynamic hypothesis, 3) formulating a simulation model to test the dynamic hypothesis, 4) testing the model until it is satisfactory and suitable for the purpose, and 5) designing and evaluating policies for improvement. In light of these activities, results of any steps can yield insights that lead to revisions in any earlier step. The details and background theory can be found in the System Thinking and Modelling for a Complex World [16].

SD uses four fundamental building blocks, *viz.*, stocks, flows (in and out), converters, and connectors [28] and [25]. Figure 1 presents the building blocks. Stocks are represented by rectangles. Flows can either add to a stock or deplete it. The inflow is the pipe into the stock while the outflow is the pipe from the stock. The converters are the circles while the connectors are the curved lines with arrows.

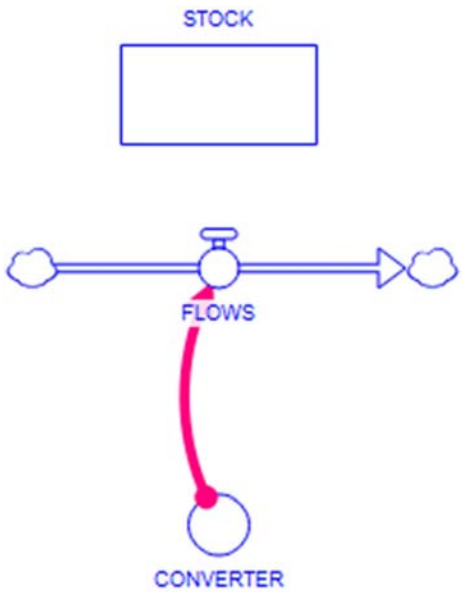

Figure 1. *Building blocks.*

Stocks are state variables that indicate the status of the system over time. Stocks are accumulations; they collect whatever flows into them over a certain period. Flows are control variables that directly change the stocks; they can increase or decrease the stocks through birth or death, respectively. Connectors connect model elements. Converters perform the following tasks: 1) holding values for constants, 2) defining external inputs to the model, 3) calculating algebraic relationships among values, and 4) serving as the repository for graphical functions. In short, they convey transforming variables. Thus, "Stella," like the "ithink" software, produces a set of finite difference equations that define the graphical model and allow users to select an arithmetical method applicable to the system. Therefore, in the course of testing a model, users may not only specify a time step, but also set a runtime for the simulation. Stella can output data in a graphical or tabular form [18]. It is worth pointing out that Stella only runs one model at a time and at any given moment.

3.3. The Electricity Consumption Model of Lomé

Like most of the emerging cities, Lomé's residential sector is facing increasing challenges. Numerous factors, ranging from population, GDP, new and aging appliances, number and size of households, to per capita electricity consumption, influence both the daily activities and the living standard of the residents.

Two time periods were considered for this study, *i.e.*, the near future of 2030 and the far future of 2050. In light of the aforementioned objectives, two models were built and tested. The first model had its principal variables set as population, GDP, and per capita electricity consumption. This model was referred to as "*Lomé Electricity Consumption System*

Dynamic with GDP and Population Growth, (LECSDGPG or simply "*A*")." The second model had population, number of households having access to electricity, and per capita electricity consumption as principal variables. This model is denoted as "*Lomé Electricity Consumption System Dynamic with Population and Households Having Access to Electricity,* (LECSDPHAE or simply "*B*")." Both models were then calibrated and validated with past electricity consumption data of Lomé over the period of 2000-2016. The coefficient of correlation was found to be 0.983 for model *A* and 0.992 for model *B*. More, the unit root test has been conducted using Augmented Dickey-Fuller test. The test shows that the test statistic (tau3) is -3.0726 for both models which is around its critical value of tau3 of -3.24 corresponding to the rejection of the null hypothesis of presence of unit root at 90% confidence level. Moreover, the p-value associated to the overall significance of test for both models is 0.0001288 less than 5%. FBR and FDR are, respectively, the fractional birth and death rates, expressed in percentage. The *Unknown*, as seen in Figure 2 and Figure 3, is any potential factor that could increase the number of deaths in the country. Consequently, models *A* and *B* are presented in Figure 2 and Figure 3, in that order.

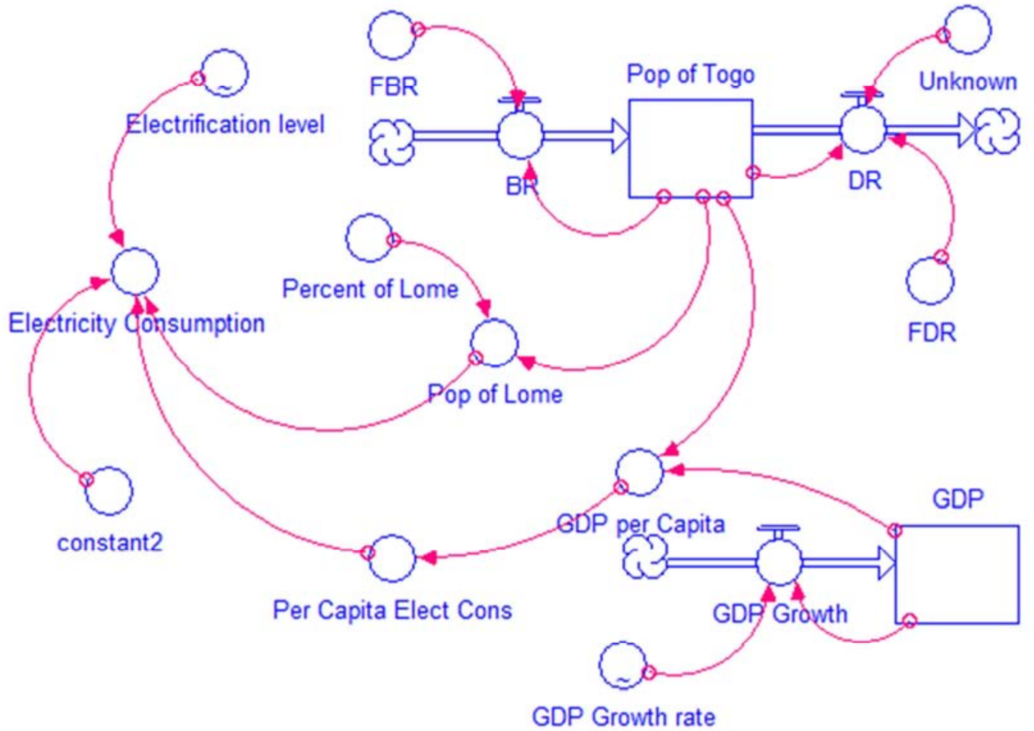

Figure 2. *Model A.*

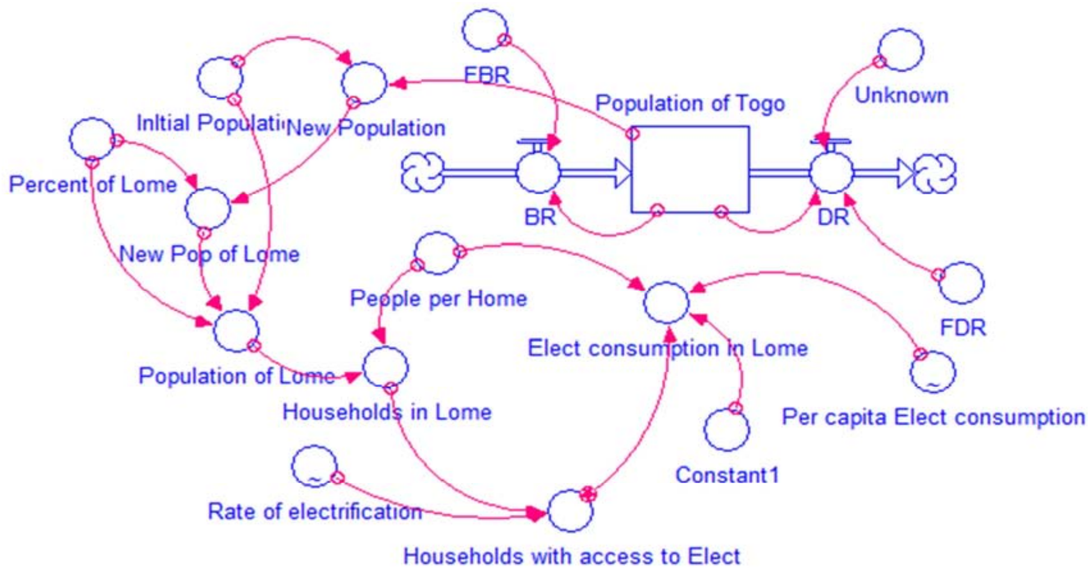

Figure 3. *Model B.*

3.4. Mathematical Formulations

A sub-layer, just beneath the graphical user interface (GUI) where the models reside, is where the mathematical equations that help to deeply understand the theory are located. These mathematical functions are the key ingredients to understanding the long-term electricity consumption patterns in Lomé. Again, the residential sector, presented in the following sections, is the focus of this study.

3.4.1. Mathematical Formulations of the LECSDGPG Model

(i). Gross Domestic Product (GDP)

The inflow to the GDP is the GDP growth. Therefore, the GDP, based on the inflow at the instant, *t*, can be estimated as in Eq. (1). The initial GDP of Togo was chosen to be the GDP of 2000. The latter was estimated in "*OECD Green Growth Studies"* to be 1330000000. In addition, the GDP growth, an important economic variable of any nation, is estimated by the rate of GDP growth times the GDP itself.

$$GDP(t) = GDP(t - dt) + (GDPG) \cdot dt \qquad (1)$$

Where,

GDP (t) is the GDP at time, '*t,*'

GDP (t-dt) is the GDP at a previous time step, and

GDPG is the increase of the GDP per year.

(ii). Population (A and B)

The inflows to the population are births, while deaths are considered as the outflows. Conversely, due to its societal and cultural connotation, death is considered in SD modelling as the decreasing or balancing factor that would bring "*population*" back to equilibrium. Therefore, based on the abovementioned dynamics at any instant (*t*), the population can be estimated utilizing Eq. (2). It should be pointed out that the population of Lomé, the capital city, is approximatively 25% of the total population of the whole country. Thus, the population, as calculated in (2), was the same for both models.

$$P(t) = P(t - dt) + (BR - DR) \cdot dt \qquad (2)$$

Where,

P(t) is the population of Togo at time, '*t*',

P(t - dt) is the population at a previous time step,

BR is the number of births in time, d*t*, and

DR is the number of deaths in time, d*t*.

(iii). Households' Electricity Consumption in Lomé

Under this model, the total electricity consumed in Lomé is the product of population, per capita electricity consumption, and the current electrification rate. In other words, this equation could be considered as the product of the number of households, the household size, and the electrification rate. For simplicity in the approach, the former was chosen and it is expressed in Eq. (3) as

$$EC = P(t) \cdot PCEC \cdot ER \qquad (3)$$

Where,

EC is the electricity consumption in Lomé's residential sector,

$PCEC$ is the per capita electricity consumption and is a linear function [26], and

ER is the electrification rate; it was 92.4% in 2016 according to the utility company [4].

In addition, the GDP per capita (GDPPC) of the country, an inherent variable of the per capita electricity, is estimated in Eq. (4).

$$PCEC = GDPPC \cdot 0.4279 + 26.2808 \qquad (4)$$

Where,

the constant 0.4279 is the slope that gives the rate of change of the per capita electricity consumption, and

the constant 26.2808 is the per capita electricity consumption intercept.

3.4.2. Mathematical Formulations of LECSDPHAE Model

(i). New Population and Population of Lomé

It is imperative, not only to accurately model the existing population, but also to be able to model the new population during the upcoming years. The knowledge of this new parameter enables us to project, as accurately as possible, the future electricity consumption in Lomé and its vicinity. Therefore, the new populations of both Togo and Lomé can be estimated through Eq. (5) and Eq. (6), respectively.

$$New\ Population\ of\ Togo = P(t) - InitialPopulation \qquad (5)$$

$$New\ Population\ of\ Lome = New\ Population\ of\ Togo \cdot Percent\ of\ Lome \qquad (6)$$

Where, *P(t)* is the population of Togo at time, '*t.*'

Furthermore, with the help of Eq. (7), the population of Lomé can be calculated as

$$Population\ of\ Lome = InitialPopulation \cdot Percent\ of\ Lome + New\ Population\ of\ Lome. \qquad (7)$$

(ii). Households in Lomé

The number of households in Lomé is expressed as the population of Lomé over the household size as seen in Eq. (8). The average household size of Lomé, at the time of the study was 5 according to the World Bank.

$$Households\ in\ Lome = \frac{Population\ of\ Lome}{Household\ Size} \qquad (8)$$

(iii). Electricity Consumption in Lomé

The electricity consumption in Lomé is the product of four factors: 1) the per capita electricity consumption, 2) the household size, 3) the number of households having access to electricity (HHAE), and 4) an adjustment constant (C1), as in Eq. (9). Furthermore, the HHAE is expressed as the total households in Lomé times the current rate of electrification of the country. The HHAE is computed in Eq. (10). The latter was inferred from the various estimates of the company in charge of energy in Togo. Hence, the energy company estimated the rate of electrification level as a quotient of the number of households having access to electricity to the total number of households. The multiplication constant, seen in Eq. (11), was introduced for adjustment purposes. The rate of electrification was increasing in accordance with the country's energy policy targets. These targets aimed, not only to improve the quality of the overall energy services, but also to further increase the access to electricity in Lomé.

$$ECL = PCEC \cdot PPH \cdot HHAE \cdot C1 \quad (9)$$

$$HHAE = HL \cdot ER \quad (10)$$

$$C1 = 1e^{+\frac{1}{5.5}} \quad (11)$$

Where,

ECL is the electricity in Lomé's residential sector,

PPH is the people per home, and

HL is the households in Lomé.

Comparative graphs of the historical versus the simulated electricity consumptions for both A and B models are depicted in Figure 4 and Figure 5, respectively. It can be observed that in both cases, the curves closely follow the same patterns. This resemblance in trends has helped to validate the proposed models.

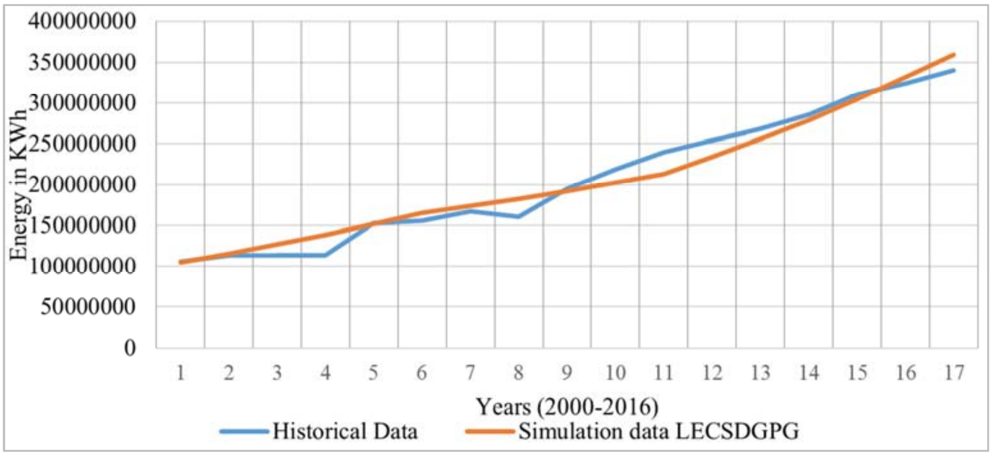

***Figure 4.** Validation of model "A".*

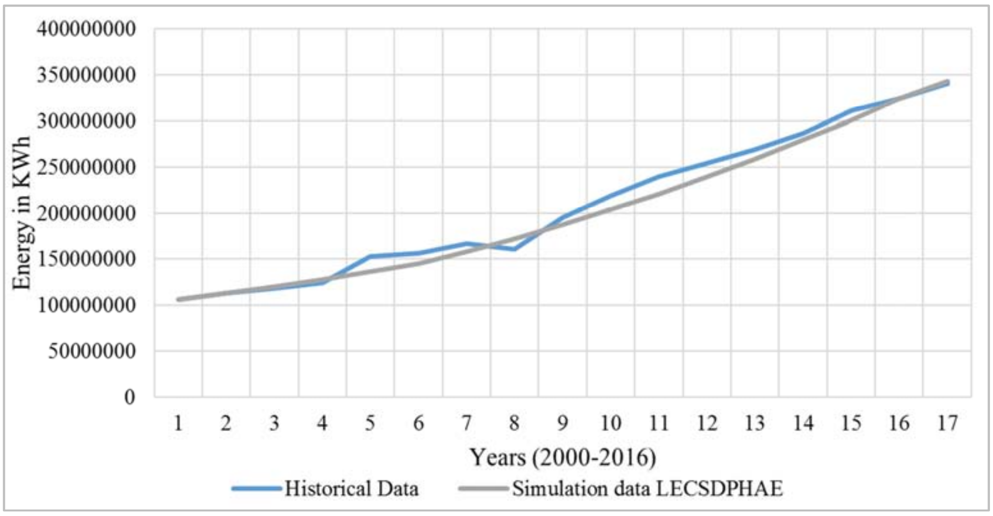

***Figure 5.** Validation of model "B".*

3.5. Data

Data were collected from various sources as illustrated in Table 1 and Table 2. The second table is a subset of the former. These data were utilized not only for calibration purposes but were also meant to validate the models. It is worth noting that the number of electrified households per year in Lomé equals the total number of customers served by the utility company (CEET). Electrification of the capital progresses due to: 1) rapid population growth, 2) unprecedented urbanization growth, and 3) increasing economic growth. The average household size of Lomé in 2016 was five according to the World Bank and [3]. Further to that, the total number of customers in Lomé was estimated to be 343,543 households. The latter represent 65.50% of the company's total clients in 2016. In addition, on average in Lomé, 83.64%of the households with access to electricity were fed through low voltage feeders. In fact, almost 80% of the total household electricity consumption in Lomé was found to be of a low voltage type.

Table 1. *Invaluable data and sources.*

Variables	Values	Sources
Population of Togo (2000)	5400000	[23]
GDP of Togo (2000) in USD	1330000000	[3]
FRB	39.3‰	[6]
FDR	10.6‰	[15]
People/household	5	World Bank (2012) and [14]
Per capita electricity consumption	120kWh	World Bank (2012)
Electrified households	(See Table 2)	[4]
Electricity consumption	(See Table 2)	[4]
Percent electrification of Togo in 2016	35.81%	[4]
Percent electrification of Lomé in 2016	92.4%	[4]

Table 2. *Households and annual energy consumption, Lomé.*

Years	Households with access to electricity	Household electricity consumption (KWh)
2000	54665.1	111334098.1
2001	58308.3	119152600.6
2002	65795.4	124812257.6
2003	71711.1	130471914.7
2004	74484	160353348.1
2005	78828.3	163854159.8
2006	83756.7	175494525.4
2007	87671.7	168774040.7
2008	94284	204865908.2
2009	100958.4	229609338.8
2010	110703.6	251575790.8
2011	124176.6	266885906.3
2012	130956.3	282174422.9
2013	141696	300300044.5
2014	158988.6	326082067.9
2015	174644.1	339906108.4
2016	193239.9	357572567.5

4. Results and Discussions

4.1. Residential Electricity Demand and Projections in Lomé Under "A"

The electricity demand of the housing sector in Lomé is a function of three variables, namely: 1) the population, 2) the GDP, and 3) the per capita electricity consumption. The aforementioned variables along with the projected electricity trends are shown in Figure 6. It can be noted that under *A*, the household's electricity consumption of Lomé grew with an increasing population, as well as GDP growth, during the past sixteen years (2000 to 2016). The forecast also mimics this growth pattern up to 2050. Therefore, a re-enforcing loop, *viz*. "more people leads to more electricity consumption," is formed. It is expected that the re-enforcing loop would persist from the present, the near future of 2030, and even the far future of 2050. The GDP and population growth both helped to understand the nature of the real drivers of the electricity consumption in Lomé's housing sector. In 2030 and 2050, the population of Lomé is likely to be, respectively, 2,839,793 and 4,991,338 habitants from the *A* model. The corresponding electricity consumptions will be 850.25 GWh and 2,886.45 GWh, in that order.

4.2. Residential Electricity Demand and Projections in Lomé Under "B"

In a like manner, the population, GDP, and per capita were the main variables utilized to build *B*. Figure 7, therefore, highlights the patterns of the total electricity consumed in Lomé. In addition, Figure 7 shows the future population trends of Togo and Lomé, as well as the household electricity consumptions of Lomé. It can be understood from the LECSDPHAE model that an increasing number of households accessing electricity would significantly burden the electricity company. If proper energy policies are not implemented in a timely manner, the electricity consumption patterns, blue curve shown in Figure 7, could have a negative effect on the whole residential sector. The past impact of the number of houses with electricity was equally captured (orange curve). Also, it can be seen (blue curve) that by 2030 and 2050, model *B* revealed an electricity consumption of 822.64 GWh and 2,495.7 GWh, respectively. This model showed a slight decrease in electricity consumption, *i.e*., 3.25% and 8.65% by 2030 and 2050, in that order, compared to model *A*. This contrast in the two models may be attributed to smart and efficient energy measures in the capital city. Also, the number of households accessing electricity was shown to be 412,763.85 and 998,268 by 2030 and 2050, respectively.

4.3. Comparison Between Models "A" and "B"

The electricity consumption simulated by model *A* was correlated to the consumption depicted by model *B*. This comparative study is illustrated in Figure 8. Either the *A* model or the *B* model may be used to simulate the past and future electricity consumption of the residential sector in any emerging nation. Despite the slight difference pointed out above, the similarity between the two models is obvious, thus making their resemblance prevail over any discrepancy.

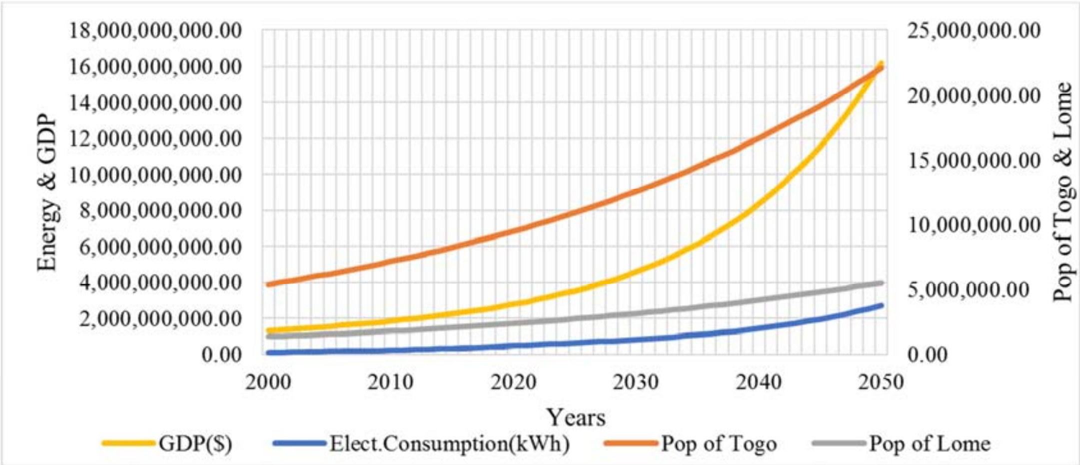

Figure 6. *Dependence of electricity consumption on population and GDP.*

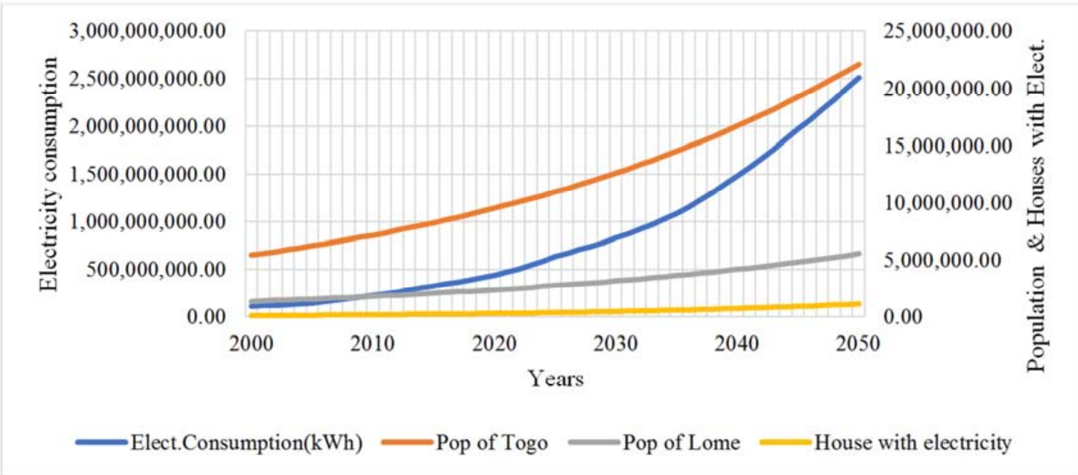

Figure 7. *Dependence of electricity consumption on electrified households.*

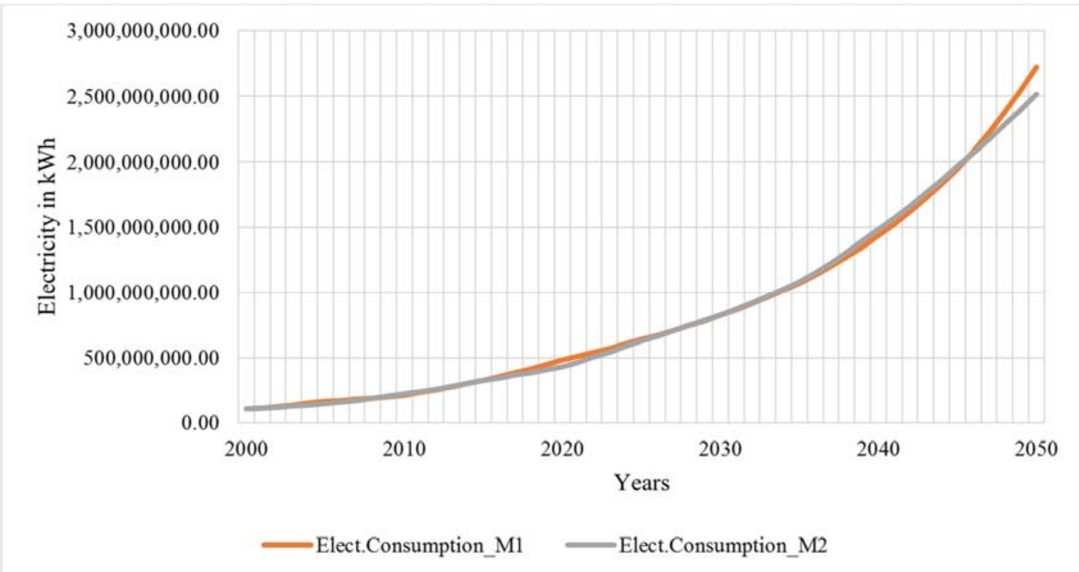

Figure 8. *Model A (Orange) vs model B (Grey).*

5. Conclusions

A system dynamics modelling of the residential electricity consumption of Lomé, the capital city of Togo, from 2000 to 2050 was attempted. The Stella software platform was utilized. Two different residential electricity consumptions models were succinctly developed and analyzed. The first model was entitled "*Lomé Electricity Consumption System Dynamics with GDP and Population Growth*, *LECSDGPG* or simply *"A"*." This model has population, GDP, and per capita electricity consumption as main variables. The second model was "*Lomé Electricity Consumption System Dynamic with Population and Households Having Access to Electricity."* Short-handed as *LECSDPHAE* or *"B",* this model has population, houses with access to electricity, and the number of households having access to electricity as variables. Socio-economic data from the past sixteen years (2000-2016) were utilized to calibrate and validate the two aforementioned models. As a result, the study showed the following findings:

a) The population in Lomé, under the current birth rate, will be close to 3 million in 2030 and 5 million in 2050.
b) With the ongoing economic prosperity in the entire country, the Togolese per capita electricity consumption is estimated to be 199 kWh in 2030 and 250 kWh in 2050.
c) Further, the findings in (b) revealed that by 2030 and 2050, the per capita energy would be increased by 25% and 63%, respectively, thus creating a self-re-enforced loop. In other words, the increasing economic prosperity and wellbeing will further drive the future electricity consumption of Lomé's residential sector, resulting in an increase close to 850 GWh in 2030 and 3 TWh in 2050.
d) Regarding the growing number of households having access to electricity, the consumption of electricity will be close to 830 GWh in 2030 and 2.5 TWh in 2050.

The electricity consumption depends on the economy and population growth as shown in the results of this study. Therefore, policy makers have to take into consideration how the aforementioned factors would evolve in short and long terms in order to better plan the supply of electricity.

Finally, it is inferred from this study that not many research activities were carried out on the Togolese household sector. Therefore, it is suggested, in order to re-evaluate and strengthen the current findings that additional research studies be carried out, not only to model all the household electricity consumptions in Lomé, but also to investigate the electricity sector of the country as a whole. By achieving this, all the hidden and intertwining consumptions driving the various socio-economic layers would be exposed.

References

[1] Bekhet, H. A. (2011) 'Assessing the Elasticities of Electricity Consumption for Rural and Urban Areas in Malaysia : A Non-linear Approach', 3 (1), pp. 208–217.

[2] Böhringer, C. and Rutherford, T. F. (2006) 'Combining Top-Down and Bottom-up in Energy Policy Analysis : A Decomposition Approach Combining Top-Down and Bottom-up in Energy Policy Analysis : A Decomposition Approach', (06).

[3] BTI (2016) 'BTI 2016 | Togo Country Report'.

[4] CEET (2016) 'Taux délectrification de 2010 à 2016-Togo', (08).

[5] Chen, L. and Samuelson, R. D. (2009) 'Residential Energy Demand Modeling Based on Multi-Economy Data', (Iea 2011), pp. 1–11.

[6] Factfish (2016) *factfish Togo Statistics and Data*.

[7] Fantu Guta, Abebe Damte, and T. F. (2015) 'Environment for Development The Residential Demand for Electricity in Ethiopia', (April).

[8] Feng, Y. Y., Chen, S. Q. and Zhang, L. X. (2013) 'System dynamics modeling for urban energy consumption and CO 2 emissions : A case study of Beijing, China', *Ecological Modelling*. Elsevier B. V., 252, pp. 44–52. doi: 10.1016/j.ecolmodel.2012.09.008.

[9] Forrester, J. W. (1989) 'The Beginning of System Dynamics', pp. 1–16.

[10] Gyamfi, S., Krumdieck, S. and Urmee, T. (2013) 'Residential peak electricity demand response - Highlights of some behavioural issues', *Renewable and Sustainable Energy Reviews*, 25, pp. 71–77. doi: 10.1016/j.rser.2013.04.006.

[11] Herbst, A. *et al.* (2012) 'Introduction to Energy Systems Modelling', 148 (2), pp. 111–135.

[12] Holtedahl, P. and Joutz, F. L. (2004) 'Residential electricity demand in Taiwan', 26, pp. 201–224. doi: 10.1016/j.eneco.2003.11.001.

[13] Hourcade, J. C. *et al.* (2010) 'Hybrid Modeling : New Answers to Old Challenges To cite this version : Hybrid Modeling : New Answers to Old Challenges'.

[14] International, E. (2014) 'The World Economic Factbook', pp. 60–61.

[15] Institut National de la Statistique (INS). (2011). *Recensement General de la Population et de l'Habitat 2010*. Lome. https://inseed.tg/

[16] John D. Sterman (2000) *Systems Thinking and Modeling for a Complex World*.

[17] Kayode, O. *et al.* (2011) 'Urban Residential Energy Demand Modeling in Developing Countries : A Nigerian Case Study.', 12 (2), pp. 152–159.

[18] Martin, L. A. (1997) 'The First Step'.

[19] Meichenbaum, D. (no date) 'www.melissainstitute.org www.roadmaptoresilience.org', pp. 6–22.

[20] Müller, T. and Tobias, M. (2000) 'Integrating bottom-up and top-down models for energy policy analysis : a dynamic framework Integrating bottom-up and top-down models for energy policy analysis : a dynamic framework *', (00).

[21] Ntagungira, C. (2015) 'Underlying Issue of Electricity Access in Togo', (SePteMBeR).

[22] OECD (2012) 'OECD Green Growth Studies', *Director*, p. 104. doi: 10.1787/9789264115118-en.

[23] Population, P., Expectancy, L. and Rate, A. I. (2009) 'TOGO / Lomé', (m).

[24] Radzicki, M. J. and Taylor, R. A. (1997) *U.S. Department of Energy's. Introduction to System Dynamics. A Systems Approach to Understanding Complex Policy Issues*. Available at: http://lm.systemdynamics.org/DL-IntroSysDyn/inside.htm.

[25] Richmond, B. (1985) *Wayback Machine 2*.

[26] Timilsina, G. R. (2009) 'Energy Demand Models for Policy Formulation A Comparative Study of Energy Demand Models', (March).

[27] Vita, G. De, Endresen, K. and Hunt, L. C. (2005) 'SEEDS S urrey E nergy E conomics D iscussion paper S eries An Empirical Analysis of Energy Demand in Namibia', (July).

[28] Zuckerman, O. and Resnick, M. (2004) 'System Blocks : Learning about Systems Concepts through Hands-on Modeling and Simulation by System Blocks : Learning about Systems Concepts through Hands-on Modeling and Simulation'.