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Master Dissertation

A Systems Dynamics approach to model Cameroon's Sustainable Energy

Submitted in partial fulfillment of the requirements for the Master degree in
ENERGY ENGINEERING

Presented by

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A SYSTEMS DYNAMIC APPROACH TO MODEL CAMEROON'S SUSTAINABLE ENERGY

By Ngagoum Ndalloka Zita,
MSc in Energy Engineering

Declaration

I, **NGAGOUM NDALLOKA ZITA** hereby declare that this thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material and results from other works presented here, have been fully cited and referenced in accordance with the academic rules and ethics.

Signature:

Date: 08th October 2021

Supervisor's signature: Csala Dénes

Date: 08th October 2021

Abstract

Energy is crucial for all development processes. Therefore, its availability in creating industries, processing raw materials and building a modern economy cannot be overemphasized. One of the challenges meeting the human race is planning for and meeting the energy needs and demands of the future. This thesis uses a systems dynamics approach to model the electricity demand of Cameroon. Considering the dynamic nature of energy systems, causal relationships and feedback loops are used to model the interactions between the different intervening variables of the sociotechnical system characterized by the energy transition. The intervening parameters considered are; population growth rates, GDP per capita, GDP growth rates, Economic growth rates represented by the Average Annual Growth Rates (AAGR), energy consumption (electricity consumption per capita), electricity prices and other socio-economic and techno-economic parameters. Furthermore, a timeseries of the dynamic evolution is developed for a period of 60 years starting from 1990 to 2050. 1990 is used as the base year from which the modelling process starts and 2050 as the end period of the modelling process. Whenever possible, the model is calibrated to reproduce the historical outputs for the period of 1990-2020.

Several scenarios were created based on transparent underlying assumptions and the country's energy sector development strategy. The model is simulated and the effects of varying any or all of the above intervening parameters on the electricity demand is examined. Our model shows that the electricity demand of the country will increase with population and economic growth and an increase share of renewables in the energy mix. The population of Cameroon according to our results is expected to reach 38.8 million and 58 million by 2035 and 2050 respectively and the actual electricity demand is expected to reach about 19.3 TWh by 2035 and about 45 TWh by 2050. Increasing the share of renewables in the energy mix is an important way of decreasing the CO2 emissions by 32% by 2035 as planned by the government in Cameroon's Vision 2035 document. Therefore, we show that, if the assumption outlined in the Vision 2035 are kept, renewables are the best energy resource for the Cameroonian economy.

Résumé

L'énergie est cruciale pour tous les processus de développement. Par conséquent, sa disponibilité dans la création d'industries, la transformation des matières premières et la construction d'une économie moderne ne peut pas être surestimée. L'un des défis auxquels est confrontée la race humaine est de planifier et de répondre aux besoins et aux demandes énergétiques de l'avenir. Cette thèse utilise une approche de dynamique des systèmes pour modéliser la demande d'électricité du Cameroun. Compte tenu de la nature dynamique des systèmes énergétiques, des relations causales et des boucles de rétroaction sont utilisées pour modéliser les interactions entre les différentes variables intervenantes du système sociotechnique caractérisé par la transition énergétique. Les paramètres d'intervention considérés sont ; taux de croissance démographique, PIB par habitant, taux de croissance du PIB, taux de croissance économique représentés par les taux de croissance annuels moyens (TCAM), la consommation d'énergie (consommation d'électricité par habitant), les prix de l'électricité et d'autres paramètres socio-économiques et techno-économiques. De plus, une série chronologique de l'évolution dynamique est développée pour une période de 60 ans à partir de 1990 à 2050. 1990 est utilisée comme année de base à partir de laquelle le processus de modélisation démarre et 2050 comme période de fin du processus de modélisation. Dans la mesure du possible, le modèle est calibré pour reproduire les valeurs historiques pour la période 1990-2020.

Plusieurs scénarios ont été créés sur la base d'hypothèses sous-jacentes transparentes et de la stratégie de développement du secteur énergétique du pays. Le modèle est simulé et les effets de la variation de tout ou partie des paramètres d'intervention ci-dessus sur la demande d'électricité sont examinés. Notre modèle montre que la demande en électricité du pays augmentera avec la croissance démographique et économique et une augmentation de la part des énergies renouvelables dans le mix énergétique. La population du Cameroun selon nos résultats devrait atteindre 38,8 millions et 58 millions d'ici 2035 et 2050 respectivement et la demande réelle d'électricité devrait atteindre environ 19,3 TWh d'ici 2035 et environ 45 TWh d'ici 2050. L'augmentation de la part des énergies renouvelables dans le mix énergétique est un moyen important de réduire les émissions de CO2 de 32% d'ici 2035 comme prévu par le gouvernement dans le document Vision 2035 du Cameroun. Par conséquent, nous montrons que, si l'hypothèse énoncée dans la Vision 2035 est maintenue, les énergies renouvelables sont la meilleure ressource énergétique pour l'économie camerounaise.

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List of Abbreviations

SD: Systems Dynamics

ENEO: Energy of Cameroon

GDP: Gross Domestic Product

RE: Renewable Energy

TWh: Terra-Watt hour

bcm: Billion Cubic Meters

mtce: Million Tonnes Coal Equivalent

GWh: Giga-Watt hour

KWh: Kilo-Watt hour

MW: Mega-Watt

Km: Kilo meter

m/s: Meter per second

m^2: Meter square

MSCF: Million Standard Cubic Feet

NDCs: Nationally Determined Contributions

MINEE: Ministry of Water and Energy

IPP: Independent Power Producers

IPCC: Intergovernmental Panel on Climate Change

EIA: Environmental Impact Assessment

UNFCCC: United Nation Framework Convention on Climate Change

Ktoe: Kilo tons oil equivalent

MtCO2-eq: Million tons Carbon dioxide equivalent

AAGR: Average Annual Growth Rate

IEA: International Energy Agency

IPCC: Intergovernmental Panel on Climate Change

PSE: Process Systems Engineering

EE: Energy Economics

GHG: Green House Gas

EROI: Energy Return on Investment

BAU: Business as usual

CHAPTER ONE: GENERAL INTRODUCTION

1.1 Introduction

Energy is very important for all development processes (Sapnken et al., 2018). It is vital for virtually every economic activity, for industries, agriculture, health, access to water, education, quality of life etc. Suganthi & Samuel (2012) in their identification of the various factors that are important for the environment, pointed out energy as the most important factor amidst water, food and natural resources. To sustain population growth, economic growth and development, a stable supply of energy with a vigorous energy policy is required to sustainably make use of energy resources and to meet population's energy demand (MINEE Cameroon, 2017a). Given the vitality of energy, attention about it has increased over the years, especially over the global imbalances between energy demand and supply, CO2 mitigation and other energy related impacts. It is therefore important for every country to ensure continuous energy access and supply both in quantity and quality to meet demand at any time (Fotsing, 2014). Meeting up with this energy demand requires a proper energy planning, management and forecast, and genuine understanding of all the factors that affect energy consumption. This study aims at understanding the intervening parameters of the energy system of Cameroon, building an energy model to forecast its demand and recommend policies that will help in the achievement of goals and visions within the energy sector. This chapter will present a comprehensive background of the study, the research problem and questions, aims and objectives and will conclude with the significance of this research and its limitations.

1.2 Background of the study

The energy demand of continents and nations keep increasing over the years, with one of the main reasons being the continuous increase in population. According to the 2019 Africa Energy Outlook report by the International Energy Agency (IEA) (Garcia & Hawes, 2021) by 2025, Africa's population is expected to exceed that of both India and China and the continent's urban population is set to grow by more than half a billion over the period from 2019 to 2040. These profound demographic changes are set to drive economic growth, infrastructure development and, in turn, energy demand, with the energy demand in Africa growing twice as fast as the global average.

Also, energy and economic growth are strongly related (Fotsing, 2014). An increase in either energy production or consumption of a country will have a direct effect on the economic growth of that country. Four views currently exist regarding the causal relationship between energy consumption and economic growth (Lechner & Steinmayr, 2011).

1. The first view, "*the growth hypothesis*", is the unidirectional relationship from energy consumption to economic growth, and says a decrease in energy consumption may restrain economic growth.
2. The second view, called "*the conservative hypothesis*", argues unidirectional causality from economic growth to energy consumption. It suggests that energy conservation policies may have little or no impact on economic growth.
3. The third view, "*neutrality hypothesis*", argues that there is no causality between energy consumption and economic growth. In other words, both energy consumption and economic growth independent or neutral with respect to each other.
4. The "*feedback hypothesis*" (fourth view) suggests that there is bidirectional causal relationship between energy consumption and economic growth reflecting the interdependence and possible complementarities associated with energy policies and economic growth.

Like every other nation, the economic growth of Cameroon is also related to its energy demand. Sama & Tah (2016) carried out a study in Cameroon to determine the effect of energy consumption on economic growth for a period of 1980 to 2014. They used petroleum and electricity to test for this relationship. Using the Generalized method of moments technique and secondary data, the results showed that GDP, population growth rate and petroleum prices have a positive relationship with petroleum consumption. They recommended as a result of this study that the government should expand the exploitation of other renewable energy sources like solar energy, wind energy and thermal energy, so as to increase the production and consumption of energy, which will in turn increase economic growth.

There also exist other different variables other than GDP that have an influence of the total energy consumption and demand of a country (Keho, 2016). Fotsing (2014) modelled the demand of low voltage electricity customers in Cameroon using electricity as an energy source from the year 1975 to 2011, with the aim of studying the consumption determinants (macro-economic indicators, demographic indicators and lagged consumption of low voltage electricity) of low voltage customers and to examine the determinants with strong influence on consumption. Parameters estimated by EVIEWS 7.2 software for linear and exponential (Cobb-Douglas) models were used. The results show that, the best linear model is a function of delayed consumption; overall gross domestic product (GDP) and population (Pt). Another study on the title “Modeling and Forecasting Gasoline Consumption in Cameroon using Linear Regression Models” by (Sapnken et al., 2018) suggested that price, gross domestic product and income are significant drivers of gasoline consumption in Cameroon. Projected results show that gasoline consumption will increase by over 7% yearly, reaching 1078 504 m3 by 2020. Also, Tamba et al. (2017) carried out a study with the aim to analyze the gasoline sector of Cameroon and examine the causal relationship between gasoline consumption and economic growth shows that there is a bidirectional causality relationship between gasoline consumption and economic growth in Cameroon. Meaning that, an increase in gasoline consumption affects economic growth with feedback effect. With such results, it means maintaining Cameroon’s economic growth entails policies that will favor and improve gasoline consumption (energy consumption) and most importantly meet the energy demands of the population.

Being able to plan and meet the energy needs and demands of tomorrow is one of the greatest challenge humans face and requires planning (Al Najjar, 2013). Therefore, energy planning and management is crucial for future economic prosperity and environmental security of a country, and it is important to know the determinants of consumption so as to better manage available resources and advice the government on the development of energy policies (Fotsing, 2014). It will not be wrong to say that forecasting our electricity demand plays an important role in the electricity planning and management process of a country. A reliable forecast can help achieve a balance in the electricity demand and supply of a country, alleviating the risk of socioeconomic instability of the country and improving the well-being of the citizens. Energy forecasts are important as they help in decision making during the process of sustainable city development.

1.3 Problem statement

The lack of energy remains a major bottle neck for economic development. Fondja Wandji (2013), in his article titled “Energy consumption and economic growth: Evidence from Cameroon”, through an Error Correction Model reveals that every percentage increase in oil consumption increases the economic growth of Cameroon by 1.1% - meaning that economic development and energy are closely intertwined.

In June 2009, Cameroon made known its goal of becoming an emergent country by 2035, and was announced as Cameroon Vision 2035. Vision 2035 is an all-inclusive comprehensive national development plan, and establishes mid-term goals for various areas, such as the elimination of poverty, economic development, industrialization, democracy, and a unified society. Vision 2035 is the reference framework guiding other Cameroon policy and national strategy and encompasses the development and cooperation of all the economic sectors and the regions of the country. This reference framework is intended to guide sector and regional policies, national strategies, development plans, and cooperation (MINEE Cameroon, 2017b; Cameroun, 2009).

The need for growth and development in Cameroon which can be realized through the achievement of Cameroon's visions and goals requires energy (Njimated & Yakum, 2020). The energy sector is therefore a critical policy area for the successful achievement of a nation's various visions and goals. Having an understanding of the possible amount of energy the Country may need in the long-term considering the various stated scenarios is crucial to achieving the various plans, goals and visions that the government has within the energy sector. Different energy forecasts for Cameroon uses different models and are purely numerical. One of such was done using the diffusion model (MINEE Cameroon, 2017b). This study plans to build and simulate a model that doesn't only go beyond being purely numerical, but that will also demonstrate the main factors that affect the energy demand of Cameroon, their interconnection and their socio-economic impact on the country's energy demand.

1.4 Research questions and working hypothesis

Questions: The main research question is

What are the causal and feedback relationships between intervening system parameters governing Cameroon's sustainable energy transition?

This main question can be broken down into:

1. What possible amount of energy will be needed by Cameroon in the year 2035? And What is the evolutionary trend of Cameroon's energy demand up to year 2050?
2. What are the sectoral distributions (transport, industries, residential and commercial, agriculture) of the demand projections?
3. How do socio-economic parameters influence overall energy demand?

Based on the research questions above, the research will construct a system dynamic model in Vensim where socio-economic and energy related parameters will be used to project future energy demand trends for the country.

Working Hypothesis: The study will test the following hypotheses:

1. A system dynamics model can be successfully used to forecast the possible quantity of energy needed by Cameroon by the year 2035 and a possible trajectory.
2. Simulation based results can help the country to achieve its energy demand goals.

1.5 Objectives of the study

This thesis seeks to achieve the following:

- To understand the energy generation and demand pattern, the various key energy plans and policies of the energy sector of Cameroon and understand the variables driving the dynamics of the energy sector.
- To build a systems dynamics model using Vensim software for the energy sector of Cameroon and show that this model can be used to effectively forecast the future energy demand of Cameroon.
- To provide a time series information on the total electricity demand of Cameroon up to the year 2050 and how the various systems variables interact, affecting this energy demand.
- To inform policies and provide recommendations from the findings.

1.6 Relevance of the study

Energy is strategic in key dimensions of sustainable development: economic, social and environment. Energy is integrated (one part of the system affects the other), it is inter-grated (energy policies affect and are affected by a myriad of other decisions/developments) and energy systems are dynamic. Therefore, energy models planning and forecasts is the right choice to deal with uncertainties in prices, technologies, policies, demand and behavior. The sustainable realization of the goals and visions which Cameroon has within its energy sector can be made possible through the use of dynamic models which can properly and successfully model the energy planning and forecast of the energy sector of Cameroon. This study will therefore be helpful in the following ways;

- It will provide a model which decision makers in Cameroon and other countries can use to simulate and evaluate the outcome of their different policies under certain scenarios and will be the first system dynamics model of Cameroon.
- It will provide a tool for stakeholders to identify controllable actions in the context of a highly uncertain set of future conditions in the Cameroon’s energy future.
- Using an advance and simple tool like SD, policy makers will be guided on how to cope with country level challenges and the occurrence of unintended outcomes from the interactions of the many different policies they are called to put in place.
- The results of the simulation can be used to access the policy gaps in achieving Cameroon’s Nationally Determined Contributions (NDCs).
- It will help in a reasonable and proper allocation of the available renewable energy resources of Cameroon such as solar, wind, hydro, biomass, in meeting future energy demands.

1.7 Organization of the study

This thesis will be divided into five chapters; In **chapter one**, the context of the study has been introduced. The research objectives and questions have been identified and the value of such research argued. In **chapter two,** the existing literature will be reviewed to try to identify the different models, modelling methods and software that exist. This chapter will also present an overview about the energy sector of Cameroon, the various resource potentials and the different plans, goals and visions within its energy sector. **Chapter three** will present the methodology of the study. The various key variables will be identified and the systems dynamics model will be built and tested. **Chapter four** will talk about the simulation design after which, the presentation and discussion of results. In this chapter, we will simulate the various scenarios of the model and discuss the results obtained, and finally **Chapter five** will present the conclusion and recommendations from the study.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The chapter provides a comprehensive review of literature on energy systems and planning, with a focus on energy demand forecast. A review of Cameroon and its energy sector is also performed.

2.2 Energy systems

There are different definitions of an energy system. The Intergovernmental Panel on Climate Change (IPCC) in its fifth Assessment Report, defines an energy system as a "system that comprises of all components related to the production, conversion, delivery, and use of energy" (Intergovernmental Panel on Climate Change (IPCC), 2013). Another definition describes an energy system as one which consists of primary resources, including both fossil fuels and renewable sources; electric power plants, refineries, and other technologies to process and convert these resources into secondary energy carriers such as electricity and gasoline; technologies such as furnaces and light-duty vehicles that use these energy carriers to meet demands for energy services; and end-use demands for services such as indoor space heating and personal transportation (Warf, 2014).

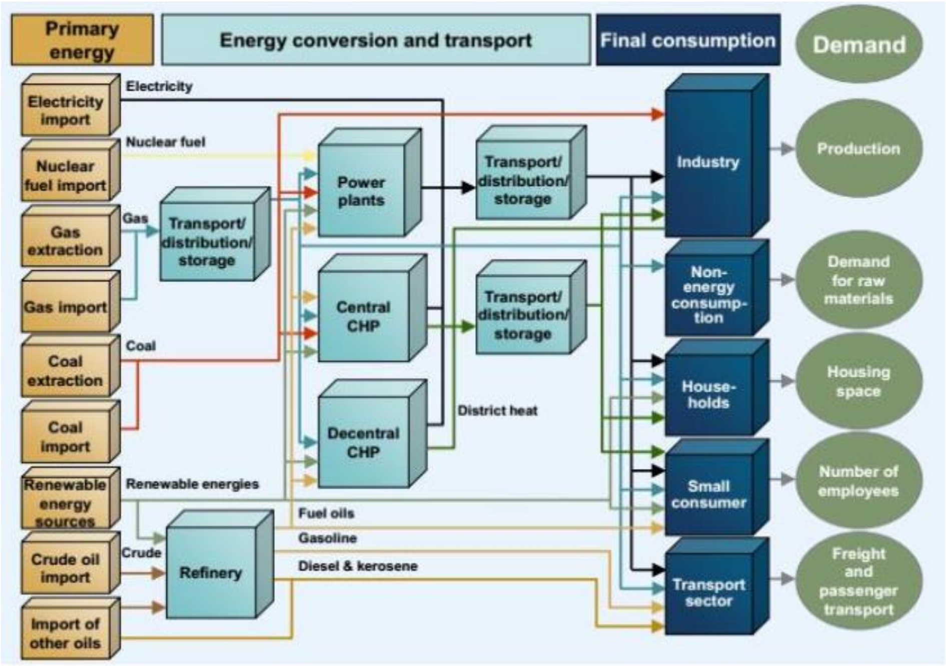


Figure 1: Architecture of an energy system. Source (Hake, 2017)

2.3 Energy system models

If the world is to successfully meetup with ecological challenges such as energy resources depletion, then there is need for proper planning and usage of the available sources. Given the complex and dynamic nature of energy systems, they do not allow experimentation since it would be dangerous, expensive or even impossible. Instead, models are used for energy planning, which are able to guide the adoption of energy policies. Energy planning and scenarios generation have two main goals: to provide guidance and material for discussion about future energy systems and to support decision-makers in developing short and long-term energy strategies (Prina et al., 2020). A well-planned energy system helps to prepare for an uncertain future in an organized, comprehensive and transparent manner. Different methods for energy planning and forecast exist. Choosing an appropriate method to represent and fit into a specific situation is important, as the results obtained is directly linked to the method of forecast used. Suganthi & Samuel (2012), in their paper titled "Energy models for demand forecasting – a review" attempts to review the various energy demand forecasting models. In this review, they identified new techniques such as support vector regression, ant colony and swarm optimization, which are being used in energy demand forecasting. Guefano et al. (2021), in one of their work which was to forecast the electricity consumption in the residential sector in Cameroon used the Gray Model (GM) and Vector Autoregressive Models (VAR) in a hybrid way known as the GM (1,1)-VAR(1) hybrid models. Their results estimated the electricity needs of the residential sector of Cameroon to be about 2641.632 GWh by 2025. Also, with the aim to compare different energy forecasting models, Han & Li (2019) carried out a research to forecast the energy consumption in East Africa using different forecasting methods such as the non-linear metabolic gray model (NMGM), metabolic gray Model-Auto Regressive Integrated Moving Average Model (MGM-ARIMA) and non-linear metabolic gray Model-Auto Regressive Integrated Moving Average Model (NMGM-ARIMA). Their results show that combine models have higher precision compared to the single models and that East Africa's primary energy consumption will grow by 4% between 2018 and 2030.

Energy demand models can be classified in several ways such as static versus dynamic, univariate versus multivariate, techniques ranging from time series to hybrid models (Suganthi & Samuel, 2012). Therefore, the development of such a system requires a comprehensive understanding of its various components and their interactions, and therefore requires approaches that can adapt to and model the dynamic complexity of energy systems.

So far, every model that we have examined is a univariate or multivariate, but linearly independent time series model. This work proposes to include the systemic dynamics, taking into account the nonlinear intra-system relationships between the variables defining the behavior of the energy system.

2.3.1 Types of energy models

Energy models characterize the energy system, its evolution, and its interactions with the broader economy. The modelling and simulation of energy systems have received significant attention over the years (Van Beeck, 1999). In recent years, the total number of available energy models has grown tremendously because of the expanding computer possibilities. As a consequence, these models vary considerably and the question arises which model is most suited for a certain purpose or situation. A classification scheme can provide insight in the differences and similarities between energy models and thus facilitates the selection of the proper energy models (Van Beeck, 1999). There are several purposes of energy models; Better understanding of current and future markets – supply, demand, prices; facilitating a better design of energy supply systems in short, medium and long term; ensuring sustainable exploitation of scarce energy resources; understanding of the present and future interactions energy and the rest of the economy; understanding of the potential implications to environmental quality.

Several authors have classified energy models in different ways. The table below provides a list of some authors, and the ways the used in classifying energy models.

Table 1: Different Classification of energy models

Author	**Classification criteria**
Van Beeck (1999)	- General and Specific Purposes of Energy Models - The Model Structure: Internal Assumptions & External Assumptions - The Analytical Approach: Top-Down vs. Bottom-Up

	- The Underlying Methodology - The Mathematical Approach - Geographical Coverage: Global, Regional, National, Local, or Project - Sectoral Coverage: Energy sector, other sectors - The Time Horizon: Short, Medium, and Long Term - Data Requirements: Aggregated or disaggregated
Neshat et al. (2014)	- Model type (descriptive or prognostic) - Purpose (prediction/forecasting, exploring and back-casting) - Modeling paradigm (top-down, bottom-up, hybrid model (bottom-up and top-down)) - The underlying methodology (econometrics, macro-economics, economic equilibrium, optimization, simulation, back-casting, multicriteria, hybrid) - Resolution technique: Linear Programming (LP), Mixed Integer Linear Programming (MILP), Dynamic Programming (DP), Fuzzy Programming (FP) or stochastic and/or interval programming (SP), Techniques such as Artificial Neural Networks (ANN), Autoregressive, Adaptive Neural Fuzzy Inference Systems (ANFIS), and Markov chain techniques. - Geographical coverage: Local, regional, national, global - Time horizon: short-term, medium-term, long-term - Data type: Aggregated or disaggregated - Endogenization degree - Addressed side: demand side forecast or supply side forecast

In addition, there are several studies which deal with reviews of energy system models proposing additional characteristics to classify them. In one of such review, Jebaraj & Iniyan (2006) made an attempt to understand and review the various emerging issues related to the energy modeling. The different types of models such as energy planning models, energy supply–demand models, forecasting models, renewable energy models, emission reduction models, optimization models were reviewed and presented. Also, models based on neural network and fuzzy theory were also reviewed and discussed. Such review paper on energy modeling helps energy planners, researchers and policy makers widely. In another review by Subramanian et al. (2018) titled "modelling and simulation of energy systems: a review", they classify energy systems models in two categories; according to the modelling approach, namely into computational, mathematical and physical models, and the second categorization according to the field, namely Process Systems Engineering (PSE) and Energy Economics (EE).

The classification of models using the Top-down, Bottom-Up criteria, explicitly describes the energy models and a closer look reveals that most of the classification criteria are embedded in this classification criteria. According to Feng et al. (2013) energy modelling approaches can be categorized into 3 types: top-down, bottom-up and hybrid models. There also exist traditional energy models.

2.3.1.1 Bottom-up energy models

This modelling approach analyzes in detail the components and interconnections between the different energy sectors. By providing detailed models from a techno-economic point of view, they enable their users to compare the impact of different technologies on the energy system and to evaluate the best future alternatives to lower GHG emissions for the achievements of the energy targets (Prina et al., 2020).This energy model has a high degree of technological detail (compared to top-down energy models) and is used to assess future energy demand and supply. However, the bottom-up approach does not take into account the connections between the energy system and the macro-economic sectors, thus neglecting the impacts on these sectors (Prina et al., 2020). Bottom-up energy models are unsuitable for very long-term energy demand and supply projections in technology areas with re-investment cycles of less than 20 years because of their high level of technological detail and transparency considering technological progress and the penetration of new energy technologies (e.g. future generations of a new technology may be quite different from its present type) (Prina et al., 2020).

Bottom-up models can be used to simulate the market penetration of and related cost changes of a new energy technology or policy with a certain degree of technical detail, although they cannot project the structural, economic and employment net impact or net cost for the society (Herbst et al., 2012). The table below gives a description of the various types of bottom-up energy models.

Table 2: Types of bottom-up energy models

Type of bottom-up model	**Description**
Partial Equilibrium Models	They focus on energy demand and supply. By neglecting certain interrelations and effects on the broader economy, they can include many more technological details than conventional computable general equilibrium (CGE) models e.g., POLES, WEM, PRIMES
Optimization Models	Optimization models try to define the optimal set of technology choices to achieve a specific target at minimized costs under certain constraints leaving prices and quantity demanded fixed in its equilibrium e.g., MARKAL (used by the IPCC to create their long-term climate forecasts), MESSAGE, DIME
Simulation Models	Simulation models aim to replicate consecutive rules that describe the associations and interrelationships among various system elements, i.e., simulation models attempt to provide a descriptive, quantitative illustration of energy demand and conversion based on exogenously determined drivers and technical data with the objective to model observed and expected decision-making that does not follow a cost minimizing pattern e.g., REEPS, MURE, WEM, LEAP etc.

Multi-Agent Models	Multi-agent modelling is a simulation approach which considers market imperfections such as strategic behavior, asymmetric information and other non-economic influences.

Bottom-up energy models can also be classified as either short-term or long-term energy models. Examples of short-term energy models are; REmix, PyPSA, EnergyPLAN, EPLANopt, Oemof, Calliope, Genesys, PLEXOS, etc. Long-term energy models are; LEAP, OSeMOSYS, MESSAGE, EPLANoptTP, Temoa, Balmorel, eMIX etc. (Prina et al., 2020).

2.3.1.2 Top-down energy models

Top-down energy models also called macroeconomic models try to depict the economy as a whole on a national or regional level and to assess the aggregated effects of energy and/or climate change policies in monetary units (Prina et al., 2020). They aim at linking the energy system to other macro-economic sectors. They are usually characterized by a simplified representation of the components and complexity of the energy system and are therefore not appropriate to identify sector-specific policies. They are better applied in fields which involves the evaluation of the impacts of energy and climate policies on socio-economic sectors as social growth, public welfare, employment etc. (Prina et al., 2020).

Top-down models can simulate sector specific future energy demand and supply, including their impacts on economic growth, employment or foreign trade. However, they are not convenient for the description of a specific technology or sectorial policies and related changes in demand, related emissions and investments at a sufficiently detailed level because they rely very much on energy price changes and financial policies. (Herbst et al., 2012).

Despite the past shortcomings of top-down energy model in the sense that they considered technological developments and that they mainly function in the context of price-based policies (taxes, surcharges, or investment subsidies) and regulatory policies (technical standards, bans, and technological targets), today, top-down models are extending to an energy demand forecasting framework of the existing models to include technological and economic feedbacks.

There are different types of top-down models namely; input-output models, econometric models, computable general equilibrium models and system dynamics. The table below gives a brief explanation of these various types.

Table 3: Types of top-down models

Model type	**description**
Input-output models	Suitable for short-term evaluation of energy policy, they are used for the structural description of the regarded economy, describing the total flow of goods and services of a country, subdividing it into sectors s and users in terms of value added and specific input/output coefficients.
Econometric models	Heavily relying on data, they are defined as a combination of economic theory, mathematical tools and statistical methods. They deal with time series analysis and estimate statistical relations between economic variables over time in order to calculate projections from the resulting model.
Computable general equilibrium (CGE) models	based on microeconomic theory and calculate how both prices and activities in all sectors change in order to reach a general equilibrium in the economy. Like the first group, these models also build on the input output data from national accounts. CGE models take into account the inter-dependencies between different sectors, agents and markets in the economy. CGE analysis can therefore shed light on the wider economic impact of policies and sometimes reveal their indirect or unintended effects.
Systems Dynamics	The aim here is to explain the behavior of an interacting socio-technical system as a result of the assumed interdependencies considering

	dynamic changes over time (differential equations and analysis) among the various components that constitute the defined system.

2.3.1.3 Hybrid models

To overcome the weaknesses and limitations of conventional top-down and bottom-up energy models, energy modelling is currently moving in the direction of hybrid energy system modelling combining at least one macroeconomic model with at least one set of bottom-up models for each final energy sector and the conversion sector. Hybrid energy models introduce moderate technological detail within a macro-economic approach. These can be either of two forms: (1) a coupling of existing bottom-up and top-down models (‘‘soft-linked”) or (2) a single integrated model which blends features of both top-down and bottom-up models (‘‘hardlinked”) (Hall & Buckley, 2016).

2.4 Systems Dynamics Models

System dynamics is a perspective and set of conceptual tools that enable us to understand the structure and dynamics of complex systems. System dynamics is also a rigorous modeling method that enables us to build formal computer simulations of complex systems and use them to design more effective policies and organizations (Bayer, 2004).

Developed in the 1950s, by Jay Forrester at the Massachusetts Institute of Technology (MIT), SD has been used to analyze the long-term behavior of social systems like large industrial companies or entire cities. In the field of SD, the problem under study is analyzed as an entire system (a collection of elements that interact continually with each other) (Sapiri et al., 2017). Since 1960s, system dynamics (SD) methodology has been widely used in numerous areas, such as in economics, finance, environmental studies, healthcare, information technology, and biology (Sapiri et al., 2017). It has also been used by several researchers in the energy sector, starting around the 1970s, and its main focus is to understand how the elements in a system interact with each other through feedback loops.

Researchers through SD modeling can analyze complex systems from a cause-and effect perspective, rather than from a statistical standpoint. SD has been used to analyze renewable energy integration of some countries, to model the Energy Return on Investment (EROI) of the energy resources, to forecast electricity demand, analyze the demand and supply gap of energy in some areas and for proper understanding of energy systems and the interrelation between its variables. SD offers the opportunity to simulate a problem by investigating its results and behavior, making the framework useful for policy testing, what-if scenarios, or policy optimization.

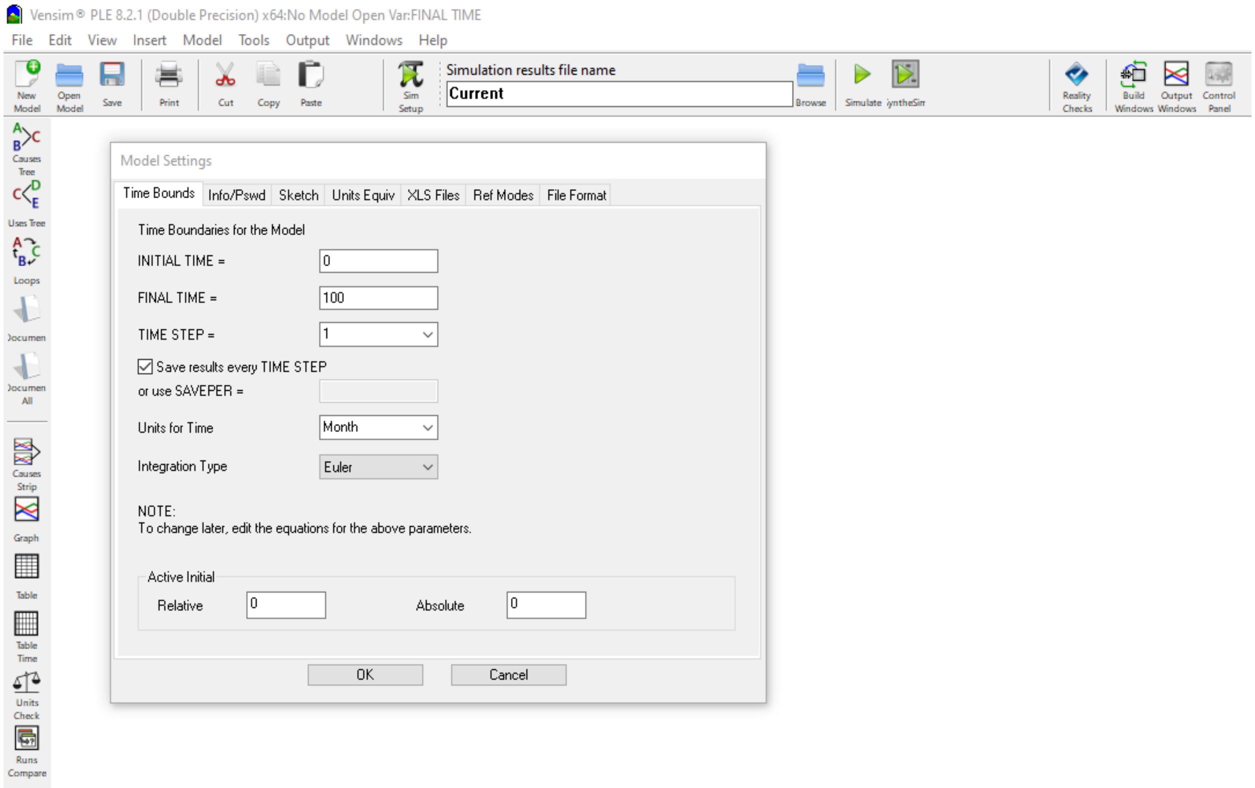
Systems dynamics is an effective technique in forecasting long-term electricity demand (Ahmad et al., 2012) and therefore modelling energy transitions. In such studies, the results obtained are reliable and could be used to make recommendations and informed decisions for the development of the area or country.

2.4.1 Types of Systems dynamics software

There are several types of system dynamics softwares used to aid systems dynamics analysis. These softwares can be classified either as those using programming languages [e.g., AnyLogic (using Java programming), PowerSim (using C++ programming) and DYNAMO (using Pascal programming)] or as those using a proprietary programming language (e.g., Stella/iThink and Vensim) (Sapiri et al., 2017). Vensim has been chosen as the systems dynamic software for this project for its ease of use and simplicity.

2.4.2 About Vensim

Developed by Ventana systems, Vensim has many advantages. In a summarized comparison of the various systems dynamic applications by Sapiri et al. (2017), Vensim software got the highest value in user friendliness (the degree of easiness to use the software) and learning curve (the learning time to develop simple model). Figure 2 below represents Vensim interface when a new model is created.



Simulation results file name: Current

Time Boundaries for the Model

INITIAL TIME = 0

FINAL TIME = 100

TIME STEP = 1

☑ Save results every TIME STEP

or use SAVEPER =

Units for Time: Month

Integration Type: Euler

NOTE:
To change later, edit the equations for the above parameters.

Active Initial

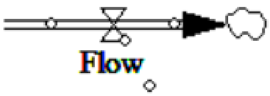
Relative: 0

Absolute: 0

Figure 2: Vensim interface

Vensim uses several tools in building the model structure as seen in the table below.

Table 4: Systems dynamics symbols. source: Lloret et al. (2009).

Symbol	**Name**	**Description**
	**Stock**	A stock represents things in the model that can accumulate. The stock will rise and drop depending on its flows, and will remain constant while in equilibrium
	**Flow**	A flow is the rate of change of a stock. Inflows add to a stock, out flows take away from the stock. Equilibrium occurs when inflows to all stocks are equal to the outflows.
	**Influence Arrow**	The blue arrows in the model represent when one variable, a, directly influences the current value of another, b.

In Vensim, a better understanding of the cause-and-effect relationship amongst system variables is done using a causal loop diagram. It contains the key elements of the model, connected in a way that shows their feedback loops. The key elements of the model are connected with arrows with either a plus or minus sign. A plus sign means an increase or decrease in the variable at the tail will cause the variable at the head to move in same direction. A minus sign mean a decrease in the element of the tail will increase the element at the head, and vice versa (Lloret et al., 2009). The figure below is an example of a causal loop diagram. The positive feedback loop is indicated with variables births and total population. This is because an increase in births will cause an increase in total population which will cause births to even increase further. The negative feedback loop is illustrated with elder deaths and total population. As the elder deaths decrease, total population increases.

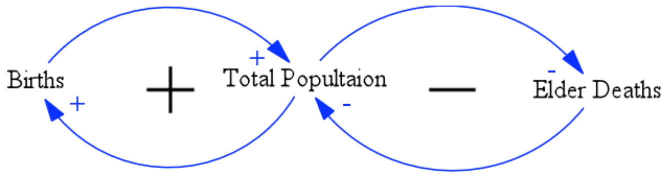


Figure 3: Causal loop diagram

In systems dynamics, stocks, flows and feedback loops represent complex systems. A bathtub with a faucet and a drain analogy can be used as a basic system to understand these terms. In the bathtub system, the bathtub is the stock, the faucet is the inflow and the drain is the outflow. Complex systems could have many stocks and flows with many feedback loops. The tub may drain in the faucet of another tub which can still drain in the faucet of another tub. This bathtub concept can be illustrated using the Vensim software as shown in figure 4 below. The stock represents the box, the valves and the blue arrows represent the flows and feedback loops respectively. The feedback loops depict the relationship between the various variables of the system in which case between the stock and the inflow, and the stock and the outflow. Depending on the purpose of the model it is up to the modeler to determine the appropriate relationships between the systems variables (Lloret et al., 2009).

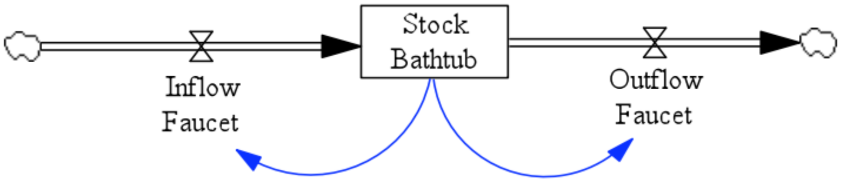


Figure 4: stock and flow structure with feedback (bathtub analogy)

2.4.3 The history of systems dynamics modelling

Forrester's originating World (1971) model, Meadows' update to World3 (1972), revised (2004), were the first global system dynamics models to address the limitations of the exponential growth paradigm and forecast overshoot and collapse behavior of global attributes such as consumption and population (Myrtveit, n.d.). While comprehensive and innovative, resources were aggregated into one variable.

Naill's natural gas model GAS1 was the first to disaggregate (1971), but it was mainly focused on natural gas and was limited to the US. This work was also capable of capturing Hubbert "peak" theory (1956). Starting with 1972, the Resource Policy Group at Darthmouth College and the System Dynamics Group at MIT have developed a series of national energy models for the US, after a winning a grant aimed at reducing dependence on domestic gas and oil: Nail and Meadows extended the natural gas model to include all major energy sources, but no specific renewables yet (GAS2) (1972) (Naill & Belanger, 1989).

A major addition for the next iteration of the model (COAL1) (1974) was the endogenous incorporation of demand. Further development of this work yielded COAL2 (1977) and FOSSIL1 (1976), which showed that the energy problem of the US is not resolvable in the short term, neither demand nor regulatory policies alone are capable of handling it and demand needed to stabilize, along with the increase of alternatives. This work was one of the most comprehensive energy dynamics models up to date, but it was still limited to US and it was not too specific regarding alternative energies. Naill extended his work after moving to the Department of Energy, resulting the development of FOSSIL2 and IDEAS models (1992), which represents the basis for today's national energy planning model (Naill & Belanger, 1989), updating Forrester's national model (1976).

Sterman added economy to FOSSIL1 which was the first model to capture energy-economy dynamics, as energy was being modeled in isolation from the economy in all previous models. He found that his model's major behaviors modes were remarkably robust (Sterman, 1983) – which he later used for his model in economy dynamics in 1986 (Sterman, 1986). Also, on energy-economy interactions, Richardson and Sterman extended Naill's natural gas model to account for endogenous technological change and created the exploration-discovery-production resource chain. Then, later, collaborating with Davidsen and using a synthetic data experimental technique, they have developed the petroleum lifecycle model (1990) which stood as one of the major supporting bases for the Hubbert theory. (*Fidda040.Pdf*, n.d.) extensively studied and added climate interactions to Sterman's model, inspired from Norhaus' DICE model (1992). His FREE model also endogenously accounted for technological change and bounded rational decision making. Fiddaman continued his work on climate-energy interactions, resulting in model updates focusing on global climate policy in (T. Fiddaman, 2007; T. S. Fiddaman, 2002).

The collaboration of Sterman, Fiddaman, Jones and others at Climate Interactive led to the development of the C-ROADS model (2012), which monitored the effect of national greenhouse gas emissions on climate and temperature. The very recent update of this, dubbed En-ROADS (2013) also accounts for the effects of changes in energy and public policy and economy on climate. Modern renewable energy dynamics have been touched in several studies, for example the case of wind turbines in (Dykes & Sterman, 1999).

In order to effectively answer the research questions, we will require extensive energy demand forecasting, in which the work of (Sterman, 2019) can serve as guideline. For a successful energy transition model, we will need to analyze both generic global energy transition dynamics as well as competitive and often conflicting dynamics of country-level energy transitions. Sustainable energy transitions dynamics have been described by (Sgouridis, 2012; Sgouridis et al., 2013) and the GAIDT model (Csala et al., 2013), developed as part of his MSc thesis shown that a current or higher profits of the industry for all players could still be maintained, while increasing the combined societal benefits if manufacturers decided to introduce innovative aircraft sooner, a feature which is also desirable for future energy transitions.

For a sustainable transition, energy also needs to be secure. Shin et al. (2013) investigate energy security, combining system dynamics with quality function deployment and Mutingi (2013), Aslani & Wong (2014) and Hu & Cheng (2013) study renewable energy adoption dynamics, using system dynamics.

2.4.4 Examples of Systems dynamics models

SD has been used by several researchers for several purposes. Laimon et al. (2020) adopted a system dynamics model to construct an integrated model for analyzing the behavior of the Australian energy sector in 2019. Their results showed that present trend in the Australian energy sector is unreliable and by 2032, the only fossil resource available in Australia will be coal. With the current growth, Australia's global CO2 emissions footprint will increase to unprecedented levels reaching 12% by 2030 (9.5% for exports and 2.5% for domestic). Oil dependency will account for 43% and 47% of total consumption by 2030 and 2050.

To forecast the energy demand of a county, Al Najjar (2013) during his master thesis develop a system dynamic model to forecast the energy demand of the county of Pueblo. In his model, he used variables such as population and housing, regional and business attractiveness, land occupied, and energy used to determine how the region will develop and how these variables will affect the energy demand accordingly.

Also, Ahmad et al. (2012) in 2012 used SD to develop a long-term electricity forecast for the case of Malaysia. They used two scenarios: the population and per capita consumption of the country to forecast the electricity demand for the country in the next 10 years, from 2011 to year 2021. The model estimated that with the current rate of energy consumption and the population growth of the country, there will be a need of about 192.5TWh of electric energy by 2021.

Feng et al. (2013) in a study uses STELLA, a systems dynamics software to model the energy consumption and CO2 emission of Beijing, China, from 2005 to 2030. According to the results, the total energy demand in Beijing was predicted to reach 114.30 million tonnes coal equivalent (Mtce) by 2030, and the value in 2005 was 55.99 Mtce, which is 1.04 times higher than the level in 2005. Also, the total CO2 emissions was predicted to reach 169.67 million tonnes CO2 equivalent (Mt CO2-eq) in 2030, 0.43 times higher than that of 2005.

System dynamic models can also be used to analyse the behaviour of the energy sector. In one such model, Laimon et al. (2020) adopted a system dynamic approach and used Australia as their case study. The results of the model showed that, With the current growth, Australia’s global CO2 emissions footprint will increase to unprecedented levels reaching 12% by 2030 (9.5% for exports and 2.5% for domestic). Oil dependency will account for 43% and 47% of total consumption by 2030 and 2050. By 2032, coal will be the only fossil fuel resource available in Australia. Expansion of investment in coal and gas production is a large risk. The Causal Loop Diagram of the model is shown below.

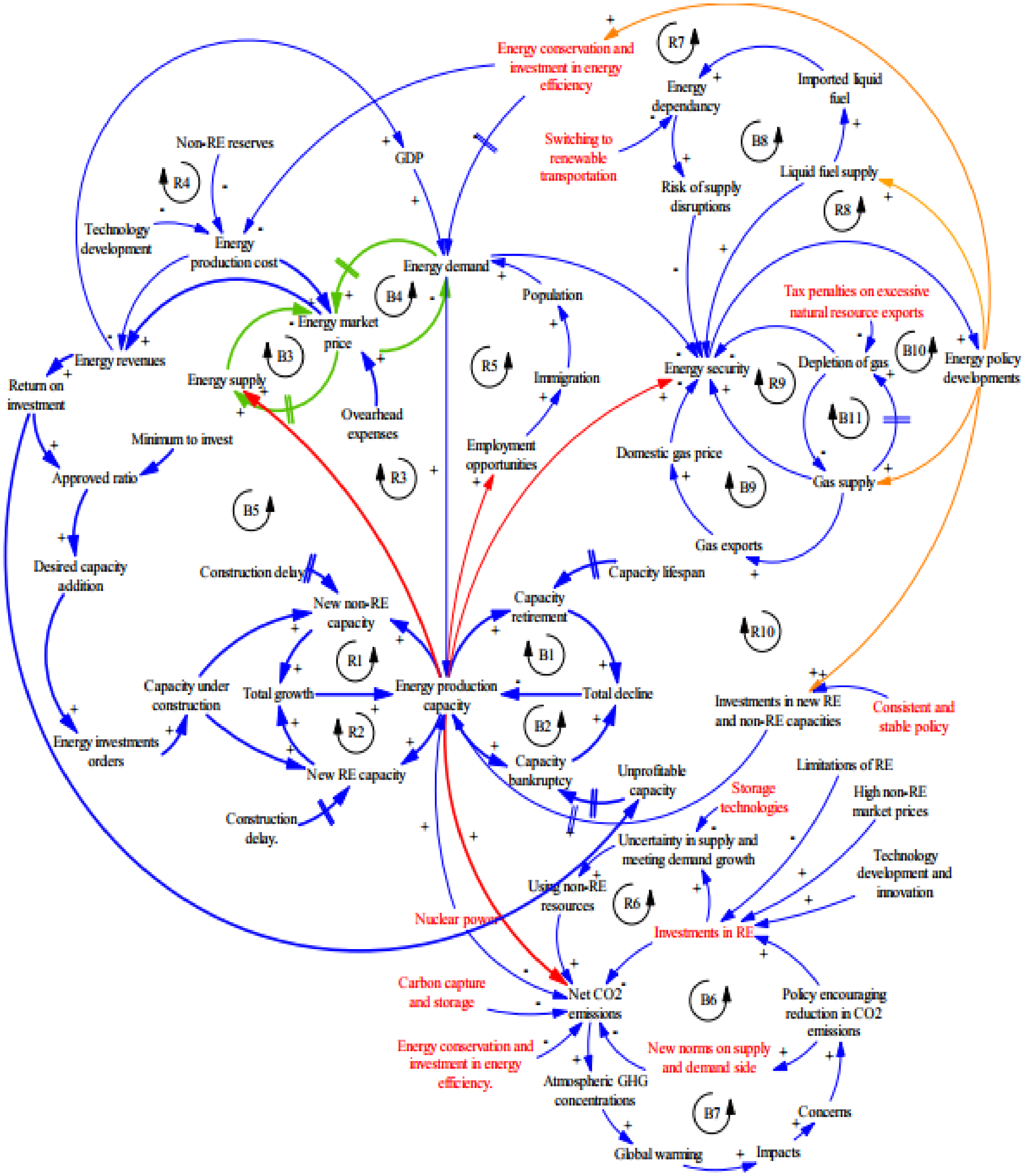


Figure 5: energy sector development model by Laimon et al. (2020)

2.5 The demography of Cameroon

Located in the Gulf of Guinea, Cameroon is a Central African Country with a total population of about 23. 29 million in 2015, increasing to about 25.87 million people in 2019 with an annual population growth rate of about 2.6% within this period. With a population density of 56 person per km^2 in 2019, the percentage of urban population was 55.7%. The life expectancy in Cameroon in 2018 was 58.9 for both sexes (60.2 female and 57.7 male) (Conceição, 2020) and an infant mortality of 50.0 (infant deaths per thousand live births) (Mortality Rate, Infant (per 1,000 Live Births) - Chad, Cameroon, Niger, Nigeria | Data, n.d.). The GDP of Cameroon was 38.7 billion USD in 2019. The real GDP growth reduced to 3.9% in 2019 compared to 4.1% in 2018. This value further dropped to 2.4% in 2020 as a result of the combined effects of the COVID-19 pandemic, the persistence of the political and security crises and a decline in the world oil prices. Cameroon shares boundaries with the Atlantic Ocean, lake Chad, Nigeria and Chad, the Central African Republic, and the Equatorial Guinea, Gabon and Congo (Brazzaville) in the southwest, northwest, northeast, east and south respectively. The two regions which share borders with Nigeria (northwest and southwest) are Anglophone, whereas the remaining regions of the country are Francophone-French speaking regions.

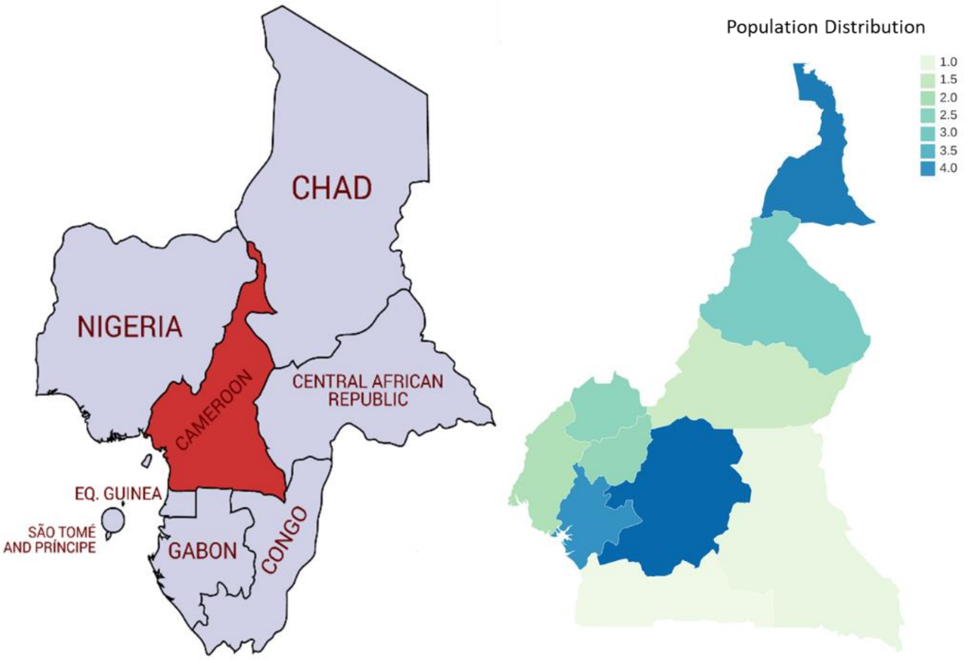


Figure 6: Location and Population Distribution of Cameroon (millions)

2.6 Main players of the power sector of Cameroon

The main players in the power sector in Cameroon are shown the structure below.

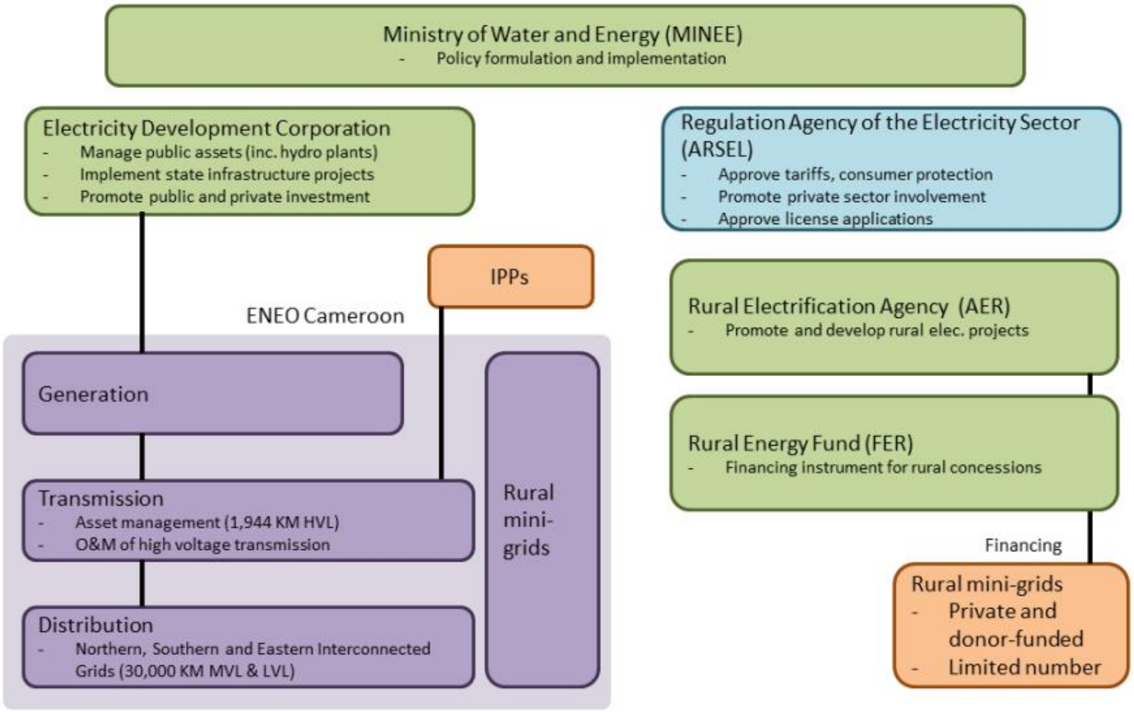


Figure 7: Cameroon Power Market Structure.

2.7 Energy resources in Cameroon

2.7.1 Non-renewable energy resources

These are resources that cannot regenerate once used or may not re-occur after millions of years. Cameroon has a reasonable potential of energy resources, both renewable and non-renewable potentials. The non-renewable energy resources include nuclear power and fossil fuels. The fossil fuel sources in Cameroon are coal, petroleum, natural gas and oil.

2.7.1.1 Petroleum, natural gas and oil

With no data on coal reserves in Cameroon, there are proven reserves of oil and natural gas. In 2014, the proven reserves of oil and natural gas were estimated to be 221.86 million barrels and 47.03 MSCF respectively. The oil reserves have increased from 140 million barrels in 2009, implying the discoveries of new wells such as the Bolongo in the Rio Del Rey region.

In 2015 EIA ranked Cameroon 47th globally based on the volumes of reserves and had 4.8 trillion cubic feet (4,800 bcm). The major oil fields are the Kribi-Campo basin and Ebome (Energy Profile Cameroon). In 2016, the proven oil reserves stood at about 0.2 billion barrels, ranking 55th in the world (Cameroon Oil Reserves, Production and Consumption Statistics - Worldometer, n.d.).

The actual estimated petroleum potential of Cameroon is 400 million barrels making Cameroon 5th from the top, when it comes to classifying countries and their petroleum potentials in Sub-Saharan Africa. Some companies such as Perenco produce petroleum within Cameroon. Cameroon also has the national oil and gas company called Societe Nationale des Hydrocarbures (SNH). Imported crude oil from neighboring countries such as Nigeria, Angola and Equatorial Guinea is refined by Cameroon's national refinery company called SONARA. A firm called Cameroon Petroleum Depot Company (SCDP) is responsible for distributing petroleum product (Find Oil and Gas Expertise in Cameroon, n.d.).

2.7.2 Renewable energy resources

Cameroon nevertheless is blessed with a great potential of renewable energy and this includes solar, biomass, geothermal, wind and hydropower. Hydropower accounts for 75% of electricity generation and has a major role in Cameroon's energy sector. The access rate of electricity will rapidly increase in both the rural and urban areas if these potentials are fully exploited and implemented at a low cost and reliable manner (Muh, Tabet, et al., 2018). The government of Cameroon regards RE as a valuable resource, capable of solving the challenges in the energy sector and knows that a country with a constant availability of secure and consistent energy resources is likely to grow faster economically. The various renewable energy potentials are;

2.7.2.1 Hydropower potential

Cameroon has the second biggest potential in hydropower amounting to 294 TWh in the whole of sub-Saharan Africa, with the first being the Democratic Republic of Congo (103 TWh/year). Because of the various barriers that the environment poses, only about 13,700 MW of this potential (frequently located the western and eastern parts of the country) is utilized. (Muh, Amara, et al., 2018). Hydropower is the major source of power generation in Cameroon.

In 2015, 88% of Cameroon's electricity production of 817MW was from hydroelectricity. The main hydropower plants in the country are Edea, Song Loulou and Lagdo with capacities of 263MW, 388MW and 72MW respectively.

There is a continual increase in electricity demand in Cameroon. This demand is forecasted to reach 5000MW by 2020 and 6000 by 2030. To meet up with these demands, the government of Cameroon has as plans to do the following; install additional 2500MW between 2012 and 2020 and 298MW from thermal sources, increase the capacity of two hydro dams (Edea and Song LouLou) by 75MW each by renovating them and has started the construction of three dams with feasibility study of 4 other dams as shown below.

Table 5: Hydropower capacities under construction

Project	**Total capacity (MW)**	**Status**
Lom Pangar	30	90% complete as of December 2015
Mekin	15	80% complete as of December 2015
Membe'ele	211	70% complete as of December 2015
Nachtigal	420	Under feasibility study as of December 2015
Song Dong	270	Under feasibility study as of December 2015
Bibi to Warak	75	Under feasibility study as of December 2015
Menchum	72	Under feasibility study as of December 2015

Source: MINEE (2015, pp. 42–44)

There also exist small hydropower potential sites in Cameroon. Extensive studies carried out over the country has revealed significant potential of these sites. For example, PDER estimated the generation of 340MW from 260 potential sites. The study made by the Tractebel Engineering, commissioned by the French Development Agency, analyzed the potential of small and medium-size hydropower (installed capacity of 10MW to 50 MW) of Cameroon

2.7.2.2 Solar energy potential

Geographically, Cameroon is located between latitude 20 and 120 north and the meridian 80 and 160 East from the Atlantic Ocean to Chad and presents a huge opportunity of solar energy resource, even though this resource is not yet fully exploited. Cameroon is very sunny throughout the year and the entire 10 regions remain a fertile ground to implement solar energy technologies.

NASA records that Cameroon's solar potentials are capable of generating solar energy more than the average (that is knowing the average is 2325W h/m2/day as yardstick for domestic load demand) (Solar and Bioenergy Potential in Cameroon: A Panacea To Some Unresolved Energy Issues. Author: Jonathan Nkwa Mbi, n.d.). The northern part of Cameroon has good solar radiation (5.8 kWh/day/m2), though the radiation potential becomes lesser, to an extent, in the more humid southern part of the country (4.5 kWh/day/m2), with the Littoral region which is Douala, recording least (Myint, 2019). The annual solar radiation is as shown below;

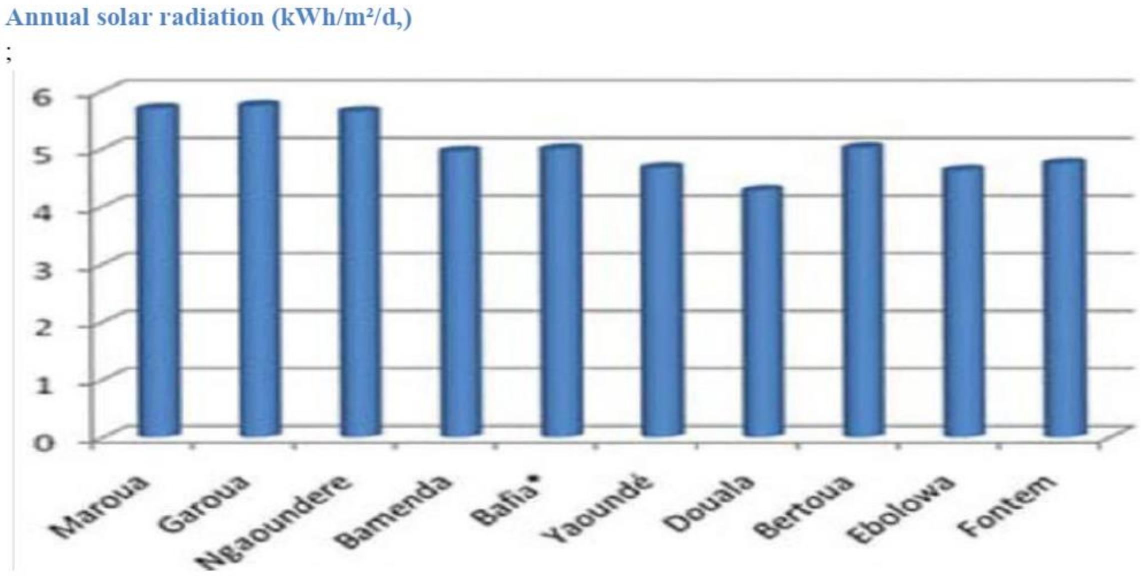


Figure 8: Annual average solar radiation of 2009 and 2010 in Cameroon

In 2016, the technical potential PDER measured by for 1/3 of the entire national area was 780 TWh/day. The technical potential was measured at 172 TWh/day for the northern and the far northern regions (MINEE Cameroon, 2017b). The map below reveals the solar insolation over the entire territory. From the map, it is seen that the solar insolation increases from the southern to the northern part of Cameroon.

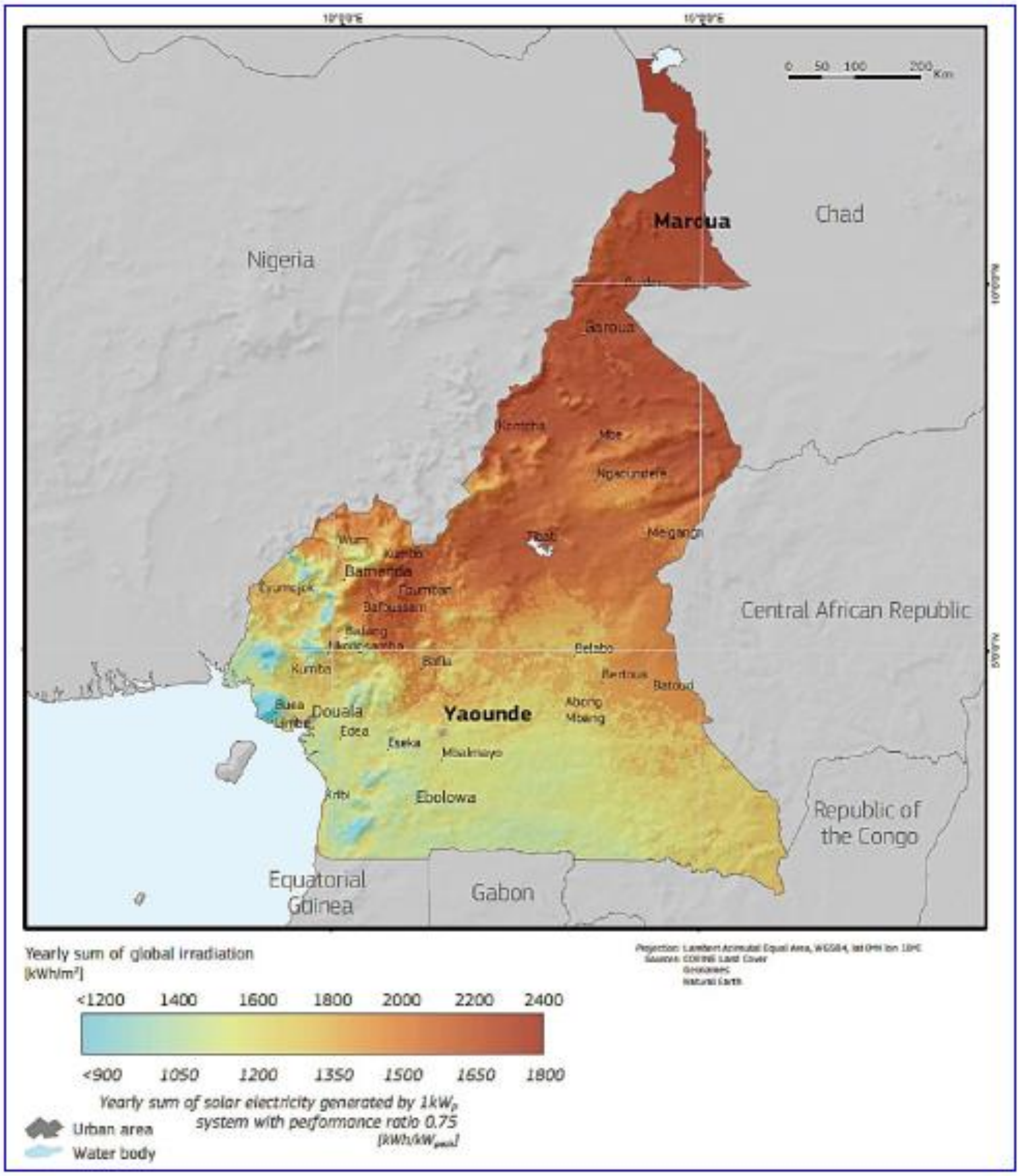


Figure 9: Resource potential of solar PV in Cameroon

Solar power is presently applied to distributed systems in the country with about 50 PV sites already installed. Several individual and institutions have adopted the use of solar PV in Cameroon. Some of the recent used of solar power in Cameroon include; the use of solar PV to power street lights in the towns of Douala and Yaounde, use in surveillance cameras by telecommunication companies, solar phone chargers and solar home systems for both remote and city applications (Muh, Tabet, et al., 2018). The multinational company Bolloré commissioned in

2013 two solar powered 30 passengers' electric mini-buses on the campus of the University of Yaoundé 1, for the transport of students and staffs.

2.7.2.3 Biomass potential

Cameroon is ranked the third largest Sub-Saharan African country when it comes to biomass potential and it has a forest potential with an area of about 25 million hectares. The primary sources of energy supply to both rural and urban population in Cameroon are Biomass and waste such as wood, sawdust and charcoal, comprising over 64% of the total sources of energy used. Cameroon's energy mix is shown below (Ackom et al., 2013).

The biomass potential of Cameroon is divided into sub categories such as; agriculture, wood, animal wastes and forest (Abanda, 2012). The massive dependence of both the residential and commercial sectors in Cameroon for uses such as heating, cooking has led to an increase rate of deforestation in the country with an annual clearance rate of 200,000 ha/year and only 3000 ha/year as regeneration. The country potential to produce electricity from biomass residues is estimated at 1076 GWh.

During a study made by MINEE Cameroon (2017b), they calculated the theoretical resource potential for generation capacities and it indicated that annual potential of forest products, agricultural by-products, and livestock manure was 39,707 TWh, 37.9 TWh, and 16.5 TWh, respectively. Biomass from forest products and agricultural by-products could be used as solid fuel and cattle manure used to produce biogas through the anaerobic digestion method.

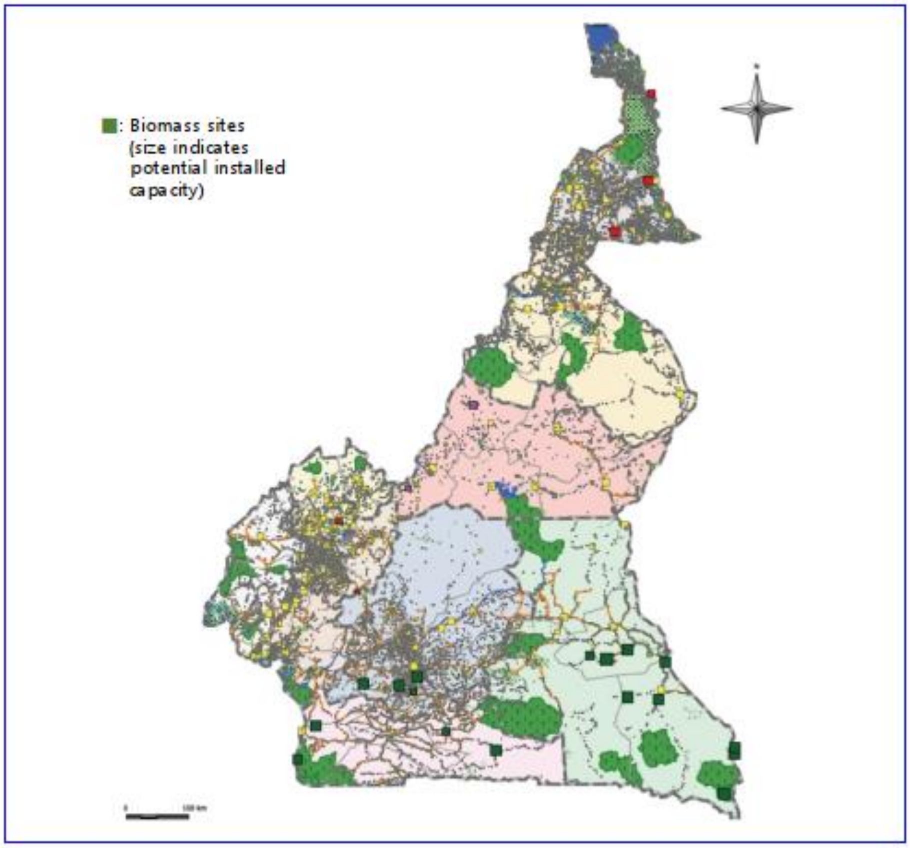


Figure 10: Biomass resource potential in Cameroon

Source: (MINEE Cameroon, 2017b)

2.7.2.4 Wind Power potential

In Cameroon, some areas in the north and coast have available wind. The wind speed (average) in is 5m/s to 7 m/s. In some regions it can be from 2m/s to 4 m/s at100m height. There are two installed wind turbines in Douala and a developing wind project in the Bamboutou Mountains (42 MW for a start, though can go up to 80MW) in Eastern Cameroon (Myint, 2019). Studies indicate that the suitable areas with relatively abundant potential and wind speeds of 5m/s are limited to the north and far north regions; however, various areas of the coastal and mountainous regions have even higher wind speeds. MINEE Cameroon (2017a) classifies wind power as an inappropriate RE source for Cameroon, considering that the overall average wind power of the country is low at 4 m/s. The figure below is a wind resource map constructed by the National Renewable Energy Center (CENER) based on the data of the wind conditions at a height of 10 m above the ground for the period 2008 to 2010(MINEE Cameroon, 2017a).

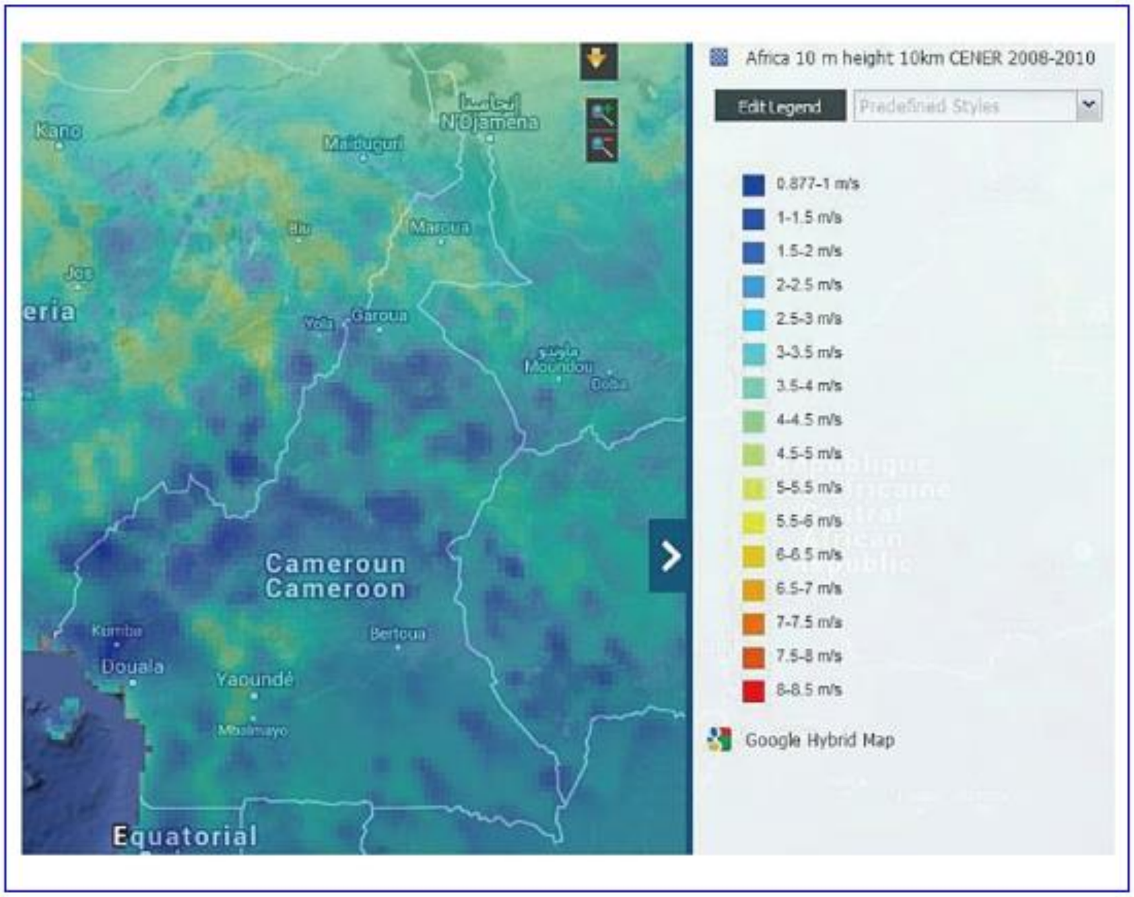


Figure 11: Wind resource map of Cameroon (10m above ground, 10km resolution)

2.7.2.5 Geothermal potential

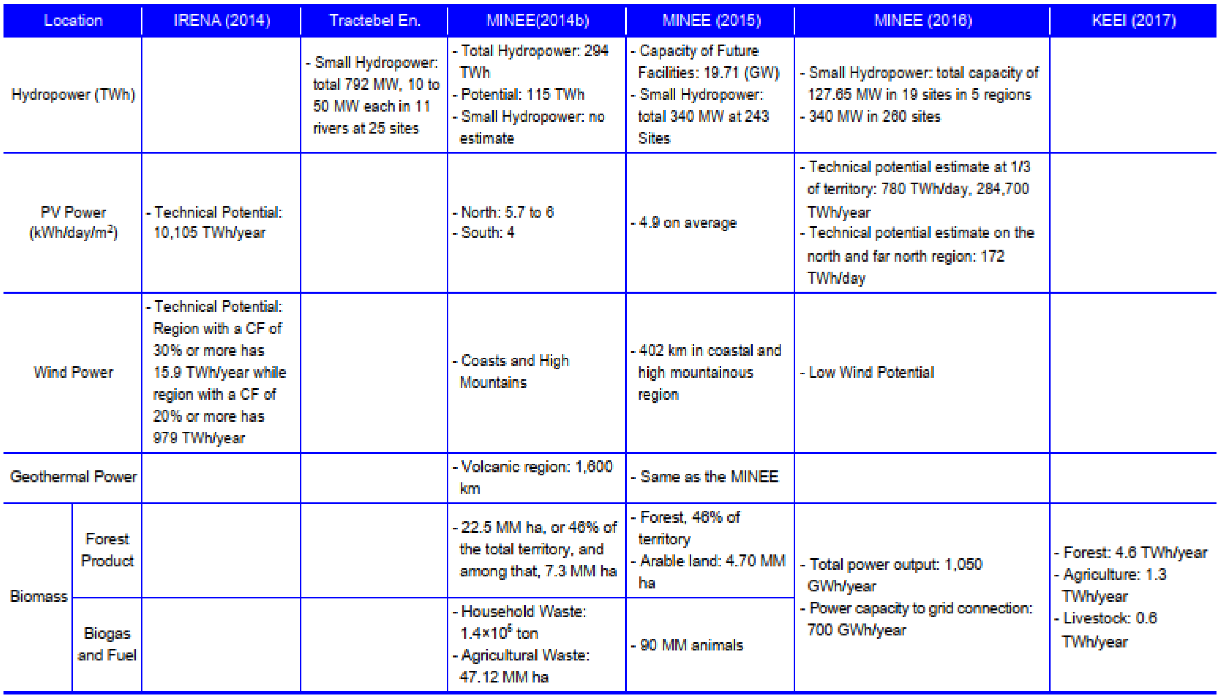
Till date, there is no proper assessment and evaluation of the geothermal potential in Cameroon, despite the presence of line with active volcanic along the Western borders of Cameroon. Mount Cameroon has hot thermal springs and its frequent eruptions also presents a favorable opportunity for geothermal resources. These springs could also be found in Ngaoundere, the lake of Moundou and around the areas of Mt Manengouba (Myint, 2019).

A spring in Cameroon is characterized as thermal when its temperature is above the mean temperature of 23°C. As a result, 130 thermal springs were recorded by Le Maréchal (1976). The hottest spring (Woulndé, 74°C) is located in the Centre region of Cameroon. at the intersection between the CVL and the Adamawa shear zone. There is another spring called the Lobe spring, with temperature of 49°C, located just behind the Woulndé, at the foot of Mount Cameroon. The Adamawa region of Cameroon has the highest number of springs. (Keutchafo et al., 2018)

2.7.2.6 Summary of RE resource potential in Cameroon

The table below comprehensively summarizes the RE resource potential of Cameroon estimated by MINEE Cameroon (2017b). According to MINEE Cameroon (2017b), the RE resource potential could be increased if biomass or small hydropower were examined with more information and data. The agricultural by-products of only a few crops were selected as the subject of their assessment. Therefore, expanding to all suitable crops would increase the bioenergy resource potential. Also, small hydropower resource potential across the country has not fully been examined; conducting assessment on this resource could increase the amount of hydropower resource potential significantly.

Table 6: Summary of renewable energy potential in Cameroon



Location		IRENA (2014)	Tractebel En.	MINEE(2014b)	MINEE (2015)	MINEE (2016)	KEEI (2017)
Hydropower (TWh)			- Small Hydropower: total 792 MW, 10 to 50 MW each in 11 rivers at 25 sites	- Total Hydropower: 294 TWh - Potential: 115 TWh - Small Hydropower: no estimate	- Capacity of Future Facilities: 19.71 (GW) - Small Hydropower: total 340 MW at 243 Sites	- Small Hydropower: total capacity of 127.65 MW in 19 sites in 5 regions - 340 MW in 260 sites	
PV Power (kWh/day/m^2)		- Technical Potential: 10,105 TWh/year		- North: 5.7 to 6 - South: 4	- 4.9 on average	- Technical potential estimate at 1/3 of territory: 780 TWh/day, 284,700 TWh/year - Technical potential estimate on the north and far north region: 172 TWh/day	
Wind Power		- Technical Potential: Region with a CF of 30% or more has 15.9 TWh/year while region with a CF of 20% or more has 979 TWh/year		- Coasts and High Mountains	- 402 km in coastal and high mountainous region	- Low Wind Potential	
Geothermal Power				- Volcanic region: 1,600 km	- Same as the MINEE		
Biomass	Forest Product			- 22.5 MM ha, or 46% of the total territory, and among that, 7.3 MM ha	- Forest, 46% of territory - Arable land: 4.70 MM ha	- Total power output: 1,050 GWh/year - Power capacity to grid connection: 700 GWh/year	- Forest: 4.6 TWh/year - Agriculture: 1.3 TWh/year - Livestock: 0.6 TWh/year
	Biogas and Fuel			- Household Waste: 1.4×10^6 ton - Agricultural Waste: 47.12 MM ha	- 90 MM animals		

Source: IRENA (2014); Tractebel Engineering (2014); MINEE (2014b, Appendix 5); MINEE (2015, p. 38); MINEE (2016, pp 137–148)

2.8 Energy mix, generation, consumption and access in Cameroon

2.8.1 Energy mix of Cameroon

The main source of energy used in Cameroon is biomass. Most Cameroonians rely on biomass for cooking, heating, than they do on electricity, mostly because of its non-availability and non-accessibility, especially in rural areas. The total primary energy supply (energy mix) of Cameroon comprises of about 65% biomass, 5.7% hydroelectricity, 5.2% natural gas and 24.1 % oil. This shows that bioenergy alone comprises almost two-thirds of the total primary energy supply in 2013. Currently, Cameroon is not considering developing any other resource type, such as nuclear or ocean energy.

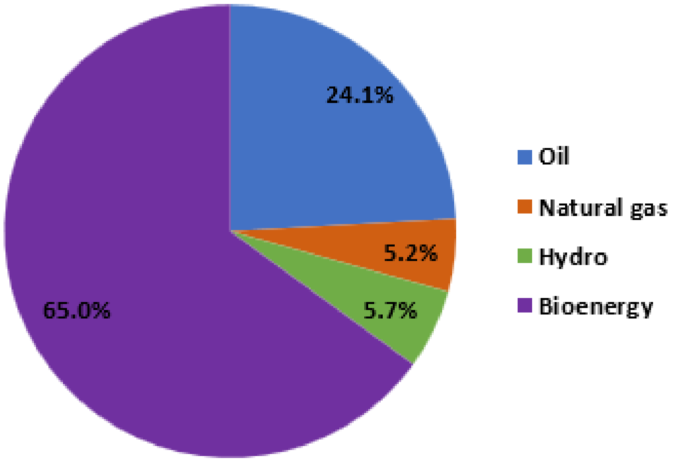


Figure 12: Cameroon's energy mix

Hydropower takes the highest percentage in the electricity mix of Cameroon, and the rest from thermal resources based on both heavy and light fuel. Since 2013, electricity is also gotten from gas with the installation of the Kribi Power Development Corporation (KPDC), which adds 216MW of electricity to the national grid. The power or electricity generation mix by source in Cameroon comprises of 70.9% hydropower, 19.1% oil, 9.0% natural gas and 1.0% bioenergy.

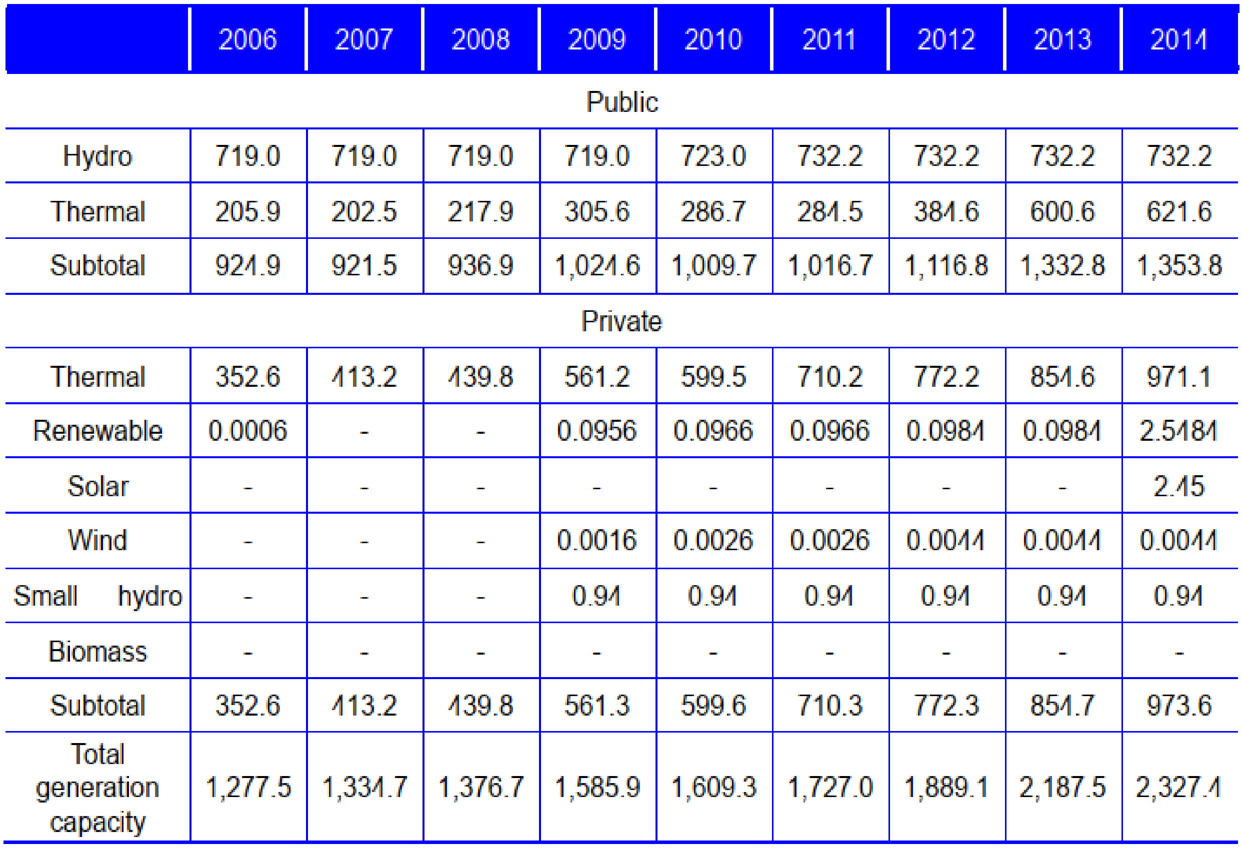
2.8.2 Energy generation in Cameroon

The total generation installed capacity of ENEO (Energy of Cameroon) in 2010 was about 1300MW. The government of Cameroon plans to attain 3000 MW by 2020 and 6000MW electricity production by 2035, increasing electricity access from 55% to 75% by 2020 (Cameroon Energy Situation - Energypedia.Info, n.d.).

The rate of increase in generation capacity in Cameroon since 2006 has been headed by thermal generation. While the public and private thermal generation capacity increased from 14.8% to 13.5% respectively, hydropower increased only by 0.2% annually. With a 7.8 % annual growth rate, the total generational capacity increased by 82% from 1,227.5 MW in 2006 to 2,327.4 MW in 2014. In terms of growth rates, the growth of RE after 2009 was quite high at 92.8% annually.

However, this represents only 0.1% of the total generational capacity and the significant growth rate is ascribed to the starting base being low and the actual increases in generational capacity being insignificant. Among the RE generation capacity, solar generation capacity was the highest at 2.45 MW, followed by small hydropower generation at 0.94 MW (MINEE Cameroon, 2017b). According to REMP, these statistics slightly differ from those of IEA (2015).

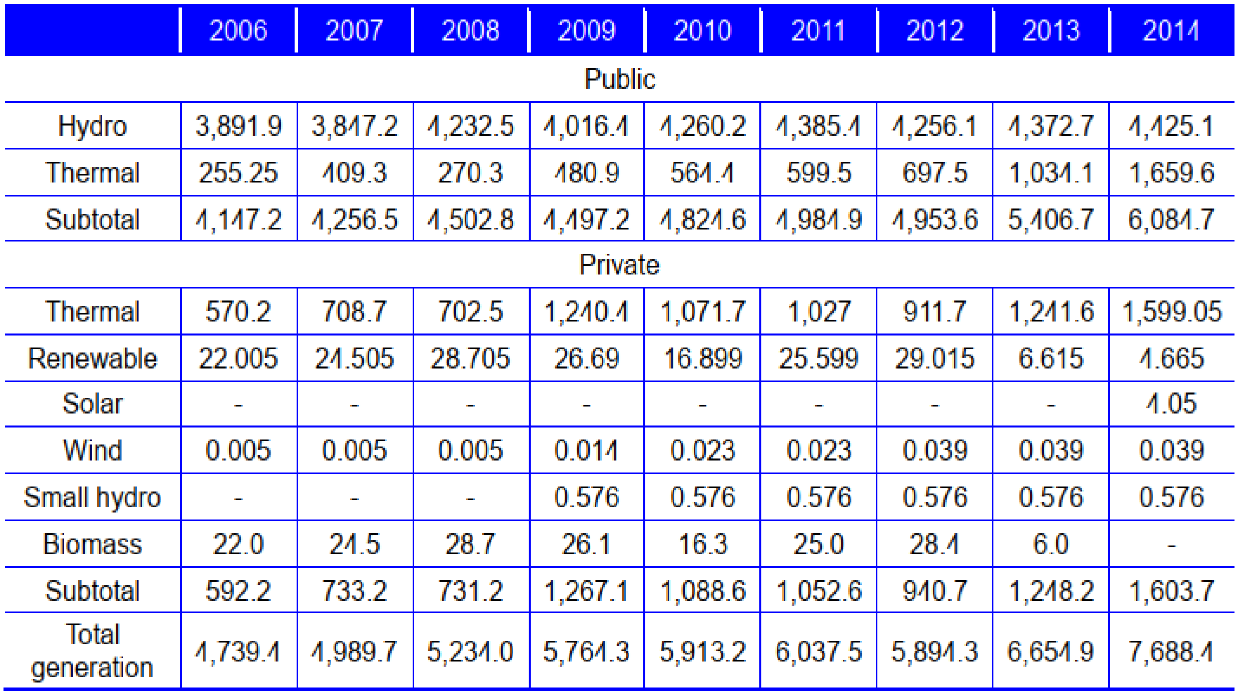
Table 7: Status of installed Capacity for generation by source. Units in MW



	2006	2007	2008	2009	2010	2011	2012	2013	2014
Public									
Hydro	719.0	719.0	719.0	719.0	723.0	732.2	732.2	732.2	732.2
Thermal	205.9	202.5	217.9	305.6	286.7	284.5	384.6	600.6	621.6
Subtotal	924.9	921.5	936.9	1,024.6	1,009.7	1,016.7	1,116.8	1,332.8	1,353.8
Private									
Thermal	352.6	413.2	439.8	561.2	599.5	710.2	772.2	854.6	971.1
Renewable	0.0006	-	-	0.0956	0.0966	0.0966	0.0984	0.0984	2.5484
Solar	-	-	-	-	-	-	-	-	2.45
Wind	-	-	-	0.0016	0.0026	0.0026	0.0044	0.0044	0.0044
Small hydro	-	-	-	0.94	0.94	0.94	0.94	0.94	0.94
Biomass	-	-	-	-	-	-	-	-	-
Subtotal	352.6	413.2	439.8	561.3	599.6	710.3	772.3	854.7	973.6
Total generation capacity	1,277.5	1,334.7	1,376.7	1,585.9	1,609.3	1,727.0	1,889.1	2,187.5	2,327.4

Since 2006, there have been annual increases of 6.2% in the volume of electricity generation in Cameroon. The total electricity generation in Cameroon by ENEO increased from 1,117.2 GWh in 2006 to 6,081.7 GWh in 2011. The generation volume of RE excluding hydropower was extremely low at 0.06% of the total generation volume, but reached 57.6% including hydropower in 2014. Table 8 below shows the total electricity generation by source in Cameroon.

Table 8: Electricity generation by source in Cameroon. Units in GWh



	2006	2007	2008	2009	2010	2011	2012	2013	2014
Public									
Hydro	3,891.9	3,847.2	4,232.5	4,016.4	4,260.2	4,385.4	4,256.1	4,372.7	4,425.1
Thermal	255.25	409.3	270.3	480.9	564.4	599.5	697.5	1,034.1	1,659.6
Subtotal	4,147.2	4,256.5	4,502.8	4,497.2	4,824.6	4,984.9	4,953.6	5,406.7	6,084.7
Private									
Thermal	570.2	708.7	702.5	1,240.4	1,071.7	1,027	911.7	1,241.6	1,599.05
Renewable	22.005	24.505	28.705	26.69	16.899	25.599	29.015	6.615	4.665
Solar	-	-	-	-	-	-	-	-	4.05
Wind	0.005	0.005	0.005	0.014	0.023	0.023	0.039	0.039	0.039
Small hydro	-	-	-	0.576	0.576	0.576	0.576	0.576	0.576
Biomass	22.0	24.5	28.7	26.1	16.3	25.0	28.4	6.0	-
Subtotal	592.2	733.2	731.2	1,267.1	1,088.6	1,052.6	940.7	1,248.2	1,603.7
Total generation	4,739.4	4,989.7	5,234.0	5,764.3	5,913.2	6,037.5	5,894.3	6,654.9	7,688.4

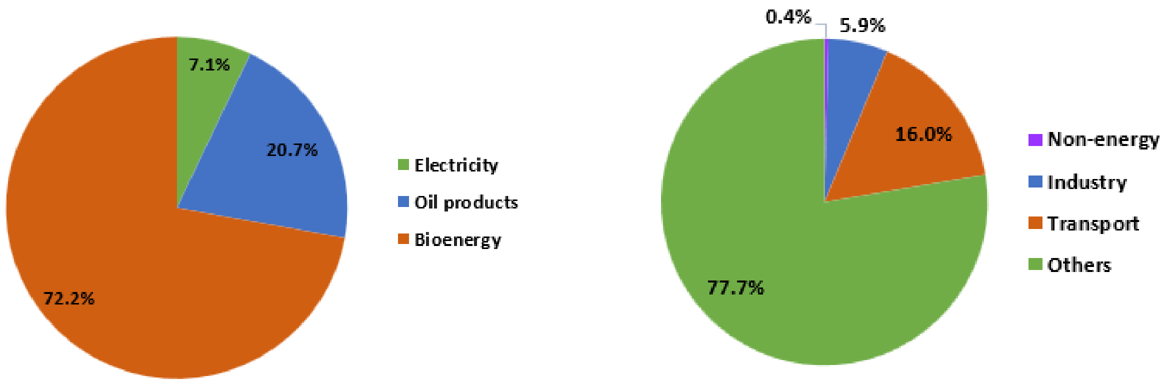
2.8.3 Energy Consumption in Cameroon

Power consumption has increased 6.6% annually from 4,222.02 GWh in 2006 to 6,875.83 GWh in 2014 in Cameroon. This is below the 7.8% annual increase in generation capacity; however, it is slightly higher than the 6.2% annual increase of generation volume.

In 2013, the final energy consumption of Cameroon comprised of 77.7% other (which includes household and public services) as the main consumer of energy, followed by transportation at 16% and industrial use at quite low 5.9%. Within the “other section”, 91% was accounted for by the household sector and regional societies while 9% for public services sector. The demand for petroleum products was used mainly for transportation and also for power generation. Almost all the bioenergy produced was used for households. The final energy demand from bioenergy was mostly from traditional biomass and used for cooking.

The industrial sector accounts for more than 50% of the total energy generation. Though it dropped from 2009 to 2012, it increased back as from 2013 due to the increased power supply by the 100 MW PTU (Thermal Emergency Program) plant in 2012 and the 216 MW Kribi natural gas fired plant in 2013 (MINEE Cameroon, 2017b).

The total final energy demand of Cameroon by source in 2013 according to the IEA (2015), was accounted for by 20.7% oil product, 72.2% bioenergy and 7.1% electricity of the total, respectively.



(a) (b)

Figure 13: Final energy consumption by (a) source b) sector

2.8.4 Energy access in Cameroon

Energy is life! Electricity access is one of the key elements to both the economic and social development of a country. As the income of the country and population increases, demand to energy also increase. Though endowed with a wealth of resources, the government of Cameroon has still not been able to meet up with the energy demand, this is partly due to the fact that the resources are not fully exploited.

Analyzing energy as a whole, access to electricity in Cameroon is at the lowest compared with other countries of the world. In 2011, the total energy consumption of Cameroon was about 6000 ktoe (Kilo tons of oil equivalent), which is equivalent to about 0.3toe (tons of oil equivalent) per capita. A vivid comparison with the world average per capita consumption of about 2toe shows that access to energy in Cameroon is still extremely low (Ndongsok, Durando; Ruppel, 2017).

The present electrification rate of Cameroon is 55%, with 10 million people without access to electricity in 2013. There is a huge gap between the rural and urban electrification rates in the country. In 2016, the urban electrification rate was 88% compared to the rural electrification rate of 17%. Though the access is moderate in rural areas compared to neighboring countries, some facilities in the rural part of Cameroon like school, hospitals, businesses are electrified mainly through grid extension, which is sometimes time consuming since the government must initiate the process, expensive and takes long to develop and implement (Muh, Amara, et al., 2018).

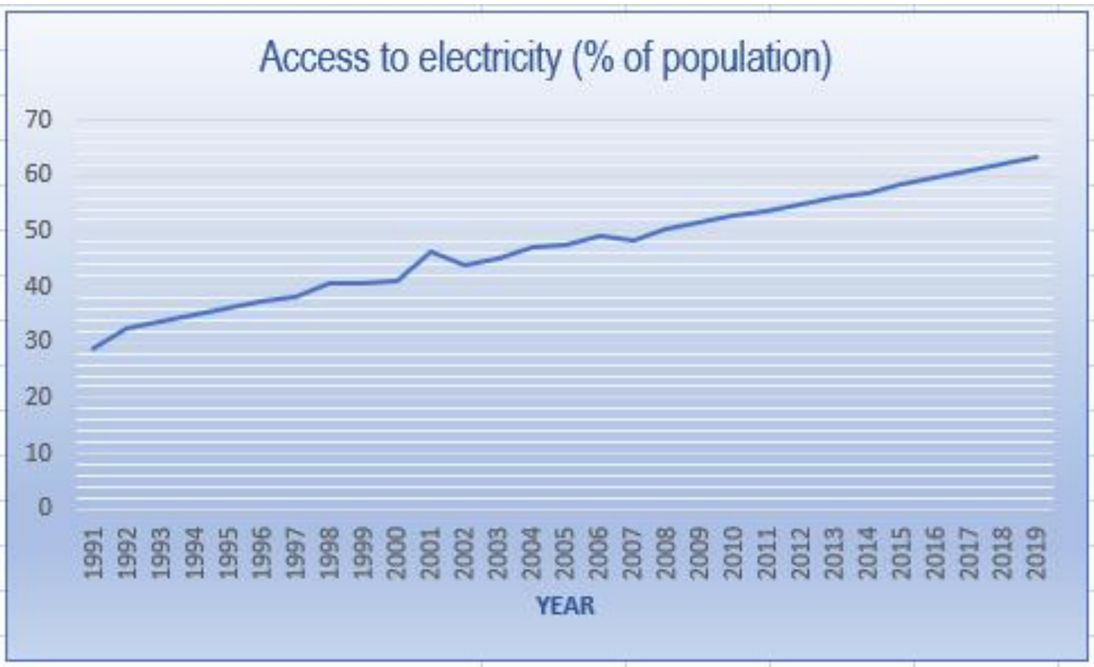


Figure 14: Electricity access rate in Cameroon

2.9 Major strategies and plans in the energy sector in Cameroon

In acknowledging the energy sector as a vital policy area for the achievement of goals and development plans, the president of Cameroon in his keynote address of 15 November 2013, said "Without it, there will be no industry, no raw material processing, and no modern economy. For that reason, I placed the energy issues in the center of policies that we must achieve".

According to Vision 2035 which forecasts the total GDP and the GDP per capita of the country, the GDP is expected to grow at AAGR of 6.5% between 2010 and 2035, while the population is expected to increase at AAGR of 2.3% during the same period. There is need, in term of energy supply to meet up with such growth. Supplying energy to meet the growth of economy and population in the future is a challenge that Cameroon faces.

Table 9: GDP, total and per capita (2000~2035) (CFA F, %).

	2000	2010	2020	2030	2035
GDP(billion)	6,569	9,157	15,550	31,278	43,952
Population	15,292,000	19,648,287	24,910,305	31,118,001	34,525,533
GDP per capita	429,571	466,059	624,265	1,005,163	1,273,029

The energy policies of Cameroon are mostly based on Vision 2035 and the Strategic document for growth and employment 2010-2020 (DSCE) which are the main important documents of the energy plans of Cameroon. A description of the various key national plans Cameroon’s energy sector is as shown in the table below.

Table 10: Key national plans of the energy sector of Cameroon (MINEE Cameroon, 2017b)

Plan/Vision /Goal	**Description**
Vision 2035	• Vision 2035 is a long-term vision for economic development and population welfare, strengthened by diversity and not division. Accordingly, the vision of Vision 2035 for the next 25~30 years is “Cameroon: An Emerging, Democratic, and United Country in Diversity”. • Vision 2035 is a reference framework that guides policies, national strategies, development plans, and cooperation for all sectors and regions of Cameroon. • It emphasizes on the importance of a stable water and energy supply for economic development. • Vision 2035 was first formulated to achieve an energy intensity (ratio of energy GDP) was 27.7%, and the goal is to increase this figure to 45% by 2035. Therefore, it aims to double energy production and therefore sets a goal or forecasts energy intensity to reach 45% by 2035.

	• It aims to achieve Energy consumption per GDP (%) of 45% by 2035, economic growth rate of 9.9% and GDP per capita (calculated using Atlas method, $US 2007 figure) of 3800.
The Growth and Employment Strategy Paper 2010-2020	• DSCE 2010~2020 is the 2010~2020 action plan for mid-term national development. It aims to achieve the goals of the first 10 years of Vision 2035. • This strategy paper stipulates that to achieve the first 10 years plan of Vision 2035, the power generation capacity of 1,009 MW in 2010 must increase to 3,000 MW by 2020. • Also, the refining capacity of SONARA must increase from 2.1 million ton in 2010 to 3.5 million ton in 2020. This indicates that the average energy production growth, which was 2.9% from 2009 to 2011, must rise to 13% between 2012 and 2020
Electricity sector development plan 2035, PDSE (2035)	• The Electricity Sector Development Plan 2035 (PDSE 2035) considers construction of electricity transmission and distribution grid, as well as power plants construction, as critical to national economic growth.
Energy Sector Development Project (PDSEN)	• As previously stated, Cameroon has revised the PDSE 2035, first introduced in 2009, in 2014 to PDSEN (MINEE, 2014). This strategy includes forecasts on electricity demand up to 2035, and suggests plans for constructing power plants to meet these demands • The electricity demands were divided into low, median, and top scenarios. The forecast on electricity demand in the median scenario show an average annual increase of 6.7% from 5,395.6 GWh in 2012 to 23,730.7 GWh in 2035 • Hydropower plants will mostly be utilized as RE, as suggested in PDSEN to meet increasing electricity demands. There are no plans for using other RE sources, apart from a brief mention of solar PV plants.
Intended Nationally	• Submitted to the UNFCCC in 2015, the government declared its intention to reduce greenhouse gas (GHG) emission by 32% compared

Determined Contributions (INDCs)	with the 2035 reference scenario, that is, it aims to limit the 104 MtCO2-eq in the Business as usual (BAU) scenario to 71 Mt CO2-eq in 2035, to come to effect by 2020. • and, related to the energy sector particularly, the intended total reduction is 4,684 kt CO2-eq of GHG emissions. • To achieve the goal, the main direction is to expand energy supply while improving energy efficiency, and, in electricity generation sector, to increase the proportion of RE up to 25%. • The government also set RE source-specific supply goals of 11%p for small hydropower, 7%p for biomass, 6%p for solar, and 1%p for wind power (total of 25% renewable energy sources
Rural Electrification Master Plan (Plan Directeur d'Electrification Rural-PDER)	• Intends expanding accessibility to electricity for households that are not connected to the grid through the electrification of 660 localities by 2035 through the Extension of interconnected grids, • Construction and rehabilitation of isolated diesel and mini-hydro plants. It is expected that 50 MW of additional electricity-generation capacity will be required by 2020 for regional electrification and 300 MW by 2030. • Installation of solar energy, both stand-alone and grid connected and to promotes the integration of national grids with neighboring countries.

Cameroon is characterized by its several power outages. There are about 10 outages per month, each lasting for 2 hours averagely. **The rate at which electrification is done is very low**. If nothing is done by the government, this scenario shows that the demand of energy which is mainly as a result of population growth becomes more than the supply thereby creating power deficits and spiked electricity prices. The figure below shows the electricity demand projections of Cameroon using BAU (Business as Usual) scenario (Muh, Amara, et al., 2018). The growth in the demand forecast is expected to increase with the industrial sector spearheading the demand.

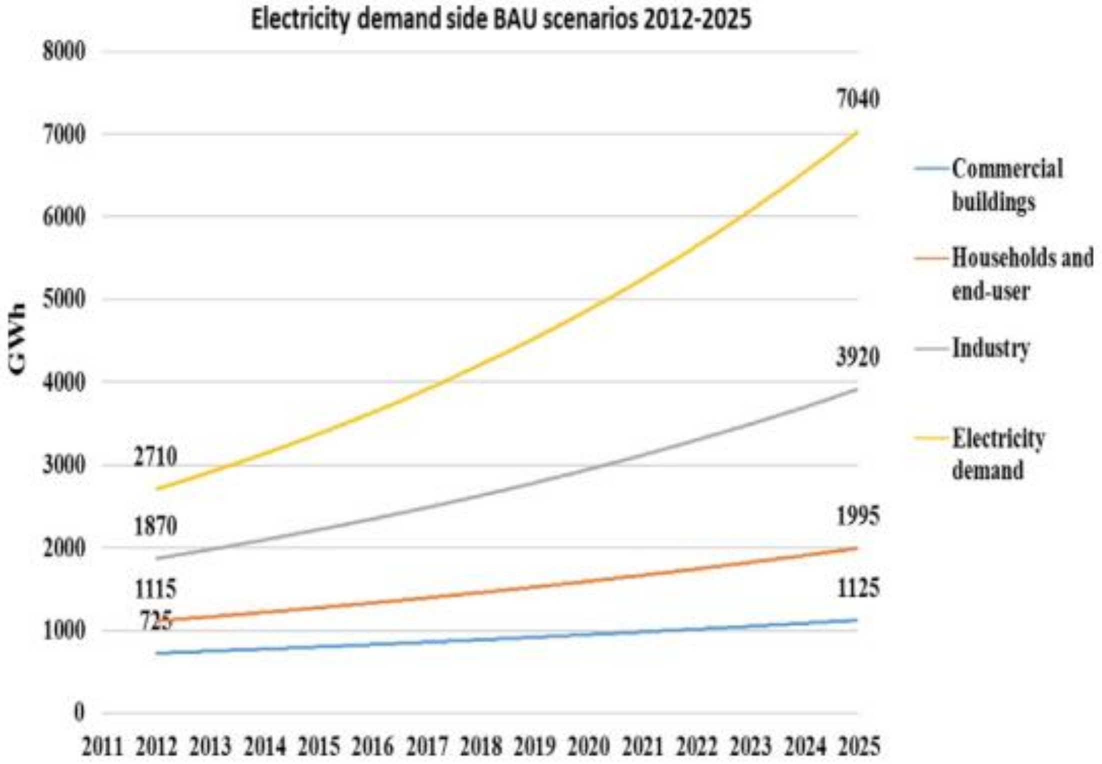


Figure 15: Electricity demand projections in Cameroon using BAU

Source: (Muh, Amara, et al., 2018)

2.10 Conclusion

Based on the review of documents, we have identified that systems dynamics is a viable method to adopt. This is because, the advantage of systems dynamics goes beyond purely numerical forecast and other socio-technical systems can be included in the model. As the country transitions towards an emergent economy by 2035, the amount of energy needed to support the different sectors of the economy will increase. This demand will depend on several factors and having a proper understanding of the evolutionary trends of the energy demand based on robust system dynamic principles paves the way for properly closing the demand- supply gap. A system dynamic model increases flexibility and dynamism on how different sectors of the economy interact and therefore this model for long term electricity projection for Cameroon will give a robust understanding of economic system interactions. The model will be built for a period of 60 years, from 1990 to 2050.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter presents a systems dynamics representation of the energy sector of Cameroon with focus on its energy demand. The systems dynamics model is built using a Vensim PLE software with the objective of showing the dynamic behavior of the energy sector. The model focuses on long term energy forecast and provides insights to changes in population, GDP and percentage of various technologies in the energy mix and a reflection of these changes on the energy demand. The model is used to simulate policy and technology choices that may influence future energy demand and supply, by providing useful policies that will aid in decision making and planning of the energy sector of Cameroon and hence investments in energy systems, including energy efficiency policies.

Building a system dynamics model is an iterative process making use of causal and feedback relationships. In order to answer the research questions above, we will proceed as follows:

- **Boundary definition and key variables identification:** Identifying the key variables entails recognizing the different variables that are directly related to the energy demand of Cameroon. Changes in such variables have a direct impact on the energy demand of the country.

- **Data acquisition:** This entails obtaining data about the key variables with respect to Cameroon. These data will be used in the model and will be obtained by reviewing scientific articles and documents, by using organization’s data such as, IRENA, IEA (International Energy Agency) etc.

- **Drawing the causal loop diagram:** After the identification of the variable, a causal loop diagram will be drawn. A causal loop diagram is a graphical representation of the various relationships that exist between the variable. The causal loop diagram will be used to understand the dynamic interactions between the various variables of the energy sector. This diagram will emphasize the feedback structure of the energy system of Cameroon.

- **Stock and flow diagram:** Stocks and flows are the main structures of SD. This diagram will be drawn from the causal loop diagram. While the causal loop diagram is only descriptive, the stock and flow diagram is actionable and therefore possible to run it in a simulation software, such as Vensim. Stocks are the accumulating variables whiles flows are the rate variables. The stock and flow diagram will emphasize the underlying physical structure of the energy system.

- **Model simulation and results:** The final model will then be simulated under different scenarios. The results obtained will be used to make informed decisions and recommendations that can help to improve on the energy system of Cameroon.

3.2 Systems Dynamics Model construction

3.2.1 Boundary definition and Key variable identification

3.2.1.1 Boundary definition

Energy models are mostly built in an explanatory manner assuming certain developments of boundary conditions such as the development of economic activities, demographic development, or energy prices on world markets.

The next step in building a model after stating its purpose is defining the model boundary. Defining the model boundary involves selecting components necessary to generate the behavior of interest as set by the model purpose (Albin, 1997). This entails selecting all components that are necessary, aggregated (should reflect the original reality of the model when included) and directional (should have a direct name).

After a careful consideration and understanding of the energy system of Cameroon and the purpose of the model, the model boundary was defined by listing the necessary components needed to achieve the behavior of interest (model purpose). The listing was done based on the following assumptions:

- Based on our analysis presented in **section 2.8**, the energy resources in Cameroon are; Solar, hydro, small hydro, wind and biomass. Geothermal energy sources were neglected since no concise data about this energy source in Cameroon is available. Also, it does not make up the present energy mix of Cameroon and no plan as well of including it in Cameroon’s future energy mix.

- The supply of electricity is limited to electricity that is generated within the geographical boundaries of Cameroon by ENEO, electricity imports are not considered in the modelling exercise given that ENEO doesn’t import energy from neighboring countries.
- The net migration wasn’t taken into consideration while building the model. This is because the value is small and hence its effect on total population is negligeable. Again, there is no available yearly data about this parameter.

3.2.1.2 Key variables identification

Key variables are those able to generate significant changes in the whole system. They are sometimes difficultly identified especially in dense of large problems (Barranquero et al., 2015). The identification of these key variables is also useful for understanding the dynamics of the model and for validation purposes, given that key variables might constitute an additional boundary adequacy and structure verification test for the model. Key variables can be divided into the following (Albin, 1997):

- Whether they are exogenous (variable that is not affected by other variables in the system) or endogenous (variables whose values are determined by other variables in the system).
- Type- this refers to how the values of the variables are used in the system dynamics model. The types include: auxiliary (used to estimate output variables), data (input variables to the model entered as a data series), level (variables that have accumulation within the system), flow (usually rate variables that affect level variables) and constant (unchanging system variables that are usually entered as a single figure).

The various key variables, their type and units used in this model are described in **table 7** below. It is important to note that the model presented is multidimensional based on the energy source and the following variables are proportionally distributed per energy source.

Table 11: The key variables used in the model

Key variable	Units	Endogenous/exogenous	Type
Total Electricity demand	KWh	Endogenous	OUTPUT
Base electricity demand	KWh	Endogenous	Auxiliary
Demand supply gap	KWh	Endogenous	Auxiliary
Demand ratio	Dimensionless	Exogenous	Constant
Price elasticity of demand	Dimensionless	Exogenous	Constant
GDP per capita	dollar/Person	Endogenous	Auxiliary
Population	People	Endogenous	Level
Birthrate	People/Year	Exogenous	Lookup
Deathrate	People/Year	Exogenous	Lookup
Births	People	Endogenous	Flow
Deaths	People	Endogenous	Flow
Initial Generation	KWh	Exogenous	Constant
Generation cost	c/KWh	Endogenous	Auxiliary
Reference generation cost	c/KWh	Exogenous	Constant
Capacity factor	Dimensionless	Exogenous	Constant
Capacity under construction	KW	Endogenous	Level
Rate of completion	KW/Year	Endogenous	Flow
Operational Capacity	KW	Endogenous	Level
Generation subsidy	Dimensionless	Exogenous	Constant
Load hour	hours	Exogenous	Constant
CO2 emission	Kg	Endogenous	Auxiliary
CO2 emission factor	Kg/KWh	Exogenous	Constant
CO2 emission price	c/KgCO2	Endogenous	Constant
Electricity price	c/KWh	Endogenous	Auxiliary
Electricity price ratio	Dimensionless	Endogenous	Auxiliary
Inflation rate	Dimensionless	Exogenous	Constant
Profitability factor	Dimensionless	Exogenous	

Investment rate	KW/year	Endogenous	Auxiliary
Plant lifetime	Years	Exogenous	Constant
Rate of aging	KW/Year	Endogenous	Auxiliary

3.2.2 Data acquisition

Secondary data was used in the model. Secondary data was obtained through a review of relevant documents including published and unpublished information. Several literatures were visited and important information related to the study was collected according to the need of relevant data. The major data sources are:

- Document titled “Study of the Establishment of the Master Plan for Renewable Energy in Cameroon”.
- Cameroon vision 2035 document.
- World Bank.

3.2.3 Causal loop diagram

To understand the behavior of a system, it is essential to understand the elements of a systems and their interactions between them. An effective way to graphically represent the feedback relationships between elements of a system is by the use of a causal loop diagram. The basic idea of a causal loop diagram is to show which elements influence other elements in a dynamic system(Sapiri et al., 2017). Causal loops can either be balancing/Self-correcting (negative feedback) or reinforcing (positive feedback)(Bayer, 2004):

- **Balancing (negative loop):** In this loop, a change in one of the variables in the loop is opposed by the feedback effect.
- **Reinforcing (positive loop):** When there is a change in one of the variables in the loop, the feedback effect reinforces the change.

A CLD was developed using the identified key systems variables, to describe the dynamics underlying interactions between constituent components of the sector. Figure 20 below shows the

Causal Loop Diagram of the Energy sector of Cameroon. It has one balancing loop and one reinforcing loops.

3.2.3.1 The balancing loop (Demand-Supply)

This loop is driven by the demand-supply gap. The demand supply gap arises from the difference created between the electrical energy demanded and electricity supplied. In this balancing loop/ self-correcting loop, the response of the variables in the loop to a change in the demand-supply gap is in such a way as to counter-act /oppose the change. An increase in demand widens the demand supply gap therefore investments are made to construct more generating capacity and increase supply thus reducing the demand supply gap.

The extent of investment in a particular generating technology either fossil or renewable to increase capacity is largely affected by whether or not the technology is profitable. A more profitable technology will have better investments. This research defines this profitability factor as the level of commitment by Cameroonian authorities to develop a particular technology from their power expansion plans.

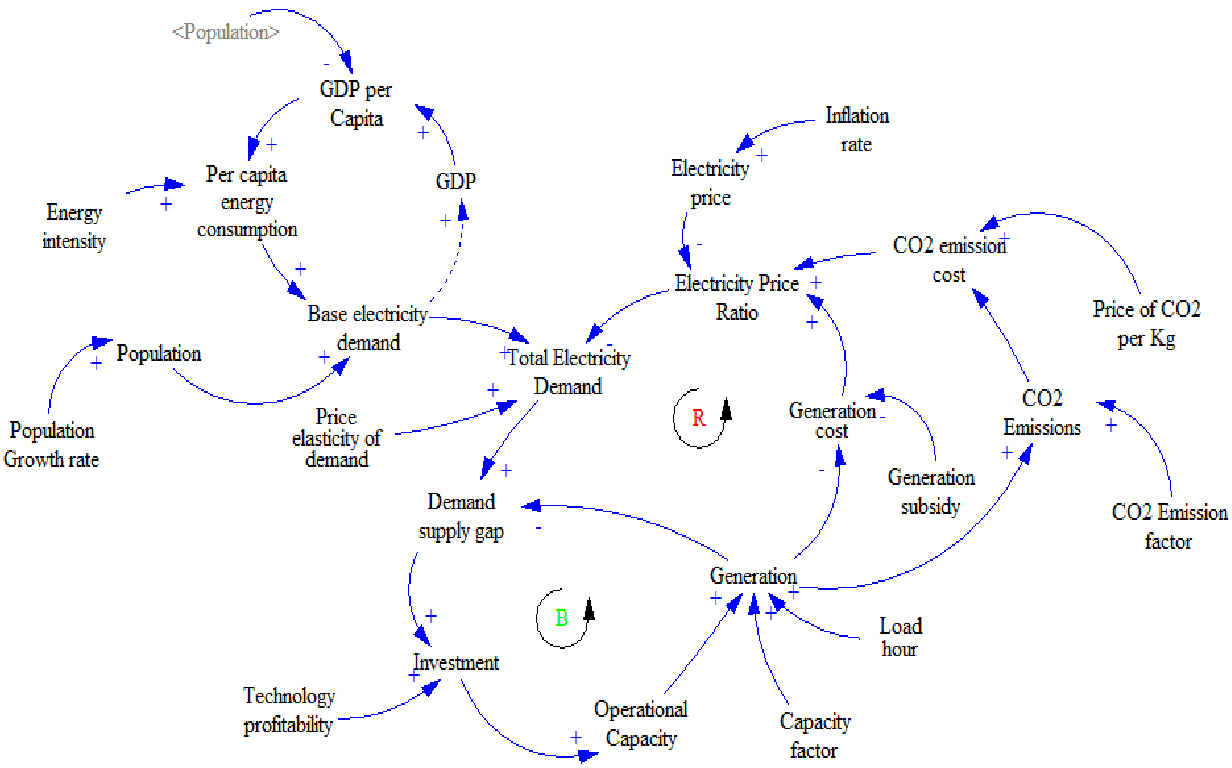


Figure 16: Causal Loop Diagram of the model with emphasis on the balancing loop (Demand-Supply).

Source: Own work

When the demand-supply gap increases, the increase triggers investment which will in turn increase the operational capacity. The increased capacity from investments will increase the generation of electricity required to close or reduce the demand supply gap. It is important to note that the amount of electricity generated is influenced by the capacity factor and the load hours of each generation technologies. Most fossil fuel technologies have high-capacity factors and they can be utilized around the clock, which is not the case for renewable generating technologies like solar and wind, relatively have low-capacity factor and reduced load hours due to their intermittent nature.

The loop is also characterized by two (2) time delays:

- Between demand supply gap and investments- there are several procedures that are followed in acquiring investments to increase generating capacity. There are applications and permits that need approval and these take time and causes a delayed response by the system to reduce the demand supply gap.
- Between investments and operational capacity- it takes time to construct additional capacities, sometimes even more than anticipated thus causing further delays in the response of the system in counter-acting the change in the demand-supply gap.

On the other hand, when demand-supply gap decreases, the systems also self-correct. Investments will no longer be made and hence no increase in operational capacity, given that the electricity generated has been able to close the demand-supply gap. When supply exceeds demand, the operational capacity reduces further such that it generates only the electrical energy demanded. This can be detrimental because after increasing the capacity by investing, only a fraction of the capacity will be used, so the electricity provider will end up “stuck with assets” which he or she can no longer use to generate income. Therefore, an ideal situation would be one in which the system continues to create a demand that needs to be satisfied.

3.2.3.2 Reinforcing loop (Energy demand-price)

The dynamism of the effect of electricity price on energy demand is shown by figure 17 below. This loop is driven by the electrical energy price ratio. Being a reinforcing loop, a change in the electricity price ratio will cause the other variables to response in such a way as to cause more of the change (amplify change). Say, the electricity price ratio decreases, the system variables will respond in such a way as to cause further decrease and if the electricity price ratio increases, the system responds by causing a further increase in the price ratio.

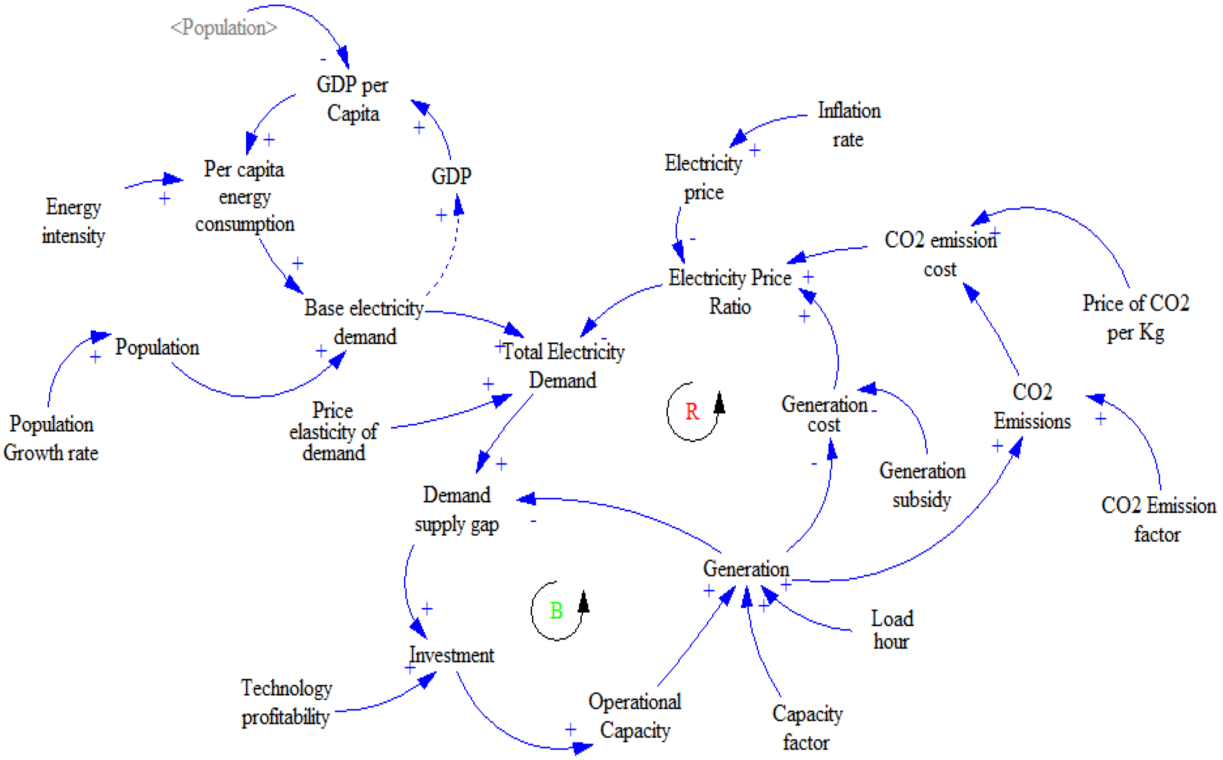


Figure 17: Causal Loop Diagram of the model with emphasis on the Reinforcing loop (Energy Demand-Price)

Source: Own work

The electricity price ratio compares the price of a generating technology to a reference price (electricity price), which in this study is considered as an average electricity price in Cameroon. When the price of the generating technology becomes cheaper, it lowers the electricity price ratio. A reduction in the electricity price ratio, causes an increase in electricity demand for that particular technology. The price elasticity of demand illustrates how consumers respond to changes in price.

An increase in electricity demand due to the decrease in electricity price ratio, increases the demand supply gap thus prompting investments to increase generating capacity in-order to meet demand. By increasing the generating capacity, the system benefits from “economies of scale” (which are cost advantages that enterprises obtain due to their scale of operation) thereby, making the generation cost cheaper. The cost of generating renewables is generally affected by technological progression and increased efficiencies as well as increased scale of operation. Cheaper generating costs, reduces the price of the generating technology and subsequently the electricity price ratio. This further reduction in electricity price ratio, increases the energy demand further and the variables in the loop continue to respond in such a way as to reduce the electricity price ratio even further. Likewise, an increase in the price ratio, decreases demand and the system responds in such a way as to increase the price even further.

The model also considers CO2 prices, which contributes to the price of a particular generation technology. CO2 prices add on to the price of the generating technology, and the more energy generated, the more CO2 emitted and the greater the CO2 price. This will result in higher prices for fossil fuel generating technologies and make renewable energy generating technologies more competitive especially now that the price per ton of CO2 emitted continues to increase. An increased price ratio, decreases demand, therefore unclean technologies will be consumed less.

Introduction of subsidies for generating technologies is also considered in this system dynamics model. Energy subsidies are any government action that concerns primarily the energy sector that lowers the cost of energy production, raises the price received by energy producers, or lowers the price paid by energy consumers. There are many different types of energy subsidies. Some have a direct effect on price, like grants and tax exemptions, while others act indirectly, such as regulations that skew the market in favor of a particular fuel or government-sponsored technology research and development, as initiatives that policy makers can implement in-order to promote the generation of electricity from a particular fuel.

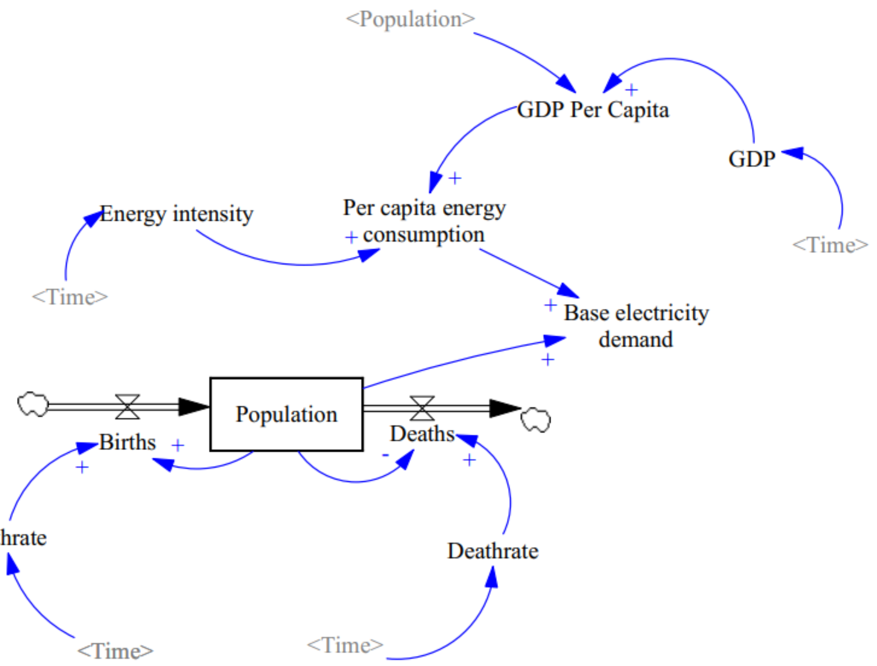
3.2.3.3 Base electricity demand-GDP and population

Electricity demand is also affected by GDP and population. An increase in GDP and population leads to an increase in electricity demand. In this research, GDP represents the level of economic growth in Cameroon. Gross domestic product (GDP) is the total monetary or market value of all the finished goods and services produced within a country’s borders in a specific time period. As a broad measure of overall domestic production, it functions as a comprehensive scorecard of a given country’s economic health. Per capita gross domestic product (GDP) is a metric that breaks down a country's economic output per person and is calculated by dividing the GDP of a country by its population. The dynamics of the effects of GDP on energy demand is shown in figure 17 above. No new graph is needed.

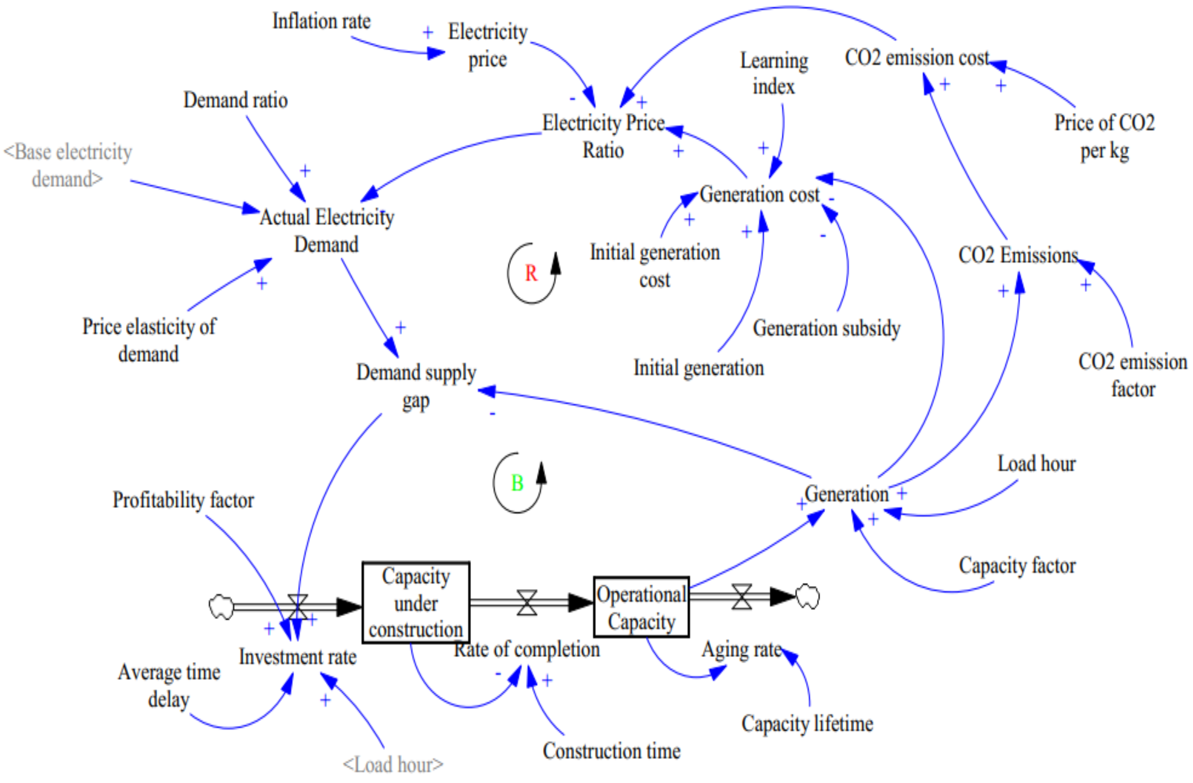
Economic growth is closely related to energy consumption. The more energy is used, the higher the economic growth. As the country’s GDP increases due to increase economic activities, the GDP per capita increases. Increase economic activities increases the energy consumption per capita and hence electricity demand.

3.2.4 Stock and Flow diagram

It is worth nothing that the structure of a systems drives its dynamic behavior. A Stock and Flow Diagram (SFD) is a structural diagram that detailly represents a system than a CLD will do. Stocks are accumulation of quantities that capture the state of a system. They start with initial values that change over time by incoming and outgoing flows only. They are sources of delay, provide system inertia and generate the information used in taking decisions and actions (Bayer, 2004). On the other hand, flows control the changes to stocks through their rates and are always measured per some unit time, by considering accumulated quantity over a period of time (Sapiri et al., 2017). Figure 18 (a) and (b) below shows the SFD of the energy system of Cameroon.


Population
GDP Per Capita
GDP
Time
Energy intensity
Per capita energy consumption
Time
Base electricity demand
Population
Births
Deaths
Birthrate
Deathrate
Time
Time
+
-

(a)


Inflation rate
Electricity price
Learning index
CO2 emission cost
Demand ratio
Electricity Price Ratio
Price of CO2 per kg
Base electricity demand
Actual Electricity Demand
Generation cost
Initial generation cost
R
CO2 Emissions
Price elasticity of demand
Generation subsidy
Initial generation
CO2 emission factor
Demand supply gap
B
Load hour
Profitability factor
Generation
Capacity factor
Capacity under construction
Operational Capacity
Investment rate
Rate of completion
Aging rate
Average time delay
Capacity lifetime
Construction time
Load hour
+
-

(b)

Figure 18: Stock and Flow diagram of the energy system of Cameroon.

Source: own work

Part of the model makes use of a Two-vintages structure to represent the dynamics in the operational capacity (Qudrat-Ullah, 2016) while the other part makes use of the model suggested by (Ahmad et al., 2012). The structure allows us to keep track of the actual capacity residing in the system. Operational capacity increases due to the additional capacity that is constructed after investments have been made while on the other hand decreases due to decommissioning of capacity that would have lived out its life time (captured by the aging rate flow variable). However, additional capacity can be considered operational after its completion, hence the flow variable, rate of completion is used to add the level in the operational capacity stock whilst at the same time used for reducing the level in the capacity under construction stock. The rate of completion is a function of the capacity that is being constructed and the time it takes to construct these capacities. The investment rate increases the level in the capacity under construction stock.

The energy demand is also affected by the population of the country. The population is represented as a stock. The inflow to the population stock is the number of births while the outflow is the number of deaths. An increase in the population of the country will demand that there should be more energy to meet up with the needs of these population and hence, leads to an increase in energy demand. The total number of births increases depending on the rate at which people are born and the total population, while the number of deaths is also affected by the rate at which people die and the population of the country. Hence, the greater the population of a country, the more energy is demanded.

3.3 Calibration of systems variables

Model calibration-the process of estimating the model parameters (structure) to obtain a match between observed and simulated structures and behaviors (Oliva, 2003). Here, we will analyze each variable and estimate it value.

1. **Actual Electricity demand**

Actual Electricity Demand is modelled endogenously using the price feedbacks. When the price of electricity increases from a particular technology, the demand decreases. Conversely, when the price reduces, demand decreases. Figure 19 below shows the variables used in the determination of actual electricity demand.

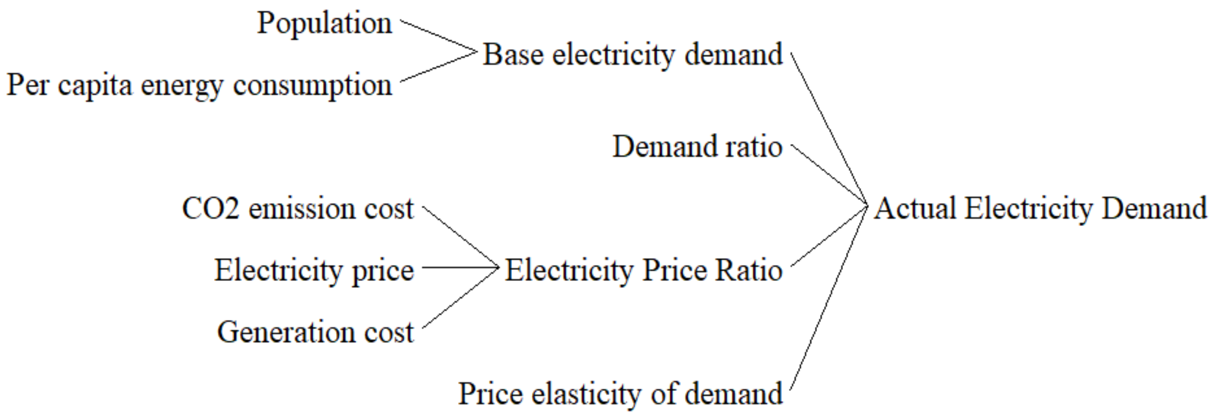


Figure 19: Actual Electricity Demand cause tree diagram

Source: Own work

Equation 1 below is used for calculating Energy Demand:

$$Demand(KWh) = Base\ Energy\ Demand * Demand\ Ratio * Energy\ Price\ Ratio^{PED} \qquad \textbf{(1)}$$

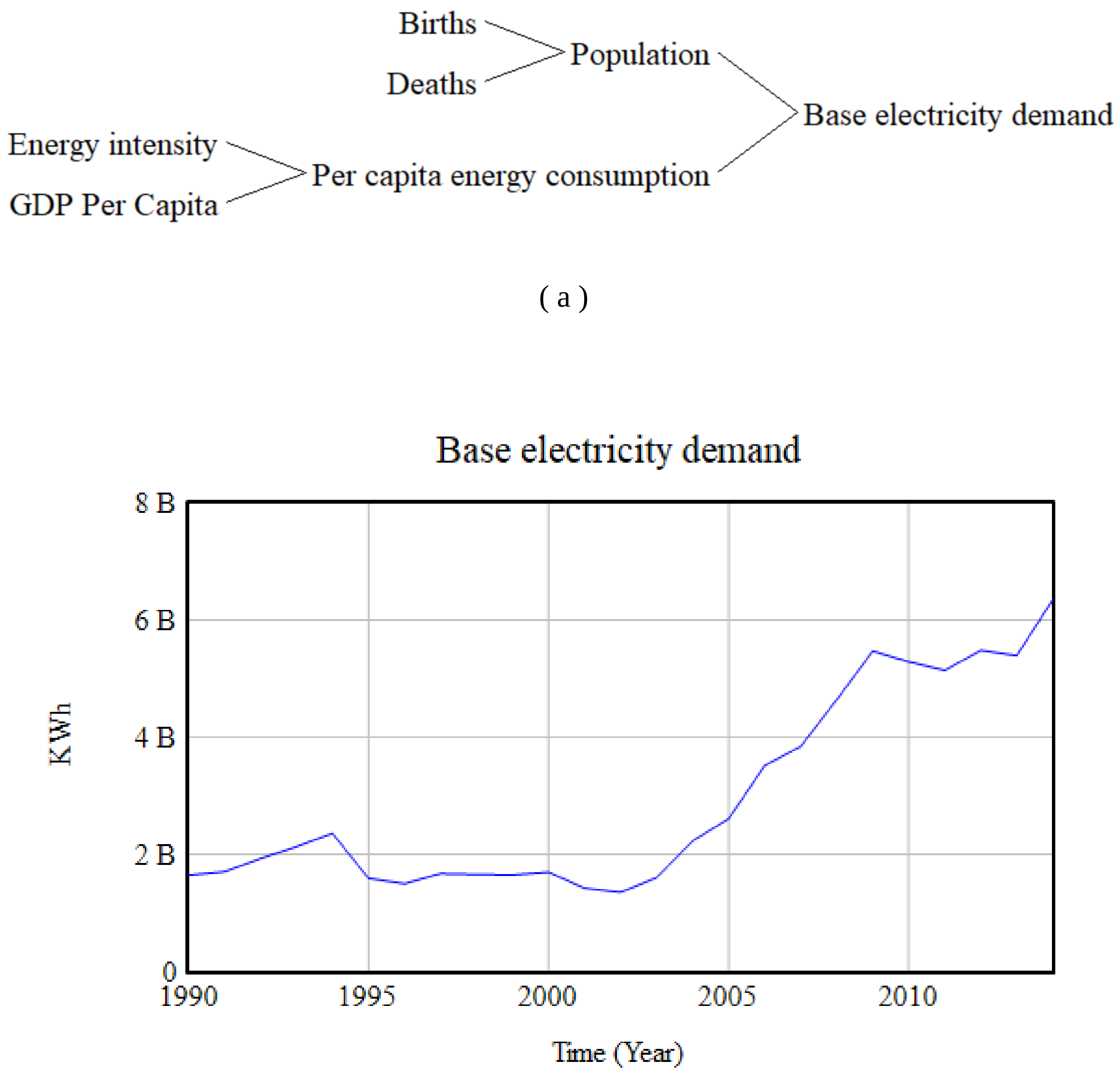
Where PED is the Price Elasticity of Demand

2. Base electricity demand

Base electricity Demand is modelled endogenously using the per capita energy consumption and population. When the level of economic activity (GDP) of the country increases, energy demand also increases and vice versa. Also, when the population of the country increase, energy demand also increases and vice versa. It is calculated using the following formula:

$$Base\ electricity\ Demand\ = Population * Per\ Capcita\ energy\ consumption \qquad \textbf{(2)}$$

The variables used in the determination of base electricity demand (a) and its graph (b) are shown below.



(b)

Figure 20: Base electricity demand causes tree diagram (a) and graph of base electricity demand (b)

Source: own work

3. Demand ratio

The demand ratio is defined as the percentage contribution of the different energy technologies in the overall electricity supply mix of Cameroon. From the literature review, the following figures exist:

- Hydropower 70.9%
- Thermal 28.1% (Oil 19.1%, Natural gas 9.0%)
- Bioenergy 1.0 %
- Solar photovoltaic (PV) and Wind (Renewables) <1%.

In one of the scenarios, renewables were included in the energy mix to represent the future energy mix of Cameroon with 25% renewables. The above percentages were altered and those of hydro and oil percentages reduced. The following were used:

- Hydropower 60%
- Thermal 15% (Oil 10%, Natural gas 5%)
- Renewables 25% (11% for small hydropower, 7% for biomass, 6% for solar, and 1% for wind power).

Energy Price ratio

The energy price ratio is calculated endogenously as the ratio between the price of the electricity generating technology and a reference price (Electricity price) which in this study is considered as an average electricity price for Cameroon. The reference price depends on the inflation rate of the country at the point in time and so subject to change after some years. The causes tree and calculation for electricity price ratio is shown in the later part of this chapter.

4. Price elasticity of demand

The price elasticity of demand measures the responsiveness of consumers to changes in price. A high price elasticity signifies a consumer base that is very sensitive to price changes. The demand for commercial energy is price and income inelastic in the short run in Cameroon and price and income inelastic in the long run in Cameroon (*A Comparative Analysis of Commercial Rents in Finland*, 2014). Figure 26 shows the both the short run and long run price and income elasticities from the work done by (*A Comparative Analysis of Commercial Rents in Finland*, 2014).

Table 12: Price and Income elasticity values in Cameroon.

Elasticities	**Short-run**	**Long-run**
Price	**-0.78**	**-0.04**
Income	**+0.87**	**+0.93**

A second study by (Jean G. Tamba et al., 2017) gives the following values for both the short run and long run price and income elasticities for diesel consumption in Cameroon. According to their study, the long run income and price elasticities for diesel consumption are 1.405 and -1.018, respectively. Elasticity signs are aligned with economic theory. Moreover, diesel consumption in the long run is elastic with respect to both price and income.

Table 13: Price and Income elasticity values in Cameroon.

Elasticities for ECM model		
	Short run	**Long run**
Price elasticity	**-0.015**	**-1.018**
Income elasticity	**0.056**	**1.405**

The effect of price on demand is a parameter whose value is based on long-term (Qudrat-Ullah, 2013). The price elasticity of **-0.04** was used for this simulation.

5. Capacity under construction (CUC)

The capacity under construction is a system variable that refers to committed projects for energy generation infrastructure in response to the demand supply gap. Figure 21 shows the variables used in the determination of the capacity under construction.

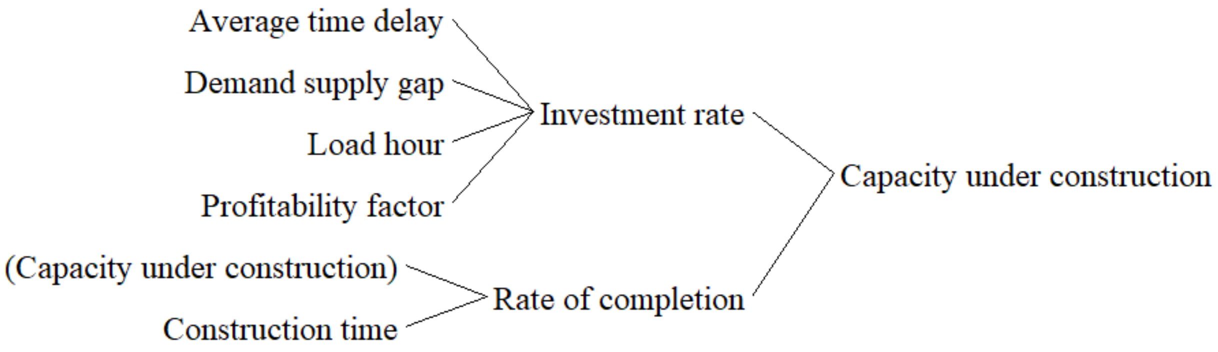


Figure 21: Capacity under construction cause tree diagram

Source: own work

The capacity under construction is a stock variable whose level at any point in time is given by the difference between the investment rate and the rate of completion. The equation for the capacity under construction is given as:

$$Initial\ cuc(KW) + \int_{t1}^{t2} Investment\ rate\left(\frac{KW}{year}\right) - Completion\ rate\left(\frac{KW}{year}\right) dt \qquad \textbf{(3)}$$

6. Investment rate

The purpose of analyzing the investment rate in this model will be to represent the investment behavior of each generation technology, not to find an investment cost for each. The investment rate is a nonlinear of installed capacity and the profitability that capture constraints on investment rates. The investment rate is given by equation below:

$$Investment\ rate\ \left(\frac{KW}{year}\right) = \frac{Demand\ supply\ gap\ (Kwh) * Profitability\ factor}{Load\ hours\ (h) * average\ delay\ time(years)} \qquad \textbf{(4)}$$

7. Demand Supply Gap (KWh)

The demand supply gap will result in commitment of investments to close the gap; however, the profitability factor of a particular generating technology determines the fraction of the demand supply gap that will be closed by investments. The demand supply gap is given by the equation below:

$$Demand\ Supply\ Gap\ (KWh) = Energy\ Demand\ (KWh) - Generation\ (KWh) \qquad \textbf{(5)}$$

8. Profitability factor

This research defines this profitability factor as the level of commitment by Cameroonian authorities to develop a particular technology evident in the power expansion plans. According to (MINEE Cameroon, 2017a), the government’s goal is to have 25% of renewable energy within the energy mix. This 25% is partitioned as follows:

- 11% for small hydropower,
- 7% for biomass,
- 6% for solar, and
- 1% for wind power

9. Rate of Completion

It is a measure used to describe the time it takes to successfully construct a particular capacity. The rate of completion for additional generating capacity is given by

$$Rate\ of\ Completion\ (\frac{KW}{year}) = \frac{Capacity\ under\ construction\ (KW)}{Completion\ time\ (year)} \qquad \textbf{(6)}$$

10. Operational Capacity (OC) (KW)

The operational capacity is calculated by the equation below:

$$Operational\ Capacity(KW) = Initial\ OC\ (KW) + \int_{t1}^{t2} rate\ of\ completion\ \left(\frac{KW}{year}\right) - Aging\ rate\ (\frac{KW}{year})\ dt \qquad \textbf{(7)}$$

The various parameters used in its calculation is shown in figure 22 below:

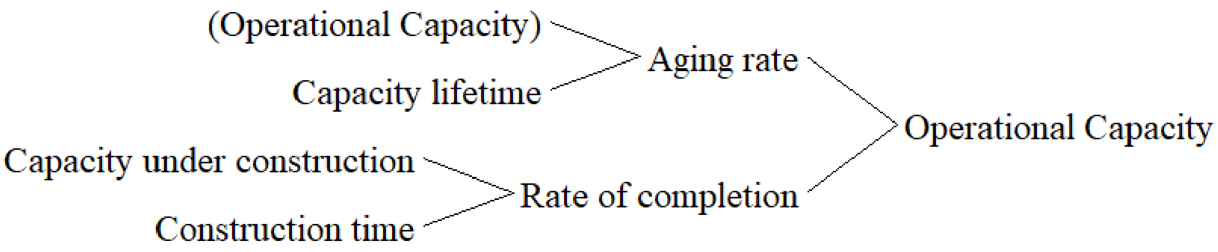


Figure 22: Operational Capacity cause tree diagram

11. Aging rate

It is used to capture the lost in capacity by decommissioning. It is calculated using the formula below:

$$Aging\ rate\ \left(\frac{KW}{year}\right) = \frac{Operation\ Capacity\ (KW)}{Plant\ lifetime\ (years)} \qquad \textbf{(8)}$$

12. Capacity lifetime

The following power plants average life exist in literature. Power plants average life is: Thermal: 40 years; Nuclear 25 year; Hydro 50 years; Others 20 years (Qudrat-Ullah, 2013).

13. Generation

The generation systems variable accounts for the amount of electrical energy that is generated and supplied to the system. The following variables are used to calculate generation.

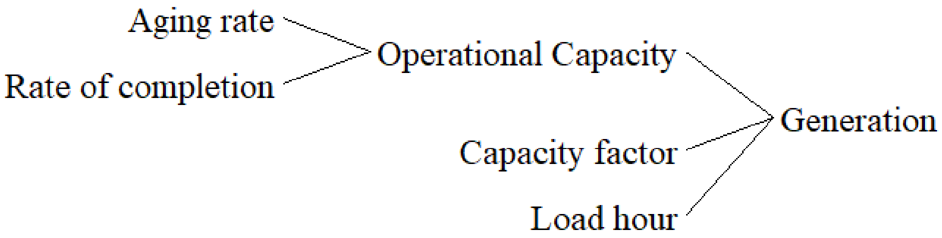


Figure 23: Generation cause tree diagram

Source: own work

Generation is calculated using the following equation:

$$Generation\ (KWh) = Operation\ Capacity(KW) * Load\ Hours\ (h) * Capacity\ Factor$$

(9)

14. Capacity Factor

Capacity factor is defined as the actual electricity production divided by the maximum possible output of electricity generated from a power plant over a fixed period of time. Capacity factor is a constant.

15. Generation Cost (GC)

Figure 24 shows the variables used in determining the generation cost for each technology considered:

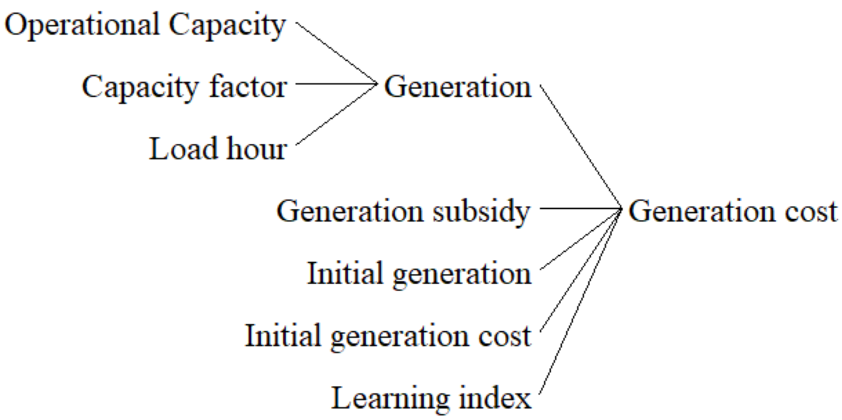


Figure 24: Generation cost cause tree diagram

Source: own work

The generation cost of each technology is calculated from the equation below:

$$Generation\ Cost\ \left(\frac{c}{KWh}\right) = Reference\ Generation\ cost\ \left(\frac{c}{KWh}\right) * \left(\frac{Initial\ Generation}{Cumulative\ Generation}\right)^{li} * Generation\ Subsidies \qquad \textbf{(10)}$$

Where, (li) is the **learning index**. The less mature technologies benefit from this phenomenon. Technology progression has a tendency to reduce the generating costs of the less mature technologies. The learning index is afflicted with high uncertainty, particularly in the early stage of a technology. As the installed capacity grows and hence generation, more experience with the technology cumulates and uncertainties are reduced. The learning curve effect is a high leverage point for long-term policymaking if we want to alter the course of development.

The technological progress for hydropower is assumed to be negligible being a mature technology with few remaining potential for development. The model estimates the following values of the learning index for the generating technologies adopted from (Vogstad, 2016). According to (Vogstad, 2016), learning indexes are uniformly distributed between 0 and 0.1 for thermal technologies and 0.1 and 0.3 for renewables.

Table 14: Learning index of different generating technologies

Generation Technology	**Learning Index**
(Natural gas & oil)	0.05

Hydropower	0
Small hydro	0.2
Solar	0.3
Wind	0.2
Bioenergy	0.05

16. Reference generation cost

Renewable energy generation technologies are increasingly becoming cheaper as the years go by. According to (IREA, 2020), in 2020, the global weighted-average levelized cost of electricity (LCOE) from new capacity additions of onshore wind declined by 13%, compared to 2019. Over the same period, the LCOE of offshore wind fell by 9% and that of utility-scale solar photovoltaics (PV) by 7%. Figure 25 below depicts such reductions.

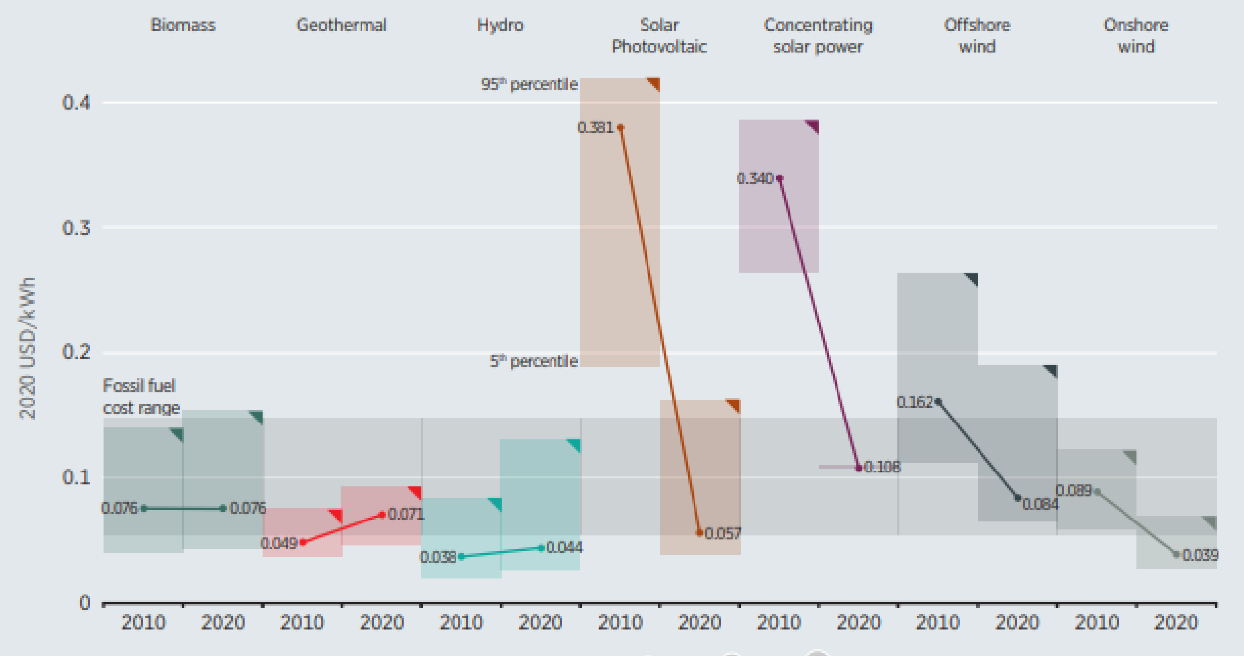


Figure 25: Global LCOEs from newly commissioned, utility-scale renewable power generation technologies, 2010-2020.

17. Generation Subsidy

After carrying out a considerable literature about generation subsidy in Cameroon, no important information has been found. In this model, it is therefore assumed that no subsidies are being currently given for each of the generation technologies.

18. Energy Price Ratio

Figure 26 below shows the parameters used in calculating the energy price ratio.

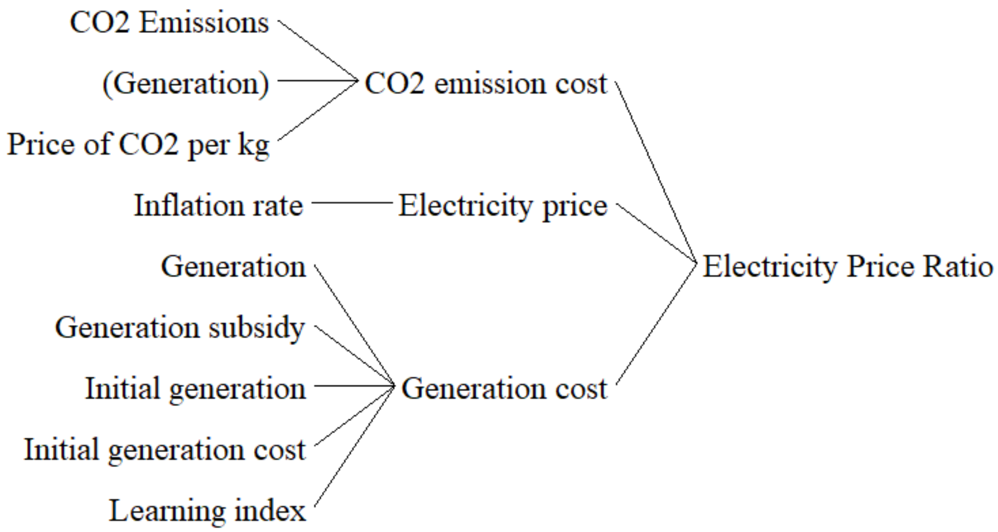


Figure 26: Electricity price ratio causes tree diagram

Source: own work

The energy price ratio is calculated from the following equation:

$$EPR = \left(\frac{Generation\ cost + CO2\ cost}{Energy\ Price}\right) \qquad \textbf{(10)}$$

The CO2 Price is given by the following equation:

$$CO2\ Price\ \left(\frac{c}{KWh}\right) = CO2\ emission\ \left(\frac{kg}{KWh}\right) * Price\ of\ CO2\ per\ kg\ \left(\frac{c}{kg}\right) \qquad \textbf{(11)}$$

The energy price is an average electricity price for Cameroon for the entire modelling period; This model uses 50 CFA/kWh (0.09 cents/kWh) for a consumption less than or equal to 110kwh, as an estimate of an averagely affordable energy price in Cameroon (MINEE Cameroon, 2017a).

3.4 Model Testing and Validation

Once a model is developed, it has to go through the validation process. Validity means adequacy with respect to a purpose. Model Validation is the process of establishing confidence in the soundness and usefulness of a model. No model built is expected to imitate the exact system behavior but a good model is able to predict the system behavior with sufficient accuracy(Sapiri et al., 2017). The basic rule of thumb is that the model behaves as expected. The ultimate objective of system dynamics model validation is to establish the validity of the structure.

For validation purposes, the model was simulated from 1990 to 2014. The actual electricity demand values obtained were plotted with the historical electricity demand values as shown on the graph below;

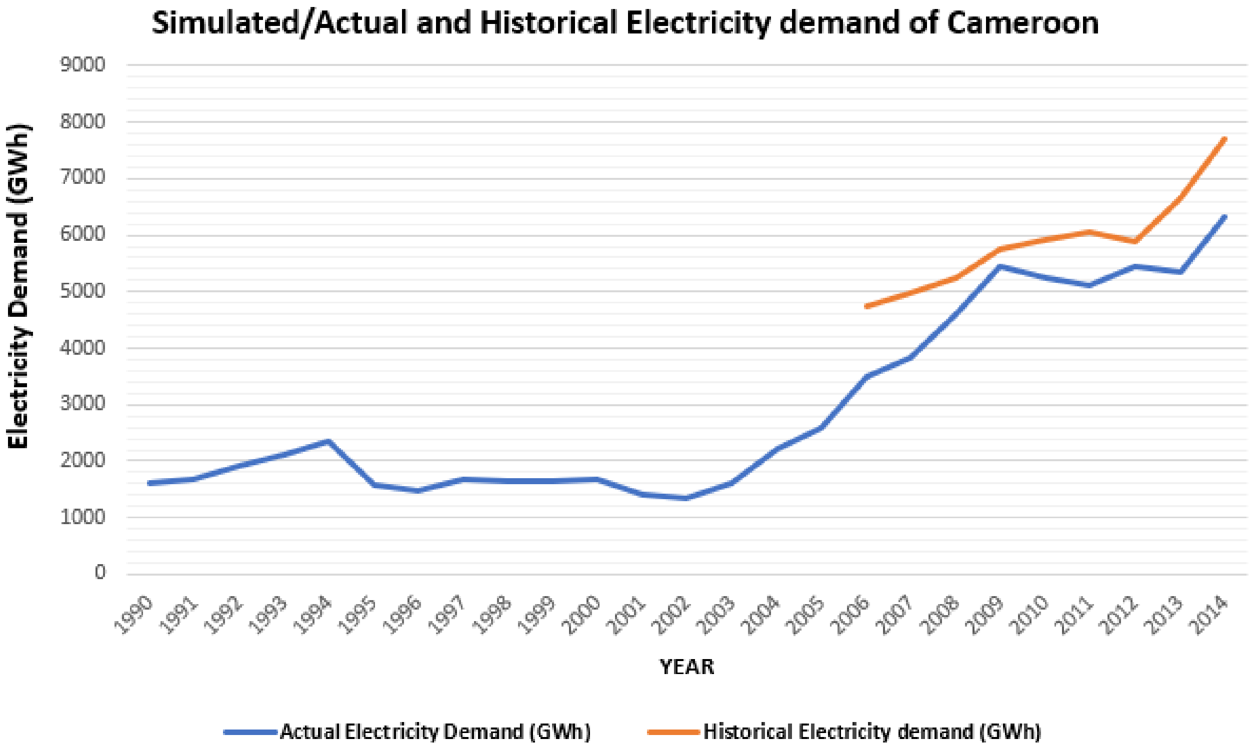


Figure 27: Simulated/Actual and historical electricity demand of Cameroon

Source: own work

From literature, power consumption increases from 4,222.02 GWh in 2006 to 6,875.83 GWh in 2014 in Cameroon while form the results obtained from simulation, power consumption increased from 3,460.6 GWh to 6,242.23 GWh as shown on the table below;

Table 15: Percentage change in simulated/actual and historical electricity demand values

Year	Historical consumption (GWh)	Simulated/Actual consumption (GWh)	Percentage change
2006	4,222.02	3,460.6	18.03%
2014	6,875.83	6,242.23	9.21%

Despite the discrepancies in the values obtained during the simulation, as stated by Sapiri et al. (2017), the ultimate objective of system dynamics model validation is to establish the validity of the structure. That is, the most important aspect is for the model to behave as expected, which was the case in our simulation as depicted by the results below.

1. Price elasticity of demand and its effects on Actual energy consumption

The graph below represents the results obtained by varying the price elasticity of demand from -0.04 (base case) to -0.01 (New scenarios). From the graph, a decrease in price elasticity of demand increases the actual energy consumption. A decrease in price elasticity of demand implies people are less sensitive to price changes and so will keep demanding energy as their need increases, therefore increasing the demand of electricity.

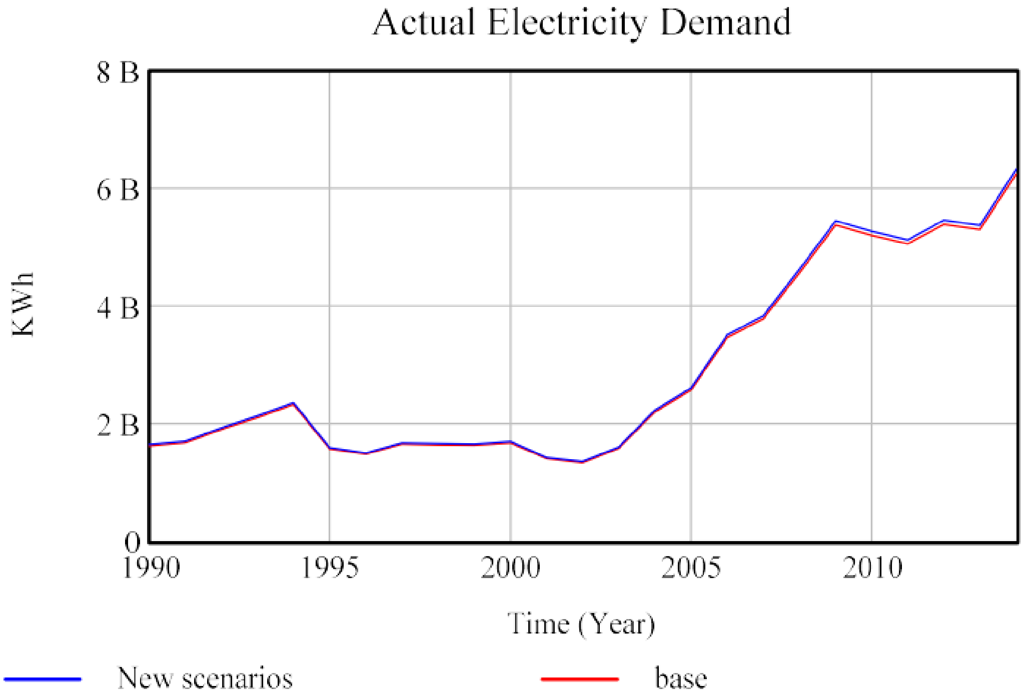


Figure 28: Effects of Price Elasticity of demand on Actual energy consumption

2. **Effects of CO2 emissions factor on Actual electricity consumption.**

The CO2 emissions factor, which is the amount of Kg of GHG emitted per KWh of electricity generated vary per technology and has an effect on the CO2 emission cost of that particular technology. The graph below shows the results obtained by varying the CO2 emission factor form 1.3 (base case), higher for fossil fuels to 0.1 (New scenario), almost zero for renewables. The results shows that a decrease in the CO2 emission factor will lower the energy price ratio for that technology and hence increase in the Actual electricity demand.

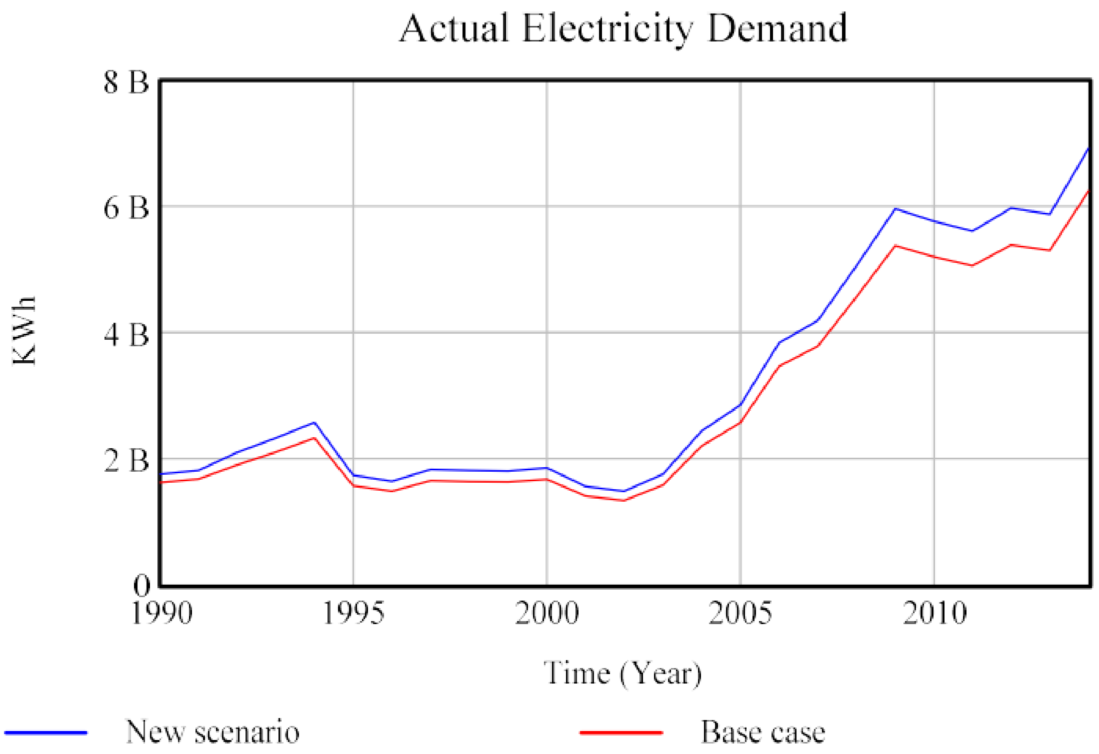


Figure 29: Effects of CO2 emission factor on actual electricity demand.

3.5 Model Scenario Design

Based on the fact that the GDP of Cameroon is expected to grow at Average Annual Growth Rate (AAGR) of 6.5% between 2010 and 2035, projected values of GDP were obtained and the model simulated up to 2050. Given the lack of data regarding the energy intensity and no previous research was found in which these values were forecasted, the energy intensity was assumed to be constant.

In another scenario, the energy intensity is assumed to be decreasing at an annual percentage of 0.5%. This decrease is accounted for by the implementation of energy efficiency programs in Cameroon.

CHAPTER FOUR: RESULTS PRESENTATION AND DISCUSSION

This chapter presents the results of the simulation exercise. Several different policies were simulated and the outcome of their simulations represented. These are shown below.

4.1 What is the long-term impact of increase incentives?

The model was simulated taking into consideration the effects of subsidies on the generation cost. Generation subsidies of 20% (subsidy base) and 60% (subsidy new scenario) were simulated. The graph below shows that an increase in the generation subsidy causes the generation cost to start at a higher value. But despite this fact, it also drops faster compared to the generation cost with a lower subsidy. An increase in subsidy from 20% to 60% leads to a decrease in generation cost by 62.1% and 79.3% from the year 2020 to 2040 and 2020 to 2050 respectively for the subsidy new scenario while in the subsidy base scenario, the generation cost decreases by 55.5% and 77.2% from the year 2020 to 2040 and 2020 to 2050 respectively.

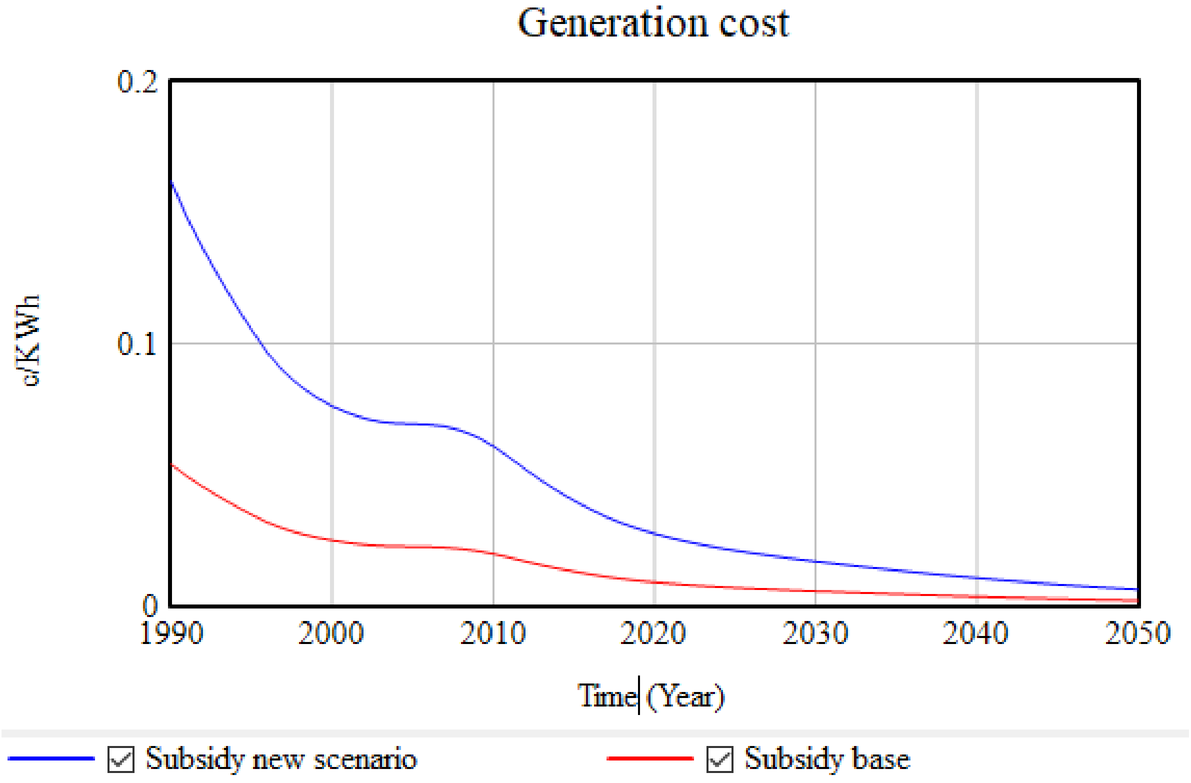


Figure 30: Effects of subsidies on generation cost

This increase in generation cost caused the electricity price ratio to increase. Despite this increase, the actual electricity demand stayed the same for both scenarios. This can be explained by the fact that Cameroon experiences a price inelasticity in both the long run and short run as seen in a study made during our methodology, and so despite the changes in price, the population still needs energy and hence no drastic drop in the actual electricity demand.

4.2 What will happen if there is a larger support of renewables in the electricity supply mix? / Low carbon economy scenario.

This policy was simulated and evaluated taking into consideration the CO2 emissions factor, the profitability factor, the load hours the demand ratio, learning index and capacity factor. The values of these various parameters where varied to represent an increase in the percentage of renewable energy. The model was then simulated and the influence of this policy on the actual electricity demand, capacity under construction, operational capacity, electricity price ratio, generation cost and CO2 emissions were evaluated. The result of the simulation is as shown below.

4.2.1 Effects of increase share of renewables in the supply mix on actual electricity demand

The graph below represents the effect of increase renewables on electricity demand. The base case and new scenario case depict the demand with a lower percentage of renewables and a higher percentage of renewables respectively within the energy mix. It can be clearly seen that the demand of electricity increases when the percentage of renewables is higher. This is because an increase percentage of renewables will lead to a decrease in the quantity of CO2 emitted. This in turn decreases the CO2 emission cost and hence the electricity price ratio. Also, the advantage of a decrease in CO2 emissions over conventional sources makes such technologies more attractive and hence, leads to an increase in their learning rate. With an increase in learning rate, the generation cost decreases which also leads to a decrease in electricity price ratio. This decrease in both cases leads to an increase in actual electricity demand, as the cost per KWh decreases.

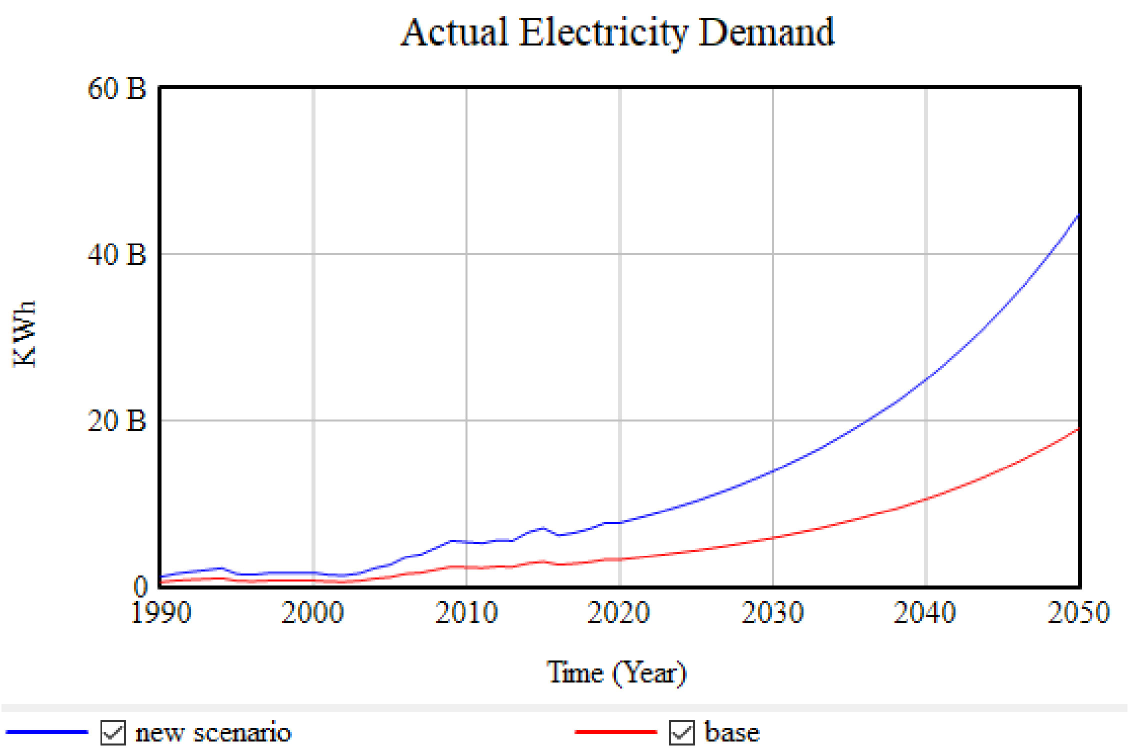


Figure 31: Effects of increase share of renewables in the supply mix on actual electricity demand

Increase in the share of renewables in the electricity generation mix means that the government is committed to these technologies and hence are more profitable. A decrease in the generation cost and CO2 emission cost were observed. The electricity price ratio decreased and hence the demand of electricity increased as these technologies become cheaper. Over the years, there has been a continues decrease in the LCOE of renewable energy technologies as presented in the methodology section of this report. This result shows that the electricity demand of Cameroon will reach about 45 TWh of electricity by 2050. With this increase in demand, it is important that the government starts planning on how to improve on the energy infrastructure of the Country.

4.2.2 Effects of increase share of renewables in the supply mix on CO2 emissions

The graph below shows the effect of increase share of renewables in the supply mix on CO2 emissions. Figure 32 below shows that an increase in the share of renewables in the electricity supply mix decreases the amount of CO2 emitted into the atmosphere. This is because, renewable energy technologies have a very low CO2 emission factor and hence don’t emit GHGs. The quantity of CO2 still emitted even with the increase in renewables share in the electricity supply mix can be accounted for by the percentage of the mix that makes up fossil fuel resources.

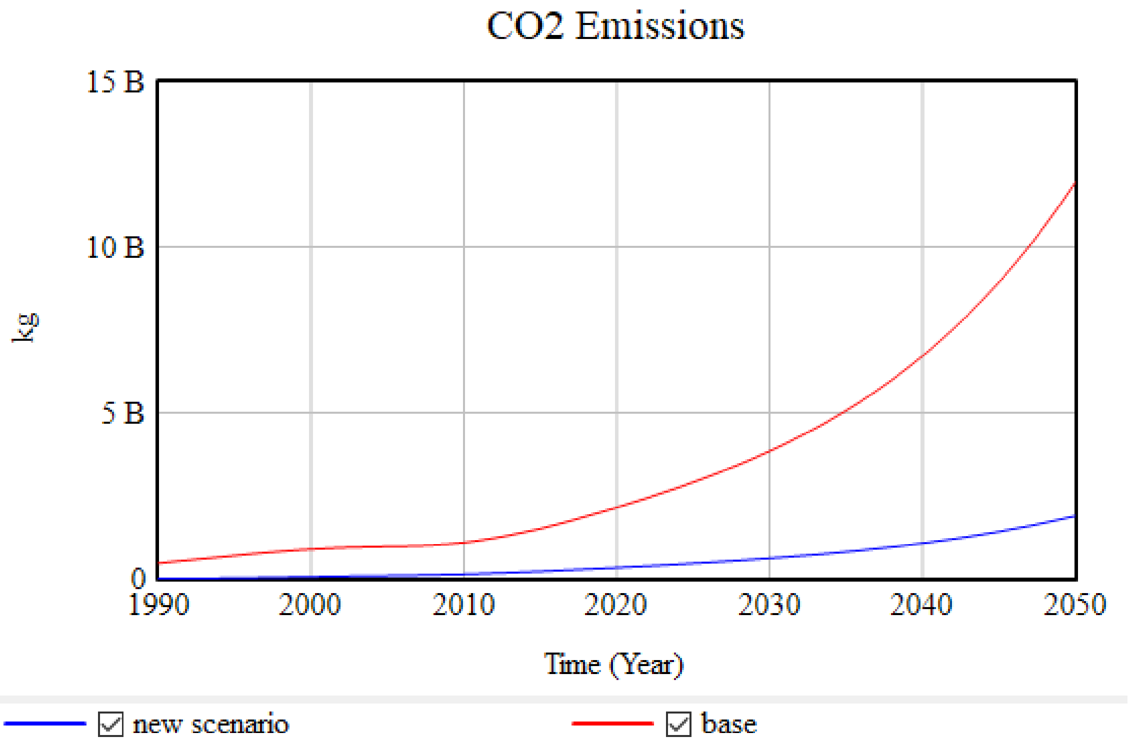


Figure 32: Effects of increase share of renewables in the supply mix on CO2 emissions

It is important to note that the government of Cameroon declared its intention to reduce greenhouse gas (GHG) emission by 32% by 2035, that is, it aims to limit the 104 MtCO2-eq in the BAU scenario to 71 Mt CO2-eq in 2035, to come to effect by 2020. And, related to the energy sector particularly, the intended total reduction is 4,684 kt CO2-eq of GHG emissions.

From the above simulations, the CO2 emission settles to about 809 ktCO2 -eq by 2035. Therefore, the adoption of renewables by the government of Cameroon plays a major role in the achievement of this low carbon goal.

4.2.3 Effects of increase share of renewables in the supply mix on capacity under construction, operational capacity, generation cost and electricity price ratio.

From figure 33 below, with an increase share of renewables in the supply mix, there were increases in both the operational capacity and the capacity under construction. This is because, increase in the share of renewables led to an increase in actual electricity demand and hence increase in the demand-supply gap. Given the level of profitability of these technologies, the government will increase the investment rate to meet up with this demand. This is accounted for by the level of commitment of the government of Cameroon to renewable generation technologies. An increase level of commitment will cause the government to increase investment for the construction of these renewable energy generation plant and hence, increasing the capacity under construction capacity.

The rate of construction of these capacities is affected by the construction time and the total capacity to be completed. Once completed, the total operational capacity in the country will increase

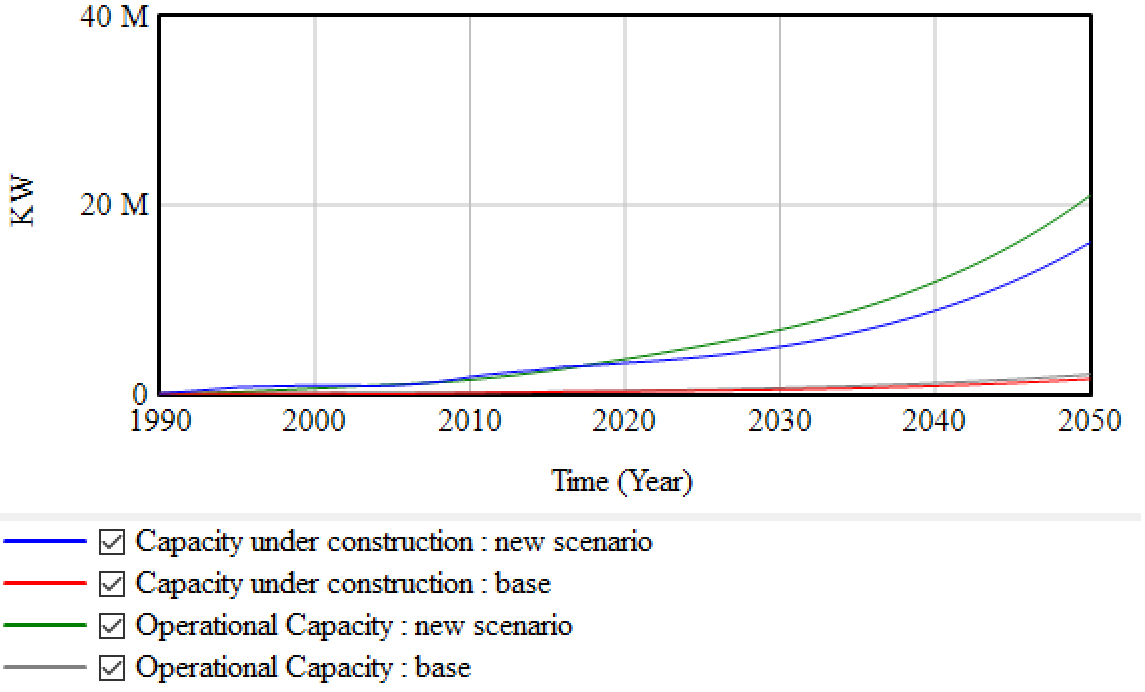


Figure 33: effects on increasing renewables on operational capacity and capacity under construction.

With an increase in operational capacity over time, the proportionate saving in cost gained also increases (economies of scale) given the increase in the quantity of electricity produced. This leads to a decrease in generation cost and hence the price of electricity. At his point, the ratio of the price of electricity to the average electricity price of Cameroon (electricity price ratio) decreases. This decrease leads to an increase in the quantity of electrical energy demanded. Hence, an increase in the operational capacity and the actual energy demand of the country.

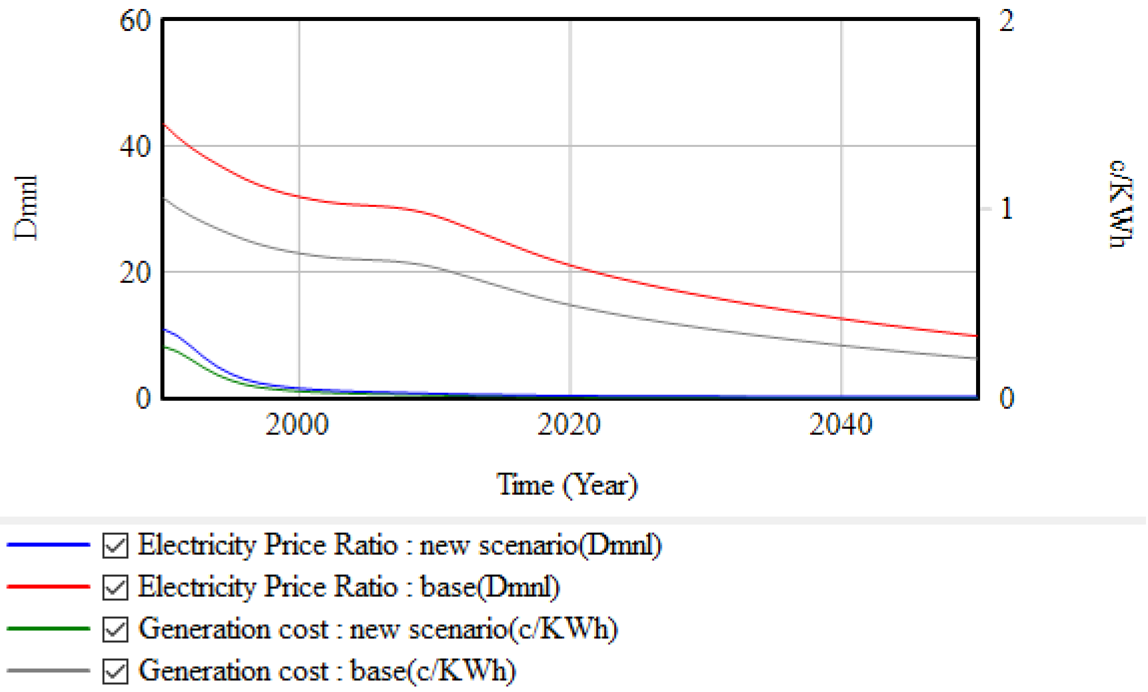


Figure 34: Effects on increasing renewables on electricity price ration and generation cost.

4.3 Effects of energy intensity on the electricity demand of Cameroon

The graph below shows the effects of changes in energy intensity on the energy demand of Cameroon. In one of the scenarios (base), it is assumed that the energy intensity remains constant over time and in the other scenario (new scenario, it is assumed that the energy intensity decreased over time as a result of the implementation of the various energy efficiency policies of the country.

The results of the simulation show that, a decrease in the energy intensity will lead to an increase in the energy demanded, but at a slower rate. Though the electricity demanded increased over time, it was lower for each year compared to the base scenario. This eventually decreased the demand-supply gap for each year, given the electricity demanded was decreased.

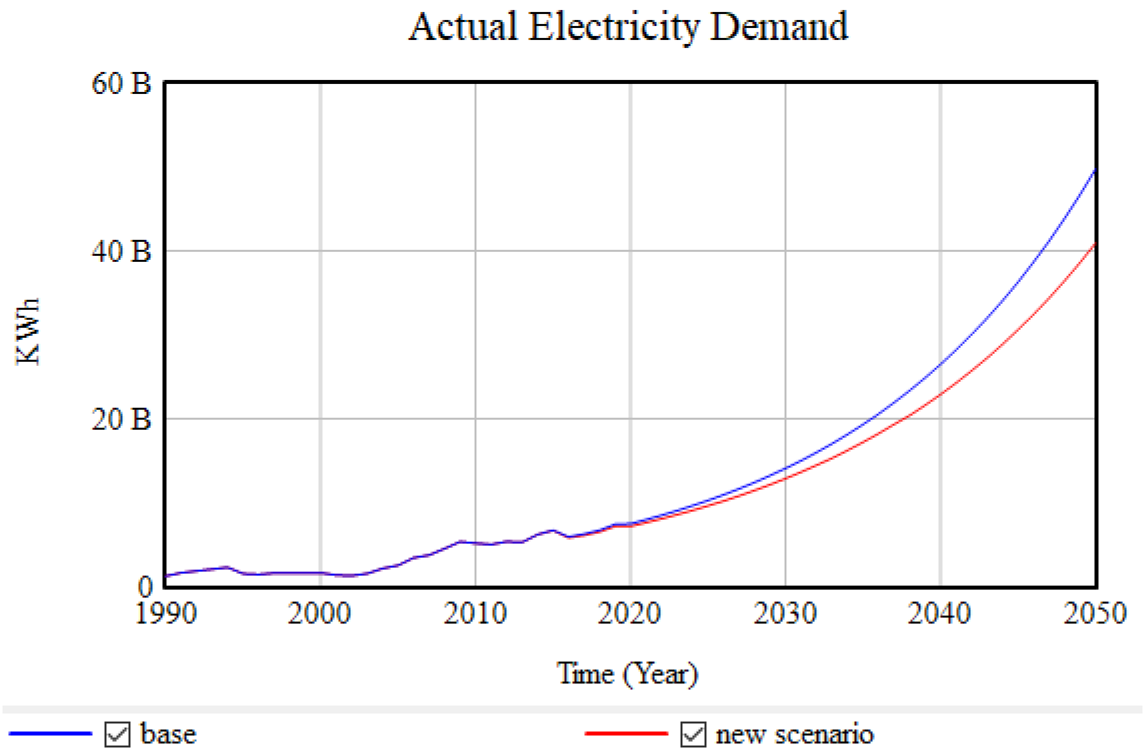
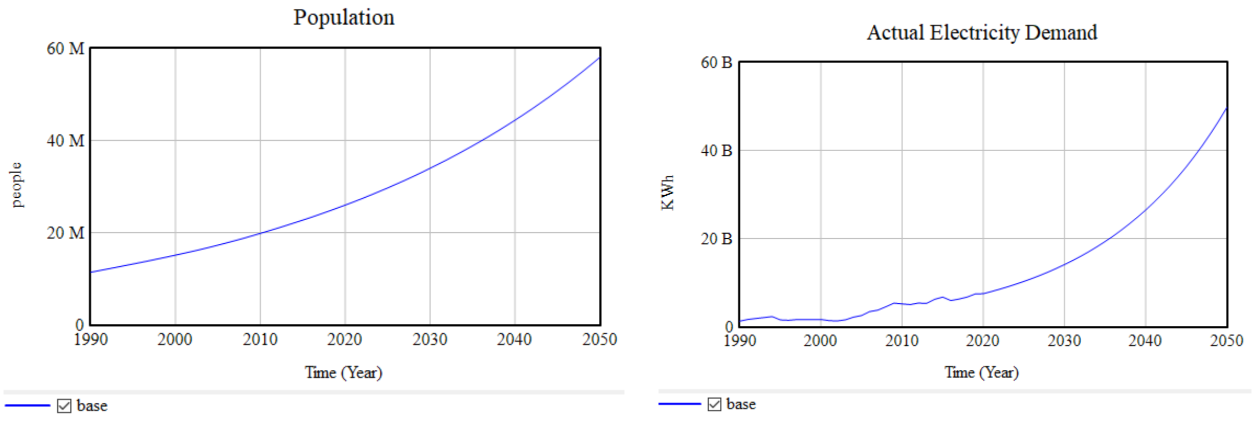


Figure 35: Effects of energy intensity on the actual electricity demand

An increase energy intensity should increase the demand of electricity, which will further increase the energy intensity. In some cases, an energy intensity that decreases with time can be as a result of the increase implementation of the various energy efficiency policies of the country. Cameroon has a number of energy efficiency policies and the implementation of these will eventually decrease the energy intensity of the country and this may continue until the electricity demand and supply gap is balanced.

4.4 The effects of population on actual electricity demand



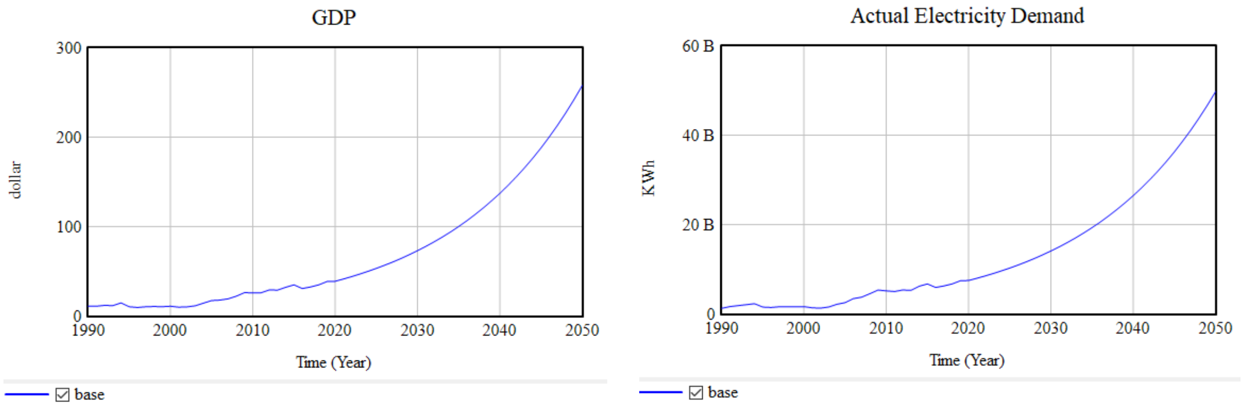
(a) (b)

Figure 36: Effects of population (a) on actual electricity demand (b).

The graph above demonstrates the effects of population on the actual electricity demand. The results show that there is a positive relationship between population and actual electricity demand in Cameroon. That is, an increase in population leads to an increase in electricity demand. The population of Cameroon according to our results is expected to reach 38.8 million and 58 million by 2035 and 2050 respectively and the actual electricity demand is expected to reach about 19.3 TWh by 2035 and about 45 TWh by 2050.

This positive relationship can be accounted for by the fact that an increase in population will mean more energy to take care of the daily needs of this increased population and therefore, increase in the electricity demand.

4.5 Effects of GDP on actual electricity demand



(a) (b)

Figure 37: Effects of GDP (a) on actual electricity demand (b)

The graphs above demonstrate the effects of increase GDP on the electricity demand of Cameroon. Projected values of GDP were obtained based on the fact that the GDP of Cameroon is expected to grow at Average Annual Growth Rate (AAGR) of 6.5% between 2010 and 2035. This was then simulated and the actual electricity graph (b) above was obtained.

As was the case of population, a positive relationship between GDP and actual electricity demand is also notice. That is, an increase in GDP leads to an increase in electricity demand. Energy is very vital for every country to maintain a certain level of economic growth and hence as the economy grows, more energy will be needed.

According to the results, the GDP of Cameroon will be about 100 billion in 2035 where Cameroon plans to be emergent.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

The focal point of this research was to create a sustainable energy transition model, forecast the electricity demand of Cameroon and to understand the effects and influence of intervening parameters on the total electricity demand of the country using the systems dynamics approach. The objectives of the research were:

- To understand the energy generation and demand pattern, the various key energy plans and policies of the energy sector of Cameroon and understand the variables driving the dynamics of the energy sector.
- To build a systems dynamics model using Vensim software for the energy sector of Cameroon and show that this model can be used to effectively forecast the future energy demand of Cameroon.
- To provide a time series information on the total electricity demand of Cameroon up to the year 2050 and how the various systems variables interact, affecting this energy demand.
- To inform policies and provide recommendations from the findings.

The model was built and calibrated. Both the structural and behavioral validity test were performed on the model. The structural test ascertains that model structure generates the right behavior while the behavioral test assesses how well the model-generated behavior mimics the observed patterns of the real system. Though the behavioral test had a lot of discrepancies (within 10% of historical values – see section 3.4 of chapter 3), the structural test was successful.

The unsuccessful nature of the behavioral test can be accounted for by the following reasons:

- The lack of appropriate data. Despite the thorough search and inquiries, data about the capacity under construction and the operational capacity of Cameroon in the year 1990 (the start of the modeling process) wasn’t obtained. Because of this, a lot of assumptions had to be made, which made it difficult to forecast long-term behavior which is sensitive to certain parameter more than others (e.g., price elasticity of demand). For example, the data used for the capacity under construction and operational capacity were assumed to be slightly lower than that of the year 2000, since the data for the year 2000 were obtained.

- Different modelling approaches and models have been built in existing literature to address different energy policies in different countries. However, there exist no systems dynamics model with explicit energy data about the energy systems of Cameroon. Therefore, building this systems dynamics model to address different energy polices over time given the complex and dynamic nature of energy systems was challenging. As a result of this modelling exercise, in order to explicitly simulated a specific policy and make informed recommendations, it is advice to build models for specific purposes.
- The existence of nonlinear and uncertainty intensive variables, several inherent time lags, and intertwined feedback loops in an energy system pose serious modeling challenges.

Based on the structural test results, we successfully developed a timeseries of the total electrical energy demanded and shown the dynamics of the effects of varying some parameters. The different built and simulated scenarios were:

- The long-term impact on increase incentives
- Effect of increase renewables in the supply mix on total electricity demand, operation capacity and capacity under construction, CO2 emissions, generation cost and electricity price ratio.
- Effect of energy intensity on actual/total electricity demand.

It was observed form the modelling and simulation process that an increase in the generation subsidy causes the generation cost to start at a higher value. But despite this fact, it also drops faster compared to the generation cost with a lower subsidy. Also, an increase share of renewables increased the total electrical energy demanded. This also increased the operational capacity and capacity under construction. Increasing the share of renewables in the energy mix lowered the total amount to CO2 emission. The CO2 emission was observed to settle to about 809 ktCO2 -eq by 2035, which is lower than the amount of CO2 estimated by the government in 2035, and hence a potential path in achieving the governments visions within the energy sector of the country. And finally, a decrease in the energy intensity will lead to an increase in the energy demanded, but at a slower rate. Though the electricity demanded increased over time, it was lower for each year compared to the base scenario. This eventually decreased the demand-supply gap for each year, given the electricity demanded was decreased. An energy intensity that decreases with time can be as a result of the increase implementation of the various energy efficiency policies of the country.

Cameroon has a number of energy efficiency policies and the implementation of these will eventually decrease the energy intensity of the country and this may continue until the electricity demand and supply gap is balanced.

Our model shows that the electricity demand of the country will increase with population and economic growth and an increase share of renewables in the energy mix. Increasing the share of renewables in the energy mix is an important way of decreasing the CO2 emissions by 32% by 2035 as planned by the government in Cameroon vision 2035 document. Therefore, renewables are a better energy resource for the Cameroon economy.

The significance of this study is to aid energy planning institutes on the priorities of energy infrastructure developments owing to the dynamics of the intervening parameters that influence the energy sector of Cameroon. For the case of Cameroon where the government plans to increase the share of renewables by 25% in the energy supply mix and reduce CO2 emissions by 32% by 2035, our results shows that renewables are a possible solution to the energy sector of the country and has a major role to play in helping the government attain its energy goals and visions. Systems dynamics can aid policy makers to be able to see the impacts of energy systems on a country’s economy. Knowing that is not an issue of just the demand and supply of electricity, but how well energy resources can be managed based on local and international constraints.

For further studies, we recommend a system dynamic study of the total electricity demand that can illustrate the contribution and influence of each of the fossil resource (natural gas and oil) and the renewables (solar, wind, biomass and small hydro) on the total electricity demand and to have a more detailed understanding on the behavior of each resource in the entire energy mix. We also recommend an expansion of model boundaries. As time goes on and as dynamic as the energy system is, many different policies will have to be considered. An expansion of the model boundary such as including energy imports and exports, other socio-economic and technical parameters like transmission losses will inform different policies when modelled.

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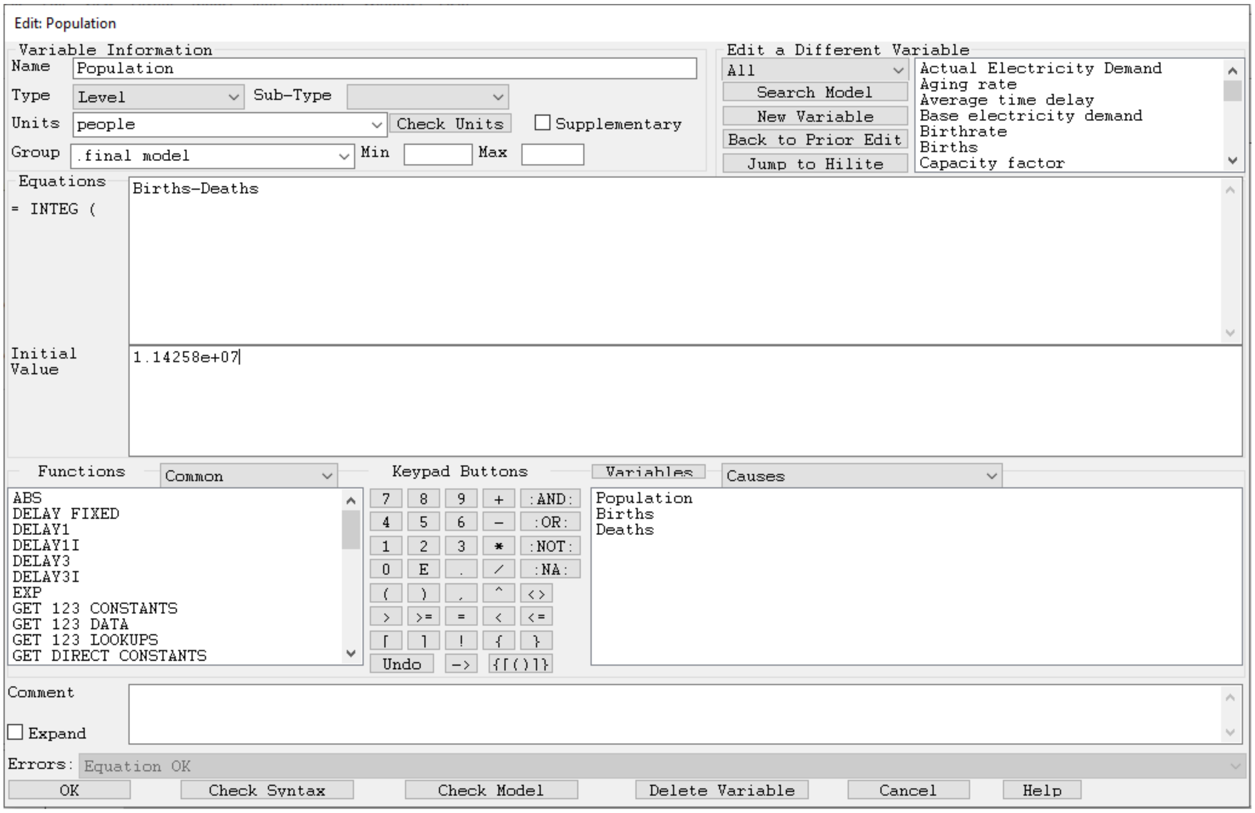
Appendix

About Vensim PLE

Vensim PLE is a fully functional version of Vensim that is free for personal and educational use. The equation tool as the environment can be seen below is used to write the different equations that govern the model. Some of the functions that exist are; INTEGER, DELAY, RAMP, IF THEN ELSE etc. The variable whose equation is being written can be defined as either a level, auxillary, lookup, etc. The units of the variable are also defined in the equation environment.

One of the limitations of Vensim PLE is that it has fewer simulations and analysis features as compared to other versions like Vensim PLE Plus, Vensim Professional.



Edit: Population

Variable Information
Name: Population
Type: Level
Sub-Type:
Units: people
☐ Supplementary
Group: .final model
Min:
Max:

Edit a Different Variable: All
Actual Electricity Demand
Aging rate
Average time delay
Base electricity demand
Birthrate
Births
Capacity factor

Equations
= INTEG (
Births-Deaths

Initial Value
1.14258e+07

Functions: Common
ABS
DELAY FIXED
DELAY1
DELAY1I
DELAY3
DELAY3I
EXP
GET 123 CONSTANTS
GET 123 DATA
GET 123 LOOKUPS
GET DIRECT CONSTANTS

Variables: Causes
Population
Births
Deaths

Comment
☐ Expand

Errors: Equation OK

Figure 38: The equation environment of Vensim PLE.