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ENERGY POLICY

Presented by

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TITLE: Modeling the future energy scenarios of Bamako city, Mali.

Defended on 02/09/2018 Before the Following Committee:

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Declaration of authorship

I state and declare that this thesis was prepared by me and that no means or sources have been used, except those, which I cited and listed in the References section. The thesis is in compliance with the rules of good practice in scientific research of Pan- African University Institute of Water and Energy including Climate Change (PAUWES).

Signature  **Date: 14th September 2018**

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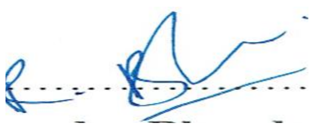
This thesis has been submitted for examination with our approval as the University Supervisor

Signature:  **Date: 12th September 2018**

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Abstract

With the average energy use of 0.27 toe per capita, whereby 78 % came from traditional use of biomass in 2016, Mali is one of the poorest country energy use in the world and the situation is projected to be worse as the country is an unlocked country without oil resources, and its population and urbanization annual growth is projected to be 3.8 and 4 % respectively. Bamako city, the largest city and the fastest growing city in Saharan Africa in 2006, is a mirror of the country. With the limited energy resources (only renewable energy resources), the best understanding of the future trends of energy demand is crucial and imperative in the purpose to help the planner and policy maker to elaborate a proper decision. This study was to have a clear landscape of next 15 years of energy consumption (end-use and by fuels) in the key sectors: Household, Commercial, industrial and transport under the business as usual scenario (BAU) and alternatives Scenarios such as Efficient Cooking stoves (ECT), Efficient Fridges (EFR), and Access to Modern Energy (ACC) for the city. The hybrid model (Bottom-up and Top-down) has been used to project the future energy demand for those key sectors from 2013 to 2033, by using the LEAP software and own generator electricity generated estimated. As an input of the model primary data has been collected through surveys, questionnaires, focuses group discussions across the key sectors and stakeholders and augmented from the literature and online sources. The results showed that, under the BAU scenario, the total energy demand in 2033 would reach 51 billion Terajoules , where the Household and Transport sectors would remain the two main energy consumption sectors , followed by Industry, and Commercial (formal and informal) sector and the Charcoal and cooking for household would remain the main fuel and energy service. Under both EST and EFR scenarios, 439.2 thousand tonnes of charcoal,229 GWh of electricity could be saving in 2033 such 166 million USD saving, while the impact of ACC scenario would reach on 252 thousand USD in 2033. From the supply side the own generator electricity generating accounted for household sector around 14 % of the household electricity consumption, over 7 % for both informal and formal commercial electricity consumption, and over 5 % for industry electricity consumption. It has concluded that both EST and EFR scenario would remain the best measures in term of energy and cost saving.

Keywords: Energy modeling, Dynamic factors, Energy scenarios, LEAP, policies.

Résumé

Avec une consommation d'énergie moyenne de 0,27 tep par habitant, dont 78% provenant de l'utilisation traditionnelle de la biomasse en 2016, le Mali est l'un des pays les plus pauvres au monde et la situation devrait se dégrader. Sans ressources pétrolières, et la croissance annuelle de la population et de l'urbanisation devrait être respectivement de 3,8% et 4%. La ville de Bamako, la plus grande ville et la plus forte croissance d'Afrique saharienne en 2006, est un miroir du pays. Avec les ressources énergétiques limitées (uniquement des ressources en énergie renouvelable), la meilleure compréhension des tendances futures de la demande en énergie est cruciale et indispensable pour aider le planificateur et les décideurs à élaborer une décision appropriée. Cette étude devait présenter un paysage clair des 15 prochaines années de consommation d'énergie (utilisation finale et par carburants) dans les secteurs clés : ménages, commerciaux, industriels et transports dans le cadre du scénario «business as usual» et alternatives. Les cuisinières (ECT), les réfrigérateurs efficaces (EFR) et l'accès à l'énergie moderne (ACC) pour la ville. Le modèle hybride (Bottom-up et Top-down) a été utilisé pour projeter la demande énergétique future de ces secteurs clés de 2013 à 2033, en utilisant le logiciel LEAP et les estimations de la production d'électricité par son propre générateur. Comme données d'entrée du modèle, les données primaires ont été collectées par le biais d'enquêtes, de questionnaires, de discussions de groupe ciblées entre les secteurs clés et les parties prenantes et complétées par la littérature et les sources en ligne. Les résultats ont montré que, dans le scénario BAU, la demande énergétique totale en 2033 atteindrait 51 milliards térajoules, où les secteurs des ménages et des transports resteraient les deux principaux secteurs de consommation, suivis par l'industrie et le commerce (formel et informel). le charbon de bois et la cuisine pour le ménage resteraient le principal service de carburant et d'énergie. En 2033, des économies de charbon de bois et de gaz naturel de 229 GWh pourraient représenter une économie de 166 millions USD, alors que l'impact du scénario CAC atteindrait 252 000 USD en 2033. Du côté de l'offre, le générateur propre La production d'électricité représentait environ 14% de la consommation électrique des ménages dans le secteur des ménages, plus de 7% pour la consommation d'électricité commerciale informelle et formelle et plus de 5% pour la consommation d'électricité de l'industrie. Il en a conclu que les scénarios EST et EFR resteraient les meilleures mesures en termes d'énergie et de réduction des coûts.

Mots clés : Modélisation énergétique, Facteurs dynamiques, Scénarios énergétique, LEAP, Politiques.

Dedication

This study is dedicated to the citizen of Bamako, for always contributed of more ongoing of the work during my stay in city.

Acknowledgement

Frist, I thank the African Union and the PAUWES for awarding me the scholarship and research grants to advance my career. Secondly, many thanks to Tlemcen University and the Algerian government for hosting us. Special thanks to all the sponsors of the PAUWES project in particular; GIZ, KFW, DAAD and the rest.

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Abbreviations and acronyms

AFREC: African Energy Commission

AMADER: Malian Agency of the Development of Domestic Energy and Rural Electrification.

ASDB : Annuaire Statistique de District de Bamako

BAU: Business As Usual

CREE: Electricity and Water Regulatory Commission.

DNE: National Energy Directorat.

DRCTU : Direction de la Régulation et de la Circulation des Transport Urbains.

EDM : Energie Du Mali

EFR: Efficient Fridge

EST: Efficient Cook Stove.

FONABES :

IEA: International Energy Agency

IRENA: International Renewable Energy Agency

GCF : Green Climate Fund

ONAP: National Petroleum Products Office

UNIDO : United Nations Industrial Development Organization

REA : Rural electrification Agency

SAMSET: Supporting Sub-Saharan African's Municipalities with Sustainable Energy Transition.

Key terminology

Energy Efficiency: Amount of energy requires to produce a specific service

Energy Intensity: measure where energy is divided by the number of a certain appliance type (e.g. water heater) or group of appliances (e.g. cooking equipment).

Gross Domestic Product(GDP): Market value of services and goods produced within the country .

Base year : Historical year marking the transition from energy estimates based on energy data to modeling-based estimates.

Activity level : output generating by consumed an amount of energy or the percent that occupied an energy service generated for a specific energy technology .

Chapter 1: General Introduction

1.1 Background of the thesis

Global energy demand is growing continuously and much of this growth is in cities. Over 4 billion of the world's population currently lives in urban areas, yet these areas are responsible for approximately the third quarter of energy consumption. As these urban populations continue to grow, there will be a significant impact on global energy demand and the resultant carbon emissions (Bazilian et al., 2012).Much of this growth is set to occur in cities, and although there are reports that look at total energy growth, little is known about the increase in energy demand in specifically cities and how this relates to energy demand in the sub-continent and globally.

Most Africa countries still at the beginning of their development trajectory and population growth is projected to be high, particularly in sub-Saharan Africa. Africa is the last continent to urbanize. However, the speed and scale of urbanization will differ vastly from other continents. The rate of urban population growth in sub- Saharan Africa between 1980 and 2014 amounted to 4.4 % per year, distinctly higher than in other regions. By 2050, sub-Saharan Africa's cities will have grown by almost 800 million people. This represents nearly half of the projected rise in numbers of urban dwellers globally as shown the figure 1.1 below:

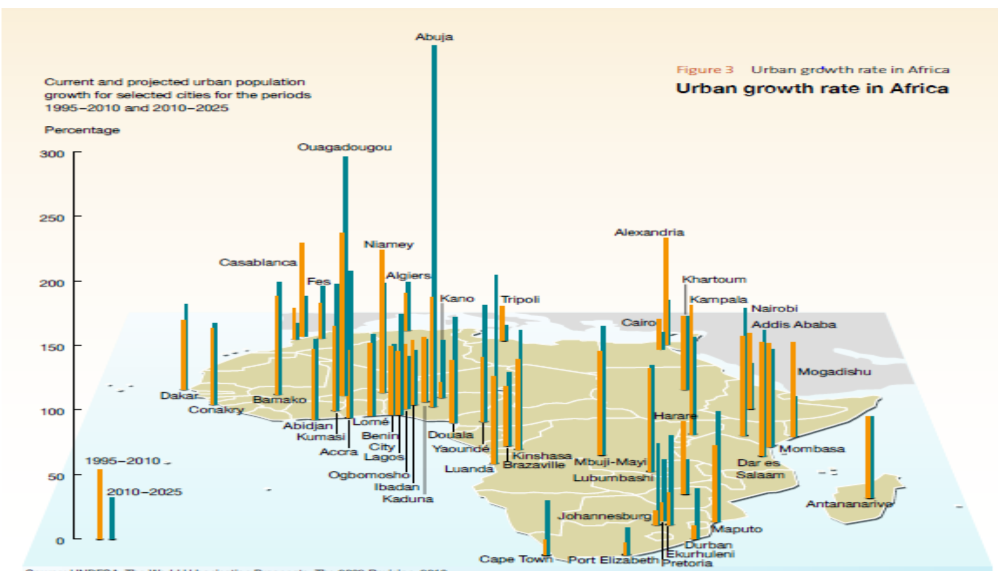


Figure 1.1: Urban growth rate in Africa.

Source: SAMSET, 2015.

Currently, Sub-Saharan Africa accounts for 13% of the world's population but it is responsible for only4% of its energy demand and much of this demand is from firewood fuels(IEA, 2014).The fact that much of energy use becomes from biomass, and due of its relatively low energy consumption per capita, Sub-Saharan Africa is typically looked at a small contributor to future global energy demand carbon emissions(IEA, 2014).

National energy policies in many sub-Saharan Africa countries often focus on rural areas and the energy supply sub-sector. Yet with the population growth in urban areas, and resulting national energy profile changes, the emphasis may need to shift towards our towns and cities.

For many few decades, scientists, researchers, governments and organization have been working on the design of potential and more sustainable landscape of future energy system. Most of these studies look at the development of whole world regions and/or nations. Only very few studies analyze energy system at the city level.

Energy system considerably differs between locations according to various factors, including availability of the energy resources, level of the development, climatic conditions, access to energy carriers and user behavior among others. Research on energy systems at a local or regional level allows narrowing down variations of energy demand, energy supply, to consider local characteristics and dynamics factors, as well as local policy and measures.

The consideration of latter is increasingly important as cities stake out a major role in climate change action. Studies that do not only integrate local policy, but also provide guidance for local policymaking is required. The analysis of potential energy future in cities can contribute to the understanding of possible future global and national energy trends, and improve the identification of opportunities for renewable energy, energy efficiency policies, regulations and measures.

1.2 Problem statement

Currently, the energy use per capita in Mali is estimated to be 0.27 toe, including the 180KWh of electricity(Enerdata-Mali country, 2017), which is less than the average of sub Saharan African countries energy use per capita and classified the country as one of the poorest country energy use in the world. The poor energy use is affecting the country's economic and social growth.

The large cities in such sub Saharan African countries such as Bamako face problems in proper energy management due to unpredicted urbanization and improper energy infrastructure and planning. The available data on energy supplies is insufficient and of low quality and is inadequate to forecast the emerging energy needs in view of population growth, fast urbanization and fluctuating fuel prices. This situation can have a negative ripple effect on the economic and social growth of the city as well as the whole country, hence the need to thoroughly scrutinize the government's energy expansion plan and provide feasible alternatives. This will help in better management of energy loads, to adapt the new advancements in Technology and to achieve the local and international goals for sustainable energy for all.

1.3 Research description and thesis structure

1.3.1Objectives

In this study the objectives had the main objective and specific objectives.

1.3.1.1 Main Objective

The main objective is to predict and understand the long term energy future pathway that would response of the Bamako citizen needs and economic development on a sustainable manner.

1.3.1.2 Specific objectives:

- To review the energy situation of the country as for the city as well,
- To determine the population growth rate, urbanization and Government energy target for the city,
- To Predict the future energy demand based on given parameters development, and
- To formulate some appropriate policies recommended modifying the pattern of energy consumption.

The remainder for this study is structured as follows: In chapter 2, the briefly review of the literature: where the software LEAP and adaption framework for the model is presented, some works which are been done on modeling by using the software in cities level in developed countries as well as in developing countries are highlighted, the current research: where the country profile and energy situation as well as for the city is presented , and city boundaries with population and urbanization rate. In Chapter 3, the methodology approach for developing the energy demand for the four key sectors such Residential, Commercial, industrial and transport for the city as well as energy supply and related data, the predicting energy demand for those sectors from the year 2013 to 2033 and related main drivers and assumptions, the scenarios descriptions and related assumptions for the Alternatives scenarios. In chapter 4, modeling results and analysis. Finally, in Chapter 5, conclusion with some recommended policies and outlook.

Chapter 2: Literature Review

2.0 Introduction

The analysis of future energy demand development and available political options to increase energy access and to reduce GHG emission is necessary to achieve the goal of sustainable energy systems. Long-term planning is crucial in energy sector regarding the lifetime of energy infrastructure and buildings (Ürge-Vorsatz et al., 2012). Complex dynamic system factor such as demographic; socio-economic change, technological development and innovation are the drivers of result of energy consumption and GHG emissions. However, many uncertainties make a future landscape of energy system and emissions difficult to predict. For many decades, scientists, researcher, organizations and governments have been working promote and develop techniques to get insight into possible evolutions of energy systems. Several useful Tools for the analysis have been energy models and scenarios.

Through Energy models development, images of the energy system builds though methodologies from mathematics and software are been simplified (Bungartz, et al., 2014). As a modeling is a process of the representation of the reality, energy models only include certain aspects of an energy system (Van Beek, 1999). As this reality can never be complete replicate, researchers use scenarios as tool to account for uncertainties in forecasting development.

Scenarios represent alternative figures or images of how the future may look under certain given conditions and assumptions (IPCC, 2000). They should not be understood as a forecast. Model developers build a scenario by taking decisions regarding underlying factors driving energy demand, political targets and the type of modeling tool they use. These decisions are conducted by model purpose and well performance, but are also subject to resources constraints, including knowledge, time and data (DEA, et al., 2013). Thus, the comparison and interpretation of results from scenarios based on energy models has to be done in the context of underlying model assumptions.

Stratification of the uncertainties associated with energy models and scenarios can be distinguished between data uncertainties, modeling uncertainties and completeness uncertainties (Functowicz et al. ,1990). Data uncertainties are referred with the quality or adequacy of the input data for the model. The uncertainties of the model appeared from a misses understanding of the phenomena modeled, or from approximations of the formal representation of dependencies. And for the end, completeness uncertainties arise through omissions due to incomplete knowledge.

However, this chapter highlights previous studies which have been undertaken in different cities in different countries on energy modeling scenarios analysis using the LEAP software and the results obtained thereof. It also highlights the studies which have be undertaken in Mali especially in Bamako city with in emphasis in future energy analysis.

It presents the brief description of the software LEAP, which was used for this study and the framework adaptation from the Software. Finally, the country and city energy profile, resources, and targets as a guide for the developing of alternatives scenarios for Bamako.

2.1 LEAP Software

The software LEAP (Long Range Alternative planning) was developed by Stockholm Environment Institute (SEI). It is employed to Assess the energy development policies (Heap ,2011). LEAP is an end use of scenario analysis and its structure is showing below:

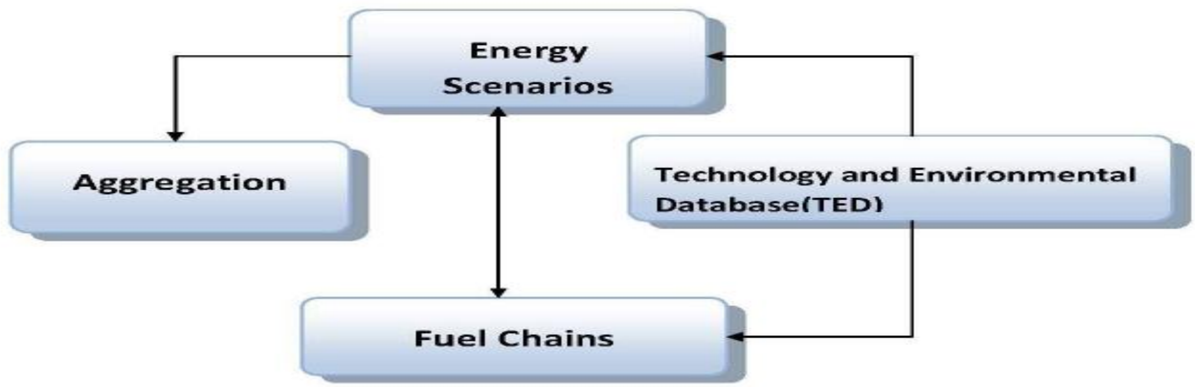


Figure 2.1: LEAP structure.

Source: LEAP tutorial

Energy scenario is the main component < heart > of the LEAP software and it shows how future energy system might evolve over time under particular set of policies. Technology and Environment Database (TED) concerns more the compilation of Technical considerations, cost and environmental data for the range of energy technologies from types of sources including the International Energy Agency (IEA), Department of Energy (DoE) and the Intergovernmental Panel on Climate Change (IPCC). The fuel chain used to compare and asses total Energy and environmental impacts of the specific fuels and technology choices per unit of energy, for service delivered and end the aggregation program which is used to display multi area results from analyses carried out in different modules of the program. LEAP is more useful and specifically appropriate to the modeling of energy systems with consider historical macro-economic

data (top-down) for trend analysis and/or short- run development issues. Indeed, initial input data require by LEAP is very low only the base year required detailed statistical data. Look at the lack of quality time series data in most African countries, the LEAP software appears as a good option.

The LEAP framework is disaggregated into hierarchical tree structure of four levels: Sector, Subsector, End- use and appliances. Its accounting platform matches demand with supply side energy technology outputs, while the scenario manager facilitates the comparison of alternative electricity generation systems over the medium to long term duration to enable technical, economic and environmental impact analysis.

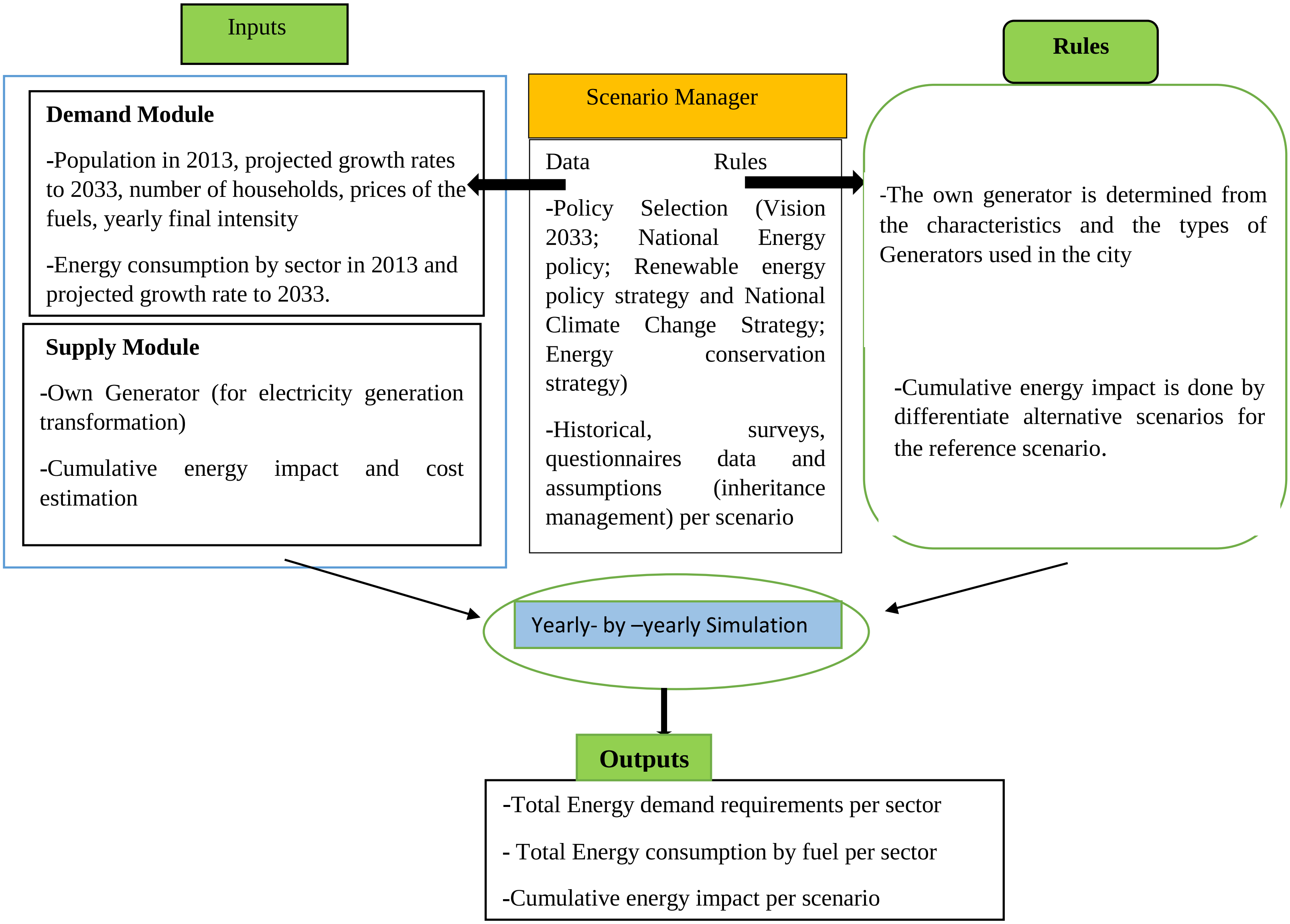


Figure2.2: Adapted framework from the summary of Bamako LEAP model inputs and outputs

Source: Based on LEAP Structure.

2.2 State of art

Various studies had been done on modeling the energy supply based on alternatives scenarios had been done for many cities on developed countries as well as on developing countries.

Abbaspour et al., (2013) analyzed the energy demand and its pollutants in the household sector in Tehran city, Iran baseline scenario for energy demand and its greenhouse emission had be developed according to the long-term policies development of the country from 2011 to 2036 by using LEAP software and the energy demand was analyzed through Energy management Scenario subdivided into to seven alternatives Scenarios: Using Energy-Efficient Light Bulbs Scenario, Implementation of the Note 19 of National Building Regulations Scenario, Expanding the Use of Solar Energy Scenario, Generation of Decentralized power System Scenario, Migration from Tehran Scenario, Using Heat Pumps Scenario , Appliance Improvement Scenario. The results showed that for the baseline Scenario the natural gas consumption will increase to 21, 084 MCM by the year 2036 and the electricity consumption rate will grow to 21,084 million over the studied period, from the energy management scenario particular the Implementation of the note 19 of National Building Regulations Alternative Scenario it gad be found that 23% of energy can be save until 2036 and which can allow almost 21.7% of the greenhouse gas emission reduction in the city.

Sukarno et al., (2015) analyzed the energy consumption pattern in four sectors of Padang city, Indonesia by using LEAP software: residential, commercial, industrial and transportation sectors. Under different population scenarios the energy consumption pattern had be analyzed using a cohort model and statistical data and the projection up to 2030. It had been found that the energy consumed in the residential sector had the major share in the total energy consumption in the city, and it had concluded that decreasing urban energy consumption could be achieved by increasing efficiency of home appliances, promoting electricity saving behavior, increasing of public awareness for saving energy and applying energy efficiency labeling for home appliances.

(Lukrafka, 2015)investigated the future residential energy demand for the Mexico City Metropolitan by using LEAP software. Based on the impact of demographic and economic developments on household energy demand. Alternatives scenario had been developed: the energy supply Scenario had been used to investigate the impact of energy demand development on the carbon dioxide emission. The results showed that for the modelling work in the absence of additional policies in the residential sector the energy demand in Mexico City Metropolitan Area in 2010 could rise by 23% in 2030 in the contrast on this , the alternative scenario suggested that the strict implementation of currently best available technologies in 2018 could decrease the energy demand of the sector by 24% by 2030 in relative to the base year 2010 and on the same base year the results showed that the energy consumption could be reduce by 60% if all old ad inefficient appliances could be exchanged by 2030 and concluded that the co2 emission caused by the activities of households in the city could be reduce by 75% in 2030.

Creutzig et al., (2014) analyzed the importance of global urban energy use mitigation to the global climate change by using LEAP software. As a method, correlation statistical, regression and threshold analysis had been used and focused on dataset of 274 cities representing all the city sizes and regions worldwide, illustrate that economic activity, transport costs, geographic factors, and urban form explain 37% of urban direct energy use and 88% of the urban transport energy use. The results showed that if current trends in urban expansion continue, urban energy use will increase more than threefold, from 240EJ in 2005 to 730EJ in 2050. The mitigation scenario showed that by considering the urban planning and transport policies the energy result can be limited to 540 EJ in 2050 and this will have contributed to mitigating the climate change. However, the results also showed that effective policies for reducing urban greenhouse emissions differ with city type. For instant for affluent and mature cities (developed countries), higher gasoline prices combined with urban form is indispensable for saving in both residential and transport energy use whereas for the developing country cities with emerging or nascent infrastructures, compact urban form, and transport planning can encourage higher population densities and subsequently avoid lock-in of high carbon emission patterns for travel.

Liu et al., (2015) modeled and analyzed based on policy scenarios on the management experiences the urban passenger transport energy consumption and CO2 emissions in Beijing. The subsystem dynamic such as economy subsystem, population subsystem, transport subsystem, and energy consumption and CO2 emissions subsystem had been modeled and used. Five policies scenarios management had been developed: development of public transport (PDPT), travel demand management (TDM), technical progress (TP), administrative rules and regulations management (ARM), and comprehensive policy (CP). The analysis showed that PDPT could significantly increase the proportion of the public transport locally and would be helpful in pursuing energy saving and emission reductions, TDM had a distinctive effect on energy saving and emission reductions in the short term while TP was more conducive to realizing emission targets, ARM had the best overall effect of the individual policies on both saving and emission reduction, and CP was have a better effect than any of the individual policies pursued separately.

Ouedraogo , (2017)modeled and analyzed the future paths of Africa energy and the related emissions. Socio-economic variables such as gross domestic product(GDP), income per capita, population and urbanization had been used and the LEAP software had been employed to analyse and project energy demand and the related emissions under alternatives strategies for the period of 2010-2040. Four scenarios included business as usual policies, moderate energy access and accelerate energy access policies, renewable energies promotion and energy efficiency policies and their environmental implications are being provided. The results showed that under the business as usual scenario the total energy demand is forecasted to reach 1214 Btoe in Africa with 716Mtoe for sub-Saharan Africa in 2040 , with an average annual growth rate of 2.8% and 499 Mtoe for North Africa, with an average annual growth rate of 5% and the CO2 emission will reach 1, 746.82 Million Metric Tonnes in 2040 ,with 842.16 and 904.66 for Sub-Saharan and North Africa respectively ; under the moderate energy access scenario the energy consumption is not much higher than business as usual scenario just less difference is from 25 Mtoe in 2015 to 10 in 2030 and 16 Mtoe in 2040 and the CO2 emissions of 1,825.07 Million metric tonnes in 2040 , with 890.83 and 934.24 respectively for Sub-Saharan and North Africa; under the accelerate energy access scenario the energy consumption will reach 1440 Btoe in 2040 with an average annual growth rate of 5% for north Africa for Sub-Saharan African until 2025 and then, with an average annual growth rate of 2% and the CO2 emissions will reach 2,307.92 Million metric tonnes in 2040, with 1368.21 and 939.71 for Sub-Saharan and North Africa ; under the renewable energies and energy efficiency promotion scenario the total energy consumption is predicted to reach 768.61 Mtoe in 2040 , with at an average annual rate of 1.3% for Sub-Saharan Africa and 3% for North Africa and the CO2 emissions to reach 965.97 Million metric tonnes in 2040 , with 890.94 and 459.03 for Sub-Saharan and North Africa respectively. The results showed also that among the end-users, the industrial sector will have the largest share of the total energy consumed in 2040 with 61% compare to just 31% in 2015, with the increased of petroleum products by 33%, followed by the residential sector with 33% and 36% for transport, Agriculture and services sectors.

Yophy et al., (2011) modeled and analyzed the long-term forecasting energy supply and demand for Taiwan by used LEAP software. The Taiwan LEAP model had been used to compare the future energy demand and supply patterns, as well as greenhouse gas emissions, for several alternative scenarios of energy policy and energy sector evolutions. Three scenarios had been developed: business as usual policies, aggressive energy efficiency improvement policies, and on-schedule retirement of the Taiwan's three existing nuclear plants and sensitivity analyzed. The results showed that under the business as usual policies, that the total energy demand forecasted for the year 2030 had 1313.0 trillion Kcal and which is dominated by the industrial sector which accounted for around 59.8% comparing of the 50% in 2008. Among the end-use in the sector, the naphtha will increase dramatically and the related CO2 emissions to the scenarios had projected to rise 414.2 million metric tons by 2030, where the demand side accounts for about 46.3%.

Zhang et al., (2011)simulated and analyzed the range of pathways in change of energy consumption and carbon emissions from 2007 to 2030 for the city of Beijing by using the long rang Energy Alternatives Planning (LEAP) software. Assumptions through dynamic and technical -economics factors such as population growth, Gross domestic Annual growth (GDP), Urbanization rate , shared of primary , secondary and tertiary industry had been used to develop four scenarios: a reference scenario (RS), control scenario(CS), and the integrated scenario(IS).The results showed that under the IS the energy demand in Beijing is excepted to reach 88.61 million tons coal equivalent (Mtce) by 2030 compared to 59.32 Mtce, such 55.8% and 32.72% lower than the RS and the CS, respectively; the total carbon emissions in 2030 under the IS, although higher than the 2007 level, will be 62.22% and 40.27% lower than the RS and the CS, respectively , with emission peaking in 2026 and declining afterwards; regarding the potential of the reduction of energy consumption and carbon emissions , the industrial sector will continue to be the largest contributor under the IS and CS compared to RS, while the building and transport sectors are identified as promising fields for achieving effective control of energy consumption and carbon emissions over the next two decades. The study concluded that an integrated package of measures is the most effective in terms of energy saving and carbon emission mitigation.

Hassan et al., (2016) modeled the status of energy consumption related to carbon emissions for the industrial sector of Islamabad city, Pakistan. The software LEAP had be used to forecast the future energy demand from 2012 to 2042. Under the Business as Usual Scenario (BAU), two alternative scenarios: Biofuel Scenario (BIO) and Fuel Efficiency Improvement Scenario (FEI) had be developed and analyzed with the aim of determining their possible impacts on the energy system. The results showed that under the BAU scenario the total energy demand in 2012 was 1.46 Mtoe (Million Tonne of oil Equivalent) and in 2042 it was estimated to be 15.81 Mtoe and the global warning potential , 2.27 MtCO2 in 2012 and estimated to be 24.6 MtCO2 in 2042; under the BIO scenario the total energy demand was decreased up to 5.08MtCO2 in 2042 as compared to the 15.81 MtCO2 for the BAU and the global warning potential was observed to be 7.92 MtCO2 in 2042; under the FEI scenario the total energy demand up to 2042 was observed to be 8.6Mtoe and the global warning potential was observed to be 3.4 Mtoe in 2042. The study concluded that the global warning potential under BIO and FEI scenarios represented 67% and 42% of the base scenario emission in 2042 respectively.

Tanoto et al., (2015)assessed base of the renewable energy potential for the long-term electricity energy planning and to implement a sustainable supply-demand framework. Selected renewable energy resources such as geothermal and solar energy based power plants be included in a bottom-up with the energy efficient and energy conservation approach in the demand side for 5 cities in the eastern part of East Java province, Indonesia had be modeled by using LEAP software in purpose to get the best option in term of respect of the resources, costs and environmental impact up to 2025.Three scenarios had be developed : Business As Usual Scenario (BAU) , Sustainable Coal-Geothermal scenario (CG), and Coal-Geothermal-Solar scenario(CGS). The results showed that under the BAU scenario the total electricity consumption for the observed area would be 6,873.8 GWh in 2025 such increase by 203% compared to year 2014 as the baseline.; under both CG and CGS scenarios the growth is in a low pace with 175% compared to the baseline such 6,222 GWh. The study concluded that regarding the given to the shortage of supply, more electricity should be imported from the interconnected system if the existing coal fired power plant is preserved the simulation period compared to planning involving geothermal and solar energy based power plants.

Khanna et al., (2016) estimated the china's Urban Energy Demand and CO_2 Emissions through the Bottom-up, energy end-use modelling approach by using the LEAP from 2010 to 2050. Four key demand sectors had been modeled: residential, transport, Commercial, and industrial and the scenarios Analysis had been also used for each of them. The results showed that Chinese industrial sector alone accounts for 56% of the Urban Primary Energy demand and 62% of the urban CO_2 emissions in 2010 and holds the greatest mitigation potential and he concluded that maximum deployment of the commercially available, cost- effective technologies across all the four sectors can also help Chinese urban CO_2 emissions peak earlier.

Mccall, et al., (2016) modeled the future energy for the municipality of Awutu Senya East, Ghana by using the software LEAP. A bottom up model based on surveys , municipality reports, and assumptions had been used to project the energy demand form 2013 to 2030 in four key sector such as Municipal, Household, Commercial , Agriculture, transport, and industry sector and sensitive scenarios base on population growth had been tested for the business as Usual scenario(BAU) and the alternatives scenarios such as Efficient cook stoves scenario(EST), Efficient fridges scenario (EFR), Households access to modern energy (ACC) had been developed for the household sector. The results showed that for the BAU scenario the households sector remains the main consumed of the energy with an increasing to 2000 Tetra joules in 2013 up to 4000 Tetra joules in2030, following by the commercial sector with the demand up to 2000 Tetra joules in 2030, then the transport sector with the demand up to 1500 Tetra joules in 2030, then municipal (Local Government), Agriculture and industry sector which will still remain low. Electricity will remain the major energy fuels use with the demand projected up to 4000 Tetrajoules in 2030 following by gasoline, Kerosene, Diesel, LPG, Wood, and Charcoal with the demand up to 2500, 500, 1500, 600, 500, and 400 Tetra joules in 2030 respectively. Under the EST scenario the cumulative charcoal saved was 92201Tonnes from 2016 to 2030, under the EFR scenario, the cumulative electricity saved for the same period of time was 29.20 KWh, and under the ACC scenario, for the cooking end-use, a cumulative of 113 116 MWh of electricity and 37148Tonnes of LPG for the same period of time are needed to substitute 73390 tonnes of charcoal used.

In 2015, the Supporting Sub-Saharan African Municipalities with Sustainable Energy Transitions (SAMSET) modeled the urban energy future of sub-Saharan Africa by using the LEAP software, the data available from the International Energy‘s Africa Energy outlook, and assumptions. The future energy demand for key sectors: Residential, Commercial, industrial, and transport had been projected from 2012 to 2040. Under the business as usual scenario (BAU), four alternatives scenarios had been developed: Universal access scenario (UA), Energy Efficiency scenario (EE), Renewable Energy scenario, and the Sustainable Energy for all Scenario (S4ALL) and carbon emission estimated. The results showed that under the BUA scenario, the residential sector will remain the major energy use with the demand estimated up to 550 million Toe (Tons of oil equivalent) by 2040, Following by the commercial, industrial, and transport sector with the demand estimated up to 300, 200, and 100 million Toe (Tons of oil equivalent) by 2040 respectively. The study concluded that energy –related carbon emissions from urban areas are likely to rise by 80% between 2015 to 2040, consequently increasing the global sharing of Urban Sub-Saharan Africa from 1% to 4%. The study concluded also that, with the Universal access to modern energy and energy efficiency implementation, as proposed in the Sustainable Energy for All goals, could mitigate the energy demand by 17% by 2040 and the implementing of the Sustainable Energy for All goals is expected to reduce energy- related carbon emissions by 20% of the business –as –Usual trajectory by 2040.

In 2016, The Management of forests and sustainable wood supply for the Sahel ‘s Cities (FONABES) Presented the schemes of the supply of the solid fuels in the city of Bamako by using sample size based on number of inhabitant, the surveys and questionnaires for the data collection had been used. The results showed that the total wood (charcoal and firewood) supplied in 2015 for the city was around 232 000 tons such as 594000 tonnes equivalent firewood, and the quantity of wood consumed was 232812 tons such 124 199 tons for the firewood and 108613 tons for a charcoals, which corresponded of 760 291 tonnes equivalent fire woods. the study concluded that since 20 years now the quantity of used of charcoal had been multiplied by 9 showed the effective transition from firewood to charcoal.

No such of research has been done in Mali still now which consider the future energy development by incorporating all the energy sources and the energy services by using the long Range Alternatives Planning system (LEAP) as well as national that local level.

2.3 Current research

2.3.1 Country profile

Mali is a landlocked country located in the Sahel region of West Africa. It covers an area of 1, 241,248 Km^2, of which two third are desert and share more than 7000 km common boundaries with seven countries: Mauritania, Algeria, Niger, Burkina Faso, Ivory Coast, Guinea, and Senegal as shown the figure 2.3 below. Its population is estimated at 15 million inhabitants and its average annual rate is 3.4%. Nearly 70% of the population resides in rural areas and its urbanization rate stands at 26.8%(DNE,2011).

Country had made significant economic, social, and political improvement over this last decade (World Bank, 2011). Indeed, in less than 10 years, the Gross Domestic Product (GDP) tripled from 2.43 USD billion in 2000 to USD 9.70 billion in 2010. Despite this improvement the country remains one of the poorest countries in the world, ranking 159th out of 181countries (World Bank, 2017).

The climate of the country is characterized by a long dry season and rainy season. The rainy season average can be one to five months per year, depending of the location of the region. Base of the rainfall level, four main areas can be identified across the country and corresponding to four various ecological zones whose agricultural potential is diversified. Wood fuel (Firewood and Charcoal) and hydroelectricity are there two main energy sub-sectors vulnerable to climate variability.

As a country without conventional energy oil and gas subsectors are characterized by total dependence on petroleum imports. This is exposing the economic as whole to the volatility of the fossil fuel prices. It is also put the economic under foreign reserves pressure, including the development of the energy sector. Indeed, in 2007 the energy bill of the country was estimated at 316 billion FCFA, such 4 million dollars and only the LPG was subsided at an among of 2.79 billion FCFA, such 5.6 million dollars USD (DNE ,2011).

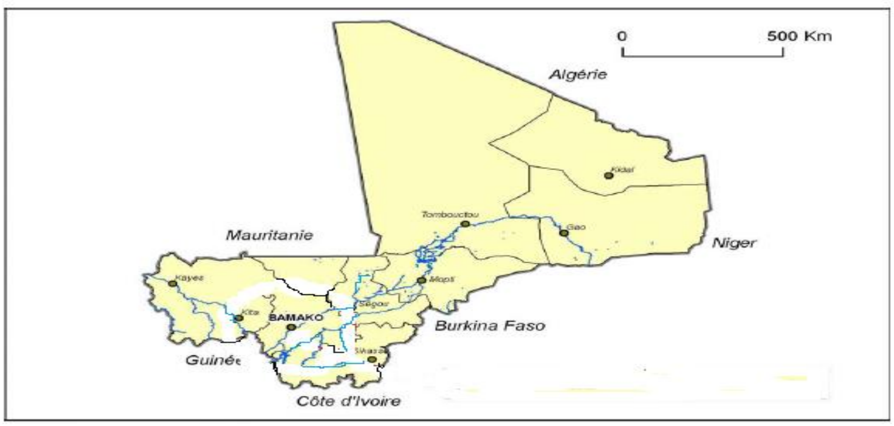


Figure 2.3 : Country map

Source : www. Country. map. Com.

2.3.1.1 Energy sector overview

Mali primary energy supply comes from oil, hydro, and biomass. In 2016, biomass (Firewood and Charcoal), which is a main energy source for the majority of the Population accounted for about 68% of the national energy consumption, followed by fossil fuel 28% and hydro 4% and the total final energy consumption was 4,860Ktoe (Enerdata-mali country, 2017)as shown the figures 2.4 and 2.5below:

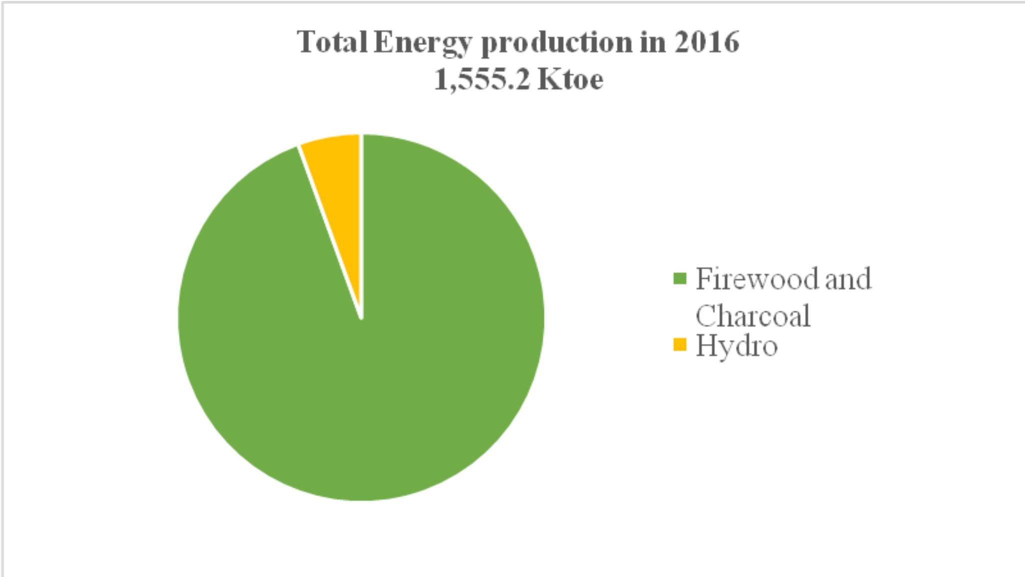


Figure 2.4: Total energy production in 2016.

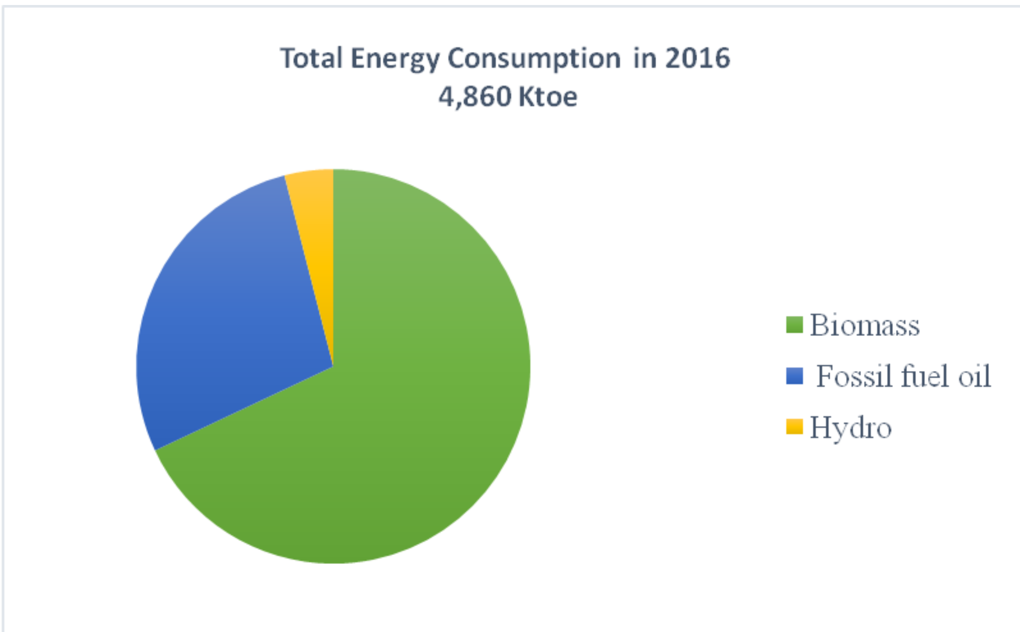


Figure 2.5: Total energy consumption in 2016.

Source: Based on Energydata-Mali, 2017.

In 2017, the national electricity access was about 35.07 % with 59% in urban areas and 14% in rural areas (World Bank, 2018). In 2015, the total amount of electricity produced was 1,709.57 GWh, of which 45% at from fossil fuels (Thermal Plant), 41 % from hydropower, and 14 % from Import/ Interconnected. In The same year only 1,101.72 GWh was consumed that means that about 607.85 GWh was lost main due of the poor transmission and distribution lines across the country. (CREE, 2015) as shown the figures 2.6 and 2.7 below:

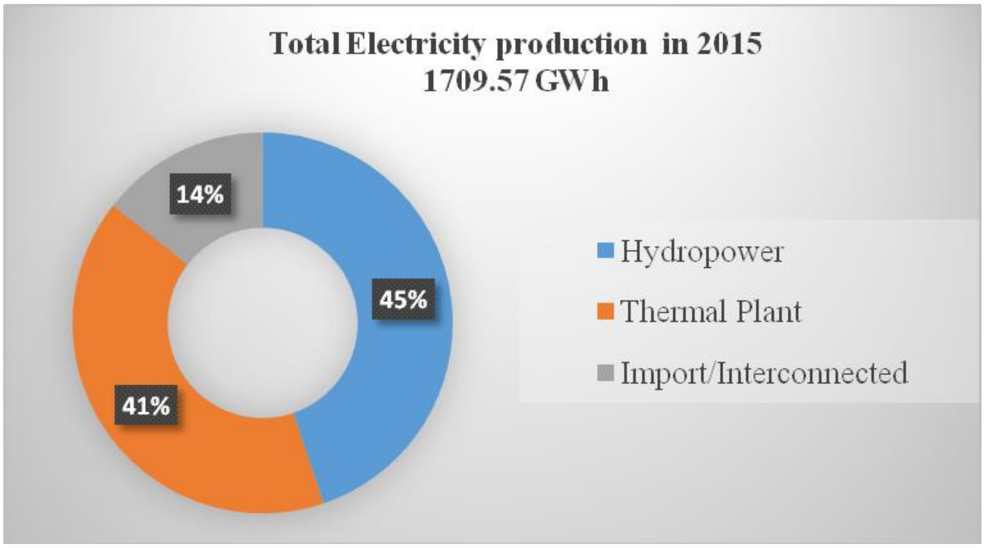


Figure 2.6 : Electricity production in 2015 .

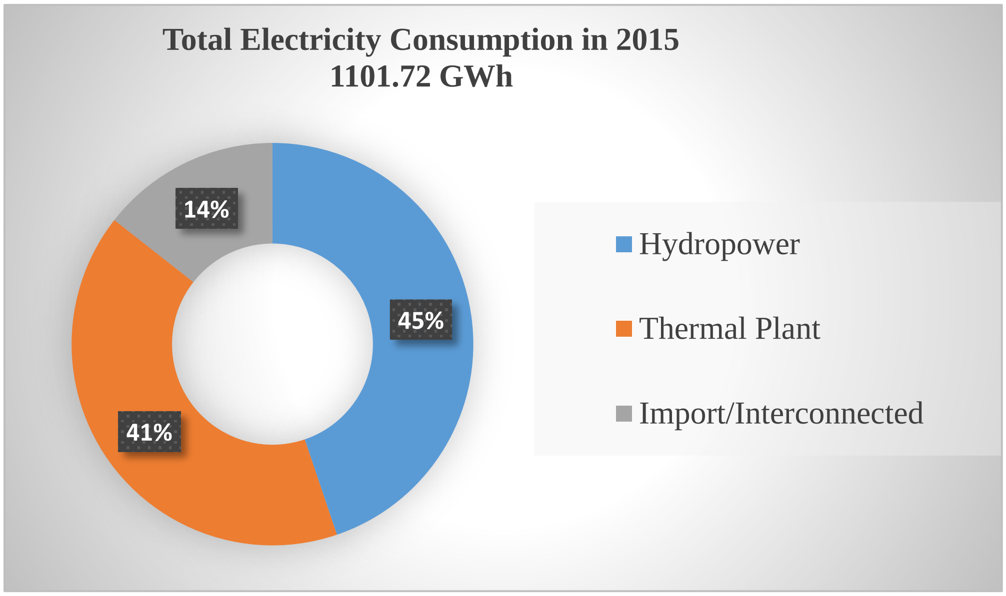


Figure2.7: Electricity consumption in 2015.

Source: Based on CREE report, 2015.

2.3.1.1.1 Electricity Network

In 2015, the total electricity network across the country was estimated at 7577.80 Km such 683.2 Km for the transmission lines (225 KV, 150KV, 66KV, and 30KV) and 6,894.6 Km for the distribution lines (15 KV, 400V, and 220 V) as shown the table 2.1 below:

Table 2.1: Transmission and distribution Network in Mali, 2015.

Voltage	**Distance (Km)**
Transmission High Voltage (225 KV, 150 KV)	383.30
Transmission Medium Voltage (66 KV, 30 KV)	299.90
Distribution Medium Voltage(15 KV)	2,010.10
Distribution Low Voltage (400V, 200V)	4,884.50
Total	**7,577.80**

Source: Based on CREE Report, 2015.

2.3.1.1.2 Electricity installed capacity

In 2015, the electricity installed capacity in the country was estimated to 339.141 MW Compared to the year 2014, which was 261,556 MW such a significant increasing of 29.6%, as shown the table 2.2 below:

Table 2.2: Electricity installed capacity (2014-2015).

Year	**2014**		**2015**		**Variation**
Energy Sources	**Installed Capacity per source (MW)**	**Percentage sharing (%)**	**Installed Capacity per source (MW)**	**Percentage sharing**	**Percentage sharing (%)**
Hydropower	92.01	35.18	141.67	41.77	53.97
Thermal Plant	137.456	52.55	170.061	50.14	23.72
Import (Thermal)	32.09	12.27	27.41	8.08	-14.58
Total	**261.556**	**100**	**339.141**	**100**	**29.66**

Source: Based on CREE report, 2015.

In 2017, the installed capacity from renewable energy for electricity generation to interconnection for the country was estimated to 190 MW such 180 MW from hydro, 6 MW from solar (Photovoltaic), and 4 MW from Bioenergy/ Biofuel (IRENA Statistic, 2017) as shown the figure 2. 8 below:

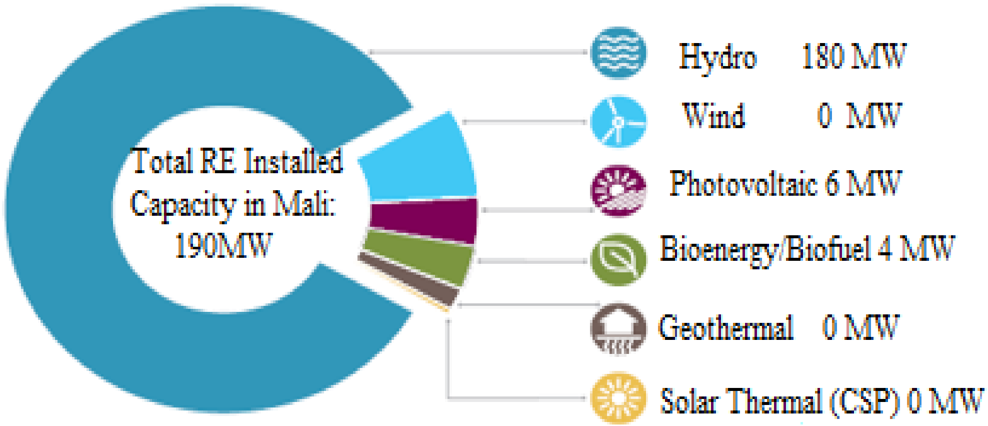


Figure 2.8: Mali renewable energy installed capacity in 2017.

Source: Based in IRENA, Capacity Statistics, 2018.

2.3.1.1.3 Energy demand by sector

The energy demand of the country is dominated by the residential sector where Principle source is fuel wood. In 2016, the residential energy demand was 64%,followed by the industrial sector (mainly mining and manufacturing) 4%, commercial sector (formal and informal) 13 %, Transport sector 18 % and agricultural sector 1% (Enerdata-mali country, 2017) as shown the figure2.9 below :

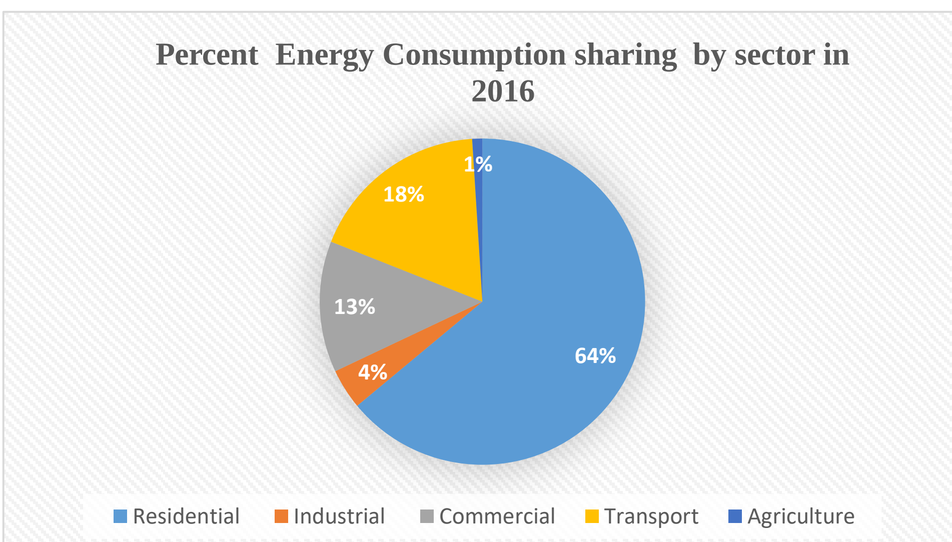


Figure 2.9: Percent energy consumption by sector in 2016.

Source: Based on EnergyMali data, 2017.

2.3.1.1.4 Energy sources

Nowadays the energy sources of the country are renewable energy sources.

2.3.1.1.4.1 Biomass energy

Fuel wood is the main source of household energy supply in Mali. Country's forestry potential is estimated at roughly 33,000,000 hectares, including a standing volume of about 520,000,000cubic meter (m^3). However, these forests are under pressure as the deforestation rate yearly is estimated at 4,000 square kilometer (Km^2) (AFREC, 2016).

As an agricultural country, Mali posed other form of biomass that could be used for energy supply include biofuel from jatropha plantations and agricultural waste such as bagasse form sugarcane, cotton stalks and rice straw. Since 1997 the overall yearly production capacity of alcohol is estimated to 2,400,000 litres and jatropha plantation for about 2000 hectares(AFREC, 2016).

2.3.1.1.4.2 Hydropower

The hydropower potential of the country is just over 1,000 MW mainly from the Niger and Senegal Rivers. So far only 180 MW has been exploited(IRENA Statistic, 2017). The existing power plants include the Selingue on the Sankarani river, an offshoot of river Niger, and the Manantali, Gouina and Felou plants on the Senegal River. The manantali dam provides the electricity for Mali, Mauritania and Niger. The country has also the various sites suitable for small hydro, where the potential is estimated to be around 117 MW(UNIDO, 2016).

2.3.1.1.4.3 Solar energy

The solar average radiation across the country is estimated at 5 KWh / m^2/day. Solar is already used for electricity generation. In 2015, about 1Ktoe of electricity had be generated by solar (AFREC, 2016)as shown the figure 2.10 below:

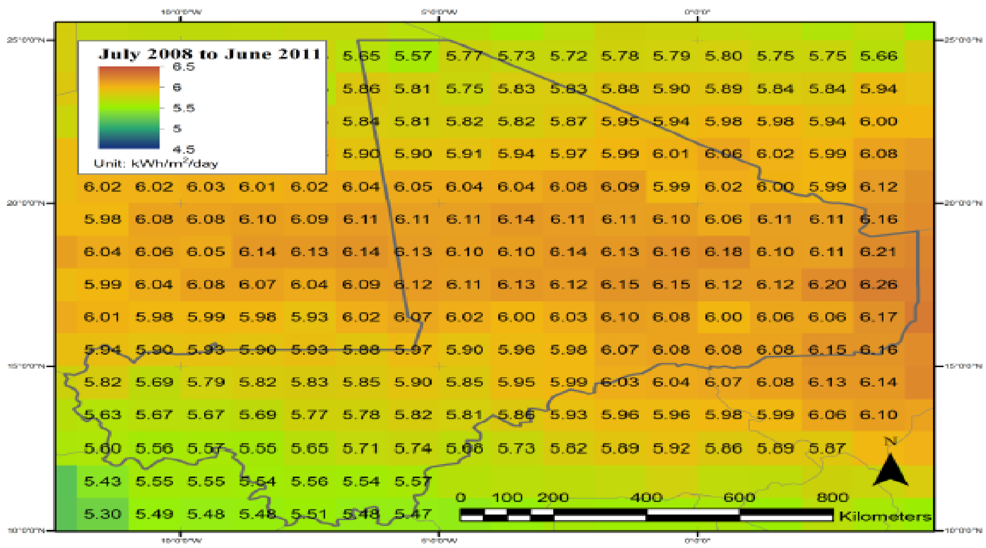


Figure2.10 : Solar radiation across the country.

Source: REA, 2017.

2.3.1.1.4.4 Wind energy

The potential of the Wind energy varies considerably across the country. With the speeds range from the lowest 2m/s to the highest 7m/s. as shown the figure 2.11 below:

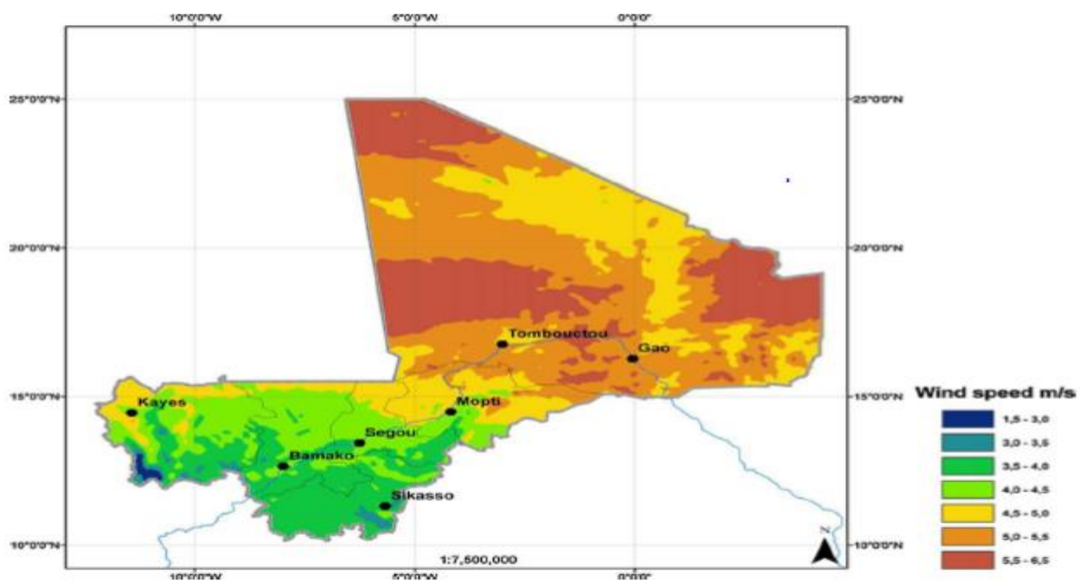


Figure 2.12: Wind speed across the country.

Source: REA, 2017

2.3.1.1.5 Energy policy

2.3.1.1.5.1 Institutional framework

The Energy sector in Mali is monitoring by many stakeholders under the supervision of the Ministry of Energy and Water except the Commission of electricity regulations, who is under the supervision of the premature. But the major payers and their attributions are:

- La Direction Nationale de l'Energie / National Directorate of Energy (DNE) a Which is in charge of defines the elements of energy policy guidelines, general planning and coordination of the different activities of the actors in the energy sector.
- L'Energie Du Mali/ Energy of Mali (EDM. SA). which is the public company in charge of production, transportation and distribution of the electricity across the country.
- Le Centre Nationale de l'Energie Solaire et des Energies Renouvelables/ National Center of Solar energy and renewable energy (CNESOLER) : Found in 1990 with the man goal is to promote and valorize the Renewables energy potential of the country.
- L' Office Nationale des Produits Pétroliers / National Office of Petroleum Products (ONAP): found in 1992 and it is charge of the management of the Petroleum products import.
- La Commission de Regulation de l' Electricite / Commission Electricity Regulatory (CREE): Found in 2000, with the main task to ensure the electricity Tariff , the consumer right , and the encourage the national electricity market competition.
- L'Agence Malienne pour le Developpement de l'Energie Domestique et de l' Electrification Rurale/ Malian Agency of the Development of Domestic Energy and Rural Electrification (AMADER): Found in 2003, the main task is to promote the development of the domestic energies, to suitable manage of the forest, and to increasing the electricity access in Rural and periurban areas.
- L' Agence Nationale de Developpement des Biocarburants / National Agency of Development of Biofuels (ANADEB): Found in 2009, when the mission is to elaboration and put in place the national energy policy of biofuels.

2.3.1.1. 5.2 Government Energy targets

Energy policy in Mali is in principle responsibility of the national government. Possibility for the municipal or district government to influence the Energy profile at the regional or city level are quite limited. Two main policy had been developed by the government for managing the energy sector: The National energy policy, and the Renewable energy policy.

2.3.1.1.5.2.1 The National energy policy

Adopted in 2006 with the principle objective to contribute of the sustainable development of the country through the provision of the affordable energy services to increase access to electricity and promote socio-economic activities, the National Energy policy (NEP) is the main policy regulating the energy sector. As the specific objectives the NEP has four:

- Meeting energy needs in terms of quality, quantity and cost;
- Ensuring the protection of persons, property and environment against the risks of inappropriate energy services;
- Strengthening the capacities of policy, management, monitoring and control of the energy sector; and
- Reinforcing the benefits of international cooperation in the field of energy.

The policy guideline principles are focused on decentralization, liberalization, a programmatic and participatory approach, competitiveness and the implementation of PPP$_s$.

The PEN is looked as a tool for:

- Establishing the better relationship between energy availability and national socio-economic development;
- Fostering synergies between the activities of major stakeholders in the energy sector;
- Effectively directing the interventions of public, para-public and private actors of the energy sector for the rapid balanced and sustainable development of the country; and
- Ensuring a better balance between energy supply and demand with a view to improving access to electrification and reducing geographic imbalance between the grid and off-grid areas covered.

In 2009, Government, for furthermore specifying the energy policy objectives and targets wrote the National Energy Sector Policy Letter.

The letter lists the projects to be achieved between 2009 and 2020, including 133MW of new hydro capacity and 100 MW of thermal capacity, the strengthening of the interconnections with Ivory Coast and Ghana and other investments in the internal transmission and distribution network.

The main policy objectives of the letter are:

- Separation of the Water entity within EDM SA to keep only the energy sector;
- Reinforcement of production, transmission and distribution infrastructures;
- Review the tariff to ensure that prices reflect real costs in order to achieve economic sustainability in the electricity sector;

2.3.1.1.5.2.2 The Renewable energy policy

Renewable development plan is mentioned in many energy document policy including the National Energy policy (2000) and the National Energy sector letter (2009) but the most important renewable energy policy guidelines is the National Strategy for the development of Renewable Energy , which was also in 2006 and the main directions was:

- Promoting the widespread use of renewable Energy technologies and equipment to increasing the share of renewable energy in the national electricity generation up to 10% by 2015,
- promoting and developing the sub-sector of the biofuels for various uses such as electricity generation, transportation, agricultural motorization and so on,
- Searching for sustainable and suitable financing mechanisms for renewable energy .and
- creating better and good Environment for renewable energy services.

As a country is without conventional oil the development of biofuels is one of the priority of the government. In 2008 the National Strategy for the development of biofuel where it aims to:

- reduce the country ‘s dependency on oil imports, and
- improving energy security of the country and meet the socio- economic needs.

Since that some targets of these documents had not be implemented or implemented not successfully, the government are started to revise them since 2015 and must concerning are the National Energy Policy (PNE) and the National Strategy for the development of the renewable Energy.

Recently the through the vision 2033 the government had retired it engagement to bring the sharing of the renewable energy from 1% to up 10% such as (10% bioenergy and 28% solar & wind) in the national electricity generation by 2033 and many projects had been identifying as shown the figure 2.13 and the table 2.3 below:

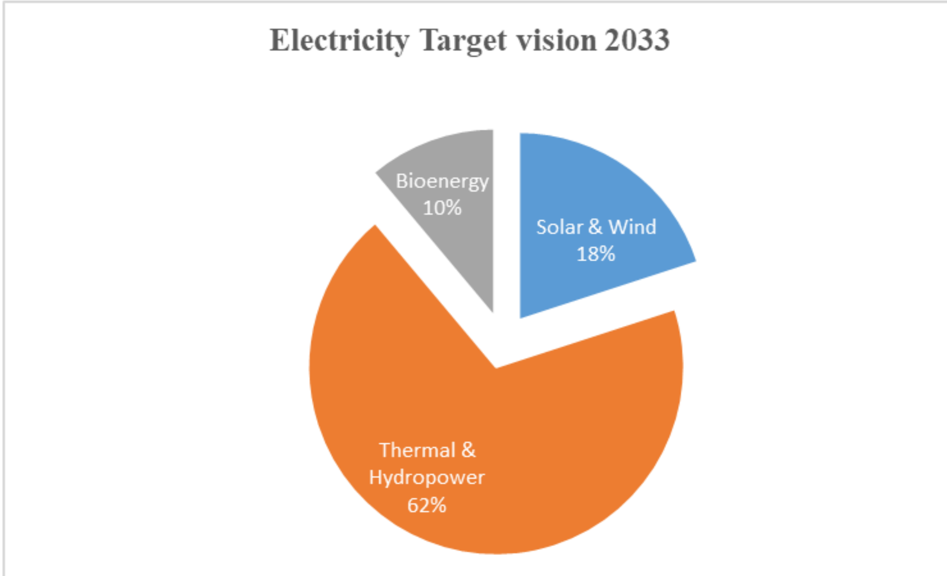


Figure 2.13: Energy vision targets.

Source: Based from REA, 2017.

Table 2.3: Some energy projects plan by Malian's Government.

Projects Names	Year of Implementation	Capacity(MW)	Financial Status
Segou Solar Farm	n.o	33	n.o
Kita Solar Farm	n.o	50	n.o
Sikasso Solar Farm	n.o	50	n.o

Koutiala Solar Farm	n.o	25	n.o
Kayes Wind Farm	n.o	10	Looked for the fund

n.o : no available information.

Source: Based REA, 2017.

2.3.1.1.6 Climate Change Policy

The traditional use of biomass is the primary source of the green house emission of the country, and accounts of around 81% of the CO_2emissions. The emitted annual of the CO_2 emissions of Mali is estimated to be around 15,450 tonnes such 0.06% of the global emissions. Despite Mali is classify as a low emitting country, the Government had on 28 December 1994 signed and ratified the United Nation framework convention Climate change and on 27 January 1999 the Kyoto protocol and engages under the nationally determined contribution the ambitions to reduce 31% of its greenhouse gas emissions from the energy sector (GCF,2017).

There are two main documents related to the vision of the country about its targets and measures to mitigate the effect of climate change: The National Climate Change and the National Climate Change Strategic both of the adopted in 2011.

2.3.1.1.6.1 National Climate Change

In 2011 the country adopted this document to mitigation the effects of the climate change and it aims is to:

- Facilitate the better integration of climate challenges inside the politic and sectorial strategies of socio-economic and the process of planning in national as well in territorial level.
- Reinforce the national capacity building to the climate change vulnerability.
- Contribute in global world effort to mitigate the greenhouse gas emissions in the atmosphere.
- **National Climate Change Strategies**

Adopted in same year with the National Climate Change of the country, the National Climate Change Strategies aims to put in place the strategies to implement the national climate change aims.

2.3.2 Scope of study

2.3.2.1 Bamako city, Mali

2.3.2.1.1 Profile

Bamako which means "Crocodile River "in Bambara local language is a capital and dominating city of Mali regarding political, economic, financial, infrastructure and education activities. The city is globally interconnected and of major importance for national and regional development. between 1960 and 1970 due to the rural migration from the drought –stricken areas the size of the city was tripled. With the population estimated of around 2, 094,000 inhabitants in 2013(ASBD, 2015), Bamako is the largest city in Mali. In 2006, it was estimated to be the fastest growing city in Africa and the sixth-fastest in the world (World city growth, 2011). Bamako is important in the overall national context of the country, as 24% of the GDP is generated form the city, in addition to 25% of the national consumption part and 70% of the commercial activities.

The Bamako city spans both sides of the wide and murky Niger River, near rapids that divide the upper and the middle Niger Valleys, in the southwestern part of Mali. With the area of 2992 Km^2 over the 1 ,241, 354Km^2 for the whole Mali, Bamako is hot and dry from February to June, reaching 101-degree F in April; rainy, humid, and mild from June to November (between 35.3 degree Celsius to 36.2); and cold and dry from November to February (between 36.2 to 36.7). Precipitation reaches 14 inches(350mm) in August. The table 2.4 below shows the annual average whether characteristics from 2009 to 2013 of the city.

Table 2.4:Annual average climate characteristics in Bamako.

Year	Average Temperature (^{0}C)	Average Relative Humidity (%)	Total Pluviometry(mm)
2009	28.0	52	929.4
2010	27.9	56.5	1164.4
2011	27.3	54.5	905.6
2012	27.2	55	1042.2
2013	27.9	54	779.1

Source: ASDB report, 2015.

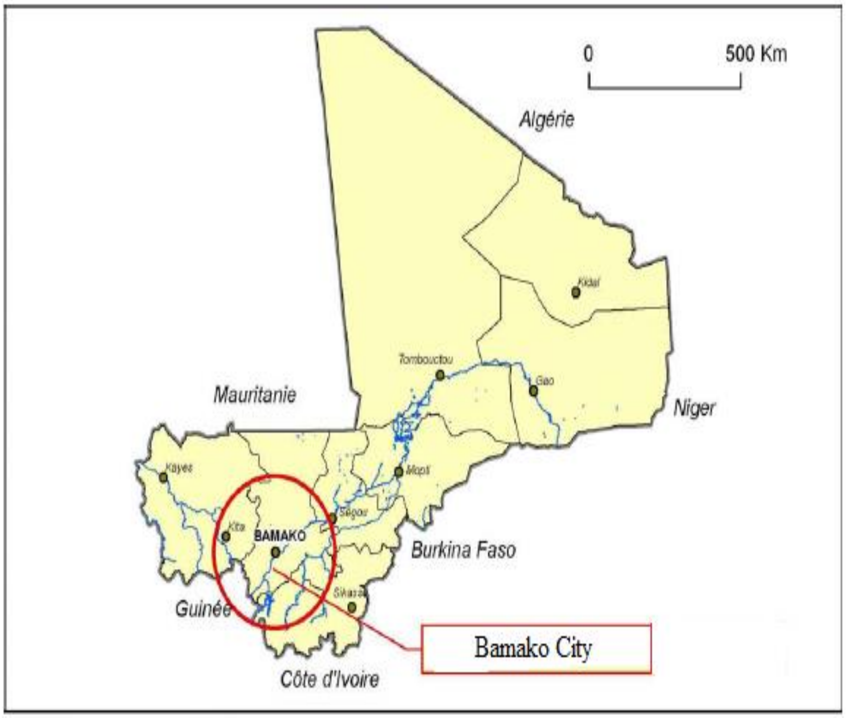


Figure 2.14: Bamako city location.

Source: Adapted from www.CountryMap.com.

2.3.2.1.2 System boundaries

The properly definition of the district's boundaries are crucial for the analysis because it can significant influence on results. Sometime the task is not easy, as it is often not clear precision in where the city area begins and ends. In addition, due to their dynamic, city's boundaries often change over the time (Cattan, 2007). There is no a specific way to define the cities areas, however, various methods to establish the boundaries of the urban areas had been named in literature. In most cases, it is relating to the country specific criteria established by local institution (CONAPO, et al., 2012).

The common types used in literature for the urban areas boundaries definition are in a number of three (Lukrafka, 2015):

- Administrative boundaries: gathering territorial or political boundaries;
- Morphological boundaries: established regarding to the characteristics of land cover or the environment of construction, and the land use; and
- Functional boundaries: focusing to connection or interconnections between areas related to such as economic Activity.

In addition, for the modelling purpose, the coverage required that data available needs also to be taken into account for the system boundaries definition of the cities. For this study the Administrative boundaries was considered.

2.3.2.1. 2.1 City boundaries

Administratively, the Bamako city is a gathering of six communes (distinguished by number, and not by named): Communes (I, II, III, IV, V, VI). From the ordinance No. 78-34/CNLM of the 18 August 1978, and amended by a law of February 1982 new boundaries of the communes III and IV has been established. In the head of each commune, we have the mayor and the municipal council, who are elected among its members. Each commune has its own boundaries:

Commune I with the population estimated to around 388, 226 inhabitants in 2013 (ASDB,2015) and a cover area of 34.26 square kilometers (Km^2) in 2009 (ASDB,2015) is bounded to the north by rural commune of Djalakorodji (Kati Cercle), in north- east by the rural commune of Sangarebougou (Kati Cercle), on the east by rural commune of Gabakourou, south by the Niger, and west by the commune II. It is also important to notify that the commune comprise nine neighborhoods: Banconi, Boulkassombougou,Djelibougou, Doumanzana, Sotuba, Korofina Nord, Fadjiguila, Korofina Sud, and Sikoroni (Mekin Sikoro). (ASDB, 2015).

Commune II, with the population estimated to around 184,971 inhabitants in 2013 and a cover area of 36.47 square Kilometres in 2009 is bounded to the south by Niger River, on the east by backwater of Korofina and at the west by foot of the Point G hill. The area is the most industrial place in the city andhas twelve neighborhoods:Bagadadji, Missira, Hippodrome, Niarela, TSF, Zone Industrielle, N'gomi, Medina-coura, Bozola, Quinzambougou, Bougouba, and Bakaribougou(ASDB,2015).

Commune III, with the population estimated to around 149,166 inhabitants in 2013 and cover area of 23 square Kilometres(Km^2) in 2009 is bounded on the east by Boulevard du peuple, which separates it from Commune II, on North by the Kati , on south by the portion of the Niger River, Between the Pont des Martyrs and the Motel de Bamako, and on west by the Farako River and Avenue Cheick Zayed El Mahyan Ben Sultan with the neighborhood of ACI-2000. the Commune is the Administrative and commercial centre of the city. It contains in particular the two largest markets of Bamako, Dibida and Grand Market. The commune contains twenty neighborhoods: Dravela, Badialan I, Badialan II , Badialan III, Bamako Coura Bolibana, Bamako Coura , Centre Commercial, N'Tomikorobougou , Dravela Bolibana, Darsalam, Same ,PointG, Nyomirambougou, Sirakora Dounfing ,Koul/KouloubaVillage, Kouloumiko, Kodabougou, Sogonafing/Minkoungo, Ouolofobougou,and Ouolofobougou Balibana. (ASDB,2015).

Commune IV, with the population estimated to around 347,342 inhabitants in 2013 and cover area of 37.68 square Kilometers (Km^2) in 2009 is bounded to the south by the Left bank of the Niger River , to the north , west by the Kati Cercle , and to the east by Commune III. Commune IV comprises of eight neighborhoods namely: Lassa, Djikoroni Para, Hamdallaye, Lafiabougou, Kalabambougou,Sébénikoro, Sibiribougou and Taliko (ASDB, 2015).

Commune V, with the population estimated to around 479,969 inhabitants in 2013 and cover area of 41.59 square Kilometers (Km^2) in 2009 is bounded to the south by the airport and the commune of Kalabancoro, to the east by Niger and Commune VI, and to the north by the Niger River . The commune is consists of nine t neighborhoods namely: Badalabougou Séma I, Badalabougou Sema II, Torokorobougou, Sabalibougou, Bacodjikoroni, Daoudabougou, Badalabougou,Quatier Mali, and Kalaban-Coura (ASDB,2015).

Commune VI, with the population estimated to 544,342 inhabitants in 2013 and cover area of 94 square Kilometres (Km^2) in 2009. the area contains ten neighborhoods: Missabougou, Niamakoro, Sogoniko, Sokorodji, Faladie, Dianeguela. Banankabougou, Yirimadio, Magnambougou, and Senou (ASDB, 2015).

In summarize , Bamako city contains 68 neighborhoods namely :Banconi, Boulkassombougou ,Djelibougou, Doumanzana, Sotuba, Korofina Nord, Fadjiguila, Korofina Sud , Sikoroni (Mekin Sikoro)Bagadadji , Missira ,Hippodrome, Niarela, TSF, Zone Industrielle, N'gomi, Medina-coura, Bozola, Quinzambougou , Bougouba, Bakaribougou, Dravela, Badialan I, Badialan II , Badialan III, Bamako Coura Bolibana, Bamako Coura , Centre Commercial, N'Tomikorobougou , Dravela Bolibana, Darsalam, Same ,PointG, Nyomirambougou, Sirakora Dounfing ,Koul/KouloubaVillage, Kouloumiko, Kodabougou, Sogonafing/Minkoungo, Ouolofobougou,and Ouolofobougou Balibana Lassa, Djikoroni Para, Hamdallaye, Lafiabougou, Kalabambougou, Sebeninkoro, Sibiribougou ,Taliko, Badalabougou Sema I, Badalabougou Séma II, Torokorobougou, Sabalibougou, Bacodjikoroni, Daoudabougou, Badalabougou,Quatier Mali , Kalaban-Coura,Missabougou, Niamakoro, Sogoniko, Sokorodji, Faladie, Dianeguela. Banankabougou, Yirimadio, Magnambougou, and Senou.

The table 2.5 below summarize the Bamako city structure:

Table 2.5: Bamako city structure in 2013.

Communes	Population & Sharing	%	Number of Household	Size of Household	Neighborhoods	Number
Commune I	388,226	10.2	52, 431	6.4	Banconi, Boulkassombougou ,Djelibougou, Doumanzana,Sotuba, Korofina Nord, Fadjiguila, Korofina Sud , and Sikoroni (Mekin Sikoro).	9
Commune II	184,971	4.9	25,185	6.3	Bagadadji , Missira ,Hippodrome, Niarela, TSF, Zone Industrielle, N'gomi, Medina-coura, Bozola, Quinzambougou , Bougouba, and Bakaribougou .	12
Commune III	149,166	3.9	20,242	6.4	Dravela, Dawdabougou , Badialan I, Badialan II , Badialan III, Bamako Coura Bolibana, Bamako Coura , Centre Commercial, N'Tomikorobougou , Dravela Bolibana, Darsalam, Same,Point G, Nyomirambougou, Sirakora Dounfing ,Koul/KouloubaVillage, Kouloumiko, Kodabougou, Sogonafing/Minkoungo, Ouolofobougou,and Ouolofobougou Bolibana.	20
Commune IV	347,342	9.3	49,394	6.2	Lassa, Djikoroni Para, Hamdallaye, Lafiabougou, Kalabambougou, Sebeninkoro, Sibiribougou , and Taliko	8
Commune V	479,969	12.6	63,836	6.5	Badalabougou Sema I, Badalabougou Sema II, Torokorobougou, Sabalibougou, Bacodjikoroni, Daoudabougou, Badalabougou,Quatier Mali , and Kalaban-Coura	9
Commune VI	544,326	14.3	75,293	6.2	Missabougou, Niamakoro, Sogoniko, Sokorodji, Faladie, Dianeguela. Banankabougou, Yirimadio, Magnambougou , and Senou.	10
City of Bamako	**2,094,000**	**55.2**	**286,381**	**6.3**		**68**

Source : Based On Annuaire Statistique Du District De Bamako (ASDB), 2015.

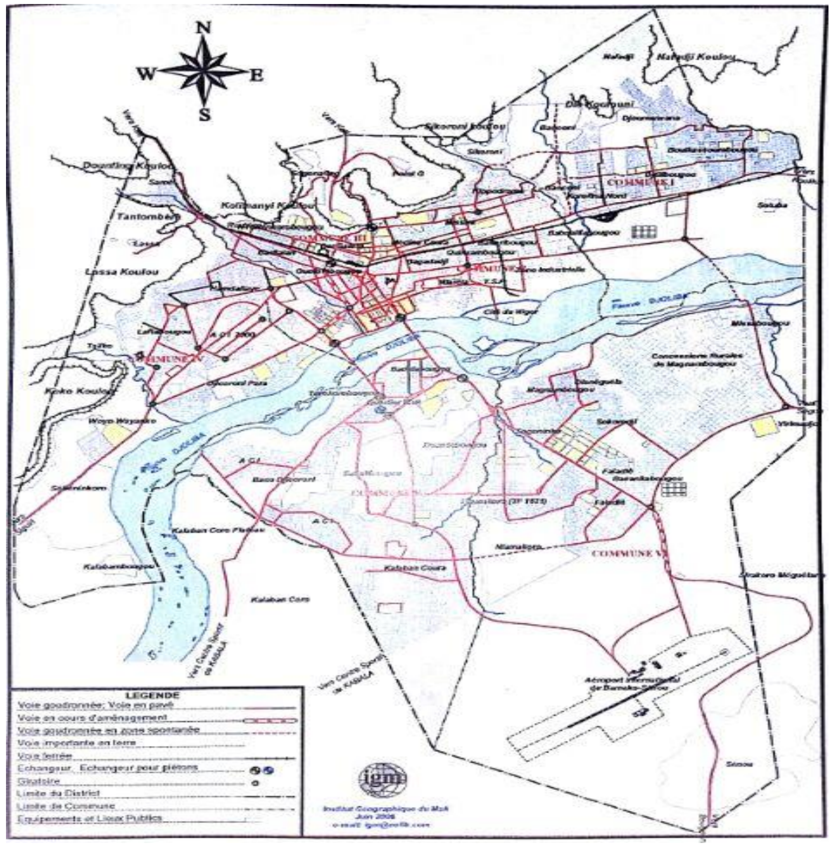


Figure 2.15: Bamako with neighborhoods map.

Source : Annuaire Statistique du District de Bamako (ASDB), 2015.

2.3.2.1.3 Energy Resources in the city

2.3.2.1.3.1 Wind energy

In 2013, the average wind speed across the district was 2.7m/s (ASDB,2015)

However, it is important to notify that, the wind speed can reach 4.5 m/s. (see the figure 2. 11 above).

2.3.2.1.3.2 Solar Energy

From July 2008 toJune 2011, the solar radiation across the city was estimated to be around 5.77 KWh/m^2/day. (see the figure 2. 10 above).

2.3.2.1.4 Energy situation in the city

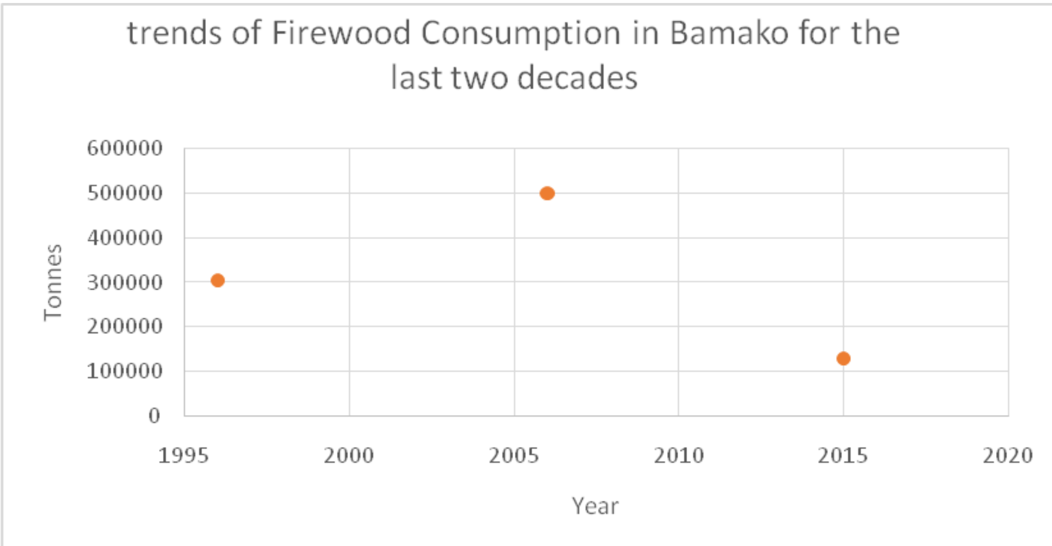
2.3.2.1.4.1Historical trends of Energy consumption in the city by fuels types

The energy consumption of the district is the mirror of the one of the country. Indeed, the primary energy supply is dominated by the use of biomass which represent almost 78% of the total energy consumed, followed by hydro 13 % (electricity generation) and petroleum product 9 % (AFREC, 2016).

2.3.2.1.4.1.1 Traditional biomass consumption

In 2015 the total wood supplied by the city was 236,812 tonnes(884, 491 tonnes equivalent firewood) such 124,119 and 108,613 tonnes for charcoal and firewood respectively. With the

population estimated to be around 2,396,800 inhabitants in that year, that corresponded of 169 Kg and 76 Kg firewood and charcoal respectively supplied per capita. At the same year, the traditional wood consumed was equal to the one supplied(FONABES, 2016).In the past two decades the Charcoal consumption had been multiplied by nine, whereas the use of firewood had been considering decreasing as shown the figures 2.16 and 2.18below:



Source: Adapted from FONABES report, 2017.

Figure 2.17: Firewood supply in Bamako.

Source: Author, 2018.

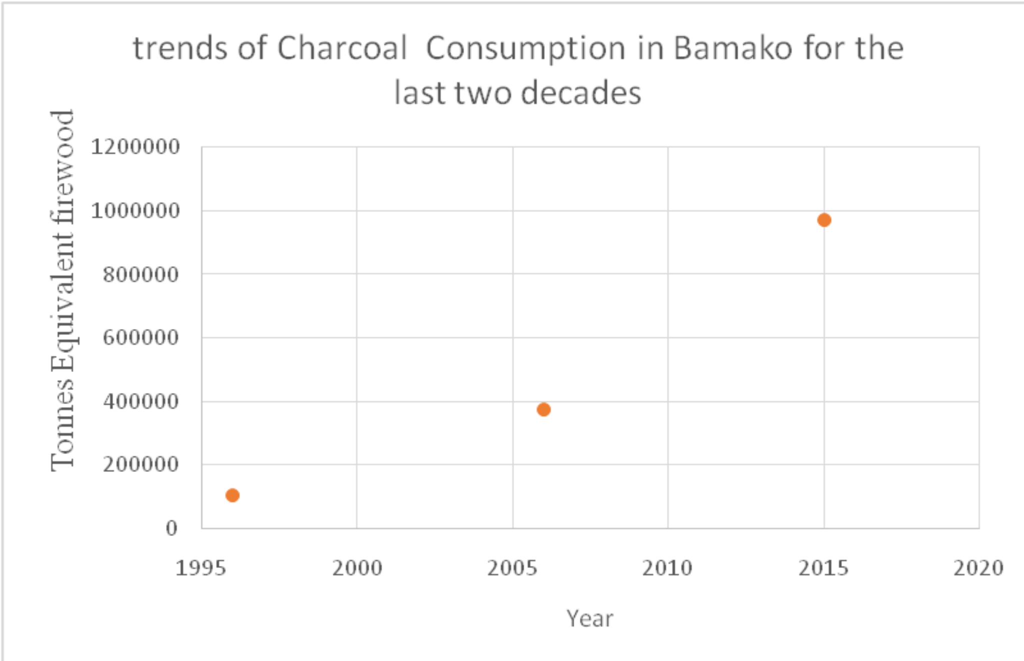


Figure 2.18: Trends of charcoal consumption in Bamako for the last two decades.

Source: Based on FONABES report, 2017.

Figure 2.19: Charcoal supply in Bamako.

Source: Author, 2018.

2.3.2.1.4.1.2 Electricity consumption

In 2015 the total electricity consumption for the district was 951.8 GWh such an increase of 7.8% compare to the year 2 014 (EMD, 2016)it is also important to notify it was accounted for 55.7 % of the total electricity produced.

2.3.2.14.1.3 Petroleum product consumption

In 2016, Bamako petroleum product consumption amounted for over 50% of total petroleum product consumed in the whole country. This consumption has dominated by diesel which accounted to 48% followed by Diesel and LPG plus other. It is important to notify that, the consumption of petroleum product had double between 2013 and 2014. The trendsof different petroleum product consumed from 2013 to 2016 by the city is showing in the table below:

Table 2.6: Trends of petroleum products and LPG consumption in Bamako.

	Year			
Petroleum Products type	**2013**	**2014**	**2015**	**2016**
Petrol(Litre)	95,271,550	49,015,361	183,072,230	19 7,778,089
Diesel(Litre)	164,567,091	297,475,753	210,921,146	266,261,026
Kerosene (Litre)	13,500	49,623	73,557	34,000
LPG (kg)	6,199,200	6,202,200	7,129,200	8,443,200
Total (excluding LPG)	**259,852,141**	**346,540,737**	**394,057,933**	**464,073,115**

Source: Based on survey Data on ONAP, 2018.

Chapter 3: Methodology

3.0 Introduction

This chapter highlights the methodology used for the simulation of the energy landscape for Bamako city from the year 2013 to 2033. The main areas of this part include: Data collection, Energy demand development model by sectors, energy supply side, design and description scenarios, main assumptions and factors drivers.

3.1 Data Collection

The data collection is primarily and secondary. based on surveys, questionnaires, and focus groups discussion with stakeholders regarding the primarily and based on world bank data, international energy Agencies data, government vision data, National Institute of Statistics, and literature regarding the secondary.

The sample size carried through questionnaires across different sectors as following:

- 373households
- 225 commercial businesses
- 9 industrial businesses

3.2 Development of the energy demand model

Many model has been used for energy Demand analysis but for this study the formulation of total energy demand as a result of total activity times energy intensity for each sector and year (Ouedraogo, 2017b)is used and expressed as follows:

- $ED_{u,s,t} = TA_{u,s,t} \times EI_{u,s,t}$………………………………………………………… …(1)

Where: ED is the energy demand in sector u, TA the total activity in sector u EI the energy intensity, s is the scenario and t the time.

Energy intensity will be calculated as a product of energy consumption and total activity:

-$EI_{u,t} = \frac{EC_{u,t}}{TC_{u,t}}$…………………………………………………………………………………(2)

However, the development of this methodology was specific for each key sectors of Bamako:

3.3 Sectorial modeling approach

3.3.1 Household sector

3.3.1.1 Data collection

The sample size of 373households such 348electrified and 25Unelectrifiedhas been taken over the around 286,381 Households that count the city and the energy consumption by end-use and by fuel has been carried across the city through a questionnaire and surveys as shown the table 3.1 below:

Table 3.1: Sampled size of households surveyed by category.

Households category	Sampled size surveys	Total estimated* household in the city	Percentage
Electrified	348	189,011	93.3
Unelectrified	25	100,370	6.7
Total	**373**	**286,381**	**100**

*For the year 2013

Source: Based on ASDB data, 2015.

The average annual consumption per household category was estimated as shown the table 3.2 below:

Table 3.2 :Annual average estimated consumption per households category.

Household Category	Firewood (Kg)	Charcoal (Kg)	LPG (Kg)	Kerosene (Litre)	Electricity (KWh)	Drycell battery(no.of singles)
Electrified	3,269	1,194	87	182.5	2228	92
Unelectrified	1,802	77	72	152	-	382

Note: Average is from the household who used or consumed the fuel.

Source: Based on surveys data in households, 2018.

The household percentage shares of fuels for end-uses had been also evaluated as shown the table 3.3 below:

Table 3.3: Household percentage shares of fuels for end-uses.

Household Category	Electrified (%)	Unelectrified (%)
Lighting	**100**	**100**
Electricity	100	-
Solar	1.5	36
Dry cells battery	0.3	48
Kerosene	0	56
Firewood	0.9	-
Charcoal	1.2	-
Cooking & Water heating	**100**	**100**
Electricity	18	-
Firewood	46	88
Charcoal	79	84
LPG	29	0
Kerosene	0.3	8
Refrigeration	**94**	-
Electricity	100	-
Entertainment	**100**	**68**
Electricity	100	-
Dry cell Battery	3	56
Solar	0.6	24
Space cooling(HVAC)	**100**	**4**
Electricity	100	-
Solar	-	4

Other Energy Services	**100**	**88**
Electricity	100	-
Charcoal	2	32
Firewood	1.8	40
Solar	0.6	4
Dry cells battery	0.9	48
Kerosene	-	52

Comments: Bolded lines refer to percentage of all households; fuel categories refer to the percentage of households that use the energy service.

Source: Based on surveys data in households, 2018.

The type of technology used for different energy service had been carried out also as shown the table 3.4 below :

Table3.4 :Percentage of efficient appliance used per household category.

Household Category	Electrified (%)	Unelectrified (%)
CFL Lightbulbs	96	16
Fridge	72	-
Charcoal stoves	62	64
Biomass Stoves	20	28

Notes: it important to notify that many respondents are not really knew the efficient fridge and most efficient charcoal or firewood stoves used are not efficient as well (slow optima **)**

Source: Based on surveys data in households, 2018.

The total electricity consumption per electrified households was also estimated as shown the table 3.5below:

Table 3.5: Electricity consumption estimated for the electrified households.

Energy Service	Households using energy service	Households using electricity for energy Service	Average daily consumption (KWh)	Days per year	Average household energy intensity KWh/yr	Consumption average for all Household
Lighting	100%	100%	0.6104	365	223	77,604
Cooking& Water heating	100%	18%	0.3052	363	111	38,628
Fridge	94%	100%	1.526	362	553	180,639
Entertainment	100%	100%	0.9156	365	334	116,232
Space cooling	100%	100%	1.9055	360	686	238,536
Other	100%	100%	0.9156	365	330	114,840
Total	-	-	-	-	-	**766,479**

Source: Based on surveys in households, 2018.

The household wood consumption was estimated as shown the table 3.6below:

Table 3.6: Household firewood consumption estimates.

Households Category	Households that use Firewood for cooking	Appliance type	Percentage that use appliance type	Averageestimated annual consumption (Kg/HH)	Total estimated consumption for all households (Kg)
Electrified	46				647,247.5*
		Efficient Stove	63	2,059.5	407,766
		Inefficient stove	37	1,209.5	239,481.5
Unelectrified	88				39,630
		Efficient stove	30	540.5	11,889
		Inefficient Stove	70	1,261.5	27,741

*This high amount of firewood may due of the used of it during the welding ceremony, which is frequently in City and it is somehow free.

Source: Based on Surveys data in households, 2018.

The charcoal consumed and the technology used by the households was also estimated as shown the table 3.7 below :

Table 3.7: Estimates charcoal consumption.

Households Category	Households that use Charcoal for cooking	Appliance type	Percentage that use appliance type	Average estimated annual consumption (Kg/HH)	Total estimated consumption for all households(Kg)
Electrified	79				**392,931.5**
		Efficient Stove	54	645	212,183
		Inefficient stove	46	549	180,748.5
Unelectrified	84				**17,884.5**
		Efficient stove	25	194.5	4,471
		Inefficient Stove	75	583.5	13,413.5

Source: Based on surveys Data in households, 2018.

3.3.1.2 Development of the energy demand model

The energy consumption profiles are based on the survey data collected, and the energy intensities of end-uses were calculated based on bottom-up calculation of the typical energy profiles of residential. So total consumption for each fuel by energy service is calculated as:

Number of residential in sub-category (electrified or non- electrified) x percentage of residential that use energy service x percentage of residential that use fuel (e.g. Charcoal) (based on survey data) for energy service x (e.g. cooking) (based on survey data) x Energy intensity per energy service (based on bottom up calculation of appliance ratings and hours of usage, and calibrated to meet total sample consumption estimate from survey data) …………………………………...(3).

3.3.2 Commercial Sector

The commercial sector of the city had been classified in two sub-sectors mainly the formal and the informal sub-sectors and the business classified as a commercial across the city had been based on some surveys operated in the city.

The formal commercial sub-sector in the city includes:

- ✓Schools,
- ✓Offices (e.g. IT, finances, consultancy, etc),
- ✓Hotels and guest houses,
- ✓Non-banks financial services,
- ✓Banks, and
- ✓Hospitals

Figure 3.1: Formal commercial business in Bamako (School).

The informal commercial sector in the city includes:

- ✓ Carpentry/Welding shops,
- ✓ Laundry,
- ✓ Blacksmith,
- ✓ Cold store,
- ✓ Corn mill,
- ✓ Drinking bar, restaurant, catering services,
- ✓ Electronic repair shops,
- ✓ Tailoring/ Seamstress
- ✓ Retail, Pretty trading, other

Figure 3.2: Informal commercial business in Bamako(Restaurant).

Source: Author, 2018

3.3.2.1 Data Collection

The total floor-space of the city was used as the main driver of the energy consumption for this sector. By assuming the sample representative, the total floor space surveyed was scaled-up proportionally to estimate the energy demand from the population for all businesses in the city (SAMSET, 2015) as shown the table 3.8 below:

Table 3.8: Sample of floor-space area and total businesses.

Comer. subsector	Number of businesses sampled	Floor-space of Sampled (m^2)	Total estimated number of businesses	Total estimated floor-space of all businesses (m^2)
Formal	18	812,208	476	21,478,389
Informal	207	42,920	1,904	394,786
Total	**225**	**855,128**	**2,380**	**21,873,175**

Assumptions: Each neighborhood has at least one business (for the case of formal sector).

Informal business is represented 80 percent of all businesses.

Comments: The floor space reserves for a collectivity represent 25% of the total floor space of the communes; percentage of market is 1.5% (based on group discussion with Stakeholder).

Source: Based on surveys data in Commercial sector, 2018.

Floor-space area, from which the energy demand was forecasted, assuming a fixed energy intensity, is projected geometrically in the model and the share by activity type for each sub-sectors (formal and informal) is showing in the figures 3.3 and 3.4 below:

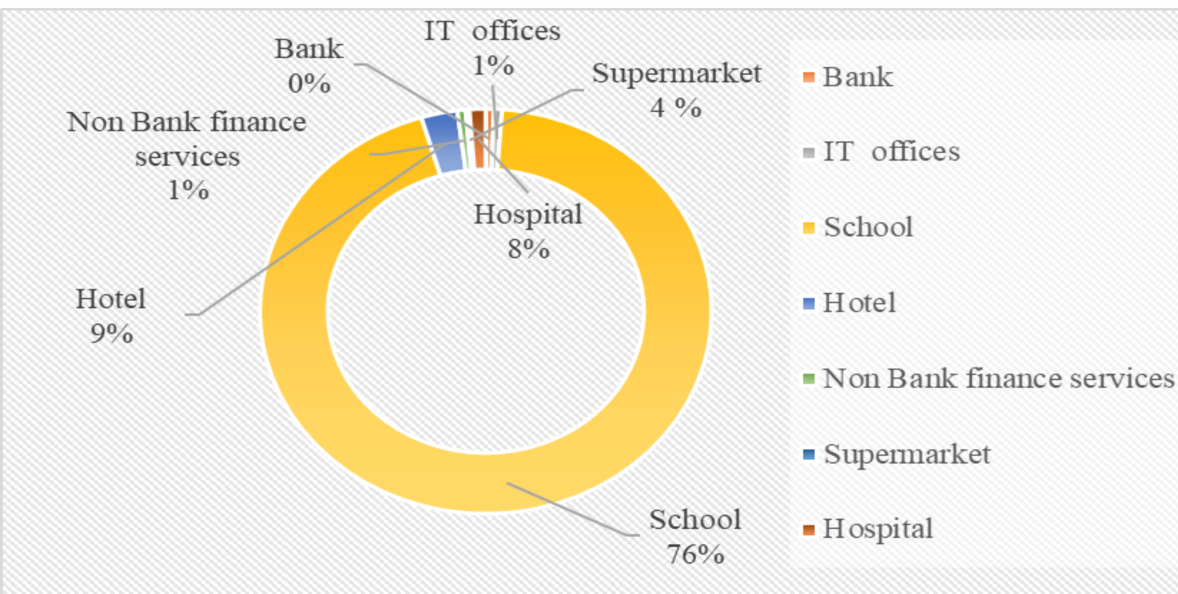


Figure 3.3 : Formal commercial floor-space sharing by business type.

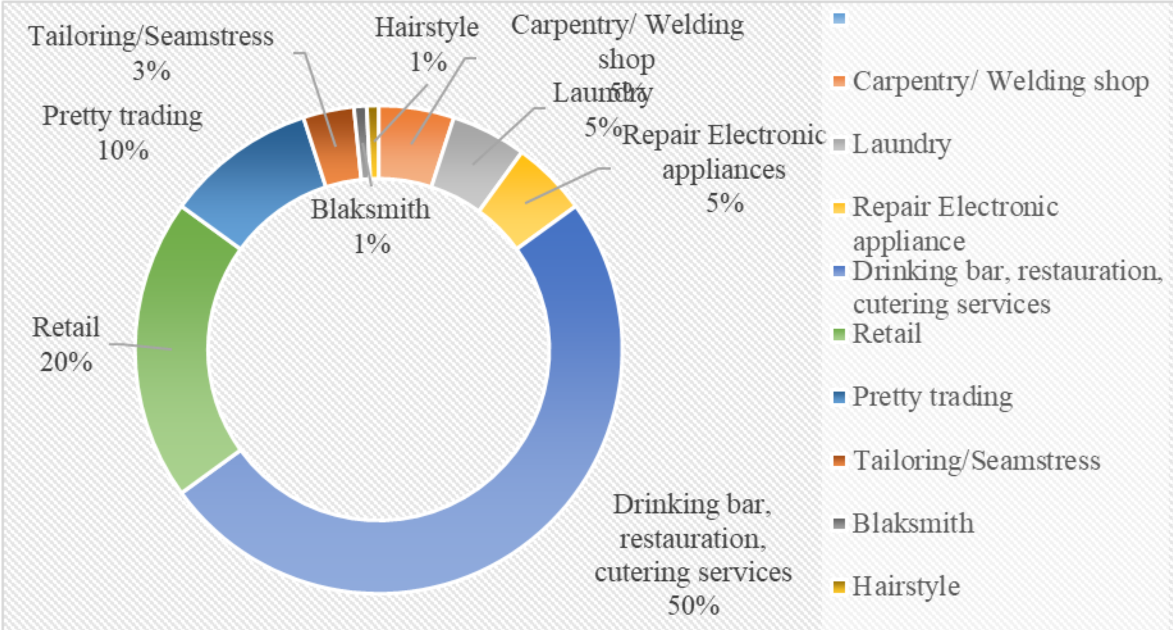


Figure 3.4: Informal floorspace sharing by business type.

Source: Based on group discussion with stakeholders, 2018.

The energy consumption characteristics obtained from surveys for different commercial sector as shown in tables3.9 and 3.10below:

Table 3.9 : Surveys results of yearly consumption by fuel and end-use for sample in formal sector.

End-uses / Fuel type	HVAC	Cooking/Water heating	Lighting	Refrigeration	Machine operation	Entertain-ment	Other	**Total**
Electricity (KWh)	42,984	4,289	28,656	14,328	35,820	12,895	4,288	**143,280**
LPG(Kg)	-	792	-	-	-	-	-	**792**
Charcoal(Kg)	-	5,475	-	-	-	-	-	**5,475**
Firewood (Kg)	-	1,460	-	-	-	-	-	**1,460**
Kerosene (L)	-	-	-	-	-	-	-	-
Dry Cell Battery (no of singles)	-	-	24	-	-	-	-	**24**

Source: Based on surveys Data in Formal commercial sector, 2018.

Table 3.10: Surveys results of the yearly consumption by fuel and end-use for sample in informal sector.

End -uses / Fuel types	HVAC	Cooking/ Water heating	Lighting	Refrigeration	Machine operation	Entertain-ment	Other	**Total**
Electricity(KWh)	224,457	14,964	130,933	134,674	149,638	74,819	18,704	**748,189**
LPG(Kg)	-	5,616	-	-	-	-	-	**5,616**
Charcoal(Kg)	-	93,536	-	-	-	-	23,384	**116,920**
Firewood (Kg)	-	71,905	-	-			-	**71,905**
Kerosene (L)	-	-	-	-	-		-	**-**
Dry cell Battery(no of singles)	-	-	735	-	-	681	-	**1,416**

Source: Based on surveys Data in Informal commercial sector, 2018.

3.3.2.2 Development of the Energy Demand

The energy consumption for a fuel = The floor area occupied by sub-sector × The share of floor area of businesses in a sub-sector that need an energy service like cooking of the floor area of the all businesses in a sub-sector ×The share of floor area of businesses that use this fuel/technology for this energy service of the floor area of businesses that use this energy service × The energy intensity (Gj /m^2 ; Kg charcoal / m^2; litres diesel/m^2; Kg LPG /m^2; etc.) of this energy service for these businesses using this fuel/technology (calibrated)(MCcall et al , 2016)…………………………………………………….(4).

The inputs to this methodology for the formal, then informal sectors determined from the survey's data are represented in the tables 3.5 and 3.6below:

Table 3.11: Formal businesses percentage of floorspace with end-use.

%of total floorspace withend-uses	HVAC	Cooking /Water heating	Lighting	Refrigeration	Machine operation	Entertainment	Other
Formal	100	56	100	60	48	73	45

Source: MCcall et al ,2016.

Table 3.12: Formal sector percentage of floor-space end-use by fuel type.

%	HVAC	Cooking/Water heating	Lighting	Refrigeration	Machine operation	Entertainment	Other
Electricity	100	53	100	100	100	100	100
LPG	0	18	0	0	0	0	0
Charcoal	0	71	0	0	0	0	0
Firewood	0	0	0	0	0	0	0
Kerosene	0	0	0	0	0	0	0
Dry cells battery	0	0	0	0	0	1	0

Source: Based on surveys data in Formal commercial sector, 2018

The final energy intensity was calculated by used the total fuel consumed for each end-use and the total floor-space which has that end-use (and fuel) for the both as shown the tables 3.7 and 3.8below:

Table 3.13: Formal sector-Annual energy intensity average by fuel and end-uses.

End-uses / Fuel types	HVAC	Cooking/Water heating	Lighting	Refrige-ration	Machine operation	Entertainment	Other	Total
Electricity (KWh/m^2)x10^{-2}	5.2	0.9	3.5	2.9	9.1	2.0	0.010	**23.61**
LPG(Kg/m^2) x10^{-2}	-	0.17	-	-	-	-	-	**0.17**
Charcoal(Kg/ m^2)x10^{-2}	-	1.2	-	-	-	-	-	**1.2**
Wood (Kg/ m^2)x10^{-2}	-	0.32	-	-	-	-	-	**0.32**
Kerosene (L / m^2)x10^{-2}	-	-	-	-	-	-	-	**-**
Dry cells battery (no of single/m^2)x10^{-2}	-	-	0.002	-	-	-	-	**0.002**

Source: Based on surveys data in Formal commercial sector, 2018.

Table 3. 14 : Informal sector percentage of floor-space with end-uses.

% of total floorspace with end use	HVAC	Cooking/water heating	Lighting	Refrigeration	Machine operation	Entertainment	Other
Informal	15	9	96	22	70	36	7

Source: MCcall et al, 2015.

Table 3.15: Informal sector total floor-space of fuel used for end-use/total floor-space with end-use.

%	HVAC	Cooking/Water heating	Lighting	Refrigeration	Machine operation	Entertain-ment	Other
Electricity	100	16	100	100	100	100	100
LPG	0	4	0	0	0	0	0
Charcoal	0	89	0	0	0	0	1
Firewood	0	13	0	0	0	0	0
Kerosene	0	0	0	0	0	0	0
Dry cells battery	0	0	100	0	0	11	1

Source: Based on surveys data in Informal commercial sector, 2018.

Based on survey data the final energy intensity values by end-use and by fuel type for the Informal sector is showing in table 3.16below:

Table 3.16: Informal sector-Annual energy intensity by fuel and end-use.

End-uses / Fuel types	HVAC	Cooking/ Water heating	Lighting	Refrige-ration	Machine operation	Entertai-nment	Other	**Total**
Electricity (KWh/m^2)	34.86	3.87	3.17	14.26	4.98	4.84	6.23	**67.37**
LPG(Kg/m^2)	-	0.95	-	-	-	-	-	**0.95**
Charcoal(Kg/ m^2)	-	24.21	-	-	-	-	6.05	**30.21**
Wood (Kg/ m^2)	-	18.61	-	-	-	-	-	**18.61**
Kerosene (L / m^2)	-	-	-	-	-	-	-	-
Dry cells battery (no of single/m^2)	-	-	0.01	-	-	0.22	-	**0.23**

Source: Based on surveys data in Informal commercial sector, 2018.

3.3.3 Industrial sector

The industrial sector in the city of Bamako is characterized by three main sub-sectors such as Construction, Manufacturing, and mining and quarrying. For each sub-sector the energy consumption of industry was gathered into six categories:

- ✓ Cooling,
- ✓ Machinery,
- ✓ Lighting,
- ✓ Process heating,
- ✓ Other machinery, and
- ✓ Other

3.3.3.1 Data collection

The sample size of 1 Constructions and 8 Manufacturing businesses over around 165 and 313 respectively had been surveys. The total industrial output and electricity consumption obtained from the surveys as shown in table 3.18below:

Table 3.18: Fuels consumption by industry sector in 2013.

Bamako industry	Sample Size Business in survey	Tonnes output from survey	Count of all busnesses*	Electricity consmption from survey (KWh)	Firewood Consumption from survey (Kg)	Petroleum consumption from survey (L)	
						Diesel	Petrol
Construction	1	48,839	165	203,748	-	-	49,544
Manufacturing	8	477,046	313	2,114,310	438,000	425,000**	-

*For the base year 2013 (ASDB, 2015).

** Production, own generator, and industry vehicle transportation.

Source: Based on surveys data in industry sector, 2018.

From the surveys, the electricity consumed by each end-use was estimated as shown table 3.19 below:

Table 3.19: Consumption by each end-use in industry sector in 2013.

Industry Subsectors	End-uses/Fuels type	Machinery	Lighting	Cooling systems	Other machine drive	Heating processing	Other	Total
Construction	Electricity(KWh)	73,349	30,562	18,338	65,199	-	16,300	**203,748**
Manufacturing		1,483,516	58,599	188,737	375,903	-	20,971	**2,114,310**
	Share in Const.	36%	15 %	9 %	32%		8%	100%
	Share in Manuf.	70 %	2.7%	8.8%	17.6%	-	0.9%	100%
	Share both	67%	3.8%	8.6%	19 %	-	1.6%	**100%**
Construction	Firewood (Kg)	-	-	-	-	-	-	**-**
Manufacturing		350,400	-	-	-	87,600	-	**438,000**
	Share in Const.	-	-	-	-	-	-	**-**
	Share in Manuf.	80%				20%		100%
	Share both	80%	-	-	-	20%	-	**100%**
Construction	Diesel	-	-	-	-	-	-	**-**
Manufacturing		259,780	-	-	-	43,474	-	**303,254**
	Share in Const.	-	-	-	-	-		
	Share in Manuf.	85.6%				14.4%		
	Share both	85.6%	-	-	-	14.4%	-	**100%**
Construction	Petrol	43,474	-	-	6,070	-		**49,544**
Manufacturing		-	-	-	-	-	-	**-**
	Share in Const.	87.7%	-		12.3%			
	Share in Manuf.	-	-	-	-	-	-	**-**
	Share	87.7%	-	-	12.3%	-	-	**100%**

Source : Based on Survey in industry sector,2018.

3.3.3.2 Development of the Energy Demand model

The energy demand in the industrial sector was calculated as:

$$Total\ energy\ consumption = The\ Share\ of\ activity\ enduse \times the\ energy\ intensity\ for\ each\ enduse. \quad \ldots\ldots. (5)$$

Where energy intensity for each sub-sector was calculated by using the total output for each sub-sector and the total energy consumption provided by the surveys data as shown the table 3.20 below:

Table 3.20: Industry end-use energy intensity values for electricity , diesel , and Firewood fuels.

End-uses / Indus. Subsector	Machinery			Lighting	Cooling	Others machine drive		Others	Process heating	
	KWh/tonne	L/tonne	Kg/tonne	KWh/tonne	KWh/tonne	KWh/tonne	L/tonne	Kwh/tone	L/tonne	Kg/tonne
Manufacturing	3.11	0.54	630.2	0.12	0.39	0.79	-	0.044	0.091	157.6
Construction	12.89	-	-	0.62	0.038	0.14	0.13	0.33	-	-

Source : Based on surveys data in Industry sector , 2018.

3.3.4 Transport sector

The transport sector in Bamako is characterized mainly by the public or common transportation by minibus called ‘Sotrama‘as shown the figure 3.5 below:

Figure3.5:Public transport minibus 'Sotrama'.

Source: Author, 2018.

. In 2011, the traffic percent was characterized as shown by figure 3.6below:

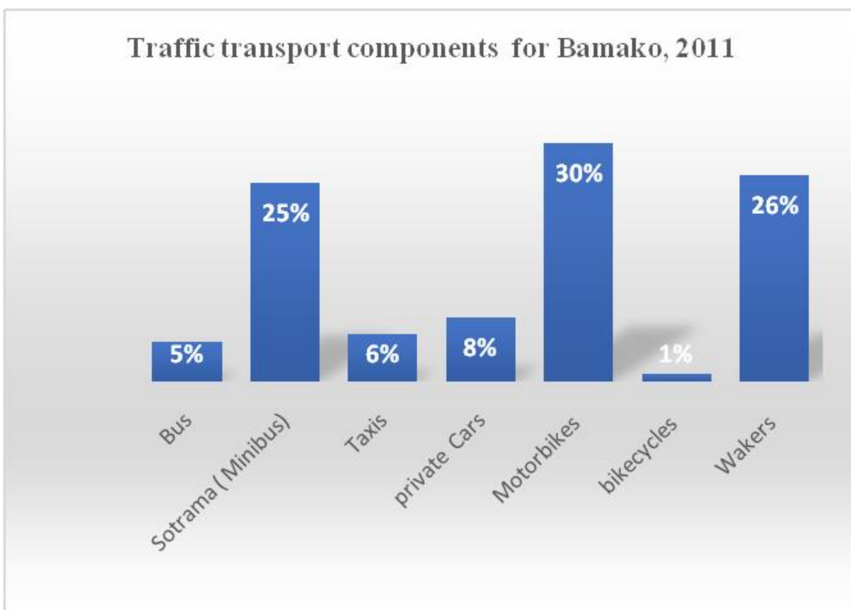


Figure 3.6: Traffic transport components for Bamako.

Source: Based on DRCTU, 2011.

3.3.4.1 Data collection

For the transport sector, the energy demand is split into the passenger and freight demands, where each has its own driver of demand. The total fuel consumed/ sold in the Bamako district was obtained from the National office of Petroleum, that included the direct survey undertaken for the other sectors (household commercial, and industrial). That means, the data inputs for the transport sector model were not carried directly form the surveys as other sectors.

The total fuel consumed or sales from the fuel service station in Bamako city for 2013 were 207,345,086 litres for the diesel and 40,547,586 litres for petrol as shown the table 3.21below:

Table 3.21: The petroleum fuels sold and number of stations services for Bamako in 2013.

No. of fuel station	**333**
No. of LPG station*	11
Avg.volume Petrol sold (litres)	**40,547,586**
Avg.Volume diesel sold (litres)	**207,345,086**
Avg.volume LPG sold (Kg)	**6,199,200**
*Main LPG Supplier.	

Source: Based on surveys Data in ONAP, 2018.

From the above information, the total energy balance was compiled regarding the total demand of each liquid fuel indicated by surveys for the other sectors (households, commercial, and industrial). However, it is important to notice that, the transport accounts for about 99.9 % of petrol and 99.8 % of diesel consumption in the district as shown in the table 2.22below:

Table3.22: Petroleum fuel energy balance for Bamako.2013.

			Diesel (L)	Petrol (L)	LPG (kg) *
Supply	Supply from fuel stations :		**207,345,086**	**40,547,586**	**61,992,000**
	Sector	Use			
Demand	Residential (Households)	Cooking	-	-	20,592
		Generators	3,780	60	-
	Industry	Machinery	259,780	-	
		Other machine drive	-	43,474	
		Process heating	43,474	6,070	
		Generators	34,400	1,800	-
	Commercial	Machine operations	-	-	-
		Cooking	-	-	6,408
		Generators	3,690	2,790	-
		Other	-	-	-
Demand subtotal			345,124	54,194	27,000
Balance to transport			206,999,962	40,493,392	61,965,000
Implied transport use % share of supply			99.8	99.9	-
Note : based on sample size surveyed					

Source: Based on ONAP and sample size surveys data, 2018.

For set up the model, the given data and review the results against known or common indicators such as yearly distance travelled by each vehicle as well as total fuel consumed were be necessary. The key inputs for this model were:

- **Vehicle count for each vehicle type**

The vehicle count for each vehicle type was obtained from the registration database and was adjusted in order to calibrate the amount of fuel consumed by the city, this justified also the fact that older vehicles may no longer operate or operate very little in practice as show in table 3.23below:

Table 3. 23: Vehicle count for each vehicle type and adjustment for Bamako, 2013.

Vehicle Type		Original data on vehicle count	Adjustment	New vehicle count	Adjustment justification
Bus	Heavy>60	2,922	100%	2,922	Did not change in fact that other logistic are not yet developed.
	Heavy<60	1,947	100%	1,947	
Minibuses (Sotrama)		10,711	100%	10,711	Did not modify due it is the major common passenger transport inside the city with a cheapest transportation price.
Car		115,043	90%	103,539	Some don’t operate in the city ,this also helps in balancing fuel consumption
Taxi		1947	90%	1,753	As above and plus the fact that taxi is somehow very expensive.
Motorbikes		12,890	100%	12,890	Did not modify since is a main Vehicle transport and this count appears very low.
Tricycles	Passenger	2,476	100%	2,476	Did not modify since is used in business as well as for passenger transport.
	freight	3,713	100%	3,713	
Light trucks-freight		4,886	100%	4,886	Did not modify since is used for many purposes.
Medium trucks-freight		11,399	100%	11,399	As above
Heavy trucks-freight		12,388	100%	12,388	As above

Source: Based on data surveys and discussion group in city, 2018.

- **Vehicle split by fuel type**

Data obtained from the surveys and registration database indicated that in Bamako city there were 136,238 Passenger vehicles and 32,386 freight vehicles operating in and around the city as shown the table 3.24 below:

Table 3.24: Vehicle split by fuel consumption in Bamako,2013.

Vehicle type		Vehicle Count	%share	Petrol(%)	Diesel(%)	LPG(%)
Bus	Heavy passenger vehicle>60	2,922	1.75	-	100	-
	Light passenger vehicle< 60	1,947	1.15	35	65	-
Minibuses(Sotrama)		10,711	6.35	47	53	-
Taxi		1,753	1.03	54	46	-
Car		103,539	61.40	42	58	-
Motorbikes		12,890	7.64	100	-	-
Tricycles(passenger)		2,476	1.47	-	100	-
Tricycles(freight)		3,713	2.20	-	100	-
Light trucks-freight		4,886	2.90	-	100	-
Medium trucks-freight		11,399	6.76	-	100	-
Heavy trucks-freight		12,388	7.35	-	100	-
Total		**168,624**	**100**	-	-	-

Source: Based on data surveys in transport sector ,2018.

- **Vehicle occupancy per trip**

The occupancy per trip, days of use per week, and vehicle return trips per day for each vehicle type was obtained from the different stakeholders involved in transportation in the city as shown in the table 3.25below:

Table 3.25: Vehicle occupancy per trip in Bamako.

Vehicle type		Occupancy (person per vehicle)	Vehicle return trips per day	Days of use per week	Total person/ week or tonnes/day
Bus	Heavy passenger vehicle>60	80	1	6	1,402,560
	Light passenger vehicle <60	30	2	6	700,920
Minibuses(Sotrama)		20	8	6	10,282,560
Cars		2	1	5	1,035,390
Taxi		2.5	6	6	157,770
Motorbikes		1.5	4	6	116,010
Tricycles (passenger transport)		6	8	6	713,088
Heavy trucks		-	-	-	5,400
Medium trucks		-	-	-	2,100
Light trucks		-	-	-	2,200
Tricycles (freight transport)		-	-	-	600

Source: based on data surveys in city, 2018.

- **Fuel economy (L/100 Km)**

The majority of the vehicle is the second hand vehicles, where sometime the efficiency is very low. The assumed fuel economies of each vehicle types used in this model are showed in table 3.26 below:

Table 3.26: Fuel economy (litres/100Km) by vehicle type in Bamako.

Vehicle types	Fuel economy (litres /100 Km)		
	Petrol	Diesel	LPG
Bus	-	30	-
Minibus (Sotrama)	15	13	-
	11	9	-
Taxi	11	9	-
Motorbikes	2.5	-	-
Tricycle	3.5	-	-

Source: based on data surveys in transport sector, 2018.

For the freight vehicles assumptions has been made as shown the table 3.27 below:

Table 3.27: Assumption of fuel economy for the freight transport.

Vehicle type	Fuel economy (litres / 100 Km)	
	Petrol	Diesel
Tricycle* (freight)	3.5	-
Light trucks	20	18
Medium trucks	40	38
Heavy trucks	-	50

*tricycle is used for both passenger and freight transport.

Source: Based on data surveys in transport sector, 2018.

3.3.4.2 Development of the Energy Demand Model

The Bamako LEAP model general approach for sectors was to employ a calibrated supply and demand modeling methodology. The fuel consumption was adjusted such as the sum of the total fuel supply in the city. This Common energy modelling methodology hinges the fact that the district can only influence the planning decision within the district. Clearly, bounded area like Bamako district is a generator and attractor of the trips in the case of transport sector needs to define properly in contrast with the unbounded model which doesn't take into account the supply energy statistics and may have a highly uncertain without a great deal of detailed measurements. To deal with this issues of boundaries and the local –scale of GHG emission inventories, the global protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC protocol) has developed a standardised approach (SAMSET,2015). The data and models be organised in different scopes which tackle the spatial problem in three different ways:

Scope 1: the trips that start and end in the boundary area only are considered. Upstream emissions integrated in energy carriers like diesel, petrol, and electricity are not considered.

Scope 2: Upstream emissions from electricity generation

are included.

Scope 3: They originate and end transboundary trips within the bounded are added. Some methods may be total trip considered. However, the approach of including the activity is preferred, whereby 50% of the length that happens outside the boundary area is accounted and the one, which pass through is excluded as shown in figure 3.5below:

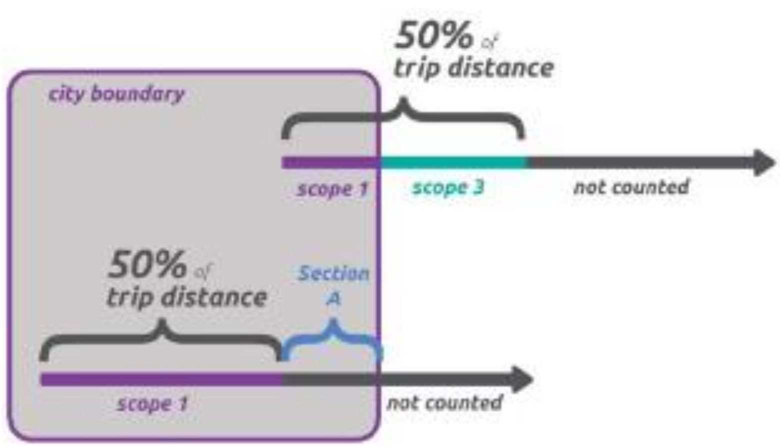


Figure 3.5 : Induced activity method for accounting for transboundary trips in GHG inventories.
Source: SAMSET, 2015.

It is important to notify that, the sophisticated traffic models for a city are recommended to track transboundary trips to this level of detail.

The methodologies used in a GHG inventory of the city advocate by the GPC protocol are (McCall et al., 2015):

- **Fuel sales approach:** GHG emissions based only on the fuel sold within the boundary area are considered.
- **Considered activity approach**: where GHG emissions from intra-boundary trips and 50% of the transboundary trips are estimated from traffic models and surveys.
- **Geographic or territorial approach**: GHG emissions only from the activity within the city's boundaries are included. However, some European traffic models usually used the local air pollutant for make this estimations (McCall et al, 2015).
- **Resident activity approach**: Where only GHG emissions from resident's activity in the city are included. This implied the surveys for the resident behavior and vehicle registration records but is limited due to the non – contribution of non-residents.

3.3.4.2.1 Selected scope for transport sector

For this study, the scope 1 had be considered for the transport energy model as shown the figure 3.6 below:

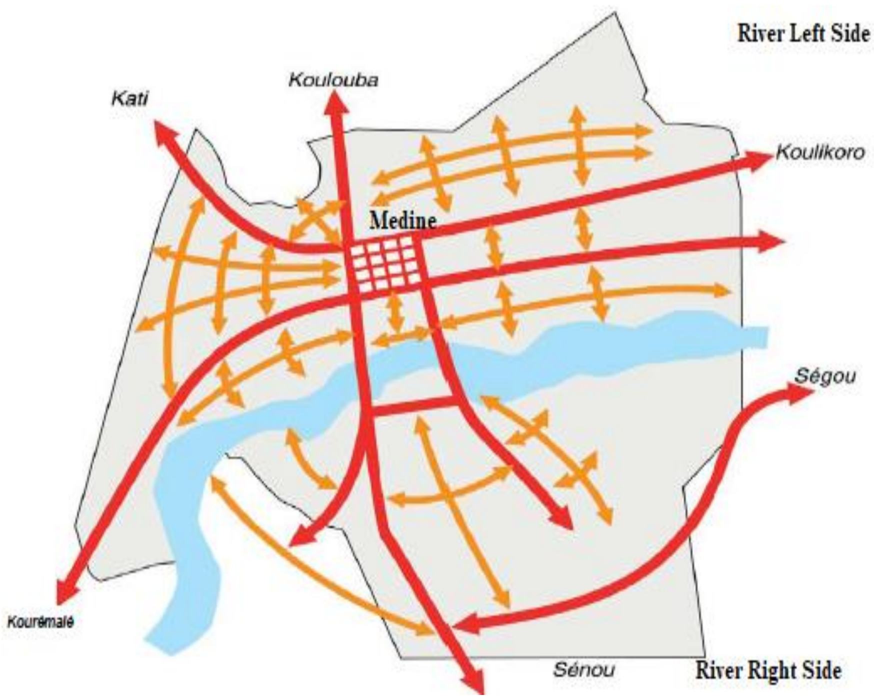


Figure 3.6: Traffic flux inside Bamako.
Source: Based on DRCTU, 2011.

- **Assumption on frequency of fill-ups for each vehicle that occurs in Bamako**

Since the mainly traffic is oriented toward the downtown (Medina-Coura) through five main corridors(DRCTU., 2011) as shown the figure below , the trips to and from Medina Coura needed to be accounted. This aspect adds more complexity for the fuel balancing when it comes for fuel used as the boundary of the city is now' porous' as showed above. Thus the total passenger-km demand for this model is set to account for the local (focused on started of the five main corridor) and 'Medina- Coura 'for trips that vehicle may take during the year and how much Bamako would be possible to effectively fueling it is based data collected and necessary assumptions.

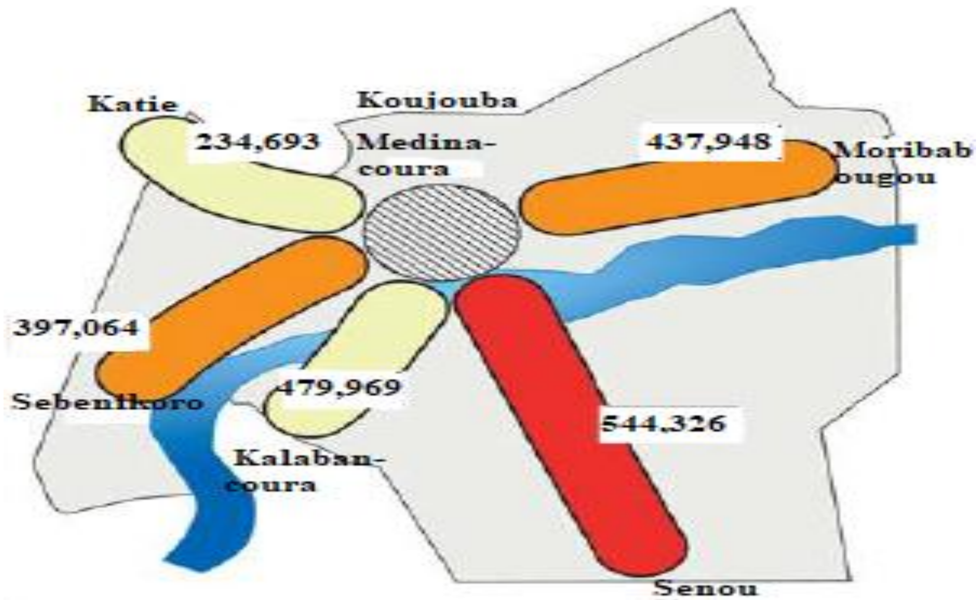


Figure 3.7: Population and main corridors in Bamako.

Source: Adapted from DRCTU, 2011 and ASDB , 2015.

The total passenger –Km demand for the transport model is set up to account for the trips between the six communes that a vehicle may take during the year, and how much Bamako district would be responsible for fueling is based on data provided during the survey and necessary assumptions.

The total effective passenger –km demand as seen by Bamako district fueling stations was follows the equation below (MCcall et al, 2016):

$$Total\ pass.km\ demand = \sum_V EAM_v \times Veh\ count_v \times Avg.Occupancy_v \ldots\ldots\ldots\ldots (6)$$

Where EAM denotes the Effective Annual Mileage (in Km per year) of each type of vehicle (V):

$$EAM = \sum_t R_{t,v} \times (\%\ Trips\ Serviced\ by\ Bamako\ District_{t,v} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where, $R_{t,v}$ is the total return trip Km for each trip type (t is either for commune or downtown "Medine") and for each vehicle type (V) for a year :

$$R_{t,v} = 2 \times (\ 1\ way\ trip\ distance\ )_{t,v} \times (\ total\ return\ trips\ per\ year\ )_{t,v} \times (Trip\ Split\ \%)_{t,v}$$

…………………………………………………………………………………………………… (8)

The distance between Medina coura and each corridor is showing in table 3.28 below:

Table3.28: Distance between Medina-coura and each corridor.

Local *	Medina-coura " Downtown"
Kati	15 Km
Senou	19 Km
Kalabancoura	8.2 Km
Sebenikoro	8.8 Km
Moribabougou	12.8 Km
local *	**63.8 Km**

***Local** is define here is a starting point of the corridor inside the city (intra-boundary).

****** All different local points had been focused in one point (total local) for this work

Source: Based on surveys in transport sector, 2018.

3.3.4.2.2 Passenger transport

The basic assumptions for the passenger transport model adopted is showing in table 3.29 below:

Table 3.29: Basic assumptions for a passenger transport model adopted.

Vehicle type (V)	% mileage on the way (a)	1 way trip distance – Km(b) Return trips per day	Trip per Day	Days of trip Use (c)	Total return trips/year
	Local* to Medina-coura	Local* to Medina-coura	Trip /day	Days/ year	
Bus	60	63.8	4	317	1,268
Minibus (Sotrama)	24	63.8	8	317	2,536
Taxi	24	63.8	6	317	1,902
Car	10	63.8	1	269	269
Tricycle	24	63.8	8	317	2,536
Motorbike	15	63.8	2	317	634

(a)Assumptions

(b)Local* distance (five main corridors) to Medina-coura.

(c) group discussion with stakeholders.

Source: Based on surveys data in transport sector, 2018.

The passenger travel between Medina-coura and local * (five main corridors) is represented in the table 3.30below:

Table 3.30: Passenger travel between Medina-coura and local (sum of corridors).

Vehicle Type	Total Km of return trips	True mileage (Km/year)	Return trips/day serviced by Bamako (assumptions)	Vehicle Km serviced by Bamako	Total(Kmyear)
	Local* - Medina-coura		Local*- Medina coura	Local*Medina-coura	Total
Bus		48,539	100%		48,539
Minibus (Sotrama)		38,831	100 %		38,831
Car		1,716	100%		1,716
Taxi		29,124	100%		29,124
Tricycle		38,831	100%		38,831
Motorbike		6,068	100%		6,068

Source: Based on surveys data in transport sector , 2018.

From the assumptions for the distance travelled per day and the vehicle occupancy yields, the passenger transport demand for each type of vehicle was calculated as shown in table 3.31below:

Table 3.31: Passenger transport demand by vehicle type.

Vehicle type		Effective annual mileage(vehicle km/year)	Total demand based on mileage serviced by Bamako, vehicle count and occupancy (passenger-Km/year)
Buses	Heavy passenger	48,539	11,346,476,640
	Light passenger	48,539	2,835,162,990
Minibuses (Sotrama)		38,831	8,318,376,820
Car		1,716	355,345,848
Taxi		29,124	7,520,370
Tricycle (Passenger)		38,831	576,873,336
Motorbikes		6,068	117,324,780

Source: Based on data surveys in transport sector, 2018.

Then the total fuel consumption for the passenger transport model by vehicle type had been estimated as shown the table 3.32below:

Table 3. 32 :Total fuel consumption for the passenger transport model by vehicle type.

Vehicle type		Fuel consumption (litres)		
		Petrol	Diesel	LPG
Buses	Heavy passenger	-	42,546,287	-
	Light passenger	10,593,151	18,420,550	-
Minibuses (Sotrama)		2,943,128	28,657666	-
Cars		8,208,417	9,274,585	-
Taxi		3,033,847	2,112,655	-
Tricycles		3,365,094	-	-
Motorbikes		1,955,413	-	-
Total		**30,099,050**	**101,011,743**	-

Note :

Source: Based on surveys data in transport sector,2018.

3.3.4.2.3 Freight transport

For the freight transportation service, the assumptions assumed based on vehicle count data is showing in table 3.33 below:

Table 3.33: Assumption based on vehicle count for freight transport.

Vehicle type	Fuel split		Capacity load (tonnes)	Assumed load factor	Annual-Km*
	Petrol	Diesel			
Tricycle	-	100%	1	50%	38,831
Light trucks	-	100%	1	50%	38,831
Medium trucks	-	100%	8	50%	48,539
Heavy trucks	-	100%	20	50 %	56,628

*Based on assumptions and group discussion.

Source: Based on surveys data in transport sector, 2018.

From the fuel economy assumption for freight transport and the table above, the inputs for the freight transportation is showing on table 3.34 below:

Table 3.34: fuel economic and annual activity for freight vehicle type.

Vehicle type	Tonne-Km	MJ/Tonne-Km
Tricycle	23,298,600	1.75
Light trucks	85,428,200	12.9
Medium trucks	101,931,900	3.14
Heavy trucks	305,791,200	1.8

Source: Based on surveys on transport sector ,2018.

The inputs data for both passenger and freight transport locally refueled in the city is showing on the table 3.35below:

Table3.35: Inputs for passenger and freight transport in Bamako , city.

Locally refueled	Passenger-Km	% share	MJ/passenger-km
Passenger	**23,557,080,784**		
Public	**23,084,410,156**		
Bus(heavy passenger Diesel)	11,346,476,640	49.16	0.12
Bus(Light passenger-Petrol)	932,307,046	4.03	0.36
Bus(Light passenger-Diesel)	1,902,855,944	8.25	0.31
Minibuses Sotrama - Diesel)	4,408,739,715	19.09	0.208
Minibuses (Sotrama-Petrol)	3,909,637,105	16.93	0.024
Taxi (Diesel)	3,459,371	0.015	19.54
Taxi (Petrol)	4,060,999	0.018	23.90
Tricycle(Petrol)	576,873,336	2.49	0.19
Private	**472,670,628**		
Car (Diesel)	340,500,592	72.04	0.87
Car(Petrol)	14,845,256	3.14	17.69
Motorbikes(Petrol)	117,324,780	24.82	0.53

Note: transboundary had been missed due of no available data for this sub-category

1 litre of petrol for transport = 32 Mega joules

Freight transport

Locally refueled	Tonne-Km	% share	MJ/tonne-km*
Freight	**5,509,302,600,000**		
Tricycle	86,507,701,800	1.57	0.00047
Light vehicle trucks	417,402,185,200	7.58	0.0026
Medium vehicle trucks	1,217,251,300,000	22.09	0.00026
Heavy vehicle trucks	3,788,141,400,000	68.76	0.00014

*The small value can be due on mileage considered in this work.

Source: Based on surveys data in transport sector, 2018.

3.3 Energy supply

It true that most of our analysis will be based on demand side but it is important to know the energy supply. The energy supply was focused on Electricity generation from own generator.

3.3.1 Own- generator data

3.3.1.1 Household sector

In the sample for the Household sector the data surveys revealed, 10 KW for the petrol generators and 120 KW for the diesel (gasoline) generator only in the electrified households. The own generators usage for both household's sub-categories is showing on the table 3.36 below:

Table3.36:Characteristics own generator usage in household sector in Bamako.

Household Category	Generator type	Capacity (KW)	Capacity factor	Sample count
Electrified	Petrol	10		1
	Diesel	120		6
Unelectrified	-	-	-	-

Source: Based on surveys data in household sector, 2018.

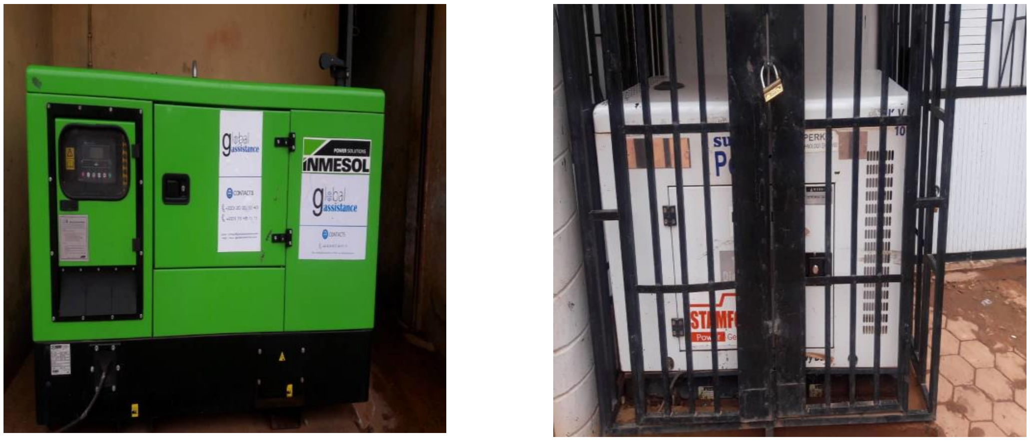


Figure 3.8: Generator in household sector.

Source: Author, 2018.

3.3.1.2 Commercial sector

In the sample for the commercial sector the data surveys revealed, 201 KW for the petrol generators and 240 KW for the diesel (gasoline) generator mainly in the formal sector and petrol generator for the case of informal sector. This difference can be attributed to the higher cost of the diesel (Gasoline) generators and because most of the time these machines have higher capacities and the case of the high petrol generator in informal sector can be attributed to the development of the informal stations service (mainly petrol product) across the city and the price is almost cheaper than the one applicable by the formal station service. The own generator usage for both commercial sector is showing on the table 3.37 below

Table 3.37: Characteristics own generator usage in commercial sector.

Generator Type	Commercial subsector	Capacity (KW)	Capacity factor%	Sample count
Petrol	Formal	40	0.25	2
	Informal	161	0.65	22
Diesel	Formal	120	0.75	6
	Informal	120	0.75	12

Source: Based on surveys data in commercial sector, 2018.

3.3.1.3 Industrial sector

In the sample for the industrial sector, data surveys revealed 0 KW petrol generators and just 1,176 KW gasoline generator and mainly in the manufacturing sub-sector. The generators characteristics in the both sub-sectors are showing on the table 3.38 below:

Table 3. 38: Characteristics of own generator usage in industry sector.

Sub-sector	Type of generators	Installed capacity(KW)	Capacity Factor
Manufacturing	Diesel	1,000	0.80
Constructions	Diesel	176	0.80

Source: Based on surveys data in industry sector, 2018.

It is important to notify that both monthly and annual volumes of diesel (gasoline) and petrol consumed were recorded as well as the monthly and annual expenditures for the fuels, because in few case there was expenditure data but no volume data and vice versa. The trends of petroleum products had been used as shown the figure 3.9 below :

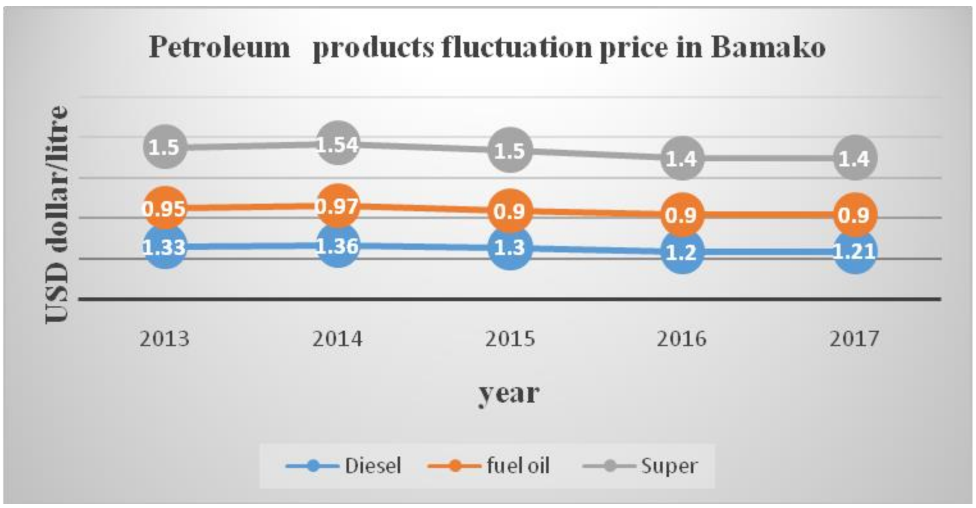


Figure 3.9: Fluctuation price of petroleum products in city for the last five year.

Source: Based on ONAP data. 2018.

3.3.2 Electricity generated calculation

3.3.2.1 Household and Commercial sector

Converting the volumes of fuel consumed to an estimate of KWh generated for the household and commercial sectors, the methodology refers to both samples and models for petrol and diesel (gasoline)were developed based on published data by various manufacturers (see Appendix C). The equations are:

For petrol-fuelled generators of capacity < 20 KVA where a load factor has been assumed:

$$\mu_p = 1.03 \times 10^{-1} \times Load\ Factor + 4.04 \times 10^{-3} \times R_p + 6.18 \times 10^{-2} \ldots\ldots\ldots\ldots (9)$$

$$VC_p = R_p/(CV_p \times \mu_p) \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

For petrol-fuelled generators of capacity > 20 KVA or where a load factor is not assumed:

$$VC_p = 5.33 \times 10^{-1} \times R_p + 5.00 \times 10^{-2} \quad \text{....(11)}$$

For diesel-fuelled generators of all capacities where a load factor has been assumed:

$$\mu_D = 1.26 \times 10^{-1} \times Load\ Factor + 5.00 \times 10^{-2} \quad \text{.. (12)}$$

$$VC_D = R_D/(CV_D \times \mu_D) \quad \text{(13)}$$

Where:

- VC = volumetric consumption (litres / hour)
- R = generator rating or capacity (KW)
- P means petrol and D means Diesel
- µdenotes the thermal efficiency of the generator
- Load factor is the ratio of average load to rated load in operation and is between 25% and 100%
- CV denotes the calorific value of the fuel, for this study, it was assumed to be 8.94 KWh/litre and 9.93 KWh / litre for petrol and diesel respectively.

It is important to notify that, by assumed the fuel consumption rate for each type of generator in the sample, we can easily estimate the average time of use of the generator.

On average, household use a generator for 0.7 hours per day, formal businesses use generators for 1.3 hours a day, and informal businesses 0.9 hours per day.

3.3.2.2 Industrial sector

Converting the fuel consumed to an electricity on industrial sector were followed the methodology below (MCcall and al,2016).

$$FC_p = 0.598R_p + 0.566 \quad \text{(14)}$$

$$FC_D = 0.3192\ R_D \quad \text{(15)}$$

$$E_p = V_p/(FC_p \times R_p) \quad \text{(16)}$$

$$E_D = V_D/(FC_D \times R_D) \quad \text{(17)}$$

Where:

FC: Volumetric consumption.

- R: Generator rating (KW).
- V: Annual fuel consumed.
- P and D: petrol and diesel respectively.
- E : Annual electrical energy produced (KWh)

3.3.4 Predicting the future energy Demand

3.3.4.1 **Main factors and Assumptions**

For this study population growth, urbanization and economy are assumed to be the main factors which drive the overall activity and hence energy consumption in Bamako.

3.3.4.1.1GDP economy

The national annual GDP growth rate is showing in table below. Although the country has improved its national growth in the last 10 years as a whole, the has been halted by the surge of energy shortage, local conflicts (impact on Mali supply chain) and declining security. Mali's economic growth as largely been driven by agriculture sector, which accounts for almost 40% of the national economic, followed by industry and commercial sector.

Table 3.39 :Trends of GDP annual growth of Mali

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
GDP Growth %	7.6	4.4	7.7	2.8	6.1	5.3	5	5	5.2	5.2	5.2	5.2

Source: Trading Economics Website, 2017

The economy of Mali growth between 4.4 % to 5.2 % from 2005 to 2016. It is assumed that, since Bamako is a main city of activity of the country, the local economy of the city would closely track that of the country. From the Trading-Economics' Website ', which complies many indicators and statistics for countries, the growth trend for Mali will likely remain relatively constant through to 2016 with around 5.2 % year on year on average. The following assumptions were made for this scenario regarding economic growth:

- remain constant to 5.2 % till 2022
- the economy will slow somewhat to 4.7 % year-on-year growth on average from 2022 to 2033.

For the same period of time the GDP per capita per is showing in the table 3.40 below:

Table 3.40 : Trends of annual GDP per capita growth.

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
GDP per capita Growth %	3.14	1.27	0.09	1.34	1.32	2.38	0.14	-3.72	-0.62	3.92	2.89	2.70	2.19

Source: World bank data, 2018.

The assumption was made for this scenario regarding economic growth per capita, it remains constant to 2.19 till 2033.

3.3.4.1.2 Urbanization

Urbanization will follow the number of household divided by the household size and the annual growth rate will be 4% from 2013 to 2033.

3.3.4.1.3 Population

The population growth rate assumed till 2033 is the average growth for all the six communes such 5% annually.

3.3.4.1.4 Fuel prices

The price in FCFA and USD of the petroleum products in Bamako were obtained during data collection as shown in table 3. 41below:

Table 3.41: Average trends of liquid petroleum products and LPG prices (FCFA/litre; USA/litre).

		2013		2014		2015		2016		2017	
		FCFA	USD	FCFA	USD	FCFA	USD	FCFA	USD	FCFA	USD
Diesel	Normal	665	1.33	678	1.36	646	1.30	591	1.20	605	1.21
	Distillate	665	1.33	678	1.36	646	1.30	591	1.20	605	1.21
Petrol	Fuel oil	474	0.95	484	0.97	453	0.90	417	0.90	415	0.90
	Super	748	1.50	770	1.54	744	1.50	683	1.40	693	1.40
Kerosene	-	555	1.11	537	1.07	568	1.14	684	1.40	Free price	
1 USD = 500 FCFA											

Source: Based on data surveys in ONAP, 2018.

It is assumed that the prices of petrol, diesel and LPG will follow the trend of the international crude oil prices. The projection of the crude oil prices by the work bank is given in table 3.42 below:

Table 3.42: Expected cost of crude oil , as projected by world bank to 2025.

	2013	2014	2015	2016	2017	2018	2019	2020	2025	2033 *
Real 2010 USD	98.1	90.9	56.8	58.2	59.7	61.2	62.2	62.7	70.8	78.8
*extrapolated followed the trends.										

Source: MCcall et al., 2016.

The cost of charcoal and wood reported by survey is shown in the table 3.43 below:

Table 3.43: Trends of solid fuel and LPG prices (FCFA/Kg ; USD/Kg).

	2013		2014		2015		2016		2017		2018	
	FCFA	USD	FCFA	USD	FCFA	USD	FCFA	USD	FCFA	USD	FCFA	USD
Wood (Kg)	50	0.09	48	0.09	48	0.09	50	0.1	50	0.1	50	0.1
Charcoal (Kg)	100	0.20	100	0.20	109	0.21	112	0.22	114	0.23	120	0.24
LPG(Kg)	583.3	1.16	583.3	1.16	583.3	1.16	583.3	1.16	583.3	1.16	583.3	1.16
1 USD = 500 FCFA												

Source: Based on surveys data in Bamako,2018.

By assuming an exchange rate of 500 FCFA to a USD, the fuel prices shown in table 3.44below are assumed in the Bamako model for the base year is:

Table 3.44: Price of solid and liquid fuels in Bamako,2013.

Fuel type		Price in USD Dollar per Unit *
Wood (Kg)		0.09
Charcoal (Kg)		0.2
LPG (Kg)		1.16
Diesel (Litre)		1.33
Petrol (Litre)	Fuel oil	0.95
	Super oil	1.50
Kerosene (Litre)		1.11
*1USD=500FCFA		

Source: Based on data surveys in city ,2018.

3.3.4.1.5 Electricity Prices

Despite the effort took by the government to afford the electricity for the population, the price still high and it is considered as one of the highest in the region and varied from the range of consumption and the types of the voltage lines as shown the table 3.45 below:

Table 3.45: Electricity tariff in Bamako.

Voltage Lines	Category	Range of Voltage consumption	Prices FCFA/ KWh	Prices USD/ KWh
Low Voltage line (5A-400V)	Social Tariff (2 lines Metering – 5 A)	0-50 kWh	59	0.12
		51-100 KWh	94	0.18
		101-200 KWh	109	0.22
		Above 200 KWh	130	0.26
	Normal Tariff (4lines Metering –5 A)	0-200 KWh	109	0.22
		Above 200 KWh	130	0.26
	Tariff of Street lighting:			
	-For the first 120 Hours	n.o	114	0.23
	- Above 120 Hours	n.o	79	0.16
Medium Voltage line (10 A-15KV)	Single Tariff :Power subscript below 25 KW	n.o	110	0.22
	Twice Tariff:		Negotiate for a specific case	Negotiate for a specific case
	-Prime Fix Annually	n.o		
	-Proportional price:			
	*High time demand (6pm-00pm).	n.o	110	0.22
	*Full time 6am-6pm).	n.o	75	0.15
	*Low time demand (00pm-6am)	n.o	55	0.11
	Tariff of Street lighting	n.o	110	0.11
1 USD = 500 FCFA ; n.o : no range				

Source : Based on EDM- SA Report, 2015.

3.3.5 Scenarios descriptions

3.3. 5.1 Business –As- Usual Scenario (BAU)

Basic assumptions and data has been used to inform the Business as usual scenario for the city of Bamako that will be the baseline against which to measure the scenarios interventions for this study the key drivers are summarizing in the table 3.46 below:

Table 3.46: BAU key factors driven assumptions summary.

Key parameters	Assumption in BAU
Urbanization growth rate	4% still 2033
Population growth rate	5 % still 2033
GDP growth rate	5.2 % still 2022 , slow somehow 4.7% still 2033

3.3.5.1.1 Household sector

The population growth rate of Mali has previously been very high, due to the high fertility rates and declining of the mortality. The country is, however, experiencing a demographic transition as fertility rates decline, due to the higher school enrolment especially for girls and changing economic opportunities, attributing to major declines in under-18 fertilities (ASDB,2015).

Household growth is mainly influencing by urbanization. As a capital city with main economic activity and the problem of security the northern part of the country, Bamako receives a lot of inward migration of household seeking access to opportunities afforded in the cities. Geographically, this city is experiencing one of the highest rate of urban growth and fastest population growth (world-growth cities, 2011).

It was assumed that, based on the survey that, the Annual average household growth will follow the population growth and the house size and will be 5 % until 2033. The composition of household categories is projected to change as shown the table 3.47below:

Table 3.47: Changes in households composition by category.

Category	Share in 2018 (%)	Project share in 2033(%)
Electrified Households	93.3	88.3
Unelectrified Households	6.7	1.7

3.3.5.1.2 Commercial sector

The projection of the energy demand for the commercial sector is driving by the floor-space and for each sub-sectors (Formal and informal), the following assumption has been made:

The formal sector will follow the economic growth of the country with and elasticity of 0.8 whereas the informal commercial sector will follow the population growth rates of the city since it is a driven largely by the incapacity of the formal economic to create or generate a job (Mccall et al., 2016).

3.3.5.1.3 Industry Sector

The projection of the demand for the industry sub-sectors are driving by the following assumptions:

- Construction sub-sector: follows local economy growth with elasticity of 0.6
- Manufacturing sub-sector: follows local economy growth with elasticity of 0.6

It is important to notify that, for the case of BAU scenario, no change is observed in the industry sector for Bamako until horizon 2033.

3.3.5.1.4 Transport Sector

For a transportation sector, the assumptions have been made regarding the freight transport, corridor transport, and the passenger transport (checking future passenger- Km demand).

3.3.5.1.4.1 Freight transport

It was assumed that, the projection follows the output from industry within Bamako. that means that the use of freight transport is linked to the activity of these industries within the city.

3.3.5.1.4.2 Passenger transport (Checking future passenger –Km demand)

The GDP per capita is usually used to estimate the future passenger-km demand, as followed the fact that, mobility is linked to the wealth of the citizens. However, this formulation of the GDP over the population would mean that a scenario where population growth outstrips, economic growth would result of the declining in transport demand. The one, which keeps the GDP per capita as the key component to transport demand and doesn't allow the net declined of the transport demand with the population growth has been used and it is highlighted below:

Private passenger demand is directly proportional to motorization (Vehicle per thousand people), which in proportional to GDP per capita (McCall et al, 2016). This can be looked as linear function of the GDP per capita:

$$M \approx K\left(\frac{GDP}{POP}\right) \quad (18)$$

Where K denotes a constant to calibrate the base year values (in the year 2013 of the model)

Then the number of private vehicle (cars "with 4 wheels" and motorbikes "with two wheels") are respectively:

$$ncars = M \times Population \times 1000 \quad (19)$$

$$nmotorbikes = M \times Population \times 1000 \quad (20)$$

Again this is calibrated to the base year value for Bamako based on survey and this is 103,539vehicles of the active four wheel private vehiclesand 12,890 motorbikes of the active two wheel private vehicles).

Then, the privately population that is motorized is:

$$mPop = Occupancy_{cars} \times cars + Occupancy_{motorbikes} \times motorbikes \quad (21)$$

Where occupancy for a base year value is assumed to be 2 peoples per car and 1.5 peoples per motorbike.

From there the private passenger –Km demand is expressed as follows:

$$Pass.Km\ demand = Occupancy_{cars} \times Avg\ Mileage_{cars} \times cars + Occupancy_{motorbikes} \times Avg\ Mileage_{motorbikes} \times motorbikes \qquad (22)$$

Where Avg Mileage denotes the weighted average of 4 wheel and 2 wheel private vehicles (private cars and motorbikes assumptions respectively) from the analysis in the transport sector of this study.

Population without private car motorization is then:

$$WCAP = Population - mpop \qquad (23)$$

From there, the passenger- Km demand for public without private car is:

$$Pass.Km\ Public = x \times WCAP \qquad (24)$$

Where x is used to calibrate to the base year values in the transport model

For such formulation, the demand for private transport is driven by population and income while the demand for public transport is driven by the growth in the population without access to a car.

For the BAU scenario, the transport sector is represented as follows:

- Private passenger Km transport demand is driven by the GDP per capita while the demand for public transport passenger –Km demand is driven by the population without access to a car. Occupancy rates, and similar fuel efficiencies are assumed tohave the same characteristics of the base year till 2033 for the private transportation, light vehicles, and tricycles.
- Future public transport is assumed to have the similar characteristics to the base year till 2033.
- Freight tonne-Km is driven by local industry growth.

3.3.5.2 Sensitivity scenario Tests

The impact of an Alternatives view of economic growth or population growth in the energy consumption of Bamako LEAP model we be explored and analyzed.

3.3.5.2.1 Population increase

In this scenario called High population growth scenario, there is an increase in population growth by 6 % till 2033.

3.3.5.2.2 Constant and increased GDP growth increase

In those scenarios, for the first one called constant GDP growth rate scenario, the general economy of Bamako does not decrease in growth by 2022 as in the BAU scenario and the growth will be continued to be observe at the same level of 5.2 % still 2033. For comparison with the second one called Higher DGP growth rate scenario where the GDP growth rate increases to 7.5% by 2017 still 2033 will be also considered.

3.3.6 Alternatives Scenarios descriptions

For this study, in addition to the reference scenario (business as usual) alternatives scenarios interventions were developed and the philosophy behind each scenario is summarizing in the table 3.48below:

Table 3.48: Philosophy behind the scenarios adopted for the Bamako case.

Scenario	Philosophy
Universal Access	Focused on moving Household from traditional biomass – based fuels to more modern clean energy use sources such as electricity and liquefied petroleum gas (LPG). However it is only affects energy use in the households and informal commercial sectors with wood and charcoal use for cooking moving to electricity, biogas and liquefied petroleum gas (LPG).
Energy Efficiency	Energy Efficiency can be found in all the different sectors In the residential sector, Energy Efficiency reflect the more efficient use of the electricity. Commercial land Industrial Sector Energy Efficiency gains were implemented for all end-use based on best practice assumptions. In Transportation sector, the model efficient were followed that the proportion of passenger kilometers attributed for public transport were maintained or slightly increasingly into the future and the energy intensity for the freight vehicle was improved over the time. Essentially, this reflects a situation where, despite rapid urbanization, the current relatively high proportions of public transport are maintained into the future rather than the less efficient alternative, which is an increasing shift to private vehicles.
Reference or Business As Usual Scenario	In this Scenario current trends and GDP and population relationships with energy demand and the government energy target are assumed to remain relatively unchanged. This is a 'do nothing different' scenario, and forms a projection baseline to assess the impact of interventions in other scenarios.

3.3.6.1Efficient fridges (EFR) scenario.

This scenario, had focused in households and behind this scenario fridges technologies had changed and it assumed that:

- Efficient fridge is less 50% electricity consumed than the old one.

3.3.6.2Efficient Cook Stoves (EST) Scenario.

Since 1992, the government had launched the programme to provide efficient cooking stoves in household, which had stopped after four years, then new same programme had be launched for the period of 2004 to 2015 where 1,581,947 stoves had been distributed but some households did not beneficiate for the programme (FONABES, 2017). by considering such programme to be launch twice time by the government for the coming fifteen years. It assumed that for this scenario:

- 5% of the household which used inefficient stove will shift to efficient stove for the first programme (2020-2024), then other 10% for during the second programme (2024-2033).
- Efficient stove is 50% less charcoal consumed than inefficient one.

3.3.6.3 Access to clean and modern energy (ACC) scenario.

Behind the universal access to modern and clean energy scenario for households and industries (manufacturing) sector, the following assumptions had been taken:

3.3.6.1.1 Household sector

3.3.6.1.1.1 Cooking and water heating

The impact of the fuel consumption in the household sector by increasing the access and utilisation of modern energy fuels for lighting and cooking Mainly LPG and electricity will be explored for this scenario. The increasing of using clean fuels in this scenario starting in 2022 through to 2033. We assume that most of households would prefer to cook on gas (LPG) than electricity.

So the percentage and energy intensity of the households, which shift to traditional biomass used to LPG and electricity are showed respectively in table 3.40 and table 3. 49 below:

Table 3. 49: Sharing percent of households for cooking & water heating in ACC scenario.

Household sub-category	End-use	Shares in % for 2033(2013)		
		Electricity	LPG	Charcoal
Electrified	Cooking &heating water	38(18)	59 (29)	40 (79)
	Other appliance use	25 (15)	-	-
Unelectrified	Cooking & heating water	-	30 (0)	49 (84)
	Other appliance use	-	-	-
Note : Share doesn't need to be 100% as some household are used several type of fuel.				

It assumed that, the use of charcoal will decrease, thus the average intensity of clean fuels usage increases while the one of charcoal decreases. It assumed that the average intensity usage of charcoal 75% .

Table 3.50 : Energy intensity for cooking &water heating for household in ACC scenario.

Household sub-category	End use	Intensity value GJ/HH for 2033 (2013)		
		Electricity	LPG	Charcoal
Electrified	Cooking	2.12 (1.5)	1.4(0.8)	6.6 (26.4)
	Other appliance use	2.08 (1.19)	-	-
Unelectrified	Cooking	-	-	0.45 (1.8)
	Other appliance use	-	-	-
Note:1KWh Electricity =0.0032 GJ ; 1Kg LPG =0.031GJ; 1Kg Charcoal =0.028 GJ; 1 Kg Dry firewood=0.016GJ.				

3.3.6.1.2 Industrial sector (manufacturing)

3.3.6.1.2.1 Machinery and processing water heating

This scenario is focused in the replacement of the used of firewood by electricity in machinery and processing water heating.

The percent share and energy intensity for machinery and processing heating water for this case are showed respectively in table 3. 51 and table 3.52 below:

Table 3.51: Sharing percentage of manufacturing for machinery for ACC scenario.

Industry sub-sector type	End-use	Shares % in 2033 (2013)	
		Electricity	Firewood
Manufacturing	Machinery	90(70)	60 (80)

it assumed that energy intensity of the electricity increase by 75% while the one of firewood decease as same percentage and this for the two end-use.

Table 3.52 : Energy intensity for machinery for manufacturing in ACC scenario.

Industry sub-sector type	End-use	Intensity value GJ/tonne for 2033(2013)	
		Electricity	Firewood
Manufacturing	Machinery	0.09 (0.05)	2.52 (10.08)

Chapter 4: Modeling Results for Bamako city, Mali

4.0 Introduction

In this chapter, the results of the Bamako LEAP model would be present and analyse. First of all, the energy demand projection from the year 2013 to 2033, for the energy demand projection, the Business as Usual scenario by sector, by fuel and sensitivity scenario tests would be present, then the energy supply through the own- generators for electricity generated by different key sectors, and end, Alternatives Scenarios such Efficient Fridges Scenario (EFR), efficient cook stove scenario (EST), and Households Access to Modern Energy Scenario (ACC).

4.1 Business as usual scenario (BAU) Results

The business as usual scenario, the energy consumption for each sector and by fuel types from the year 2013 to 2033 was presented and analyzed:

4.1.1 Energy consumption per sector and by fuel types.

4.1.1.1 All the key sectors.

The total energy consumption and the fuels types by the keys sectors of consumption are shown below:

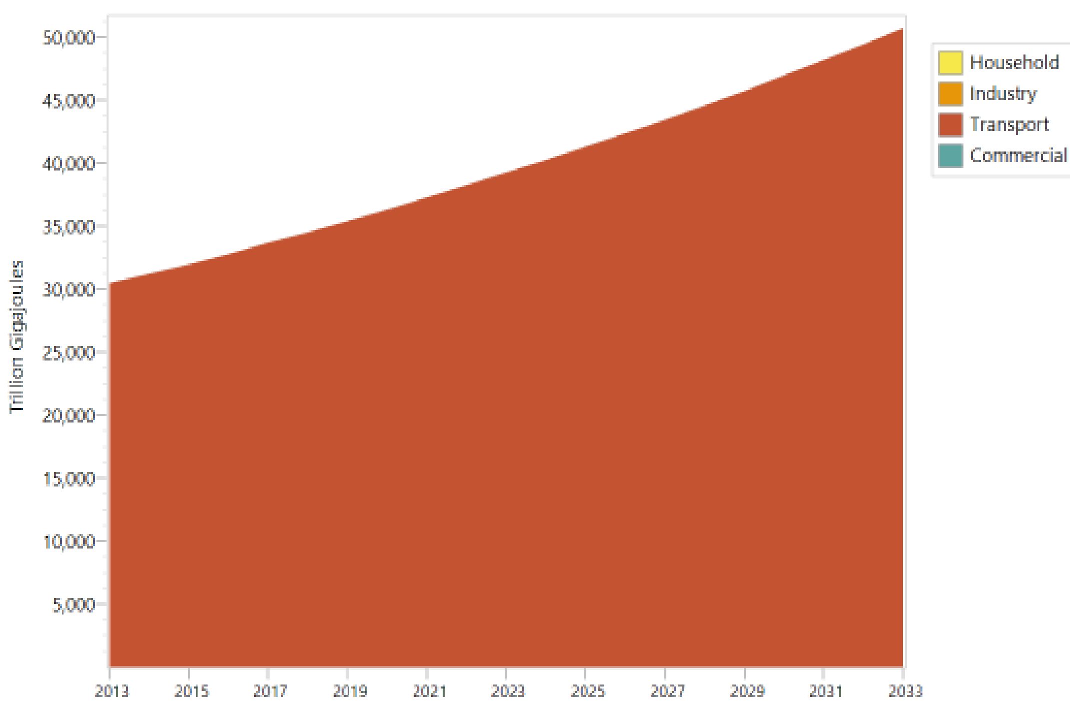


Figure 4.1: Energy consumption by all sector in BAU scenario.

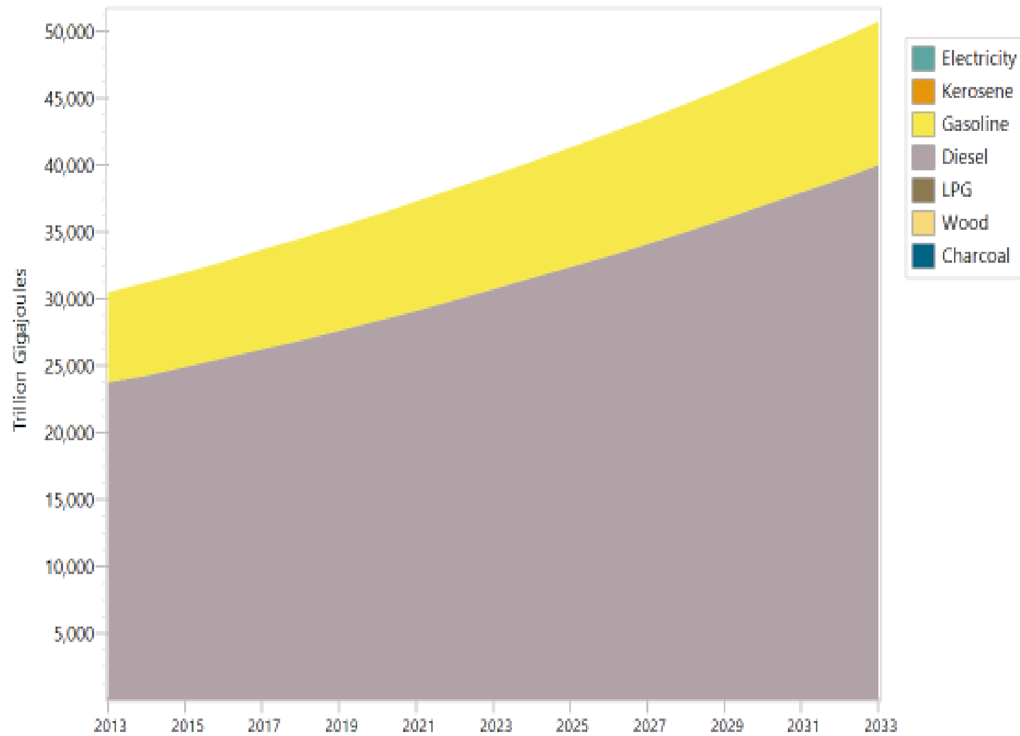


Figure 4.2: Energy consumption by fuel types in BAU scenario.

In the business as usual scenario, the transport and household sectors would remain the main major of energy consumption followed by industry and by commercial sector. However, it is important to notify that the higher consumption of the energy by the transport sector as shown the figure xxx above is strongly linked to the methodology used for modeled the sector which is totally different for those used for other sectors. Looked at the fuel types consumption would also notice that it is dominated by diesel followed by gasoline, which are used for the transport purpose and where this lager sharing in fuel consumption in the city can be without any hesitation related also to the methodology used for the sector.

4.1.1.2 Household sector

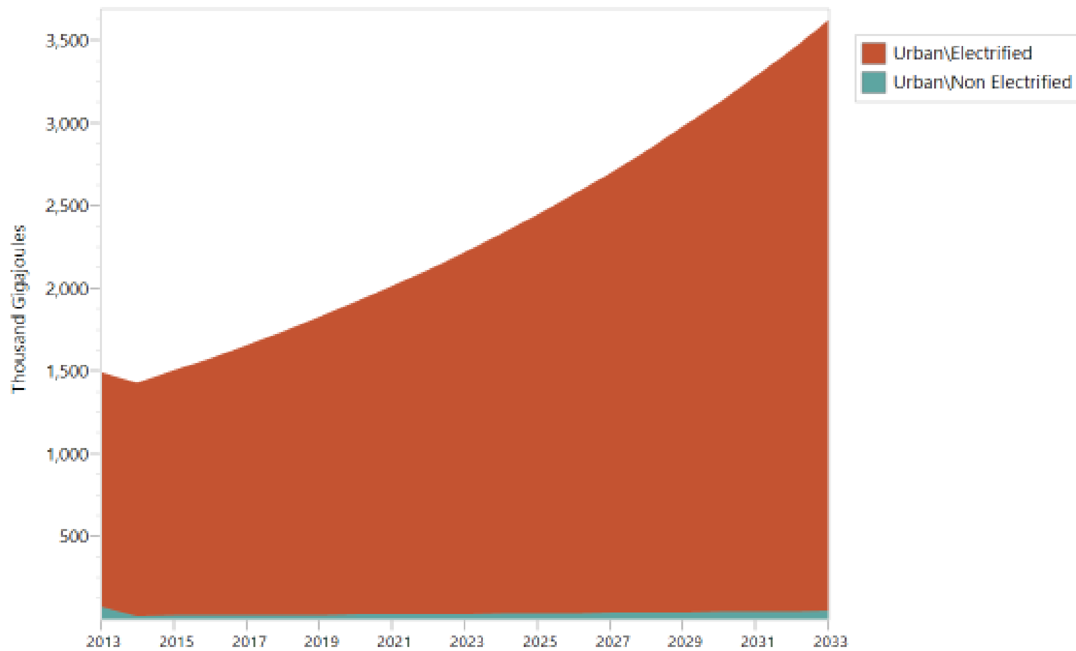


Figure 4.3: Energy consumption by household category in BAU scenario.

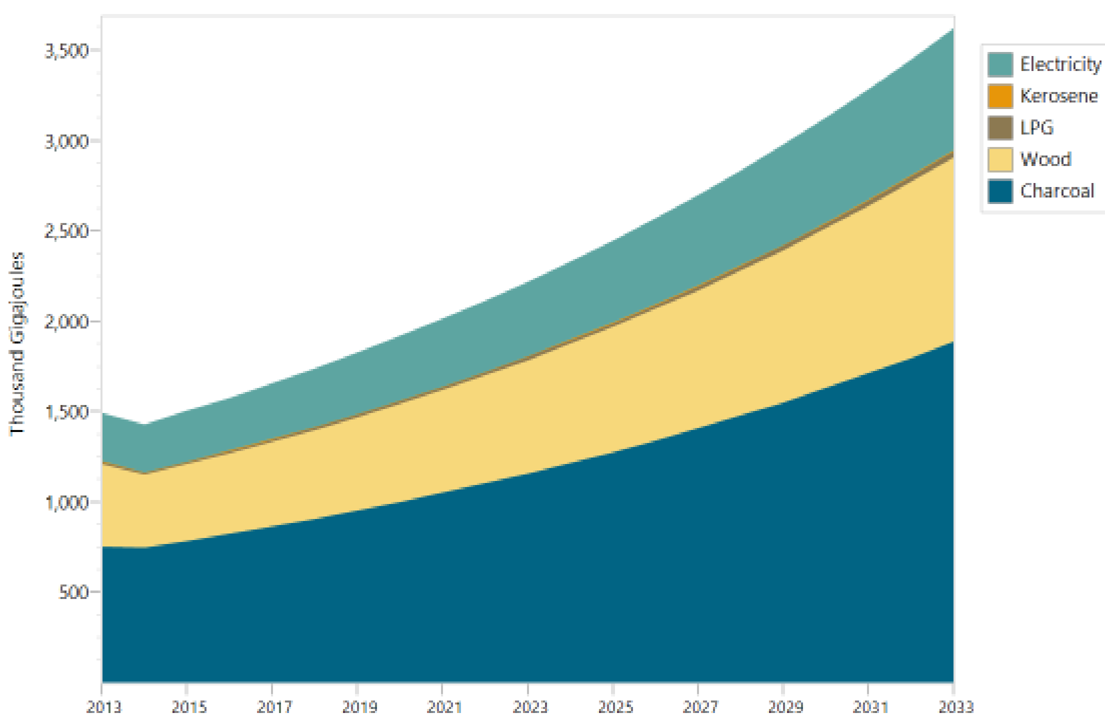


Figure 4.4: Household energy consumption per fuel types in BAU scenario.

In household sector, the energy consumption is dominated by electrified household over the period. The increase on the energy consumption accounted for around 3,500 thousand gigajoules in 2033, while for the non-electrified households this value is almost constant and accounted for around 100 thousand gigajoules in 2033 such for both sector around 3,600 thousand gigajoules of energy will require for Bamako household sector as shown the figure 4.3 above.

Regarding the figure 4.4, the charcoal would remain the main fuel used and it would accounted for around 1000 thousand gigajoules in 2033, followed by wood which accounted for around 500 thousand gigajoules in 2033,while electricity and LPG would have accounted for just around 300 thousand and 100 gigajoules in 2033 respectively. This high account of the charcoal is due to the higher share of the fuel the energy service especially for cooking.

4.1.1.3 Commercial sector.

The results of energy consumption on commercial sector and per fuel types are presented on figure 4. 5 and 4.6 below:

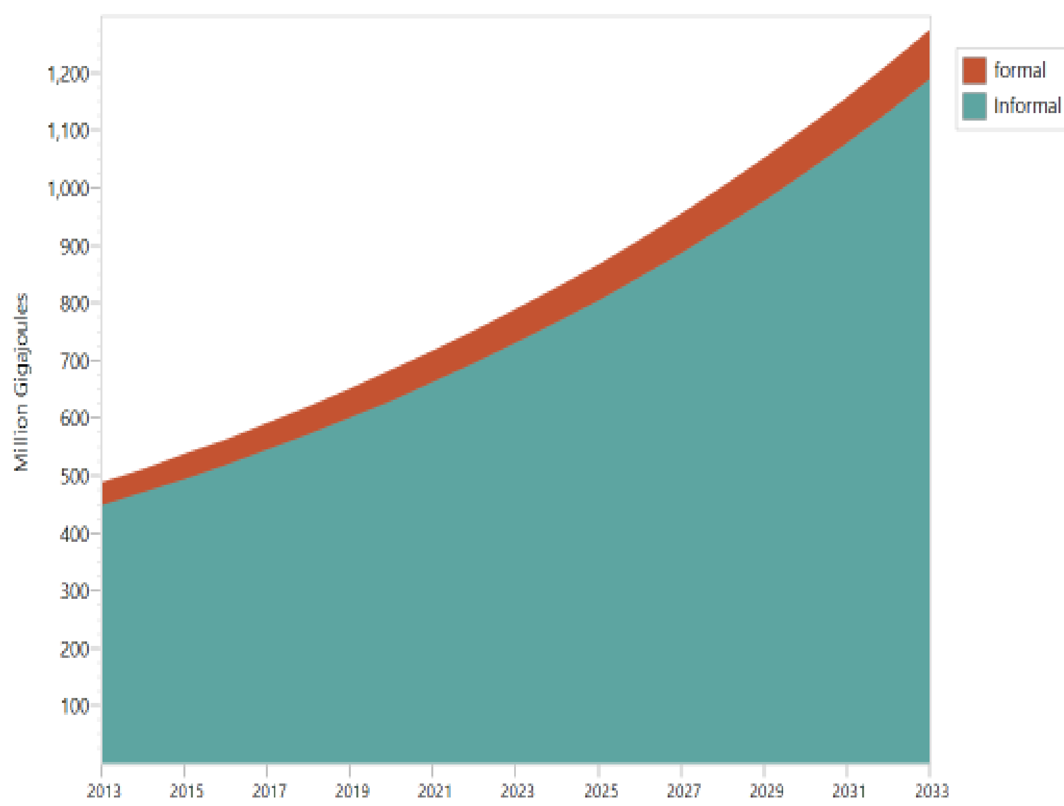


Figure 4.5: Energy consumption by commercial subsector in BAU scenario.

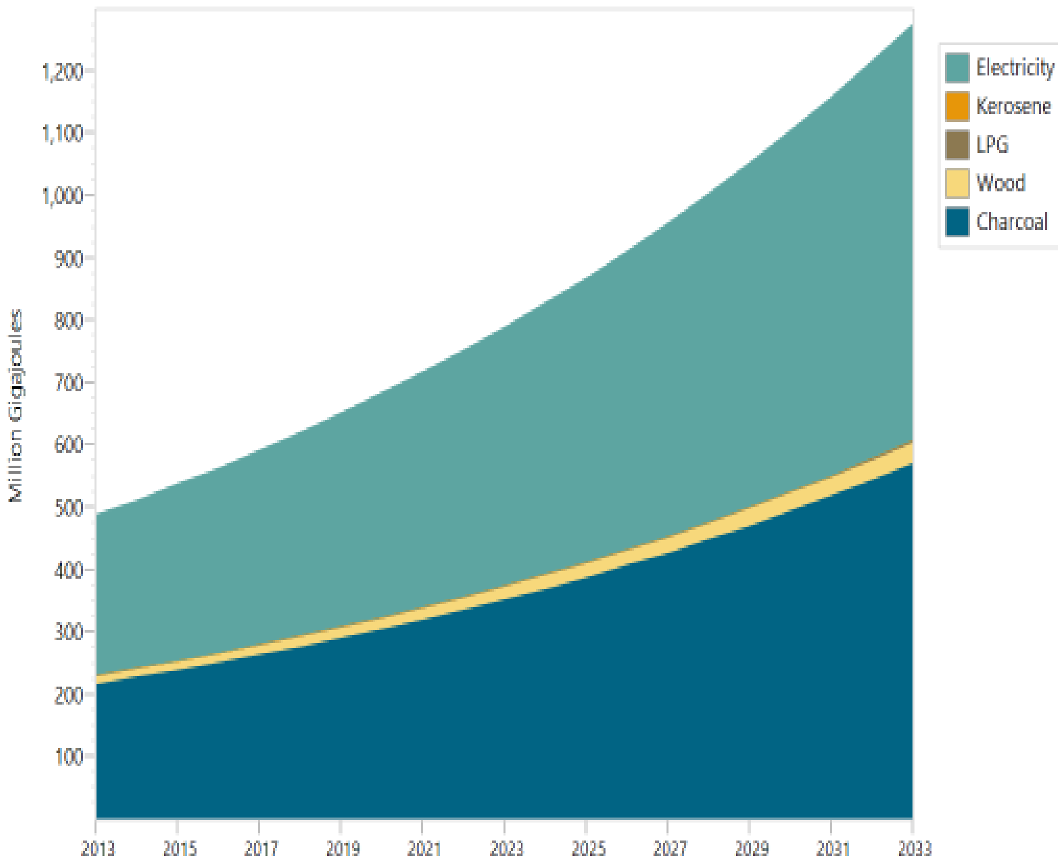


Figure4.6: Energy consumption by fuel types by commercial sector in BAU scenario.

For the commercial sector, the formal subsector remained the more fuel consumption over the period and its consumption reach over 1,200 million gigajoules in 2033, while for the informal sector, the fuel consumption increases also but less than one of the formal sector and can reach 1,100 million gigajoules in 2033. So for a commercial sector the energy demand requirement will reach 2, 3000 million of gigajoules in 2033.

What in figure 4.6 above, by looking for fuel types consumption in the commercial sector, the electricity would remain the most fuel used and it would have accounted for around 300 million gigajoules in 2033, followed by charcoal with over 200 million gigajoules in same year, while wood and LPG would be around 100 million gigajoules and less than 50 million gigajoules respectively.

4.1.1.4 Industrial sector.

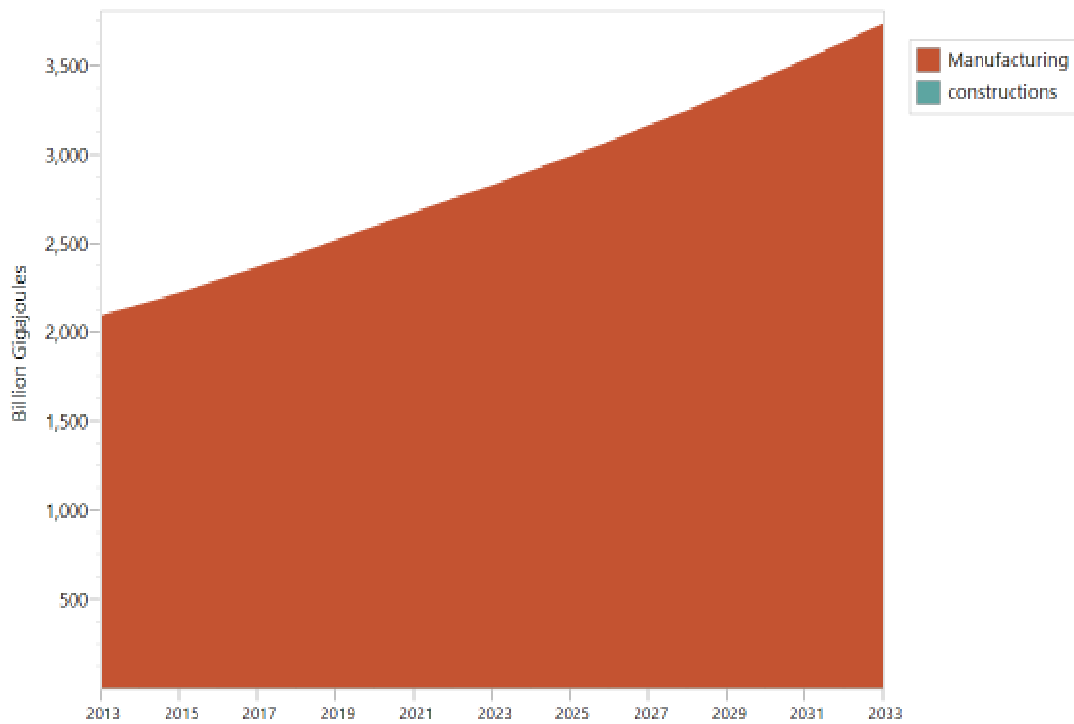


Figure 4.7: Energy consumption by industry subsector in BAU scenario.

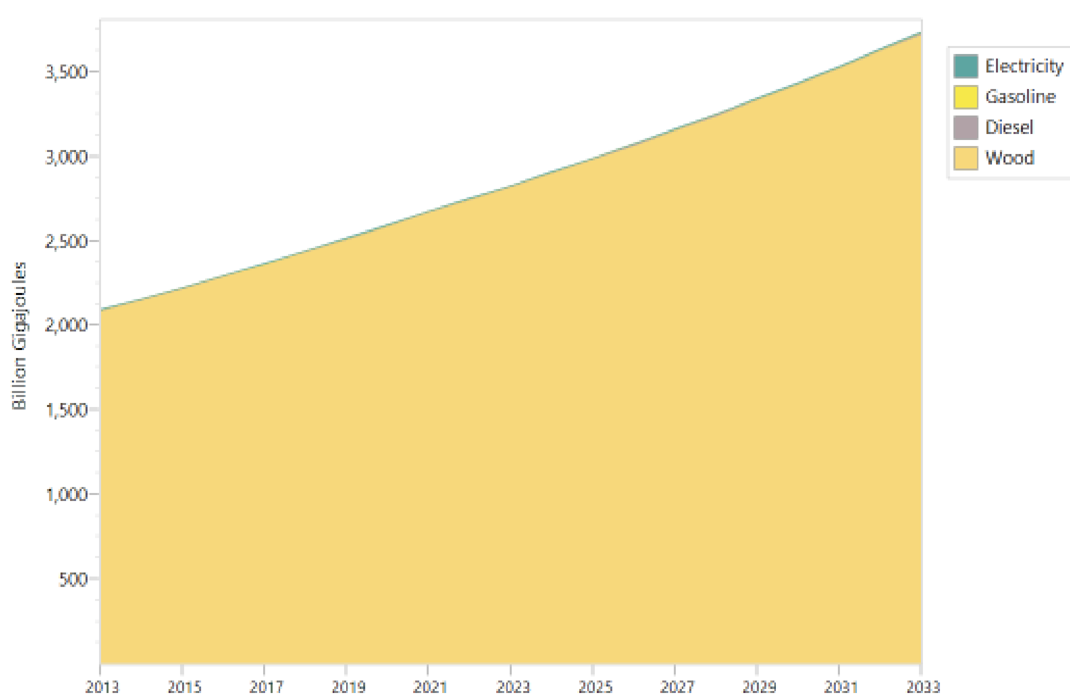


Figure 4.8: Energy consumption by fuel types for industry sector in BAU scenario.

In industry sector, the manufacturing subsector dominated and its energy consumption increases over the period of time, while in construction subsector is almost constant as shown the figure 4.7 above. This is due of fact that only one surveyed had been made in construction subsector comparing to nine in the manufacturing subsector. The increase on manufacturing subsector would reach around 3,500 billion gigajoules in 2033, while in the construction subsector remain constant value would have been less than 50 billion gigajoules.

By looking the figure 4.8, the fuel consumption large fuels consumption is dominated by wood and electricity. This domination of the wood can be related to the higher share and fact that it is only used for only one energy service which is machinery in the manufacturing industry.

4.1.1.4 Transport sector

The results on energy consumption and demand by fuel types for the transport subcategory are presented in figures below:

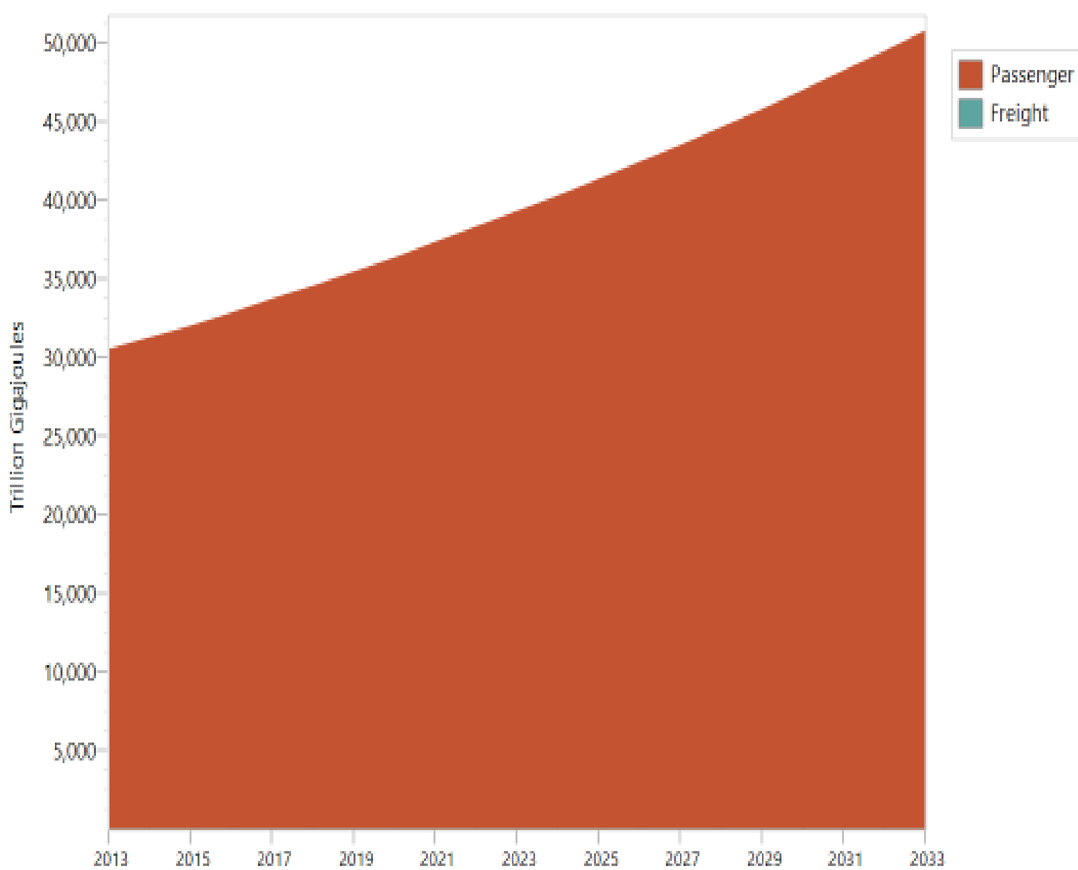


Figure 4.9: Energy consumption by transport sector in BAU scenario.

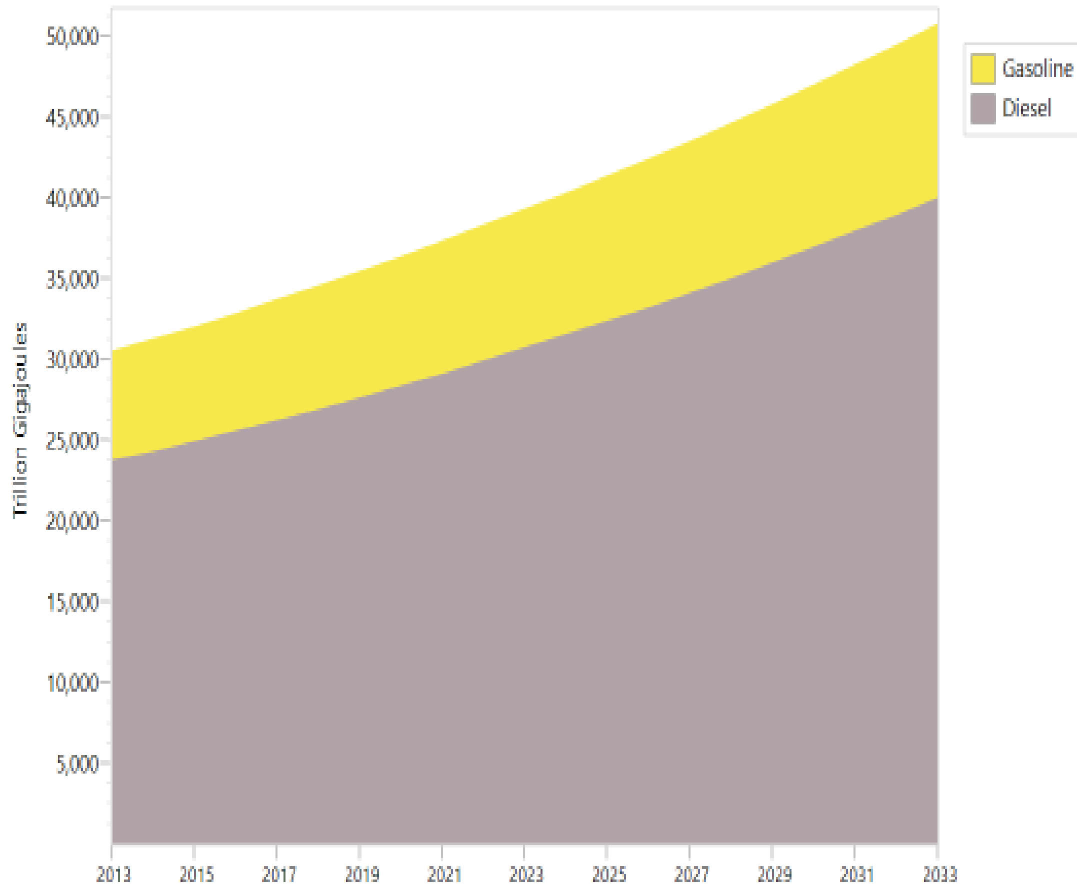


Figure 4.10: Energy demand by fuel types for transport sector in BAU scenario.

The fuel demand in transport sector in the city would rest dominated by the passenger transportation, which the consumption is increasing over the period of time, while a little increasing is observed. For a passenger transportation, the fuel demand would reach 45,000 trillion gigajoules in 2033 as shown the figure 4.9 above.

Regarding the fuels consumption in the sector, the diesel would remain the must fuel consumption and would reach around 30,000 trillion gigajoules in 2033, while gasoline would account for 25,000 trillion gigajoules in 2033 such an around of the total fuel demand of 55,000 trillion gigajoules in 2033 for the transport sector as shown the figure 4.10 above.

4.1.2Sensitivity Scenarios results

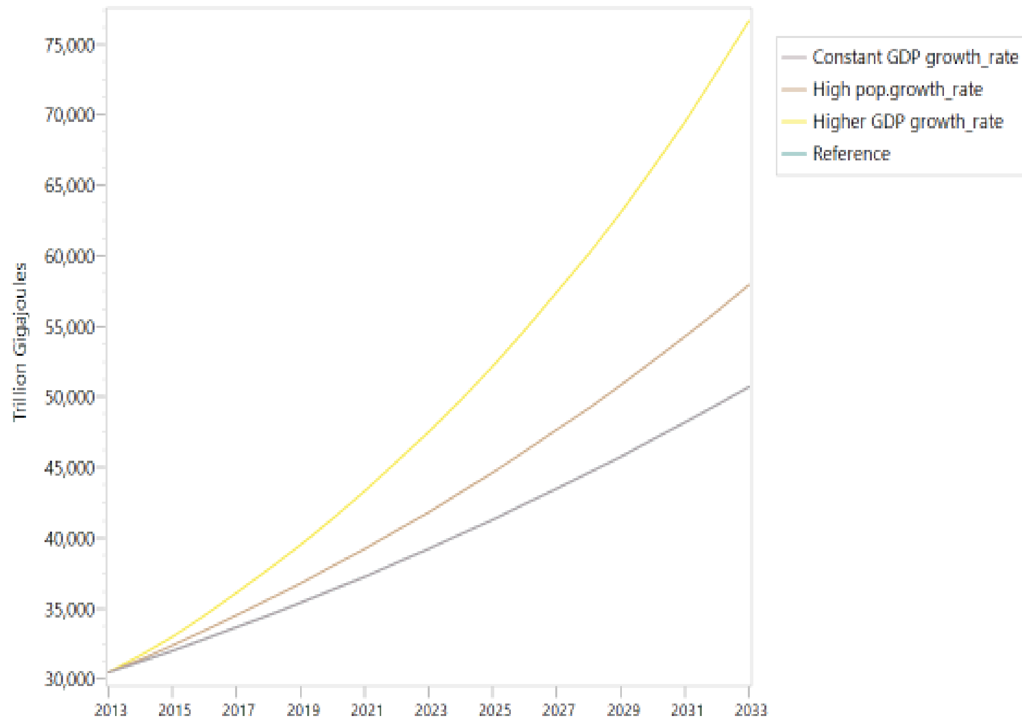


Figure 4.11: Comparing of Bamako energy consumption between two sensitivity and reference scenarios.

The constant economic growth rate of 5.2% from 2013 to 2033 has not different for the reference scenario in term energy consumption and that corresponding of about half the impact that increasing the high population growth rate from 5% to 6% for the same period of year, while increasing the GDP growth rate from 5.2% in 2017 to 7.5% in 2033 has a significant impact of energy consumption , which is also the doubt of the one the high population growth rate scenario and more than third referring to the business as usual scenario as shown the figure 4.11 above.

Household and transport sectors considered as the most sectors energy consumption, the next results of sensitivity scenarios were focused on those sectors as showed in figure 4.12 and figure 4.13 below:

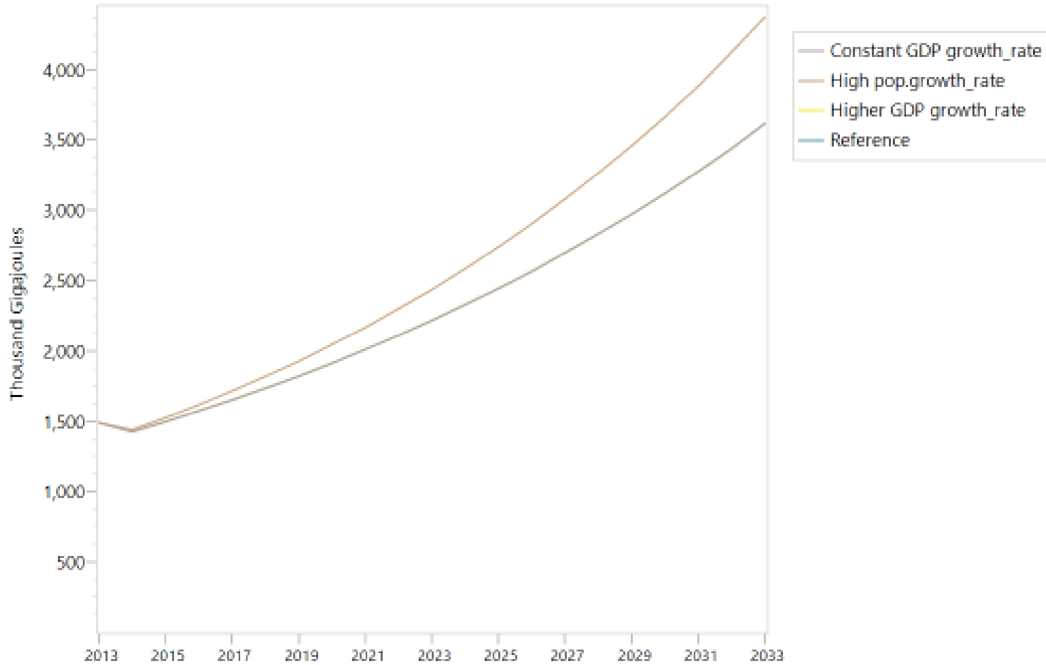


Figure 4.12: Household energy consumption for the sensitivity scenarios.

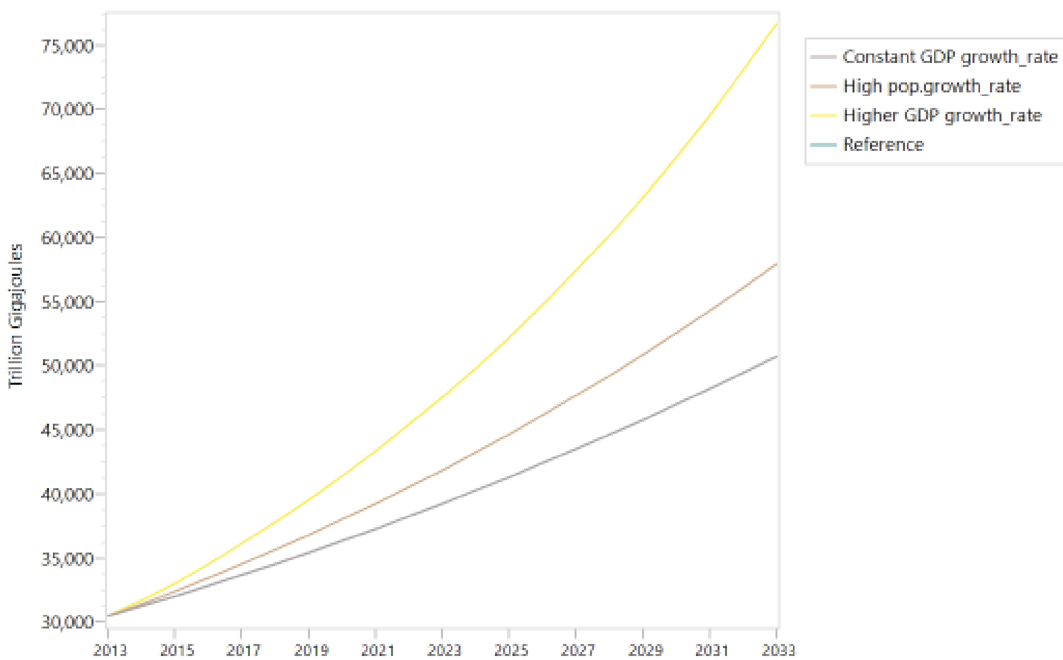


Figure 4.13: Transport sector fuel consumption for sensitivity scenarios.

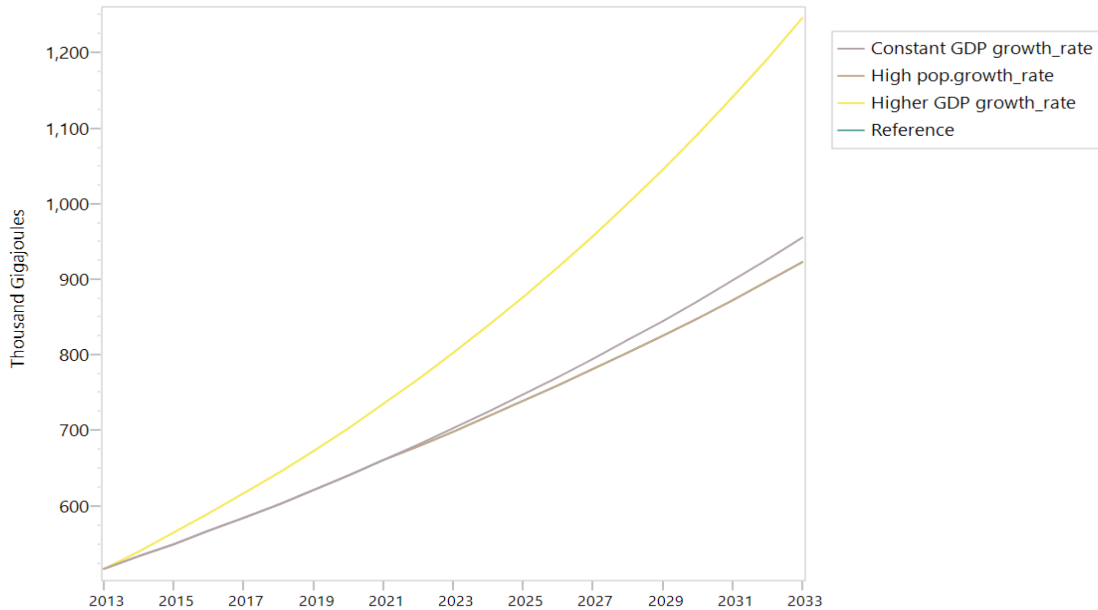


Figure 1.14 : Transport freight fuel consumption for Bamako in the sensitivity scenarios.

The significant impact on energy consumption in household came from the high population growth rate by 5% in 2013 to 6% in 2033, related to reference scenario, the energy consumption for about 30% in 2033, while the lack of change is observed with GDP growth and this can have attributed on the current model structure whereby the household are not strongly linked to GDP. However, the shift of share in household category over time discussed in the business as usual scenario on figure 4.14 above is the one with the inputs directly related to GDP as with all knew, the increasing of GDP per capita, which definitely encourage household to purchase appliances and consume energy services. This is therefore an area interest for future work that would greatly improve the model**.**

Contrarily to the household sector, the assumed economic growth rate is more sensitive in transport sector than high population growth rate. Maintaining the GDP rate constant at 5.2% from 2018 to 2033, no change will be observed, referring to the reference scenario, while by increasing to GDP by 7.5% for the same period of year, the fuel consumption stepping up the population growth rate from 5% in 2013 to 6% up to 2033, a 2.2 % total increase in population growth rate scenario relative to the reference scenario over the period. This can be attribute to both high intensity of private vehicle transportation, which is linked to wealth per GDP and the increase in the demand for freight transport which is more linked to a larger economy as shown the figure 4.13 above. As can be seen from the freight demand consumption sensitivity presented in figure4.14 above, the constant GDP growth rate is on par with the high population growth rate scenario till 2025, but from 2025 to 2033, the demand consumption is significant higher, indicating that the freight demand increase.

4.3 Energy Supply Results

The energy supply result is more about, the own electricity generated from generator and for the specific sector, it was calculated by used equations 9and 12 and then sharing on their electricity analyzed.

4.3.1 Electricity generating from own generator

The results obtained from own generator electricity generating after estimation of each key sector is shown below:

4.3.1.1 Household Sector

The electricity generating from own generator in the household sector after calculation is showing the table 4.1 below:

Table 4.1: Electricity generated from own usage generator in household sector.

Group	Grid status	Own generated electricity (KWh)	Grid electricity (KWh)	Total Electricity (KWh)	Share of own gen.electric	Fuel types		Estimated average utilisation(hours /day)
						Petrol used (litres)	Diesel used (litres)	
Sample (with genset)	Electrified	5,265	31,814	37,079	14%	60	3780	0.7
	Unelectrified	-	-	-	-	-	-	-
Population estimated	Electrified	50	2,356					
	Unelectrified	-	-	-	-	-	-	-

Source: Author, 2018.

For the household sector, the own generator was available only in the electrified household's category and the annual average electricity generating by the own household's generator is 5,265 KWh, which represents 14% of the annual average electricity generating share of the own generator and it is important to notify the population estimated for this own electricity generating form the generator is 50 by assuming the annual average electricity consumed by household got form the surveys as shown the table 4.47 above.

4.3.1.2 Commercial Sector

The results of the electricity generating from own generator in commercial sector both formal and informal after calculation is showing in the table 4.2 below:

Table 4.2: Electricity generated form own usage generator in commercial sector.

Generator Type	Commercial subsector	Capacity (KW)	Litres used	Electricity generated (KWh)	Capacity factor
	Formal	40	360	3,219	0.25
Petrol	Informal	161	3,330	29,770	0.80
	Formal	120	1,260	12,512	0.75
Diesel	Informal	120	1,530	15,193	0.75

Source: Author, 2018.

For the commercial sector the electricity generating from the own generator is more important for the formal commercial sector than for the informal one. And the results got from surveys in the sector revealed that:

With the capacity of 40 KW and 120 KW, regarding the petrol and diesel generator for the one concerning the formal commercial sector , the annual average electricity generating is 15,731 KWh , which represents 11% of the annual average electricity share of own generator in electricity consumed in formal commercial sector , whereas for the informal commercial sector , 161 KW and 120 KW respectively for petrol and diesel had been installed and it annual electricity generating is 44,963 KWh m which represents 6 % of the annual average electricity share of own generation in the electricity consumed in informal commercial sector ,which both accounted for 7 % of the average total electricity in commercial sector as shown the table above .

4.3.1.3 Industrial sector

For industrial sector the electricity generating obtained after calculation is showing in the table 4.3 below:

Table 4.3: Electricity generated form own generator usage in industry sector.

Subsector	Total Capacity -KW		Annual average Litres consumed		Annual average electricity KWh output		Annual average electricity share of own generation
	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	
Construction	176	-	1,800	-	5,636	-	0.3%
Manufacturing	1,000	-	34,400	-	107,770	-	4.7%
Total	**1,176**	**-**	**36,200**	**-**	**113,406**	**-**	**5 %**

Source: Author, 2018.

The use of the diesel generator preferring to petrol is main due to the price of the diesel which is little cheaper than petrol price. For the only construction industry surveyed, the annual average electricity generating output from the generator this 5,636 KWh which represent 0.3 % of the annual average electricity share of the own generation whereas for the manufacturing industry, the annual average electricity generating from the generator is 107,770 KWh , which represent 4.7 % of the annual average electricity share of the own generator which both accounted 5 % of the total average electricity consumed in the industrial sector as shown table 4. 3above.

4.4 Alternatives Scenarios Results

For alternatives scenarios considered, the obtained results of each of them are highlighted below:

4.4.1Efficient Fridges Scenario (EFR) results

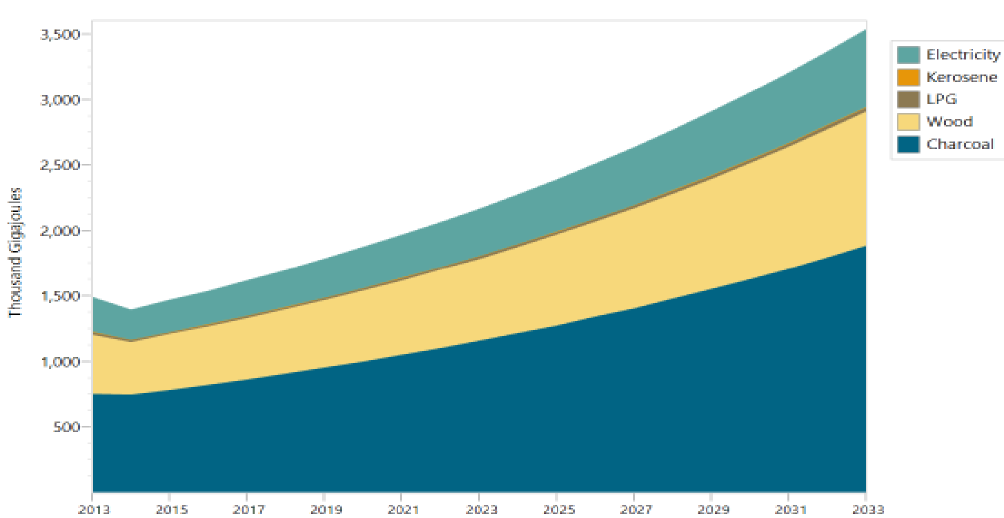


Figure 4.15: Household sector fuel consumption for the EFR scenario.

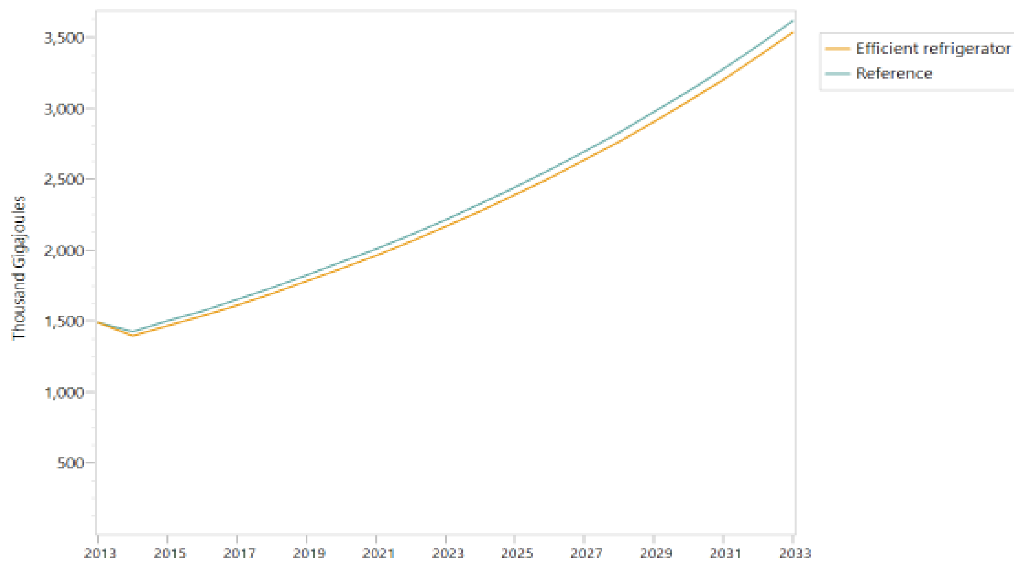


Figure 4. 16: Comparing Bamako household energy consumption for efficient fridge and reference scenarios.

From this scenario, referring to the reference scenario, fuel consumption is decreasing over the period of year. This decrease is characterized by the total reduction of the household energy consumption by 10 % in 2033 as shown the figure 4.16 above. The net result in a decrease in energy consumption of around 200 thousand gigajoules in the year 2033.

For the efficient Fridge scenario, the cumulative energy saving and its cost had been calculated from the fuel type price as shown the table 4.4 below:

Table 4.4: Cumulative energy and cost saving from efficient fridge scenario in household sector.

	2020	2025	2030	2033
Electricity (GWh)	73.6	143.8	233.5	299
Million FCFA(2013)	9,568	18,694	30,355	38,870
Million USD(2013)	19.1	37.4	60.7	77.7
1USD = 500 FCFCA				

4.4.3 Efficient cooking stoves scenario (EST)results

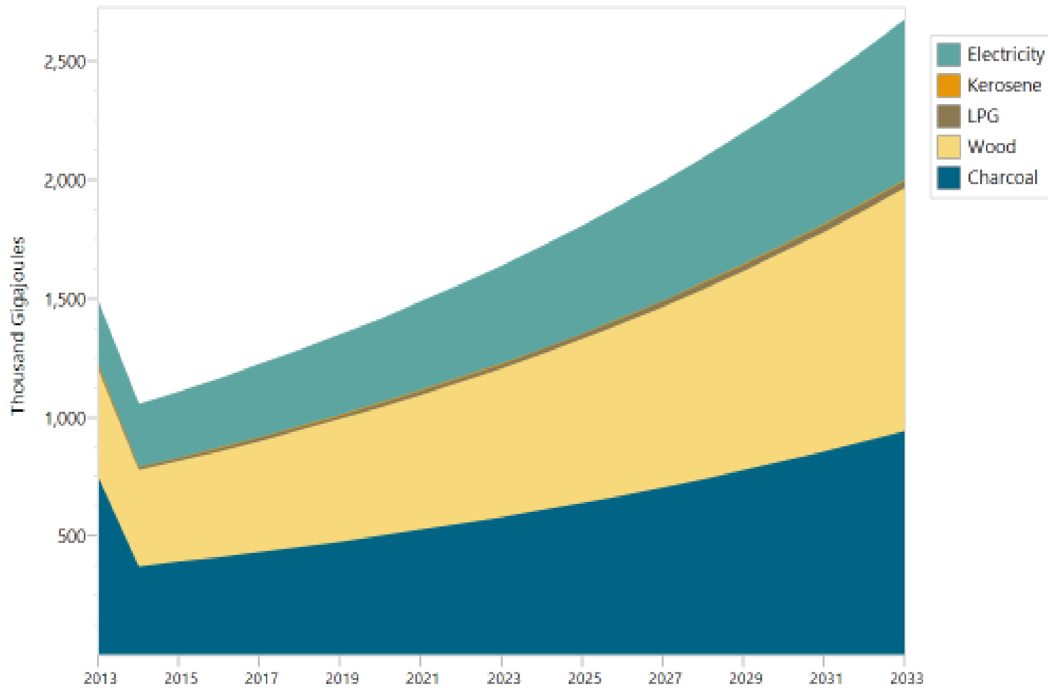


Figure 4.17: Household energy sector consumption for EST scenario.

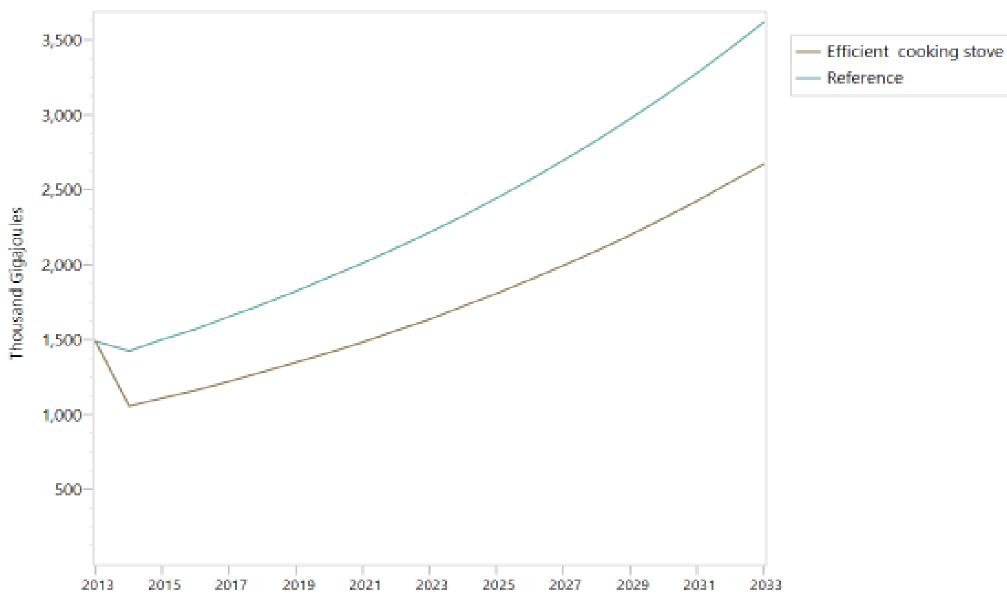


Figure 4.18: Comparing Bamako household energy consumption for EST and BAU scenarios.

Referring to the reference scenario, we observed a significant energy consumption reduction the total energy consumption in household. This reduction corresponded of 43% in 2033 of the total household energy consumption relative to reference scenario. The net result is a decrease in total energy consumption of around 1,500 thousand gigajoules in the year 2033 as shown the figure 4.18 above.

The cumulative energy saving and its cost from the efficient cook stove scenario had been calculated as shown the table 4.5 below:

Table 4.5: Cumulative fuel and cost saving from the efficient cook stove scenario in household sector.

	2020	2025	2030	2033
Charcoal saved (Thousand Tonnes)	107.1	211	343	439.2
Million FCFA(2013)	10,710	21,100	34,300	43,920
Million USD(2013)	21.4	42.2	68.6	87.8
1USD = 500 FCFCA				

By looking both alternatives scenarios and referring to the reference scenario, there is a relative small energy saving in efficient fridge as showed the table 4.4. This small energy saving can be attributed on the methodology used of household energy consumption accounted for by refrigeration while for cooking, the high energy saving con be attributed on high share of household for cooking which accounts for over 75 % of energy demand in the efficient cook stove scenario and thus interventions on this energy service have a greater effect as shown the figure 4.18 below.

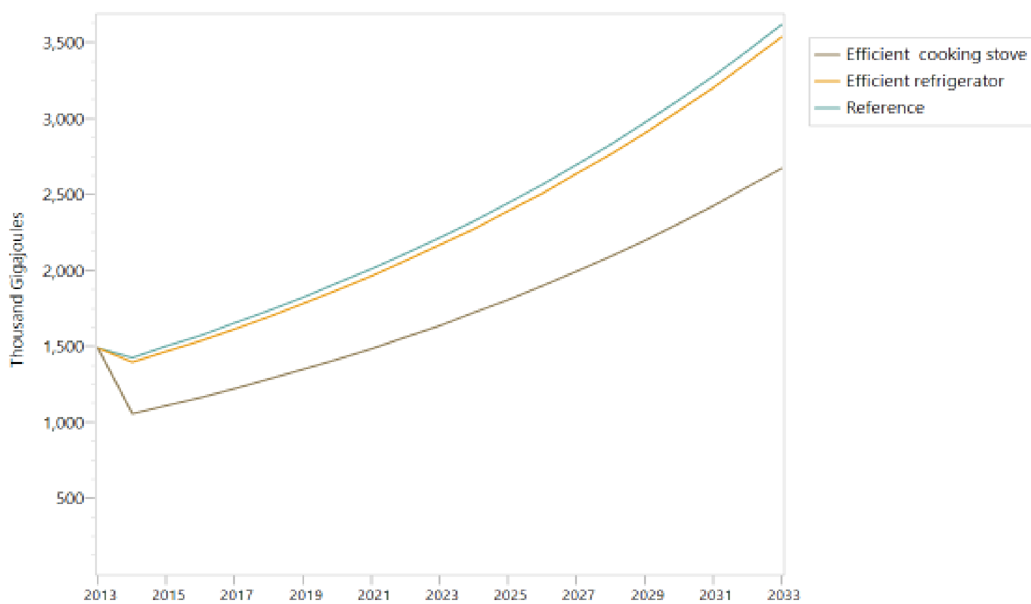


Figure 4.19: Comparing household energy consumption in EST, EFR, and BAU scenarios.

from both scenarios, the cumulative cost saving in million FCFA base on fuel price in 2013 comparison for household scenarios is higher for the cook stove scenario as shown in table 4.6 below:

Table 4.6: Cumulative cost saving comparison for household scenarios.

	2020	2025	2030	2033
Efficient fridge (Million FCFA)	9,568	18,694	30,355	38,870
Efficient cook stove (Million FCFA)	10,710	21,100	34.300	43,920
Efficient fridge (Million USD)	19.1	37.4	60.7	77.7
Efficient cook stove (Million USD)	21.4	42.2	68.6	87.8
1USD = 500 FCFCA				

4.4.3Access to Clean Modern Energy Scenario Results

Behind the philosophy of the access to clean modern energy scenarios, the energy forecasting by fuel type in household, and industry sector is shown in figure 4. 20 below:

4.4.3.1 Access to clean modern energy scenario (ACC) results for household sector.

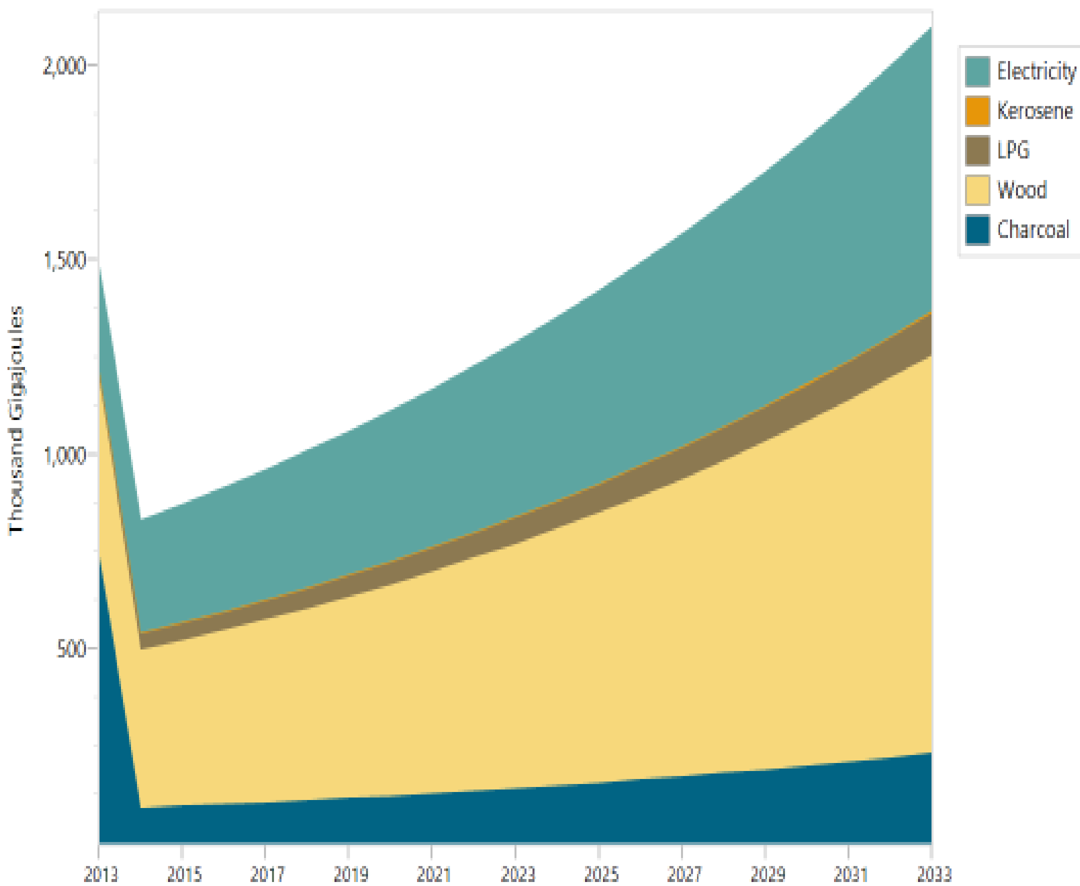


Figure 4.20: Household energy consumption by fuel for the ACC scenario.

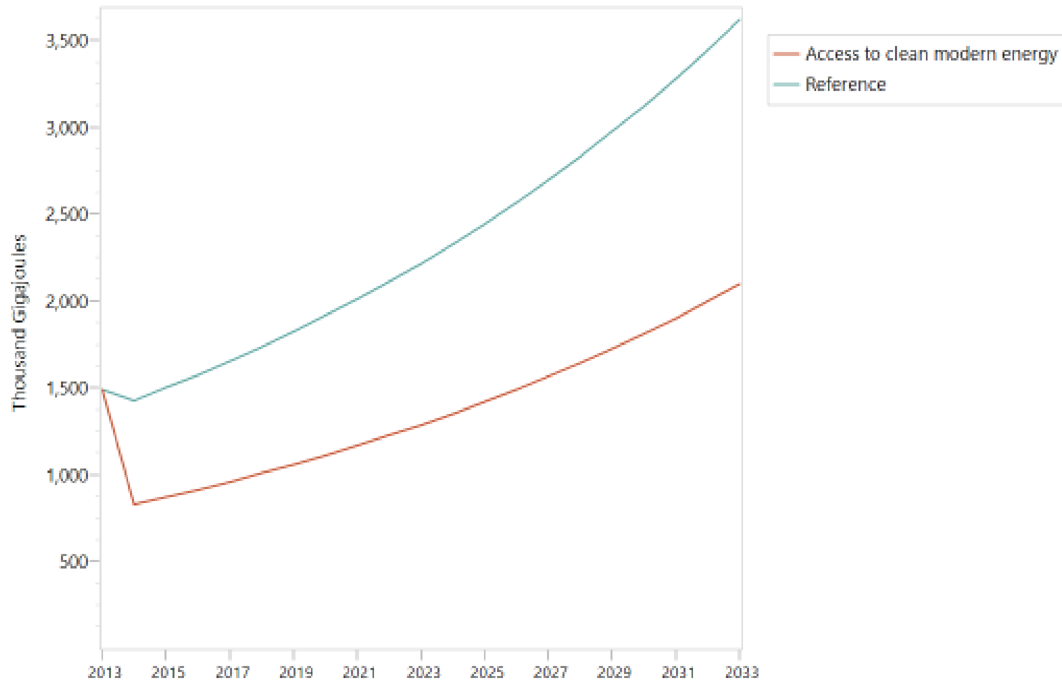


Figure 4. 21: Comparing household energy consumption for ACC and reference scenarios.

Comparing to the business as usual scenario, overall the fuel consumption decreases in the household sector as indicated in the figure 4.21 above. This decrease is a result of the large decline in charcoal consumption by about 88% in 2033 relative to the reference scenario, while LGP consumption uptake by about 225% and electricity consumption only by 8.3%. The net result is a decrease in fuel consumption of 1, 519 million gigajoules in the year 2033.

4.4.3.2 Access to clean modern energy scenario (ACC) for industry sector

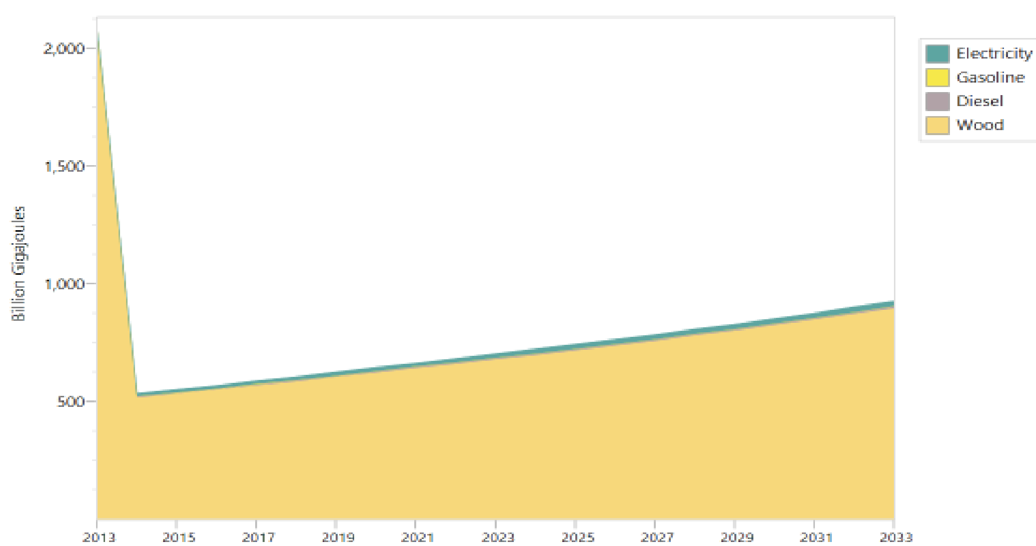


Figure4.22: Industry energy consumption by fuel types in ACC scenario.

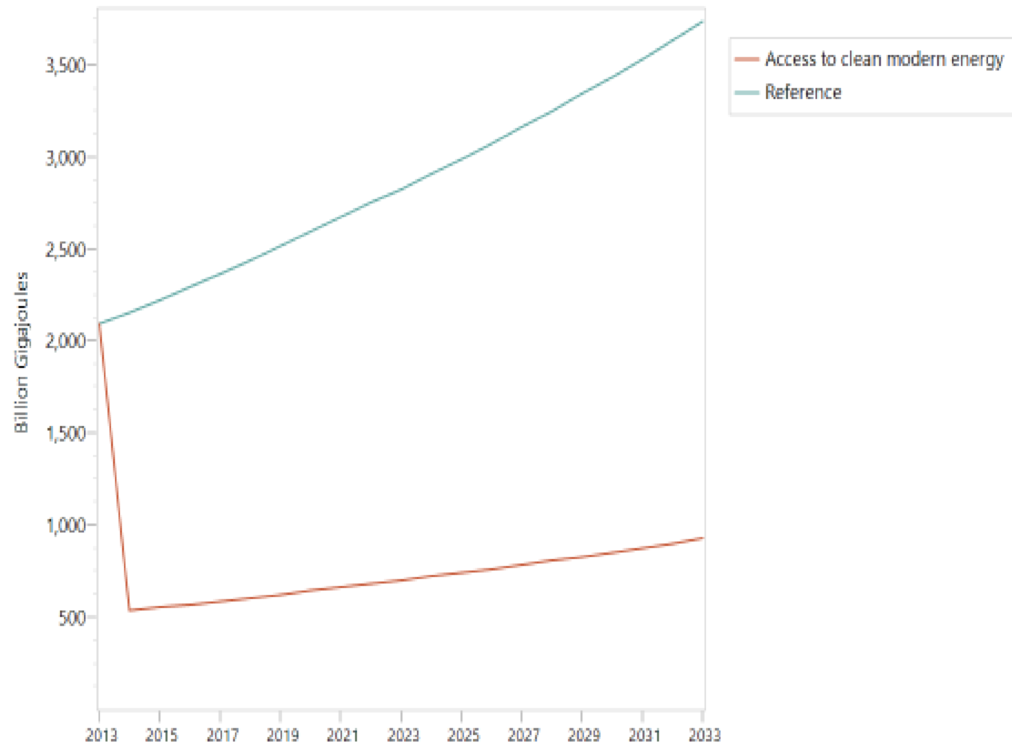


Figure 4.23 : Industry sector energy consumption comparing in ACC and reference scenarios.

Significant fuel consumption is decreasing referring to the reference scenario as indicated in figure 4.23above. This decrease is a result of the significant reduction of wood consumption by 75 % in 2033, while electricity consumption increase by 393 % in the same year. The net result in a decrease in fuel consumption of 2,805 billion gigajoules in 2033.

For this last scenario, the cumulative energy impact for the considered sectors (Households and industry) had been calculated as shown the table 4.7 and table 4.8below:

Table 4. 7: Cumulative fuels impact from Access to clean modern energy in household sector.

	2025	2030	2033
Electricity (GWh)	111	167	222
LPG (Thousand Tonnes)	16.1	26	32.2
Charcoal(Thousand Tonnes)	-371.4	-603.6	-771.4

Table 4.8: Cumulative energy impact from Access to clean modern energy in industry sector.

	2025	2030	2033
Electricity (GWh)	27,777,778	55,555,556	83,333,333
Wood (Billion Tonnes)	-1,450	-2,219	-2,738

The access to clean modern energy in household sector showing a large increase in LPG for about 32, 200 tonnes and in the industry sector the large increase of electricity for about 83,333,000 GWh.

Then the cumulative cost impact in ACC for both sector had been calculated as shown the table 4.9below:

Table 4.9: Cumulative fuel cost impact in Access to clean modern energy scenario.

	2025	2030	2033
Electricity (Billion FCFA)	3,611,126	7,222,244	10,833,362
LPG (Billion FCFA)	9. 4	97.4	18.79
Charcoal (Billion FCFA)	- 37.2	- 60.4	-77.1
Wood (Billion FCFA)	- 72,500,000	-110,950,000	-136,900,000
Sum FCFA (2013)	**-68,888,902**	**-103,727,719**	**-126,066,696**
Sum USD (2013)	**- 137,777**	**- 205,455**	**- 252,133**
Note: 1USD = 500 FCFCA It assumed that, the cost of electricity saved in industry sector followed the calculation of the electricity in household's sector.			

The substitute of charcoal and wood by electricity and LPG in both industrial and household's sectors showed a negative cumulative sum cost that can have been interpreted as a cost saving by applied access to clean modern energy scenario in those sectors.

Chapter 5: Conclusion and Policy Recommendation

This study was aims to have a deeply understanding the energy behavior for the Bamako citizens and the next 15 years in purpose to help the decision maker as well in city level as a national level. For reach that aims , the review of the energy situation of the city as well as for the whole country had been highlighted where it had been found that , the city energy situation is on mirror of the whole country dominated by an important used for traditional biomass especially in households sector , then for deeply have on overview in what will the Bamako next 15 years energy landscape, some key dynamic factors such as urbanization growth , population growth, growth domestic product government energy policy , and fuel prices fluctuation had reviewed , and the by considering those key factor the energy demand for the key sectors of the city such as residential , commercial , industrial , and transport had been modeled by using the LEAP software . hybrid simulation (top-down and bottom- up) model had been developed and as the inputs dataset of the model, a surveys, group stakeholders discussion , and questionnaire for a sample size of 373 households (348 electrified and 25 un-electrified) , 225 commercial (18 formal and 207 informal), and 9 industries (8 manufacturing and 1 construction) had been taken across the city. This dataset has been used to develop an energy systems model that projects long term scenarios of energy use and the impact of interventions to make energy use more sustainable and cumulative energy impact assessment.

The results show that the household and transport sectors dominate energy use in Bamako, with biomass (mostly charcoal) still accounting for just under half of household sector consumption in the ‘Business as usual’ case.

Energy demand share by the transport sector is strongly links on whether the trips is originating inside or outside the city but considering also if the trans-boundary trips must be included or no. but due to the limited data in the sector, the results based on the Global Protocol for Community-scale Greenhouse Gas Emission Inventories (GPC) has been presented only for the scope 1, calibrated to only the local fuel sale without trans-boundary trips.

From the supply side, due to the poor transmission lines and power unreliable from the grid, significant electricity demand is generating form own generator on commercial, household and industry sectors.

From those of own generator in household sector, around 14% of their electricity consumption can from came from there, over 7 % in both formal and informal commercial subsectors, and over 5 % for both manufacturing and construction industry subsectors.

For looking of some interventions measures in the demand side to illustrate a likely impacts of possible energy saving, alternatives scenarios lead with government energy target and vision for the year 2033 had been modeled and simulated. However, the Government must adopt new energy policies especially at the city level for the sustainable manner of the energy need of the citizens of Bamako and it economic development for the next 15 years.

5.1 policy recommendation and outlook

The policies would have focused on some measures that the government must take in energy at level of the city and the recommendations most more focused in the limitations of the work and what must do for the future work.

5.1.1 Policies recommendation

The local government must take some measure to ensure the sustainability of energy system at the level of the city to reach that some measures are highlighted below:

- develop and adopt an energy master plan for the city,
- Promoting and encourage a small scale manufacturing of optima Charcoal cooking stoves;
- Develop and adopt an energy and energy efficiency master plan for each key sector of energy consumption.
- Promoting the use of efficient vehicle and fridges through tax exemption on importation
- Develop a local logistic to avoid the penuries of the petroleum product supply especially LPG product.
- Creation of the legal framework in the field of wood-energy for it sustainability and the livestock pressure management.
- Awareness citizen of Bamako on LPG used instead charcoal especially informal sector (Restaurant).
- Promoting research and development of renewable energy and efficient technologies charcoal processing.

5.1. 2 Outlook

Some data issues were identified - particularly the very large discrepancy observed between LPG supply and demand which was an issue in the surveys for the city.

In the general view, the reel population of the city needs to be investigated because the one received from the Annual statistics of the city was based on assumptions.

The vehicle type on buses and minibuses in the transport sector need to be assess also, because the one received from the statistics of transport, vehicles are not count per type also the methodology use for modeling the transport demand need to be more investigate by considering other scopes, trans-boundary and reel mileage of each vehicle types in the city. Passenger transport surveys is also needed to get hard transport model on vehicle type passenger and on how far and how long hour.

For the commercial sector, reel floor space area of a business type need to be investigate as for this work was based on the percentage keep for per the sector in the total land available, only the floor space of the school had been assessed and the rest was based on assumptions and focused group discussion.

More data need also to be carried and the industry sector as the city accounts for almost 500 industries such 9 industries had been surveyed and most of them are government industries.

The methodology for determined the energy service share of electricity must also be considering as the one use for this work was based and period of month demand, where almost all appliances such air conditional, fridge is operated and the period months of low demand where only bulbs and some entertainment are operated.

The own generator electricity generating methodology in appendix C need to be use for a future work.

The validated, reviewed and finalized datasets and models would be very useful to researchers and planners and should be published into the public domain in an easily accessible way as part of the RASUS-SMali project.

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Appendix A: Questionnaires in different key sectors

SECTEUR MENAGES OU HABITATIONS / HOUSEHOLDS SECTOROR HABITATION

RARSUS-SMALI

1.UTILISEZ-VOUS DU BOIS COMME SOURCE D' ENERGIE? / ARE YOU USED WOOD AS ENERGY SOURCE ?

OUI/YES ☐ NON/NO ☐

2.SI OUI QUELLE QUANTITE UTILISEZ-VOUS PAR JOUR ?/ IF YES WHICH AMOUNT PER DAY?

0-2 Kg ☐ 2-4 Kg ☐ PLUS DE 4Kg / MORE THAN 4 Kg ☐

3.UTILISEZ-VOUS DE ELECTRICITE COMME SOURCE D'ENERGIE ?/ USED YOU ELECTRICITY AS ENERGY SOURCE ?

OUI /YES ☐ NON/NO ☐

4.SI OUI QUELLE QUANTITE UTILISEZ-VOUS PAR MOIS ?/ IF YES WHICH AMOUNT PER MONTH?

0-50 KWh ☐ 51-100 KWh ☐ PLUS DE 100 KWh /MORE THAN 100 KWh ☐

5.UTILISEZ-VOUS DU CHARBON COMME SOURCE D'ENERGIE ? /USED YOU CHARCOAL AS ENERGY SOURCE ?

OUI /YES ☐ NON/NO ☐

6.SI OUI QUELLE QUANTITE UTILISEZ-VOUS PAR JOUR ?/IF YES WHICH AMOUNT PER DAY?

0-2 Kg ☐ 2-4 Kg ☐ PLUS DE 4Kg /MORE THAN 4 Kg ☐

7.UTILISEZ-VOUS DU GAZ DOMESTIQUE COMME SOURCE D' ENERGIE? / USED YOU LPG AS ENERGYSOURCE?

OUI /YES ☐ NON /NO ☐

8.SI OUI QUELLE QUANTITE UTILISEZ-VOUS PAR MOIS ? / IF YES WHICH AMOUNT PERMOMTH ?

0-6 Kg ☐ 6-12 Kg ☐ PLUS DE 12Kg /MORE THAN 12 Kg ☐

9. UTILISEZ-VOUS UNE LAMPE TORCHE COMME SOURCE D'ENERGIE? / USED YOU A LAMP TORCH ?

OUI /YES ☐ NON /NO ☐

10. SI OUI COMBIEN DE PAIRE DE PILES UTILISEZ-VOUS PAR MOIS ? / IF YES WHICH AMOUNT OF PAIRE OF DRY CELLS BATTERY? 0-1 2-PLUS /2-MORE

11. DISPOSEZ-VOUS D'UN GROUPE ELECTROGENE ? /HAVE YOU A GENERATOR ? OUI /YES NON /NO

12. SI OUI DE QUEL TYPE ?/ IF YES WHICH KIND? ESSENCE/PETROL GASOIL /DIESEL

13.QUELLE QUANTITE CONSOMMEZ-VOUS PAR MOIS? / WHICH AMOUNT ARE YOU CONSUMED PER MONTH?

0-5 LITRES 5-10 LITRES PLUS DE 10 LITRES / MORE THAN 10 LITRES

14. A COMBIEN HEURE EVALUEZ-VOUS UTILISATION DU GROUPE PAR SEMAINE ?/ HOW MANY HOUR USED YOU A GENERATOR PER WEEK ?

0-3 3-6 PLUS DE 6/ MORE THAN 6

15.QUELLE SOURCE D'ENERGIE UTILISEZ-VOUS POUR ECLAIRAGE? / WHICH SOURCE OF ENERGY ARE YOU USED FOR LIGHTING?

ELECTRICITE /ELECTRICITY SOLAIRE /SOLAR BOIS / WOOD CHARBON/CHARCOAL

PILES / BATTERY PETROLE /KEROSENE AUTRES/OTHERS

16.QUELLE SOURCE D'ENERGIE UTILISEZ-VOUS POUR LA CUISSION ET LE CHAUFFAGE DE L' EAU? / WHICH KIND OF ENERGY SOURCE ARE YOU USED FOR COOKING AND HEATING WATER?

ELECTRICITE /ELECTRICITY SOLAIRE /SOLAR BOIS / WOOD CHARBON/CHARCOAL

PILES / BATTERY PETROLE /KEROSENE AUTRES/OTHERS

17.QUELLE SOURCE D'ENERGIE UTILISEZ-VOUS POUR LA REFRIGERATION? / WHICH KIND OF ENERGY SOURCE ARE YOU USED FOR REFRIGERATION?

ELECTRICITE /ELECTRICITY SOLAIRE/ SOLAR AUTRES /OTHERS

18.QUELLE SOURCE D'ENERGIE UTILISEZ-VOUS POUR DES DIVERTISSEMENT (TELEVISION, Radio …) ? /WHICH KIND OF ENERGY SOURCE ARE YOU USED FOR ENTERTAINMENT (TV, Radio …….) ?

ELECTRICITE /ELECTRICITY SOLAIRE / SOLAR PILES /BATTERY AUTRES /OTHERS

19.QUELLE SOURCE D'ENERGIE UTILISEZ-VOUS POUR LA VENTILLATION? / WHICH KIND OF ENERGY SOURCE ARE YOU USED FOR VENTILLATION?

ELECTRICITE/ELECTRICTY SOLAIRE /SOLAR GROUPE ELECTROGENE/ GENERATOR

20 . QUELLE SOURCE D'ENERGIE UTILISEZ-VOUS POUR D'AUTRES SERVICES?/ WHICH KIND OF ENERGY SOURCE ARE YOU USED FOR OTHERS SERVICES

ELECTRICITE /ELECTRICITY ☐ SOLAIRE /SOLAR ☐ BOIS / WOOD ☐ CHARBON/CHARCOAL ☐

PILES / BATTERY ☐ PETROLE /KEROSENE ☐ AUTRES/OTHERS ☐

21. QUELLE TYPE D'AMPOULES UTILISEZ-VOUS POUR ECLAIRAGE? / WHICH KIND OF BULB ARE YOU USED FOR LIGTHING?

AMPOULE INCADESCENCE / INCADESCENCE BULBAMPOU ☐)NOMIQUE /LFD BULB ☐

22. QUELLE TYPE D'APPAREIL UTILISEE VOUS AVEC DU BOIS OU DU CHARBON ? / WHICH KIND OF STOVE ARE YOU USED FOR WOOD OR CHARCOAL ?

FOUR DE BOIS / WOOD STOVE ☐ UR DE CHARBON /CHARCAOL STOVE ☐ FOYER A TROIS PIERRES /THREE STONES

23. QUEL TYPE DE REFRIGERATEUR UTILISEZ-VOUS ? / WHICH KIND OF REFIDGE ARE YOU USED ?

ECONOMIQUE / EFFICIENT ☐ NON ECONOMIQUE/ INEFFICIENT ☐

24.QUEL MOYEN DE TRANSPORT DISPOSEZ- VOUS ?/ WHICH KIND OF LOGISTICDO YOU DISOPSED ?

VOITURE /CAR ☐ MOTOR / MOTOR ☐ PIED / FOOT ☐ AUTRES/OTHERS ☐

20.COMBIEN DEPENSEZ-VOUS PAR MOIS POUR VOUS BESION ENERGETIQUE DOMESTIQUE? / HOW MUCH ARE YOU SPENT FOR YOU DOMMESTIQUE ENERGY NEED?

25000- 50000 ☐ 50000-75000 ☐ 75000-100000 ☐ PLUS DE 100000 ☐

SECTEUR COMMERCIALFORMEL & INFORMEL / COMMERCIAL SECTOR FORMAL & INFORMAL

RARSUS- SMALI

1.UTILISEZ-VOUS DU BOIS COMME SOURCE D' ENERGIE ? / ARE YOU USED WOOD AS ENERGY SOURCE?

OUI/YES ☐ NON/NO ☐

2.SI OUI QUELLE QUANTITE UTILISEZ-VOUS PAR JOUR ?/ IF YES WHICH AMOUNT PER DAY?

0-2 Kg ☐ 2-4 Kg ☐ US DE 4Kg / MORE THAN 4 Kg ☐

3.UTILISEZ-VOUS DE ELECTRICITE COMME SOURCE D'ENERGIE ? / USED YOU ELECTRICITY AS ENERGY SOURCE ?

OUI /YES ☐ NON/NO ☐

4.SI OUI QUELLE QUANTITE UTILISEZ-VOUS PAR MOIS ?/ IF YES WHICH AMOUNT PER MONTH?

0-50 KWh ☐ 51-100 KWh ☐ PLUS DE 100 KWh /MORE THAN 100 KWh ☐

5.UTILISEZ-VOUS DU CHARBON COMME SOURCE D'ENERGIE ? /USED YOU CHARCOAL AS ENERGY SOURCE ?

OUI /YES ☐ NON/NO ☐

6.SI OUI QUELLE QUANTITE UTILISEZ-VOUS PAR JOUR ?/IF YES WHICH AMOUNT PER DAY?

0-2 Kg ☐ 2-4 Kg ☐ PLUS DE 4Kg /MORE THAN 4 Kg ☐

7.UTILISEZ-VOUS DU GAZ DOMESTIQUE COMME SOURCE D'ENERGIE ? / USED YOU LPG AS ENERGY SOURCE?

OUI /YES ☐ NON /NO ☐

8.SI OUI QUELLE QUANTITE UTILISEZ-VOUS PAR MOIS ? / IF YES WHICH AMOUNT PER MOMTH ?

0-6 Kg ☐ 6-12 Kg ☐ PLUS DE 12Kg /MORE THAN 12 Kg ☐

9. UTILISEZ-VOUS UNE LAMPE TORCHE COMME SOURCE D'ENERGIE ? / USED YOU A LAMP TORCH ?
OUI /YES ☐ NON /NO ☐

10. SI OUI COMBIEN DE PAIRE DE PILES UTILISEZ-VOUS PAR MOIS ? / IF YES WHICH AMOUNT OF PAIRE OF DRY CELLS BATTERY ? 0-1 ☐ 2-PLUS /2-MORE ☐

11. DISPOSEZ-VOUS D'UN GROUPE ELECTROGENE ? / HAVE YOU A GENERATOR ?
OUI /YES ☐ NON /NO ☐

12. SI OUI DE QUEL TYPE ?/ IF YES WHICH KIND?
ESSENCE/PETROL ☐ GASOIL /DIESEL ☐

13.QUELLE QUANTITE CONSOMMEZ-VOUS PAR MOIS? / WHICH AMOUNT ARE YOU CONSUMED PER MONTH?

0-5 LITRES ☐ 5-10 LITRES ☐ PLUS DE 10 LITRES / MORE THAN 10 LITRES ☐

14. A COMBIEN HEURE EVALUEZ-VOUS UTILISATION DU GROUPE PAR SEMAINE ?/ HOW MANY HOUR USED YOU A GENERATOR PER WEEK ?

0-3 3-6 ☐ PLU☐E 6/ MORE THAN 6 ☐

15.QUELLE SOURCE D'ENERGIE UTILISEZ-VOUS POUR ECLAIRAGE? / WHICH SOURCE OF ENERGY ARE YOU USED FOR LIGHTING?

ELECTRICITE /ELECTRICITY ☐ SOLAIRE /SOLAR ☐ BOIS / WOOD ☐ CHARBON/CHARCOAL ☐

PILES / BATTERY ☐ PETROLE /KEROSENE ☐ AUTRES/OTHERS ☐

16.QUELLE SOURCE D'ENERGIE UTILISEZ-VOUS POUR LA CUISSION ET LE CHAUFFAGE DE L' EAU? / WHICH KIND OF ENERGY SOURCE ARE YOU USED FOR COOKING AND HEATING WATER?

ELECTRICITE /ELECTRICITY ☐ SOLAIRE /SOLAR ☐BOIS / WOOD ☐HARBON/CHARCOAL ☐

PILES / BATTERY ☐ PETROLE /KEROSENE ☐ AUTRES/OTHERS ☐

17.QUELLE SOURCE D'ENERGIE UTILISEZ-VOUS POUR LA REFRIGERATION? / WHICH KIND OF ENERGY SOURCE ARE YOU USED FOR REFRIGERATION?

ELECTRICITE /ELECTRICITY ☐ SOLAIRE/ SOLAR ☐ AUTRES /OTHERS ☐

18.QUELLE SOURCE D'ENERGIE UTILISEZ-VOUS POUR DES DIVERTISSEMENT (TELEVISION , Radio ….) ? /WHICH KIND OF ENERGY SOURCE ARE YOU USED FOR ENTERTAINMENT (TV, Radio ,…….) ?

ELECTRICITE /ELECTRICITY ☐ SOLAIRE / SOLAR☐ PILES /BATTERY ☐ AUTRES /OTHERS ☐

19.QUELLE SOURCE D'ENERGIE UTILISEZ-VOUS POUR LA VENTILLATION? / WHICH KIND OF ENERGY SOURCE ARE YOU USED FOR VENTILLATION?

ELECTRICITE/ELECTRICTY ☐LAIRE /SOLAR ☐UPE ELECTROGENE/ GENERATOR ☐

20.QUELLE SOURCE D'ENERGIE UTILISEZ-VOUS POUR D'AUTRES SERVICES?/ WHICH KIND OF ENERGY SOURCE ARE YOU USED FOR OTHERS SERVICES

ELECTRICITE /ELECTRICITY ☐ SOLAIRE /SOLAR ☐ BOIS / WOOD ☐ CHARBON/CHARCOAL ☐

PILES / BATTERY ☐ PETROLE /KEROSENE ☐ AUTRES/OTHERS ☐

22. QUELLE TYPE D'AMPOULES UTILISEZ-VOUS POUR ECLAIRAGE? / WHICH KIND OF BULB ARE YOU USED FOR LIGTHING?

AMPOULE INCADESCENCE / INCADESCENCE BULB ☐ AMPOULE ECONOMIQUE /LFD BULB ☐

23. QUELLE TYPE D'APPAREIL UTILISEE VOUS AVEC DU BOIS OU DU CHARBON ? / WHICH KIND OF STOVE ARE YOU USED FOR WOOD OR CHARCOAL ?

FOUR DE BOIS / WOOD STOVE ☐ FOUR DE CHARBON /CHARCAOL STOVE ☐ FOYER A TROIS PIERRES /THREE STONES

24. QUEL TYPE DE REFRIGERATEUR UTILISEZ-VOUS ? / WHICH KIND OF REFIDGE ARE YOU USED ?

ECONOMIQUE / EFFICIENT ☐ NON ECONOMIQUE/ INEFFICIENT ☐

U.S.T.T-B

Pan African University Institute of Water and Energy Sciences

SECTEUR INDUSTRIAL: CONSTRUCTION, MANUFACTURATION & MINIER & CARRIERE

INSDUSTRIAL SECTOR: CONSTRUCTION, MANUFACTURING & MINING& QUARRING

RASUS-SMALI

1.DANS QUEL TYPE D'INDUSTRIES EXERCEZ-VOUS?/ WHICH KIND OF INDSUTRY ARE YOU WORKING FOR?

CONSTRUCTION /CONSTRUCTION ☐ MANUFACTURATION /MANUFACTURING ☐ MINIER ET CARRIER/ MINING & QUARRING AUTRES/OTHERS ☐

2.COMBIEN DE TONNES PRODUCEZ-VOUS PAR AN ?/ HOW MANY TONNES ARE YOU PRODUCING PER YEAR?

0 – 500 ☐ 500-10000 ☐ Plus de 10000 ☐

3. QUELLE SOURCE D'ENERGIE UTILISEZ-VOUS? / WHICH KIND OF ENERGY ARE YOU USE?

ELECRICITE /ELECTRICITY ☐ SOLAIRE/SOLARE ☐ OLIENNE /WIND ☐ AUTRES / OTHERS ☐

4. QUELLE QUANTITE CONSOMMEZ- VOUS PAR MOIS/ WHICH AMOUNT ARE YOU CONSUMED PER MONTH?

10000-20000 KWh ☐ 20000-50000 KWh ☐ Plus de 50000 KWh ☐ AUTRES/OTHERS ☐

5. UTILISEZ-VOUS UN GROUPE ELECTRROGENE? / USED YOU A GENERATOR? OUI /YESNON /NO ☐ ☐

6.SI OUI QUEL TYPE DE GROUPE ELECTROGENE UTILISEZ-VOUS? / IF YES WHICH KIND OF GENERATOR?

GASOIL /DIESEL ☐ ESSENCE /PETROL ☐

7. QUELLE CAPACITY INSTALLATION DU GROUPE? / WHICH INSTALLED CAPACITY?

0-100 KW ☐ 100-300 KW ☐ 300-500 KW ☐ Plus 500 KW/ MORE THAN 500KW ☐

8.QUELLE QUANTITE DE CARBURANTS UTLISEZ-VOUS PAR MOIS?/ WHAT IS THE AMOUNT OF FUEL USED PER MONTH?

0 -10000 LITRES ☐ 10000- 50000 LITRES ☐ PLUS DE 50000 LITRES/MORE THAN 50000 LITRES ☐

9.QUELLE QUANTITE DE CARBURANTS UTLISEZ-VOUS PAR MOIS POUR LE GROUPE ELECTROGENE? / WHICH AMOUNT ARE YOU USED FOR GENERATOR PER MONTH?

0 - 1000 LITRES ☐ 1000- 5000 LITRES ☐ PLUS DE 500 LITRES / MORE THAN 5000 LITRES ☐

10.QUELLE QUANTITE DE CARBURANTS UTLISEZ-VOUS PAR MOIS POUR LA MACHINERY ?/ WHICH AMOUNT ARE YOU USED FOR MACHINERY ?

0 - 10000 LITRES 10000- 50000 LITRES PLUS DE 50000LITRES / MORE THAN 50000 LITRES

11.QUELLE QUANTITE DE CARBURANTS UTLISEZ-VOUS PAR MOIS POUR AUTRES MACHINES DE COMMANDE ?/WHICH AMOUNT ARE YOU USED FOR OTHERS COMMAND MACHINES PER MONTH ?

0 - 100 0 LITRES 1000- 5000 LITRES PLU E 5000 LITRES/MORE THAN 5000 LITRES

12.QUELLE QUANTITE DE CARBURANTS UTLISEZ-VOUS PAR MOIS DANS LE PROCESSUS DE PRODUCTION DE LA CHALEUR ?/WHICH AMOUNT ARE YOU USED FOR HEAT GENERATING ?

0 - 1000 LITRES - 5000 LITRES PLUS DE 500 LITRES/ MORE THAN 5000 LITRES

13.QUELLE QUANTITE D' ELECTRICITE UTLISEZ-VOUS PAR MOIS POUR L ECCAIRAGE? /WHICH AMOUNT OF ELECTRICITY ARE YOU USED FOR LIGHTING?

0 - 300 KWh 3000- 5000 KWh PLUS DE 500 KWh /MORE THAN 5000KWh

14.QUELLE QUANTITE D' ELECTRICITE UTLISEZ-VOUS PAR MOIS POUR LA MACHINERIE? /WHICH AMOUNT OF ELECTRICITY ARE YOU USED PER MONTH FOR MACHINERY?

0 - 5000 KWh 5000 -20000 KWh PLUS DE 50000 KWh /MORE THAN 20000KWh

15.QUELLE QUANTITE D' ELECTRICITE UTLISEZ-VOUS PAR MOIS POUR D' AUTRES MACHINES DE COMMANDE? /WHICH AMOUNT OF ELECTRICITY ARE YOU USED FOR OTHER COMMAND MACHINE?

0 - 1000 KWh 1000- 5000 KWh PLUS DE 5000 KWh /MORE THAN 5000 KWh

16.QUELLE QUANTITE D' ELECTRICITE UTLISEZ-VOUS PAR MOIS POUR D' AUTRES CHOSES? /WHICH AMOUNT OF ELECTRICITY ARE YOU USED FOR OTHER THING?

0 - 500 KWh 500- 1000 KWh PLUS DE 1000 KWh/MORE THAN 1000 I

Appendix B: LEAP Bamako models data

Table xx: Bamako LEAP Model

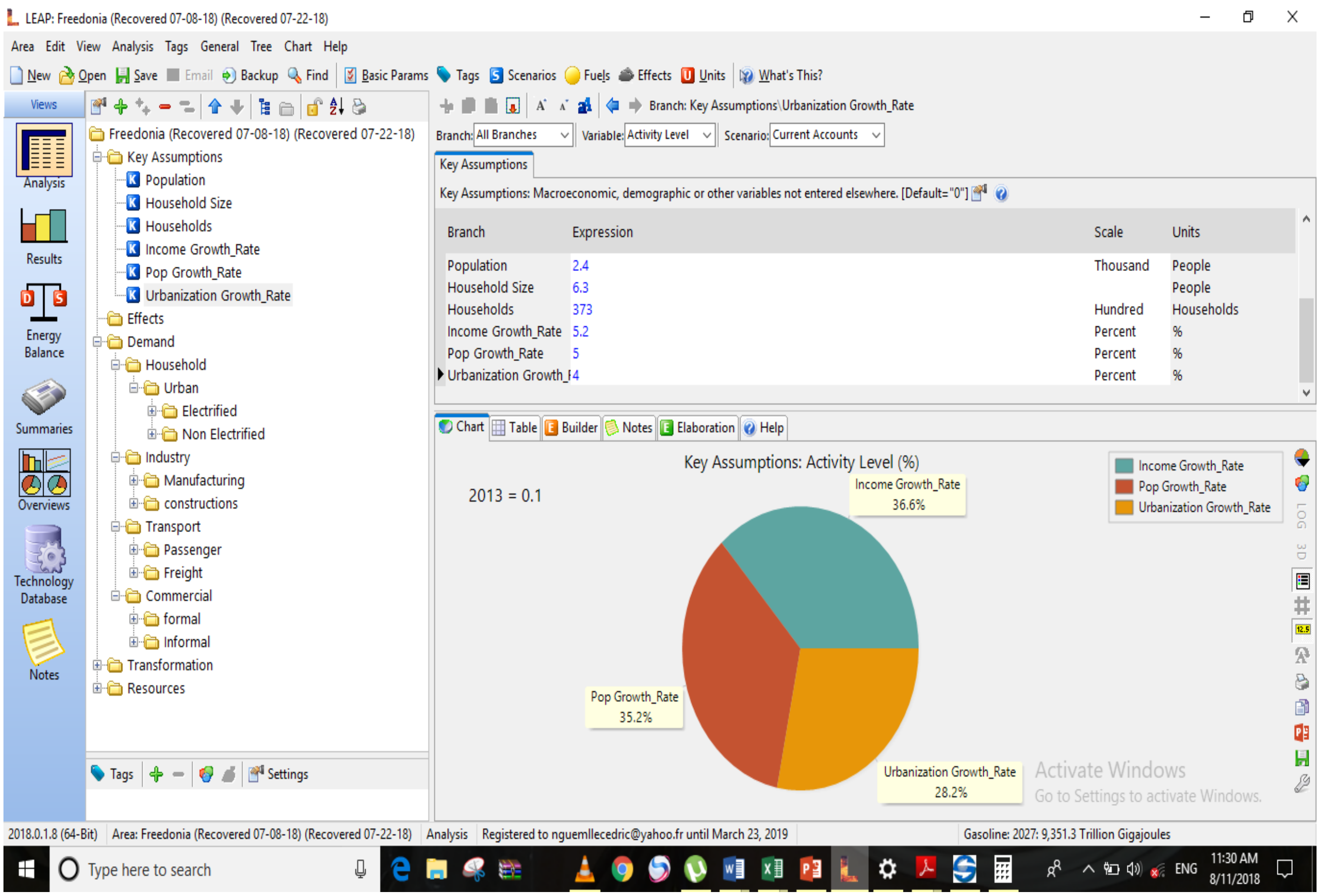
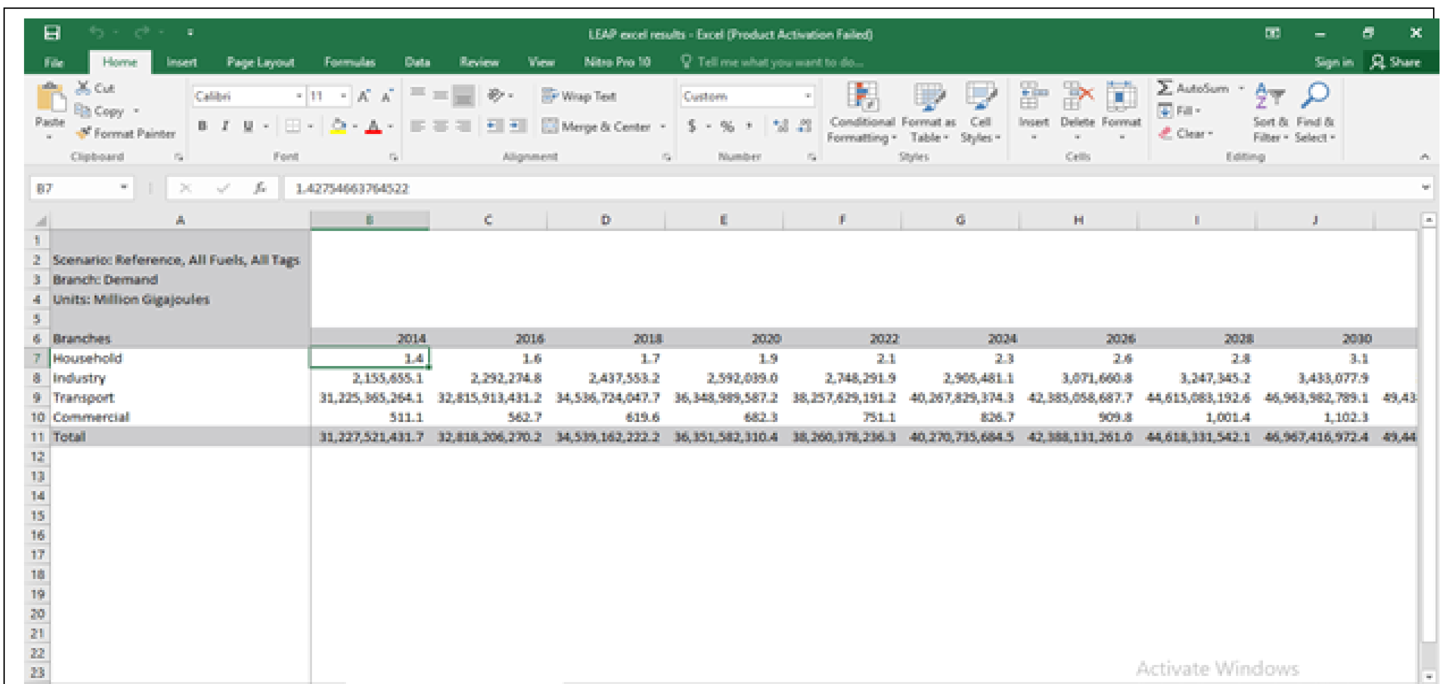


Table xx total energy demand in the city

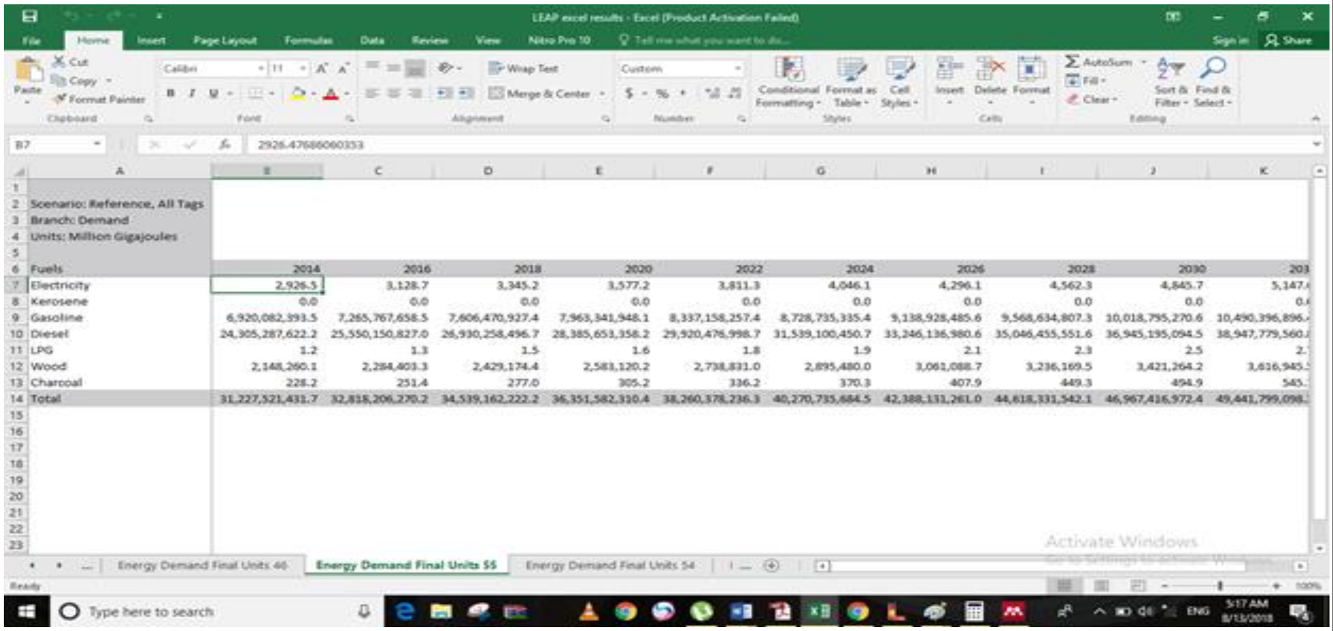


Scenario: Reference, All Fuels, All Tags
Branch: Demand
Units: Million Gigajoules

Branches	2014	2016	2018	2020	2022	2024	2026	2028	2030
Household	1.4	1.6	1.7	1.9	2.1	2.3	2.6	2.8	3.1
Industry	2,155,655.1	2,292,274.8	2,437,553.2	2,592,039.0	2,748,291.9	2,905,481.1	3,071,660.8	3,247,345.2	3,433,077.9
Transport	31,225,365,264.1	32,815,913,431.2	34,536,724,047.7	36,348,989,587.2	38,257,629,191.2	40,267,829,374.3	42,385,058,687.7	44,615,083,192.6	46,963,982,789.1
Commercial	511.1	562.7	619.6	682.3	751.1	826.7	909.8	1,001.4	1,102.3
Total	31,227,521,431.7	32,818,206,270.2	34,539,162,222.2	36,351,582,310.4	38,260,378,236.3	40,270,735,684.5	42,388,131,261.0	44,618,331,542.1	46,967,416,972.4

Table total fuel types consumption in the city .

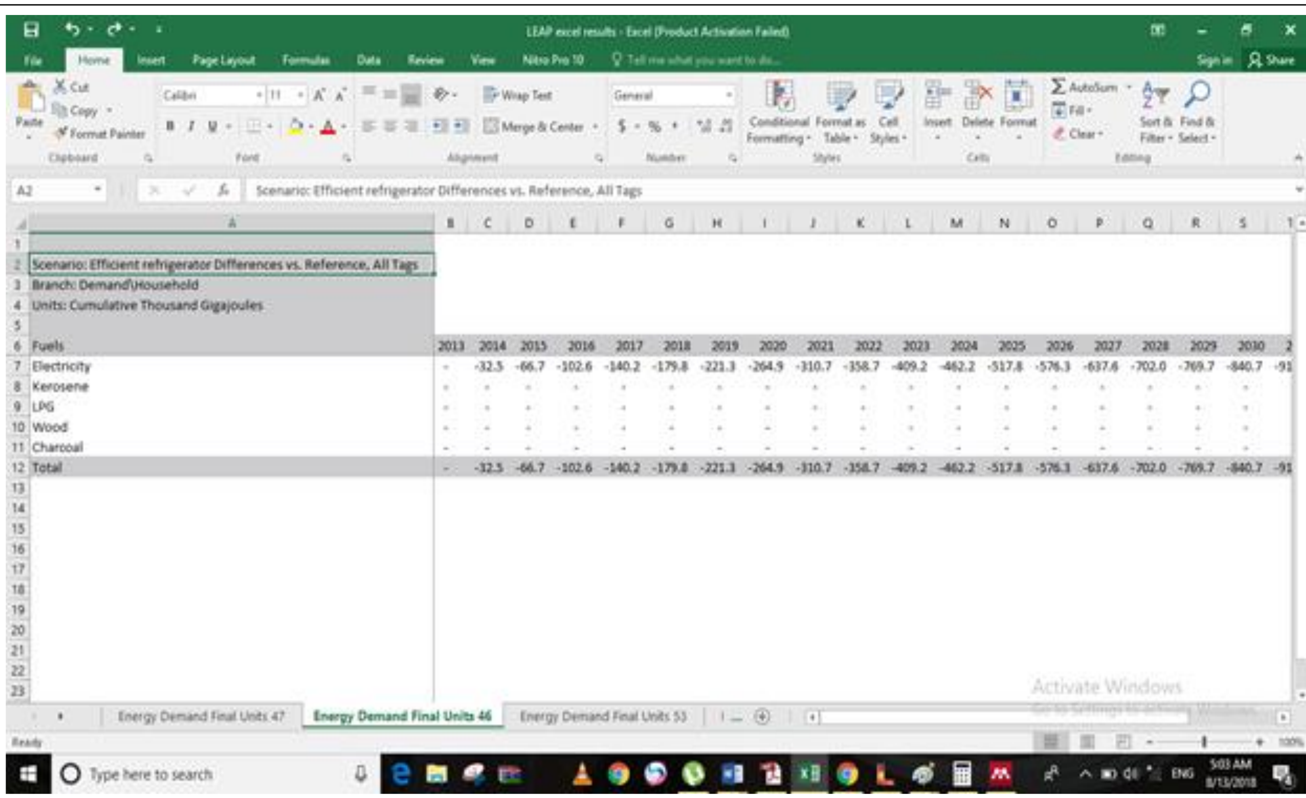
Table : Total fuel types consumption for the city of Bamako



Scenario: Reference, All Tags
Branch: Demand
Units: Million Gigajoules

Fuels	2014	2016	2018	2020	2022	2024	2026	2028	2030	203
Electricity	2,926.5	3,128.7	3,345.2	3,577.2	3,811.3	4,046.1	4,296.1	4,562.3	4,845.7	5,147.
Kerosene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.
Gasoline	6,920,082,393.5	7,265,767,658.5	7,606,470,927.4	7,963,341,948.1	8,337,158,257.4	8,728,735,335.4	9,138,928,485.6	9,568,634,807.3	10,018,795,270.6	10,490,396,896.
Diesel	24,305,287,622.2	25,550,150,827.0	26,930,258,496.7	28,385,653,358.2	29,920,476,998.7	31,539,100,450.7	33,246,136,980.6	35,046,455,551.6	36,945,195,094.5	38,947,779,560.
LPG	1.2	1.3	1.5	1.6	1.8	1.9	2.1	2.3	2.5	2.
Wood	2,148,260.1	2,284,403.3	2,429,174.4	2,583,120.2	2,738,831.0	2,895,480.0	3,061,088.7	3,236,169.5	3,421,264.2	3,616,945.
Charcoal	228.2	251.4	277.0	305.2	336.2	370.3	407.9	449.3	494.9	545.
Total	31,227,521,431.7	32,818,206,270.2	34,539,162,222.2	36,351,582,310.4	38,260,378,236.3	40,270,735,684.5	42,388,131,261.0	44,618,331,542.1	46,967,416,972.4	49,441,799,098.

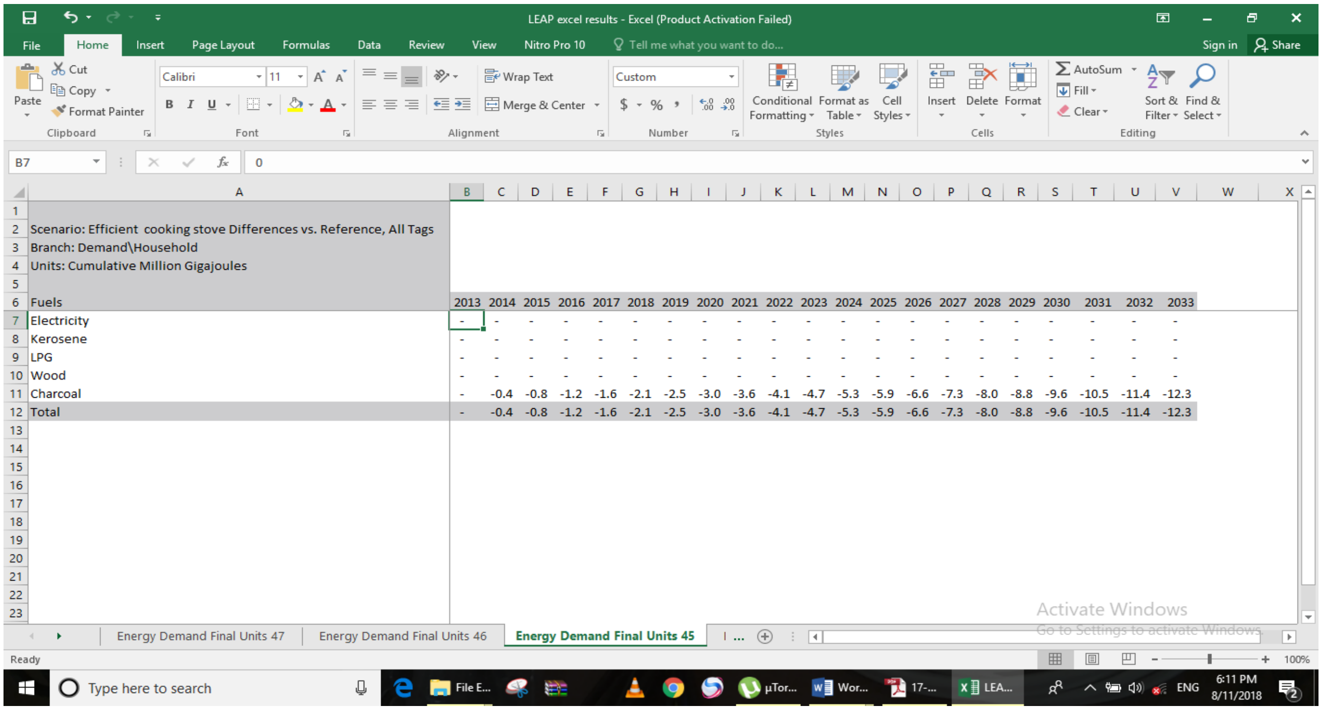
Table xx : Cumulative value on difference EFR and BAU scenarios



Scenario: Efficient refrigerator Differences vs. Reference, All Tags
Branch: Demand\Household
Units: Cumulative Thousand Gigajoules

Fuels	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2
Electricity	-	-32.5	-66.7	-102.6	-140.2	-179.8	-221.3	-264.9	-310.7	-358.7	-409.2	-462.2	-517.8	-576.3	-637.6	-702.0	-769.7	-840.7	-91
Kerosene	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
LPG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Wood	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Charcoal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Total	-	-32.5	-66.7	-102.6	-140.2	-179.8	-221.3	-264.9	-310.7	-358.7	-409.2	-462.2	-517.8	-576.3	-637.6	-702.0	-769.7	-840.7	-91

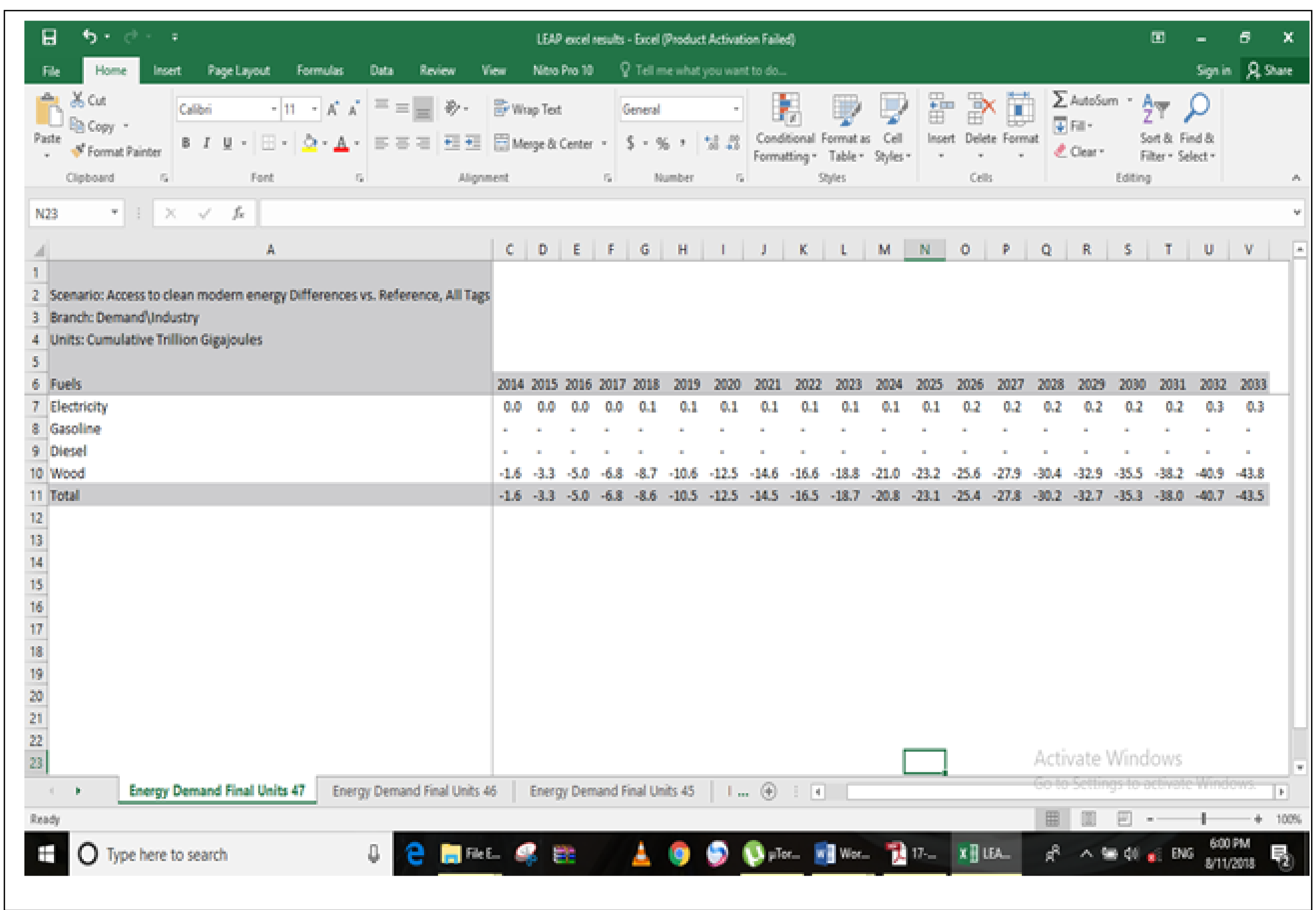
Table xx: Cumulative value on difference between EST and BAU scenarios.



Scenario: Efficient cooking stove Differences vs. Reference, All Tags
Branch: Demand\Household
Units: Cumulative Million Gigajoules

Fuels	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Electricity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kerosene	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LPG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wood	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Charcoal	-	-0.4	-0.8	-1.2	-1.6	-2.1	-2.5	-3.0	-3.6	-4.1	-4.7	-5.3	-5.9	-6.6	-7.3	-8.0	-8.8	-9.6	-10.5	-11.4	-12.3
Total	-	-0.4	-0.8	-1.2	-1.6	-2.1	-2.5	-3.0	-3.6	-4.1	-4.7	-5.3	-5.9	-6.6	-7.3	-8.0	-8.8	-9.6	-10.5	-11.4	-12.3

Table :Cumulative value on difference between ACC and BAU scenarios in industry sector



Scenario: Access to clean modern energy Differences vs. Reference, All Tags
Branch: Demand\Industry
Units: Cumulative Trillion Gigajoules

Fuels	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Electricity	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3
Gasoline	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diesel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wood	-1.6	-3.3	-5.0	-6.8	-8.7	-10.6	-12.5	-14.6	-16.6	-18.8	-21.0	-23.2	-25.6	-27.9	-30.4	-32.9	-35.5	-38.2	-40.9	-43.8
Total	-1.6	-3.3	-5.0	-6.8	-8.6	-10.5	-12.5	-14.5	-16.5	-18.7	-20.8	-23.1	-25.4	-27.8	-30.2	-32.7	-35.3	-38.0	-40.7	-43.5

Appendix C: own generator characteristicsand efficiency Model.

Based on published data, the model on diesel and gasoline (petrol) generator was developed in the purpose to convert the annual fuel consumption from own generator into electricity by considering its generator rating.

The equation … was evaluated from linear regression of the gasoline generator data, while the equation… was evaluated from the linear regression of the diesel generator data. The square of the pearson correlation co-efficient of correlation(R^2) was 62% and 66% for gasoline (petrol) and diesel generator respectively.

Table xx: Gasoline generator data used to derive a model of generator fuel consumption and efficiency as a function of rating and load factor *Sources: www.centralmainediesel.com; www.globalspec.com;* www.buffalotools.com; *gens.lccdn.com; powerequipment.honda.com; www.homedepot.com; www.northerntool.com*

Model	Rating (kVA/kW)	Load factor	Consumption (litres/hour)	Efficiency (%)
AlphaGen™ ACX2000i	1.9	1	1.77	12
AlphaGen™ ACX2000i	1.9	0.25	0.71	8
Champion 80 cc	1.2	0.5	0.55	12
GEN154	1.2	0.5	0.62	11
Generac 15,000	15	0.5	6.06	14
Generac 6500E	6.5	0.5	2.37	15
Generac GP15000E	15	0.5	6.06	14
Generac GP17500E	17.5	0.5	6.06	16
Generac iQ2000	1.6	0.25	0.52	9
Generac XD 5000	5	0.5	1.40	20
Honda GX 390	7	1	3.37	23
Honda GX 390	7	0.75	2.73	22
Honda GX 390	7	0.5	2.37	17
Honda GX 630	11.7	1	6.44	20
Honda GX 630	11.7	0.75	5.30	19
Honda GX 630	11.7	0.5	4.16	16
Honda GX 630	14	1	6.44	24
Honda GX 630	14	0.75	5.30	22
Honda GX 630	14	0.5	4.16	19
Honda GXH50 OHV	0.9	1	0.60	17
Honda GXH50 OHV	0.9	0.25	0.27	9
NorthStar 15,000	13.5	0.5	5.20	14
Robin R650	0.55	1	0.47	13
Unknown	2.7	1	1.71	18
Unknown	5.5	1	3.52	17
Unknown	6.8	0.5	2.52	15

Table xx : Diesel generator data used to derive a model of generator fuel consumption and efficiency as a function of rating and load factor

Sources: www.centralmainediesel.com; www.dieselserviceandsupply.com/Diesel_Fuel_Consumption. aspx;www.kohlerpower.com/onlinecatalog/pdf/g5412.pdf https://powersuite.cummins.com/PS5/ PS5Content/SiteContent/en/Binary_Asset/pdf/Commercial/Diesel/d-3372.pd

Model	Rating	Load factor	Consumption (Litres/hour)	Efficiency (%)
Unknown	20	0.25	2.3	22
Unknown	30	0.25	4.9	15
Unknown	40	0.25	6.1	17
Unknown	60	0.25	6.8	22
Unknown	75	0.25	9.1	21
Unknown	100	0.25	9.8	26
Unknown	20	1	6.1	33
Unknown	30	1	11.0	28
Unknown	40	1	15.1	27
Unknown	60	1	18.2	33
Unknown	75	1	23.1	33
Unknown	100	1	28.0	36
Unknown	20	0.75	4.9	31
Unknown	30	0.75	9.1	25
Unknown	40	0.75	12.1	25
Unknown	60	0.75	14.4	31
Unknown	75	0.75	17.4	33
Unknown	100	0.75	22.0	34
Kohler Diesel 6,500 Watt Diesel Generator	6.5	0.5	1.3	25
Kohler Diesel 6,500 Watt Diesel Generator	6.5	0.75	1.7	29
Kohler Diesel 6,500 Watt Diesel Generator	6.5	1	2.2	30
Kohler 35REOZT4	30	1	10.5	29
Kohler 35REOZT4	30	0.75	7.8	29
Kohler 35REOZT4	30	0.5	5.4	28
Kohler 35REOZT4	30	0.25	3.1	24
Kohler 35REOZT4	28	1	9.8	29
Kohler 35REOZT4	28	0.75	7.3	29
Kohler 35REOZT4	28	0.5	5.0	28
Kohler 35REOZT4	28	0.25	2.9	24

Cummins DSKAB	15	0.25	1.3	29
Cummins DSKAB	15	0.5	2.6	29
Cummins DSKAB	15	0.75	3.9	29
Cummins DSKAB	15	1	5.2	29
Cummins DSKAB	13.6	0.25	1.2	29
Cummins DSKAB	13.6	0.5	2.3	29
Cummins DSKAB	13.6	0.75	3.5	29
Cummins DSKAB	13.6	1	4.7	29

Budget justification

Items	Cost in local country	Cost in USD	Comment
Transport for internship in CDER (Algiers) and to the airport	**30,000 DZA**	**260 USD**	Several logistic had been taken during the one and half month of internship in CDER as well the traffic to Tlemcen –Algiers.
Flight ticket to Bamako	**47,577DZA**	**415 USD**	Traveled to the field of study for data collection.
Cost of data collection ,transportation , questionnaires prepared, and badges conception in the city	**372,000 FCFA**	**744 USD**	12 Students of University of Bamako had been recruited for data collection across the city: Report available with both supervisors
Network data cost	**5,000 DZA** **40,000 FCFA**	**45 USD** **80 USD**	Network data used during the internship as well as during the data collection in the field.
Software training and data analysis	**-**	**300 USD**	3 Weeks online software training had been carried and data analysis.
Cost of visa fee application	**8,300 DZA**	**75 USD**	Visa application to attend the conference.
Fight ticket of attended conference in ISES 2018 (poster work presentation)	**120,707 DZA**	**1,050 USD**	Traveled to present the work on the international School in Energy System ISES 2018, Germany.

Cost of Master Thesis printed and poster.	**8,760 DZA**	**76 USD**	6 hard copies of my master thesis and poster work presentation had been printed for the defense and correction.
Total	**-**	**3,045 USD**	
Exchange rate: **1 USD = 115 DZA= 500 FCFA**			