Pan African University
Institute of Water
and Energy Sciences

PAN-AFRICAN UNIVERSITY

INSTITUTE FOR WATER AND ENERGY SCIENCES

(including CLIMATE CHANGE)

Master Dissertation

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

[ENERGY POLICY]

Presented by

Nedal, SAYED EBNOUF

The System Dynamics of Electricity Demand-Supply Gap in Sudan: The Socio-Economic Impacts and Integrated Modelling Approach

Defended on 17/09/2019 Before the Following Committee:

Chair	Prof.	Abdelhalim Benmansour	University of Tlemcen
Supervisor	Dr.	Dénes Csala	University of Lancaster
External Examiner	Prof.	Sumeya Bedrane	University of Tlemcen

DECLARATION

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

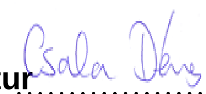
Signed:  Date: ...8th September, 2019

Nedal Sayed EBNOUF

Reg No: MEP

APPROVAL

This research project is submitted for examination with my approval as the University Supervisor.

Signatur ........................... Date: 8th **September, 2019**

Dr. Dénes Csala (PhD)

SUPERVISOR

PAUWES, TLEMCEN

ABSTRACT

Efficient and reliable electricity supply is critical for economic growth. Sudan is facing multiple challenges of meeting country's electricity requirement, finding suitable resource transition from depleting fossil fuels and addressing the concern of climate change. Sudan among the medium electrification rate in Africa, in spite of the remarkable energy resources and the huge potential of renewable energy. Economy of Sudan is growing at fast pace in which with increasing demand for electricity. Khartoum the capital of Sudan has been subjected to frequent electricity outage since 2011 after the secession of South Sudan which left a significant effect on the thermal power plants productivity which the country was depending on. Urbanization level in Khartoum is another challenge to the electricity sector and one of the main variables causing the demand-supply gap. System Dynamics approach is used for understanding the interconnection between the electricity subsystem and the variables. This research using System Dynamics has developed models for electricity demand and supply in the country. In order to meet the growing demand of electricity per capita.

RÉSUMÉ

L’approvisionnement en électricité efficace et fiable est essentiel à la croissance économique. Le Soudan rencontre plusieurs défis pour satisfaire les besoins électriques du pays, en trouvant une transition appropriée des ressources, l'épuisement des combustibles fossiles et la prise en compte du changement climatique. Soudan a un taux d'électrification moyen en Afrique, malgré les ressources énergétiques remarquables et le potentiel énorme des énergies renouvelable. L’économie soudanaise se développe à un rythme rapide et, avec la demande croissante de l’électricité. Khartoum, la capitale du Soudan, a subi de fréquentes coupures d’électricité depuis le 2011 après la sécession du Sud-Soudan qui a eu un impact significatif sur les centrales thermiques dont dépendait le pays. Le niveau d'urbanisation à Khartoum est un autre défi du secteur de l’électricité et l’une des principales variables à l’origine de l’écart entre offre et demande. L’approche System Dynamics est utilisée pour comprendre l’interconnexion entre le réseau électrique sous-système et les variables. Cette recherche utilisant System Dynamics a développé des modèles pour demande et offre d'électricité dans le pays. Afin de répondre à la demande croissante d'électricité avoir par habitant

DEDICATION

This project paper is dedicated to the Sudanese martyrs since the independence until the current revolution for the precious price of freedom and peace they paid it on behalf of the whole Sudanese, I dedicate it also to the missing brothers and sisters all over the country, we are still looking for you and we will come together one day. To the mothers and families who lost their loved ones, we are your family and we are together in this transformation.

ACKNOWLEDGEMENTS

First, I would like to thank the Almighty ALLAH for his grace and mercies that have been sufficient for me always, for it has been Him from the beginning. I express my earnest appreciation to my supervisor **Dr. Dénes Csala** (PhD) for his overwhelming intellectual guidance, encouragement, patience and tireless effort towards the actualization of this research project.

I would like to thank my friends and my family for always believing and supporting me along this journey. There are countless moments when they have lifted me up and encouraged me to chase my 10 dreams. I would personally like to thank my parents, family, and siblings for their financial, moral and spiritual support. I also warmly appreciate my associates: Ashraf, OTI Jonathan, KABASINGWA Evelyn, Mutsindikwa Cynthia, Rana Osman, the Energy Policy class and the entire PAUWES class of 2019. Bravo, we made it! A vote of thanks goes to all the respondents in Military Head Quarter sit-in, Khartoum, for their active participation in this research.

Finally, yet most importantly, I express my sincere gratitude to all the entire staff of Pan African University of Water and Energy Sciences for their commitment in creating a good learning environment throughout the course, and I gratefully acknowledge the African Union in partnership with GIZ for the scholarship and research grant offered to me, without which this journey would not have been a success.

TABLE OF CONTENTS

DECLARATION i
ABSTRACT ii
RÉSUMÉ iii
DEDICATION iv
ACKNOWLEDGEMENTS v
TABLE OF CONTENTS vi
LIST OF ABBREVIATIONS x
LIST OF FIGURES x
LIST OF TABLES xiii
CHAPTER ONE 1
1 INTRODUCTION 1
1.1 Background Information 1
1.2 Statement of the Problem 3
1.3 General Objective 4
1.3.1 Global Objective 4
1.3.2 Specific Objectives 4
1.4 Research Questions 4
1.5 Scope and Limitations 5
1.6 Significance of the Study 6
1.7 Difficulties Encountered During Data collection 6
1.8 Organization of the study 7
CHAPTER TWO 8
2 LITERATURE OVERVIEW 8
2.1 Power Access 9
2.2 Electricity Demand 9
CHAPTER THREE 14
3 CASE STUDY: SUDAN OVERVIEW 14
3.1 Sudan's Energy Sector Background 14

3.2 Energy Sources in Sudan 15
3.3 Sudan’s Renewable Energy Sector 16
3.3.1 Wind energy 16
3.3.2 Hydropower plants 17
3.3.3 Solar energy in Sudan 18
3.3.4 Geothermal energy in Sudan 20
3.3.5 Biomass energy in Sudan 20
3.4 Energy Sector Problems and Challenges 22
3.5 Background of Sudan’s Electricity Sector 22
3.6 The National Electricity Corporation (NEC) 24
3.7 Electricity Demand and Consumption 25
3.8 Electricity Generation 26
3.8.1 Electricity generation 28
3.8.2 Thermal Generation and Hydro Power Generation 29
3.9 Electricity Consumption 31
3.9.1 Electricity consumption per capita 32
3.10 Electric Power Transmission and Distribution Losses 33
3.10.1 Electrical power losses in Sudan 33
3.10.2 Technical losses 33
3.10.3 Non-technical losses 33
3.10.4 Administrative losses 34
3.11 Khartoum The Capital of Sudan 35
3.11.1 History and background of Khartoum 35
3.11.2 Role of the capital Khartoum and formal local government 35
3.11.3 Settlement patterns in Khartoum 36
3.11.4 Urbanization 38
3.12 Sudan’s Economy Brief 39
3.13 Inflation rate in Sudan 40
CHAPTER FOUR 42
4 RESEARCH METHODOLOGY 42
4.1 Preparation 42
4.2 Research Design and Data Collection 42
4.3 Research Instruments 43
4.4 Data Collection Techniques 43
4.5 Data Processing and Analysis 43

4.6 Limitation of the Study 43
4.7 Ethical Considerations 44
4.8 System Dynamics Modelling 44
4.9 Modelling 45
4.10 Reporting Phase 47
CHAPTER FIVE 49
5 RESULTS AND DISCUSSION 49
5.1 Demographic and Socio-economic Characteristics of Respondents 49
5.1.1 Family members number 49
5.1.2 Electricity access from the national grid 50
5.1.3 Average income per capita 50
5.1.4 Electricity appliances 50
5.1.5 Multi-tiers framework 51
5.2 Electricity Prices and Cuts off 52
5.2.1 Electricity cuts off 52
5.2.2 Electricity prices 53
5.2.3 Social support for future electrification plans 54
5.3 Electricity Tariffs 55
5.4 Challenges Faced by the Continues Electricity Cuts Off 56
5.5 Green Energy 57
5.5.1 Electricity from renewables 57
5.5.2 Renewable energy prices 58
5.6 System Dynamic Approach of Electricity System 60
5.6.1 Electricity demand subsystem 61
5.6.2 Electricity generation subsystem 62
5.6.3 Technology subsystem 64
5.6.4 Environment subsystem 64
5.6.5 Price and Tariff Subsystem 65
5.6.6 Policies and regulation 66
5.7 Externalities in Electricity System 67
5.7.1 Urbanization 67
5.7.2 Available generation capacity 68
5.7.3 Market instructure 68
5.8 Electricity System Summary 69
CHAPTER SIX 73

6 POLICES, CONCLUSION AND RECOMMENDATION 73
6.1 Conclusion 73
6.2 Recommendations 74
7 References 76
8 Appendix 81

LIST OF ABBREVIATIONS

IEA	International Energy Agency
NEC	National Electricity Corporation of Sudan (NEC)
TWh	Tera Watt hour
MWh	Mega Watt our
kWh	Kilo Watt hour
Ktoe	Kilo Ton oil equivalent
ML	Million Liters
SD	System Dynamics
P.P	Power Plant
UN	United Nation
IRENA	International Renewable Energy Agency
GDP	Gross Domestic Product
NEPA	National Electric Power Authority
OPEC	Organization of the Petroleum Exporting Countries.
PV	Photo-Voltaic Cell
CSP	Concentrated Solar Power
MHESR	Sudan created the Ministry of Higher Education and Scientific Research
NCR	National Center for Research
ERI	Energy Research Institute
UNDP	United Nation Development Program
CEFA	Cleaner Energy Fund for Agroindustry
ME&M	Ministry of Energy and Mining
EEPCo	Ethiopian Electric Power Corporation
NTL	Non-Technical Losses
SE4ALL	Sustainable Energy for All Initiative
TD	Technology Development
DSM	Demand Side Management

LIST OF FIGURES

Figure's Number	Page number	Figure's Title
Figure(1)	15	Hydroelectric and Thermal power plants
Figure(2)	17	Wind Energy Potential in Sudan
Figure(3)	19	Sudan's Global Horizontal radiance map
Figure(4)	20	North Africa Solar Energy Potential
Figure(5)	22	Bioenergy Potential in Africa
Figure(6)	24	Sudan's National Grid
Figure(7)	25	Sudan's National Grid, 220kV and 110kV lines
Figure(8)	27	Hidden Cost of Losses of Sudan's National Grid
Figure(9)	28	Sudan Electricity Generation 2018
Figure(10)	30	Sudan Electricity Generation, Ethiopian Connectivity 2016
Figure(11)	31	Sudan's electricity production timeline 2000-2018
Figure(12)	32	Sudan Electricity Consumption 2007 – 2018
Figure(13)	34	Power Transmission and Distribution Losses 2010
Figure(14)	36	Khartoum's Formal Local Government Structure
Figure(15)	37	Khartoum's Settlements map
Figure(16)	40	Sudan's Economy 1985 – 2018
Figure(17)	41	Inflation Rate in Sudan
Figure(18)	45	Modelling Settings Window, VENSIM
Figure(19)	46	Flow, Stock and Variable
Figure(20)	46	Loops and Lookup
Figure(21)	49	The number of family members,
Figure(22)	50	The electrical Appliances
Figure(23)	52	Electricity Outage
Figure(24)	53	The electricity prices Affordability
Figure(25)	54	The electrification support
Figure(26)	56	Green Energy Knowledge
Figure(27)	57	The Interest Percentage of Accepting Renewable Energy
Figure(28)	58	Renewable Energy price acceptability
Figure(29)	59	Electricity System
Figure(30)	61	Electricity Demand subsystem
Figure(31)	62	Electricity Generation subsystem
Figure(32)	63	Power plants life cycle
Figure(33)	64	Technology subsystem (A) and Environment subsystem (B)
Figure(34)	65	Price and Tariff subsystem

Figure(35)	65	Polices and Regulation subsystem
Figure(36)	66	Urbanization
Figure(37)	67	Available Generation Capacity
Figure(38)	68	Market Instructure
Figure(39)	71	Residential Tariffs 1997-2016
Figure(40)	72	Casual Loop Diagram of the Demand-Supply Gap

LIST OF TABLES

Number	**Name**
Table (1)	Electricity Demand by Sector
Table (2)	Hydroelectric power plants in Sudan
Table (3)	Electricity Consumption, Maximum and Minimum
Table (4)	Multi-tier Framework
Table (5)	Multi-tier Framework Matrix
Table (6)	The electricity Tariff for Residential

CHAPTER ONE

1 INTRODUCTION

1.1 Background Information

Electricity demand-supply gap is one of the most problems that facing most of the developing countries namely in African and some of Asian countries in which the electrification rate is still low in the rural areas of the countries. According to World Bank (2018) there is a dearth of energy, which affects over 1.1 billion people globally. It is also estimated that over 3 billion people worldwide still lack access to clean cooking [1]. Majority of these people are from developing countries in Asia and Africa [2]. It estimates that over 60,000 mini-grids which translates into 3,600MW is needed by 2020 and 128,000 mini-grids (7,680MW) by the end of 2030 to achieve electricity access in Sub Saharan Africa alone; as such the African Union and her partners have dovetailed to also ensure that the over 600 million people without electricity on the continent is reduced [3]. This has triggered massive investments, policies and programs geared towards energy access to safeguard the continent from the catastrophic effects of climate change, and energy poverty, which together has devastating effect on biodiversity and socioeconomic wellbeing of the people.

In planning electricity conservation, demand and supply, electricity balance information of the energy systems is of great use. However, electricity balance is influenced by technical and non-technical factors together with the socio-economic challenges, the main characteristics of the electricity demand-supply gap such as the exponential growth of the population and energy Consumption and the increasing level of urbanization, energy losses and administrative losses. Due to the interconnected nature of energy balance components, it is evident that accurate and reliable predictions of professional responses of societies are becoming extremely important due to their help in planning and managing energy resources. Therefore, understanding the relationship between electricity sector components and physical parameters by energy resources planners and managers is very essential since the socio-economic processes being dealt with are very complex when carrying out any energy resources development related projects.

Globally, electricity is the most consumed form of energy all over the world, due to the fact that industrial and residential sectors are the main consumers. On the other hand, electricity is not equally accessed spatially yet as a source, continues to play a vital role in our daily usage not only for industrial and residential usage but also for supporting development of nations. In recent past, electricity demand and electricity availability has elicited national and regional attention due to its fundamental importance in line with health, education quality, and other industrial uses. Therefore, bridging the demand-supply gap and electricity balance components is high importance for electricity sources management at national and regional scales.

As population increases in Asia, demand for electricity is increasing therefore, acting as a major influential factor towards increasing the industrial awaking in that region [4]. On the other hand, increase in population means more electricity is being generated causing a threat to most fossil fuels resources in Asia. Shanghai is a city that has a high level of urbanization and a fast increasing population which results in a sharp increase in demand for electricity [5]. The shortages happen when the electricity demand exceeds the supply in strict way, which affect the economic growth of the whole city.

Africa's development of electricity resources just as other parts of the world has largely been grappling with activities supporting economic growth which have been shifting from agriculture to industrialization, and electricity as a form of energy play a vital role in the socio-economic and technological development of any nation [6]. This transformation, strong income growth and rising living standards of a growing middle class have led to sharp increases in electricity use, and creating imbalance between supply and demand, especially where supplies are from of state monopoly where electricity use, distribution, price, consumption and management are poorly managed or regulated. In Nigeria, the over centralization of electricity failed to keep the pace between the supply and the population growth and their activities and that create one of the biggest electricity demand-supply gap in the world by providing over 160 million the population of Nigeria with only 4000 megawatts of electricity [7].

Historically, Sudan's power sector has characterized by inadequate and inefficient power supply since the country's independence in 1956. The only responsible body for the country's electricity generation, transmission and distribution is the National Electricity Corporation of Sudan (NEC), and the other uncovered regions in the country are depending on private owned diesel generators. Hence, challenges arising with regard to losses in transmission and distribution networks which is direct losses in addition to indirect losses in terms of lost productivity, trade sagging economic activity, rapidly shrinking of domestic and foreign investment in the sector. In recent past, Sudan government decided to establish a separate Ministry of electricity and to restructure the previous National Electricity Corporation of Sudan (NEC) in to five state holding Companies. However, beside all this changes and developments in the electrical power sector in Sudan, but supply still there are a lot of struggles facing authorities to effectively electrify the country and less attention has been on how balance between electricity demand and electricity availability is influencing electricity system in the country [8].

Therefore, this study aims at looking into the connection between bridging the electricity demand-supply gap and the socio-economic impacts of this gap. This is because, there is a need to assess electricity system for future development and socio-economic monitoring and this requires understanding if organizational and governance structures are working for or against full implementation of covering the existed gap and it is effects on the country. Including how institutions operations are influenced by the balance between the electricity demand and electricity availability; how is it responding to new governance structure of the country and newly designed; formulated national electricity policies to achieve more adaptation for electricity resources. This is important because identify the main causes of the gap and relate it to the country's socio-economic situation compared with existing variability and broader agenda of sustainable development and adaptation.

1.2 Statement of the Problem

Sudan's electrical power sector has been subjected to poor infrastructure, frequent power cut off and many parts of the country have been experiencing frequent power outage in daily bases. The citizen who are affected by the electricity supply interruption create a sense of complaints to the government, due to the fact that the absence of the electricity is affecting their lives socially and economically. Based on the current status of power shortage in Sudan, the country is facing challenges to build strong economic, and industrialization and modernization cannot be achieved without proper access to electricity. People living in Khartoum are subjected to regular power outage, as a result of the fast growing communities and urbanization level which over load the old notational grid. Electricity sector in Sudan has been a victim to many challenges, starting from the increasing of oil price after 2011 due to the separation of the country into Sudan and South Sudan, and the two-third of the oil deposit was for South Sudan. The effect of oil lack was direct on the thermal power plants that generating the electricity in the country which was counted as 44% of the total installed capacity from fossil fuel. In response to this problem, our study proposes to investigate several options to bridge the gap between the demand and supply of electricity in Khartoum. We plan to carry out a model that highlight the main factors which are affecting the electricity sector together with the socio-economic impacts of the electricity demand-supply gap on the population of Khartoum and their interconnection.

1.3 General Objective

1.3.1 Global Objective

The global objective of the study is to assess the electricity demand-supply gap and its impact on socio-economic development of the livelihood of the capital Khartoum, Sudan.

1.3.2 Specific Objectives

1- To understand the key drivers of electricity demand growth.

2- To identify the electricity capacity and demand in Khartoum.

3- To estimate the electricity demand-supply gap effects on individual level and city level.

4- To describe the socio-economic impacts of the electricity demand-supply gap.

5- To understand the variables driving the dynamics of Energy, Demography and Economy.

6- To inform policy from the findings.

1.4 Research Questions

1. What are the drivers of electricity demand growth?

2. What is the installed capacity for electricity generation in Khartoum?

3. How to estimate the electricity demand-supply gap effects on individual and city level?

4. What are the socio-economic impacts of electricity demand-supply gap?

5. What are the variables which they are driving the dynamics of energy, demography and economy?

6. Which policies could be extract from this study?

1.5 Scope and Limitations

This study is designed to understand the electricity demand-supply gap and its social and economic effect in Sudan's capital Khartoum; therefore, the intent of this study is to address the social and economic phenomena in practical and technical way. The scope area of the study is urban and pre-urban residential areas in Khartoum, Sudan. The study conducted on sampling household survey. The survey contains 17 questions that covers the main objectives of the study to precisely know the house appliances in order to obtain the electricity load, to calculate the blackout and cuts off in different time periods and the survey covered as well some question about the effects and challenges that facing the community as a result of the unstable electricity supply in different aspects. The last part of the survey was about the green energy and carbon free energy, what is known about it and the willingness of the community to have electricity from green source however it is more expensive than the electricity from fossil fuel.

Due to the limited amount of time and the political situation in the country, the research shall primarily be based on secondary data and responses to questions conducted with a university professor and a representative from the Sudanese Ministry of Water and Resources and Electricity. The secondary data shall mainly consist but not limited to:

- Organization's data such as UN, IRENA (The International Renewable Energy Agency), IEA (Internarial Energy Agency), etc.
- Scientific peer reviewed articles.
- Case studies in the Sudan and other countries with similar conditions.

The research experience many limitations in terms of collecting relevant updated data. Few reasons contributed to this such as:

- Very limited studies, information, papers concerning the new Sudan (North Sudan)
- Very limited well documented data on electricity
- Lack of updated data from official bodies.
- Limited time that has prevent the study from conducting field survey for the far areas from the center of the capital Khartoum.

The limitations of the study here by could be summarized in main three points:

- Firstly, the time period of the study, due to the unstable situation of Sudan during the period of data collection, collecting data was challenging as a result of insecurity of the targeted areas,
- Secondly, the different information for the same data based on the sources and variation of the values and the severe repetition,
- Thirdly, the absence of the most recent data sources in most platforms.

This study is based on governments data without including any data from the private sector.

1.6 Significance of the Study

This study is significant endeavor to promoting good understanding of the main reasons of electricity demand-supply gap. The findings from this study will guide policy makers and project implementers and agencies which is a transformative effort to increase the electrification rate through all the means in the country and the continent as well. This study will therefore add up to knowledge on how best to design implementation approaches that suits communities and countries how to promote and increase electricity access and energy supplying through the country [9]. The outcome of this study will also help the government of Sudan in her pursuance of Sudan Energy and electricity expansion vision as well various stakeholders on how to embark on community base electrification projects especially in the Western part of the Country. More so, this study will contribute to attainment of the African Union Agenda 2063 in relation to sustainable development and energy access. This background justifies why this study is of relevance in ensuring sustainability and accessibility of energy at national levels.

1.7 Difficulties Encountered During Data collection

Data collection process had faced many obstacles, starting from the personal security for the researcher her/himself, the hardship of the movement in the capital Khartoum at the time of collecting data as a result of the emergency status of the country and the early curfew. People in Khartoum some were not cooperative as a result of many reasons one of them is the ongoing revolution that created a cloud of misunderstanding the kind request of the survey filling and the clarifying was needed for better understanding.

1.8 Organization of the study

This study is presented in six chapters. The first chapter comprises the general introduction which constitutes the background of the study, statement of the problem and significance of the study. Chapter two presents the literature review on the electricity demand-supply gap and its modelling while chapter three highlights the overview of Sudan as the case study, including energy profile of the country and more detailed in the capital Khartoum as the main study area. Chapter four presents the methodology used during the study. Furthermore, chapter five is a presentation of results of the study and discussions and finally, chapter six presents the conclusion and recommendations derived from the study.

CHAPTER TWO

2 LITERATURE OVERVIEW

The global demand- supply balance is weighed in favour of demand side, according to the International Energy Agency (IEA), more than one billion of the world's population and 145 of the total population lack access to electricity. The people live in rural areas take the lion share, about 84 % are living in rural areas, and 95% of those people are mainly located in Sub-Saharan and South Asia [10]. This ratio shows that rural areas are barely electrified, expanding electricity to these areas is usually hindered by the high cost required for infrastructures. Rural areas host most agriculture projects that considerably contribute to the African economies. The agriculture sector in Africa is highly depending on animals and human which surplus the production and subsequently economic growth [11]. Despite the cost of extending electricity might be expensive in short term, the outcome in long term of socio-economic development is rewarding, if the costs and benefits are taken together at electrifying rural areas, expanding electricity to rural areas impacts many sectors such as education, agriculture and healthcare. In fact, the benefits are much more than the costs in long term [12]. On the other hand, electrifying urban areas has also great benefits; it increases household income as discussed in a workshop on electrification held in Brazil in 2005, the cost of legal electricity is less than the cost of illegal operators. It also has a positive impact on improving health care and reducing the indoor pollution [13]

In Africa, the rate of access to electricity has been slow for many years. In fact, this is a deterioration if other factors like population growth and economic development are considered. Access to electricity must increase to meet the growing needs of energy for socio-economic development. In developed countries, the rate of access to electricity has witnessed an increase of 20 % in the last two decades. The development in Africa has been faced by limitedness of electricity production and lack of information about the demand and supply. According to [14] 620 millions of Africans do not have access to electricity. Furthermore, the consumption of electricity per capita is very low in Sub-Saharan Africa countries. Unless serious actions to be taken, the situation is more likely to be worse as the population and demand for energy are going to increase. The electricity demand-supply gap can be bridged via managing energy resources and understanding the relationship between electricity sector components and its physical parameters.

Even though, Africa is endowed with huge energy resources, yet most countries in the African continent are still in the dark after nightfall. It is no wonder that Africa's underdeveloped power sector affects its gross domestic product (GDP) [14]. Countries which the electrification rates less than 80% of the population consistently suffer from reduced GDP per capita as a result of different factors related to energy lack and undeveloped economic. The only countries that have electrification rates of less than 80% with GDP per capita greater than $3,500 are those with significant wealth in natural resources, such as Angola, Botswana, and Gabon [15]. Africa's power supply is unreliable. African manufacturing enterprises are experiencing power outages on average 56 days per year. As a result of the outages firms lose 6% of sales revenues in the informal sector [16]. If back-up generation is not available, the losses can be as high as 20 percent of the sales revenues. Additionally, power tariffs in most parts of the developing world fall in the range of US$0.04 to US$0.08 per kilowatt-hour. However, in Sub-Saharan African countries, the average tariff is about US$0.13 per kilowatt-hour. In countries where they are depending on diesel-based systems, tariffs are higher still. Given poor reliability, many firms operate their own diesel generators at two to three times the cost with attendant environmental costs [17].

2.1 Power Access

Sub-Saharan Africa alone accounts for 13% of the world's population and 48% of the share of the global population without access to electricity. Africa in general faces low access and insufficient capacity – About 24% of the population of sub-Saharan Africa has access to electricity versus 40% in other low income countries. Excluding South Africa, the entire installed generation capacity of sub-Saharan Africa is only 28 Gigawatts, equivalent to that of Argentina [17].

2.2 Electricity Demand

Observing energy consumption patterns across various countries at different stages of economic development reveals that in general, as a country prospers, per capita consumption of energy increases as well. For example, Roland Berger Strategy Consultants (2013) estimated that per capita energy consumption in the United States was nearly 13 times greater than in India in 2012. In spite of increased effort in increasing and improving Africa's generation capacity, electricity consumption has been growing faster as a result of the economic growth. Whereas power generation is increasing at 4.4% annually, consumption has been increasing at 2%.

Africa’s consumption rate is far below other continents. The Average consumption of electricity in sub-Saharan Africa, excluding South Africa, is only about 150 kilowatt-hours per capita. This is same as a fraction of consumption rates in Brazil, India, and South Africa. According to the International Energy Agency, the world electricity consumption was 18,608 TWh in 2012. Out of this, Africa consumed only about 3% [18].

Low income countries are experiencing overwhelming demands. One of the parameters increases those demands is the inefficiency in operating power sectors. In sub-Saharan countries, loses amount of electricity due to technical and nontechnical issues account for 30%- 35% which is very high ratio. These inefficiencies are highly affecting the economic growth of the countries. It costs the Sub-Saharan countries about 1.8 % percent of gross domestic product [19]. The problems face power sector can be summarized in the following points [19]:

- **Power capacity**

Small ratio of the African power capacity has been exploited; the geothermal capacity of Africa is estimated at 14,000 MW, less than 0.5 % has been harnessed. This reflects very low utilization of the power capacity of Africa [20]. Generally, Africa has the lowest generation capacity, about 28 gigawatts, if South Africa is excluded. This capacity is not even fully exploited, 7 gigawatts is lost because of many reasons, on the top of them is that the power supply is unreliable and the aged power plants dwindled precipitously from lack of regular maintenance.

- **Unexploited energy resources**

Africa has diverse resources of energy, ranging from traditional energy resources of oil, natural gas and coal reserves, to renewable energy resources such as hydroelectric energy, solar energy, wind energy and biogas. Although Sub-Saharan is rich in energy resources, the majority of these resources are not yet exploited. For example, only 7 percent of the total hydropower is exploited, the statement holds true for gas and oil reserves. Other energy resources such as solar energy and wind energy are not giving accurate statistics for the mean time.

- **Economic approach**

There is a growing need for investments in developing countries; this can be seen from the money that was spent through 2010 decade, $ 160 billion. The economic actor plays a vital role in bridging the demand-supply gap, according to the estimation of the International Energy association (IEA), the developing countries needs to secure about $ 210 billion of investments through the 2030 decade which is 13 % more than the budget that is estimated to be allocated through 2020 decade. The challenge is that only 50 % is foreseen to be secured and that exacerbate the demand-supply gap of electricity which is a corner stone in achieving the millennia goals of sustainable development. This gap is highly affect any future plan in economic development. Unless a tedious work is put to close the gap, economic growth plans will be highly affected [21].

The cost of electricity in Sub-Saharan Africa is high when compared to other developing countries. The limited scale of power system restricts the extension of electricity to distant areas. That leads most countries to depend on oil to generate electricity which in turn add extra cost to the total cost. Another factor aggregate the issue is that most Sub-Saharan countries rely on imported diesel and heavy oil to meet the demands of small domestic power markets. The cost of these forms of power is subject to trade prices which fluctuated rapidly in the last two decades [22].

In fact, there is preventable cost arises from underpricing as well as distribution losses. The failure also in collecting billing represent burden on the governments. Some Sub-Saharan countries such as Sudan overcame this issue by a pre-paid system imported from South Africa, yet other main obstacles need to be addressed urgently for sustainable electricity service.

However, the cost and pricing the electricity for consumers depend on each country, as the cost varies from one country to another. At the end, it should be suitable to cover the operations costs and other costs required for sustainable service.

In addition to all these economics measures, polices are important in reducing the cost of electricity generation. For instance, activating trade exchange between African countries will reduce the generation cost; Sub-Saharan countries can export the hydroelectric power to its neighbors or import it depending on the location like the grid link between Sudan, Egypt and Ethiopia. Exchanging hydroelectric also has an environmental impact as the case if South Africa was to import hydroelectric power from the Democratic Republic of Congo, this would cut the annual carbon dioxide emission by 40 million tons emitted by South African coal-based power emission [23]. Therefore, suitable measures and polices have remarkable effect on economic and environment of Africa.

Nigeria is one of the richest country in Africa in energy resources, though it is blessed with enormous electricity generation resources, transmission and distribution, the known fact that Nigeria is among the countries in which the electricity demand override the available supply [24]. Nigeria has great potential for economic transformation in which energy play an important role in the development but the country is faced with severe energy crisis which has prevent the economic growth and development [25].

For many decades Nigeria power's sector had been operated as a state monopoly then called the National Electric Power Authority (NEPA) till 2005. NEPA in control of all of generation, transmission and distribution facilities with all the deep inherent problem in public monopoly. Through this centralization, the electricity supply faced many challenges to keep the pace together with the population growth and the increasing of economic activities. Nigeria's electricity demand-supply gap is considered as one of the biggest gap in the world, as a matter of fact that 160 million of its population are provided only 4000 MW of electricity [26], about 45% of the country's population have electricity access and only 30% of their demands needs is met. As a result of power sector plagues, 90% of industrial customers and considerable number of residential sector and non-residential equipped their own power utilities at a high cost of fuel price.

The installed capacity in Nigeria is about 8,000 MW but only 4000 MW is operable which is only 1,500 MW is available for electricity generation. In 2011, 1750MW was generated while the installed capacity was around 5600 MW which was not withstanding the demand about of 6000 MW. The current country's energy demand was estimated by 200,000 MW by the minister of power, while the government roadmap for the power sector target the provision of 40,000 MW of generating capacity by the year 2020 [27].

As a result of this historical electricity demand-supply gap and the available capacity this led to the current huge power shortage and the inefficiency of the consequents of self-generation of power by the industrial and residential sector customers. [28]

Modeling tools will be of a great help in this regard, it gives decision takers an obvious sight about what should be done both in short and long term. Unfortunately, there are a few modeling frameworks which do not enable the countries to get clear view about demand-supply gap in African countries. Sudan is challenged by this issue.

CHAPTER THREE

3 CASE STUDY: SUDAN OVERVIEW

3.1 Sudan's Energy Sector Background

Sudan like most of the oil importing countries suffered from a sharp increase of oil prices in the last decades. South Sudan became independent country in 9 July 2011, after the referendum in South Sudan where people voted for independence. Before the separation, the unified country Sudan was the second largest producer of oil in Africa in 2010 outside of the OPEC. In 2009, Sudan was among the African countries in the world share of energy production in oil and gas together with Algeria, Angola, Cameroon, Democratic Republic of Congo, Equatorial Guinea, Gabon, Libya, and Nigeria [29]. The production had declined sharply after the split of Sudan and South Sudan, both countries fall to the fourth largest producer's countries outside of the OPEC in 2013 [30]. As a special case as Sudan after the independence of South Sudan and taking two thirds of the oil reserves and left Sudan with one third of the original amount, Sudan is suffering from trades imbalance as result of oil large quantities purchased abroad, from Saudi Arabia 47%, United Kingdom 22% and United Arab Emirates 24% with total cost 59.1 Million dollars in 2017 [31].

Energy demand in Sudan is driven by main different sectors, residential sector is dominating the consumption in the country with percentage of 56.6% as the highest, followed by industrial sector with 15.4%, the services and commercial sector is 12.1% and agriculture 6.7% [32]. Table (1) is illustrating the energy balance in Sudan categorized in five sectors, the quantity measured in ktoe and the percentage per sector in 2012.

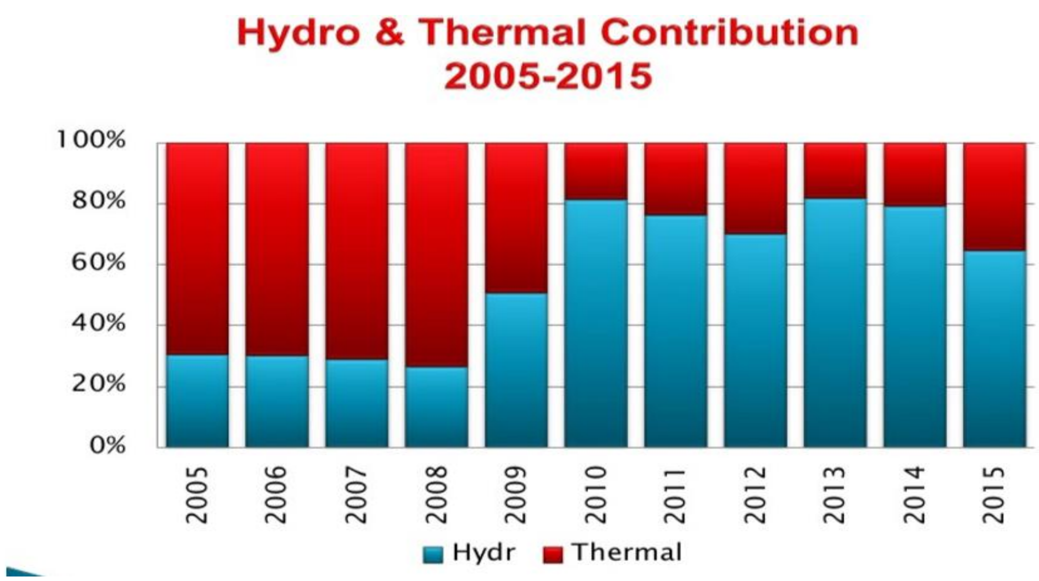
Demand sectors	Power		Oil		Biomass		Total	
	ktoe	%	ktoe	%	ktoe	%	ktoe	%
Residential	401	54.3	298	7.9	3088	62.2	3911	40.0
Transportation			2994	79.2			3073	31.4
Services	181	24.5	43	1.1	1303	26.2	1579	16.1
Industry	120	16.3	400	10.6	575	11.6	1133	11.6
Agriculture	36	4.9	43	1.1			85	0.9
Total	738	100	3778	100	4966	100	9781	100
Share of energy supply	7.5		38.6		50.8		100.0	

Source: Modelling of Sudan′s Energy Supply, Transformation, and Demand, 2016

3.2 Energy Sources in Sudan

Sudan has different resources of energy, the main sources of primary energy are oil, hydroelectricity, biomass, and renewable energy. Sudan has no uranium, coal. The main transformation and conversion processes are electric power generation, oil refinery, and wood-to-charcoal conversion. The energy sources could be classified as conventional sources as electricity, biomass and petroleum products, and non- conventional which are renewables energies Hydro, Solar and wind [32]. Renewable Energy in Sudan is not very common, however the country is classified among the top countries in the world in term of renewable energy potential, especially Solar Energy with both types PV and Concentrated Solar Power CSP. Wind Energy in Sudan has a good potential as well, three sites have been selected for the near future wind power program to increase the electrification rate in the country, the sites are located in the North-east in the Red Sea shore, the West in Nyala and the North in Dongola. Figure (1) is showing the conventional thermal power plants and non-conventional source represented by hydropower plants both contribution in the total electricity generation process through the country.

Fig (1): Hydroelectric and Thermal power plants contributions in the total generation of electricity in Sudan.



Source: Sudan Portal Data, Open Data for Africa

3.3 Sudan's Renewable Energy Sector

In 1991, Sudan created the Ministry of Higher Education and Scientific Research (MHESR) to be the main responsible of all renewable energies concerns. Till this day, all renewable energy aspects are covered by MHESR and the tasks are policymaking, planning and promoting together with management and coordination between the different parties [33]. Now, the Sudan's Energy Research Institute (ERI)- National Center for Research (NCR) are managing the renewable energy technologies such as biogas plants, micro hydropower plant, wind energy turbines and solar thermal system and PV.

3.3.1 Wind energy

Wind energy is one of the renewable energy forms, which is not in steady state all over the year, due to many factors as space, time of the year and the variation of the wind speed and direction, and Sudan is blessed with abundant wind energy potential ready to be exploited. Since 1980, wind energy was used in rural areas in Sudan as a result of the increasing of production demand in rural areas. That was a reason for the Sudanese government to pay more attention to wind energy utilities especially in rural areas. Wind energy potential is very good in different locations in Sudan and its attractive for wind pumps and as a matter of fact that the fuel is not sufficient, the wind pumps will spread widely through the rural areas. Currently, different types of wind pumps are commercially manufactured in Sudan. Wind Energy in Sudan would be more profitable in local, small scale applications for rural and remote areas in which the lack of electricity access is dominating [34].

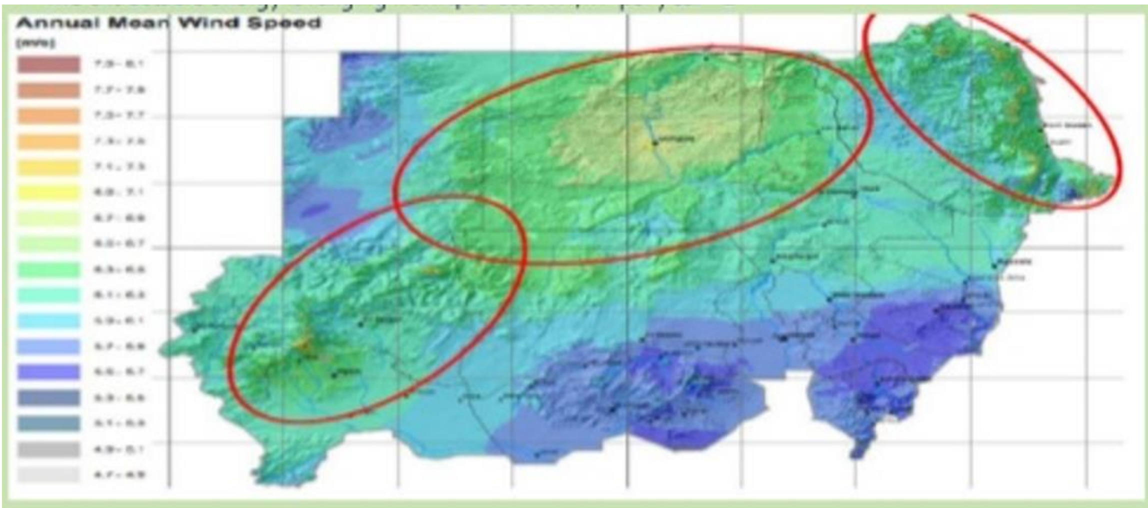
Currently, Sudan has plans for utility scale wind farm development in three different regions in the country, they are:

- Northern Sudan state, Dongola with capacity 100 MW
- Western Sudan state, Nyala with capacity of 20 MW
- The coastal region of eastern Sudan, the Red Sea coast with capacity of 180 MW

The wind energy project's outcomes categorized into four which are, implementation, policy and regulations, resources mapping and documentation. The project is cooperative scheme with national and international partners and stockholders and they are UNDP country office Khartoum, Ministry of Water and Resources and Electricity, Ministry of Finance and National Economy, Ministry of Oil and Gas, Higher Council for Environment and Natural Resources, Sudanese Metrology Corporation and private sector companies [35].

Figure (2) is showing the highest wind energy potential and its location in the map, illustrate the wind speeds in the different location as, in Dongola the speed is 7.2 m/s, Nyala 7.9 m/s and the Red Sea region is about 7.0 m/s all of the readers at 60 m heights and the extractable amount of energy is ranging from 400 to 600 kW/m^2**.**

Fig (2): Wind Energy Potential in Sudan



3.3.2 Hydropower plants

Sudan is a rich tropical country, has excellent amount of water resources that can be exploited in efficient way while considering the profitability and the sustainability. There are many hydro power plants operating across the country and including the following five pioneer dams with the associated capacity as:

1. Merowe dam with capacity of 1250 MW
2. Roseires Dam with capacity of 280 MW
3. Sennar Dam with capacity 15 MW
4. Jabel Aulia Dam with capacity of MW
5. Khasm ELGriba Dam with capacity of 10 MW

Merowe dam is last dam that joined the dams chain in the country and lifted the total installed capacity to 1585 MW [36]. Hydropower sector is dominating the power supply in the country with amount of 767 Ktoe in 2014, this is approximately about the 70% worth of power supply to Sudan. The following table (2) showing the operational, under construction and planned hydropower plants with the installed capacity amount and the years of operating and the net production.

Table (2): Hydroelectric power plants in Sudan

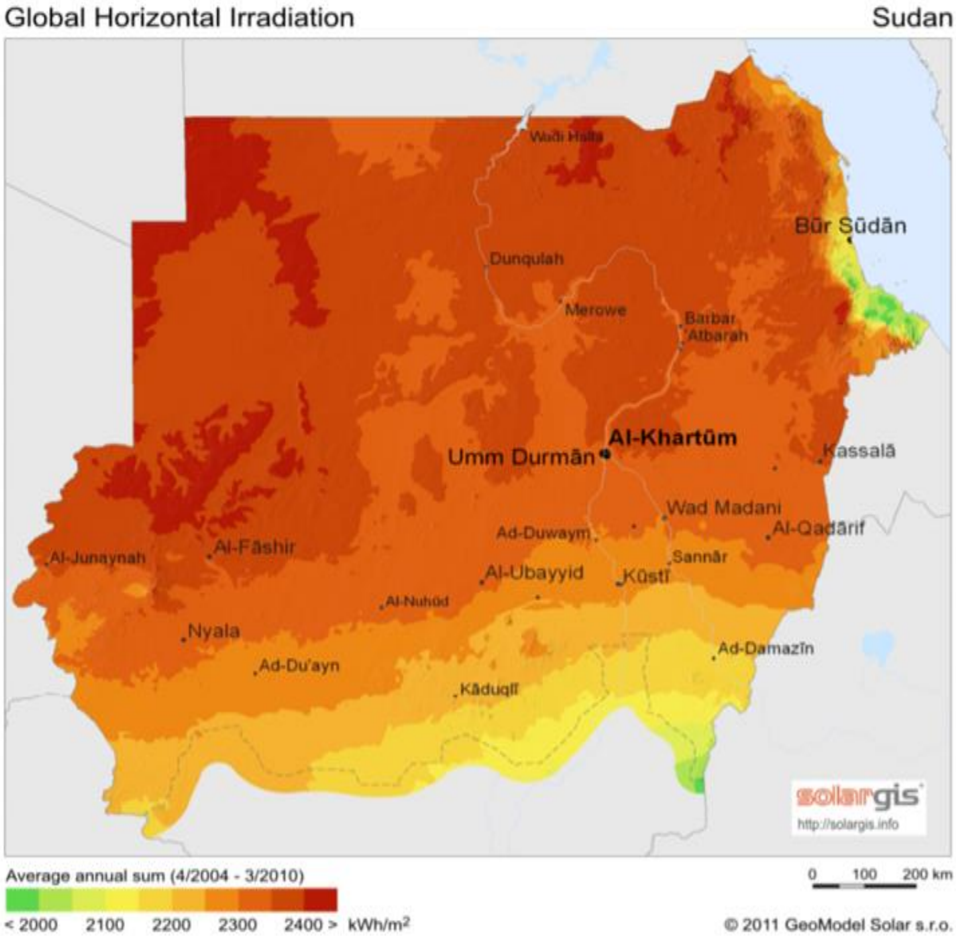
Number	Name	Year	Installed MW	Capacity Nominal MW	Production GWh
		Operational plant			
1	Merowe Dam	2009	1250	1240	5580
2	Roseires Dam	1966	280	270	1050
5	Sennar Dam	1962	15	12	49
3	Jebel Aulia Dam	2003	30	19	55
4	Khasm El Girba Dam	1964	10	10	15
	Subtotal A		*1585*	*1551*	*6749*
		Under-construction plant			
5	Upper Atbra and Sitat	2015	323	320	834
6	Sennar upgrading	2015	11	13.7	66
		Planned plant			
7	Shereik		420		2103
8	Kajbar		360		1799
9	Sabaloka		205		866
10	Dal Low		648		2185
11	Dagash		312		1349
12	Mograt		312		1214
	Subtotal B		*2257*		*9515*
	Total (A + B)		*384*		*16264*
	Available power%		*38*		*39*

Source: Modelling of Sudan′s Energy Supply, Transformation, and Demand**, 2016**

3.3.3 Solar energy in Sudan

Sudan is a gifted country in term of solar energy potential, the sun shine records in the country are excellently high in annual pace with average duration about nine hours per a day and the mean daily radiation is in interval of 3.05 to 7.62kWh/m^2. Northern state in Sudan has the main share of the solar potential, as a fact of the area is desert and the rain fall during the year is rare and the highest sun shine records is from the same area. Figure (3) is showing the horizontal irradiation in Sudan, the map illustrates the different potential of solar energy all over the country and highlighting the highest amount of radiance in deep dark color. The country's map showing the average annual summation of radiance ranging from 2000 kWh/m^2 to 2400 kWh/m^2.

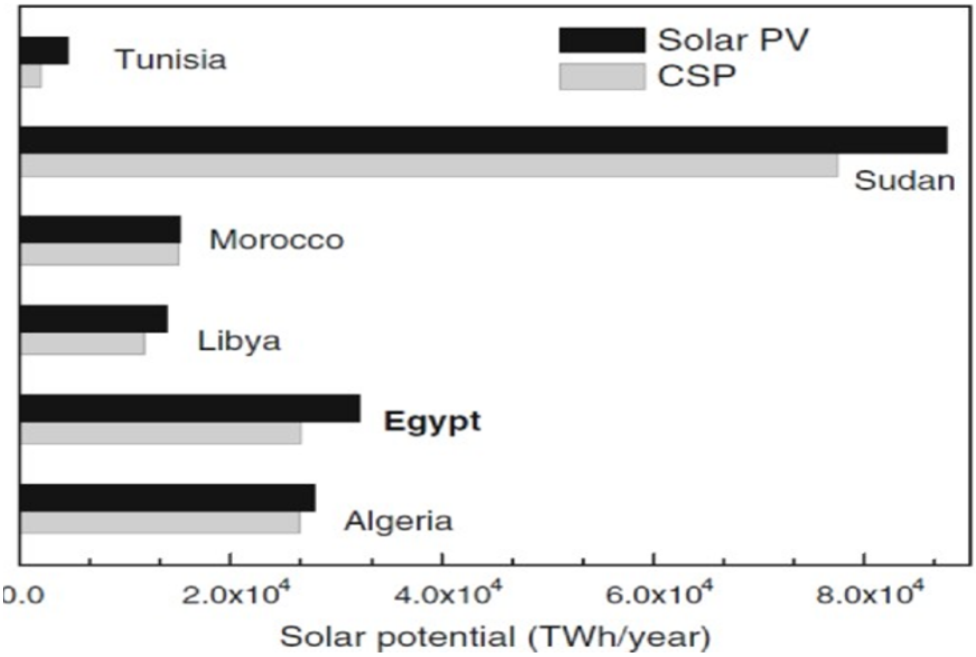
Fig (3): Sudan's Global Horizontal radiance map



Source: GeoSun Africa, 2017

Sudan compared to North African countries as Libya, Egypt, Morocco, Tunisia and Algeria has the best potential of solar energy, both as Photovoltaic (PV) and Concentrated Solar Power (CSP), with solar potential estimated around $8.0X10^4$ TWh/year which is excellent amount of energy that can cover a remarkable area of the whole country. Figure (5) showing the various solar energy potential for North Africa countries.

Fig (4): North Africa Solar Energy Potential



Despite of the huge potential solar energy in Sudan, the installed capacity is only 2 MW as Photovoltaic (PV) cells, and approximately half of this amount is dedicated to the telecommunication industries such as remote off-grid antennas and satellites [36]. Recently, various areas which are classified as rural they started adopting the solar technology for residential use, for charging, lighting and low load activities. While there is a remarkable spread of solar technologies in the west of the country at the refugees' camps.

3.3.4 Geothermal energy in Sudan

Sudan has some areas with geothermal energy potential but there is no real exploitation of this resource, the different locations of geothermal energy potential are [37]:

- Tertiary to recent age volcanic fields in the west of Sudan,
- The coastal plain adjacent to the Red Sea rift zone,
- The central Sudan rift Zone.

3.3.5 Biomass energy in Sudan

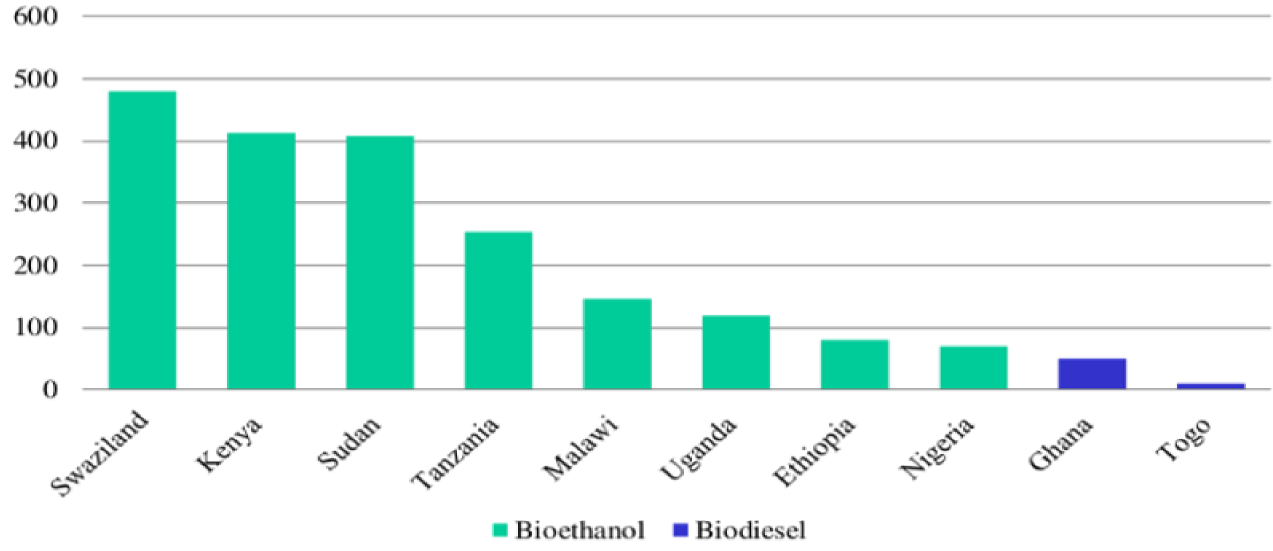
In Sudan the man usage of biomass is the direct burning of fuel-wood and agriculture residues, bio mass resources contributed into the Sudan's energy supply. Sudan government started reforestation program of $1.05X10^6$ hectares as a result of the fact that the environmental and health effects from the bio mass inefficient usage are very high and alarming to major dangerous results [33]. For example, firewood and charcoal consumption is high as $13X10^6$ m^3 per year from the total bio mass resources [33].

Sudan has different type of bio mass usage for energy, including:

- Agriculture Residue, it used as animal feed as major and small portion of it used as fuel, paper industry and building material in rural areas.
- Bagasse (sugar cane product), from 2005 till 2011 Sudan had produced bagasse about 2 – 2.5 million per year [37], this amount located Sudan in the eighteenth place worldwide in bagasse production. A feasibility study was carried out by Cleaner Energy Fund for Agroindustry (CEFA) in Africa, from the current installed capacities in Sudan in bagasse energy outputs for leading sugar industries may reach 55 MW per year [38].
- Bioethanol, Kenana is one of the largest sugar companies in Sudan that produce first-generation Ethanol as a product of molasses fermentation, the approximated annual production is about 65 million Liter, while only 10% of this amount is consumed locally and the remaining 90% is for exportation.
- Animal Waste, Sudan is reach in term of livestock, it provides the country with a remarkable amount of dung which is used for biogas production. Biogas was abandoned in Sudan because of the crude oil production in the past before the country separation. Animal waste is not considered in the energy balance of Sudan, due to the lack of available information about it. Total of 49 Mton dung from cows, goats, camels, and sheep in 2014, this is corresponding to 20,337 ktoe of energy used for biogas production [36].

The following chart (Fig 6) is showing the biofuel potential in some selected African countries and Sudan is classified as the third country, the quantity of fuel is measured in Million liters (ML), Sudan has potential of bioethanol estimated by 400 ML.

Fig (5): Bioenergy Potential in Africa



Source: 17 OILGASMINE

3.4 Energy Sector Problems and Challenges

The Sudanese energy sector has been subjected to many different types of problems, ranging from trivial to sever challenges. The main challenge is lack of the technological advancement and equipment in the sector due to the sanctions that put by United States of America since 1997- 1998. On the other hand, inefficiency in conversion, production and use as a result of extravagant loss. The absence of renewables, solar, wind and geothermal in the energy mix put pressure on the conventional source [35].

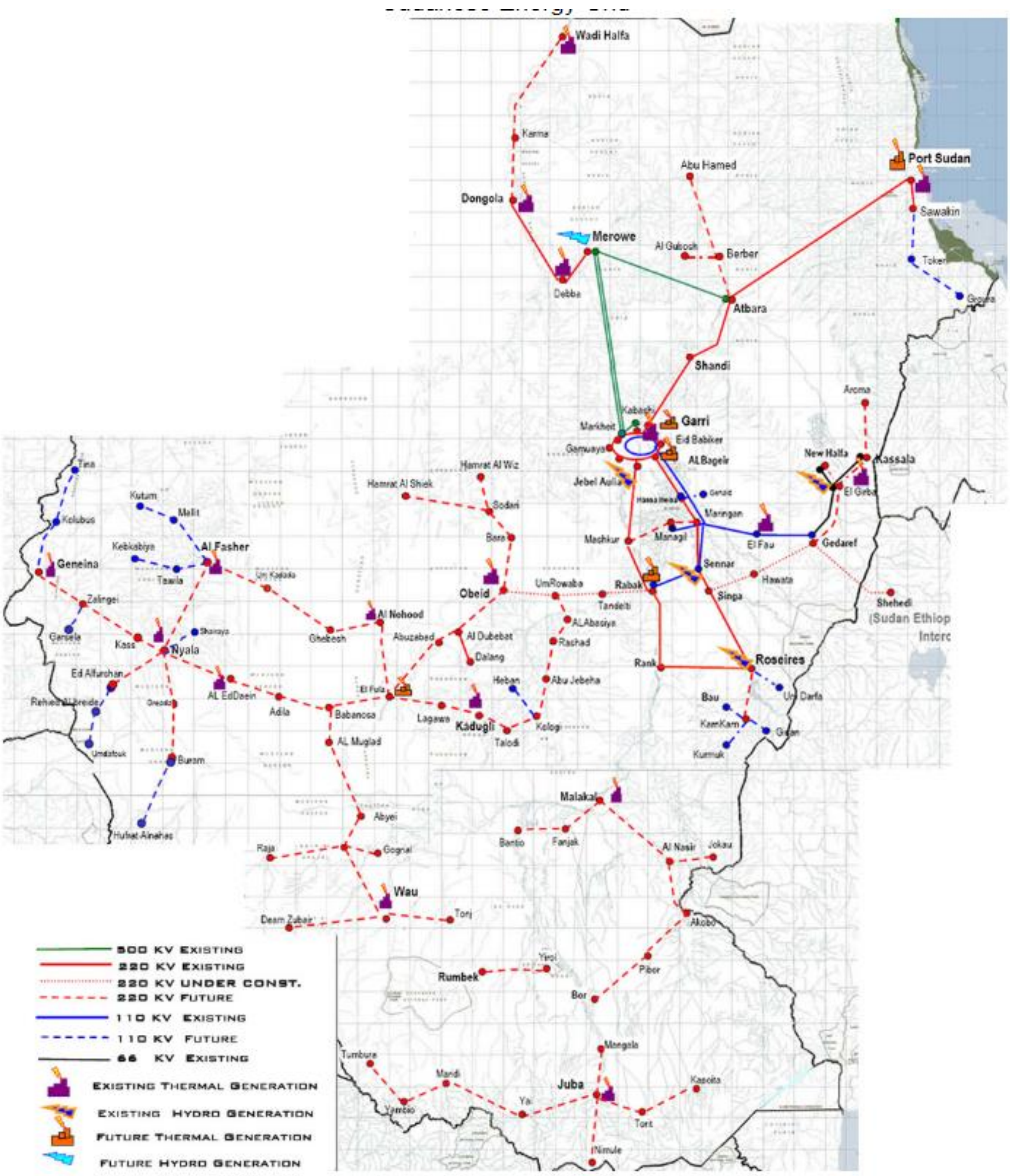
3.5 Background of Sudan's Electricity Sector

Sudan had joined the electricity industry in 1908, the English Electric company installed the first 100 Kw and later increased it to 500 KW at Buri thermal power station in the capital Khartoum. In 1925, a contract had been signed with group of British companies for thirty years as a result of electricity demand growth and development of electricity sector in the country. In 1960, Central Electricity and Water Corporation was established by the government of Sudan to extend the electricity and water services in the main big cities in the country [35].

The electrical power sector has been facing many difficulties, and has been subjected to poor infrastructure and frequent power outage all over the country. The installed generating capacity of electricity in Sudan is 3.736 million kW, from hydro-plants accounted as 51% of total installed capacity and from fossil fuels as 44% of the installed capacity and from renewables only 6% of the total installed capacity, while 70% of this amount consumed in the capital of the country Khartoum and 65% of the consumption is for domestic sector alone [30] [39] [40]. The electrical power is transmitted through two interconnected grid, the Western grid and the Blue Nile Grid which they are covering only small portion of the country, while the other rural areas are using diesel generators for power [30]. Sudan is putting electricity access as a priority by the national grid expansion plans to reach the un-electrified areas in the country. The general electricity access in Sudan is 38.53% for the country's population, and for the rural areas is only 22%(of rural population), while for the urban is 70%(of urban population) [35]. The total electricity consumption in Sudan per year is about 12.12billion kWh, and energy per capita is 299kWh [41].

The national grid reaches a half million households, less than 10% of the population; major and minor local grids serve another 5%. As result, only 30% of the population has access to electricity. NEC, the national electricity utility, transmits electricity through two inter connected electrical grids, the Blue Nile Grid and the Western Grid, which cover only a small portion of the country. the regions which are not covered by the grid often rely on small diesel-fired generators for power. Figure (7) is showing the national grid on the country's map and the generation types of technology, hydro and thermal plants.

Fig (6): Sudan's National Grid

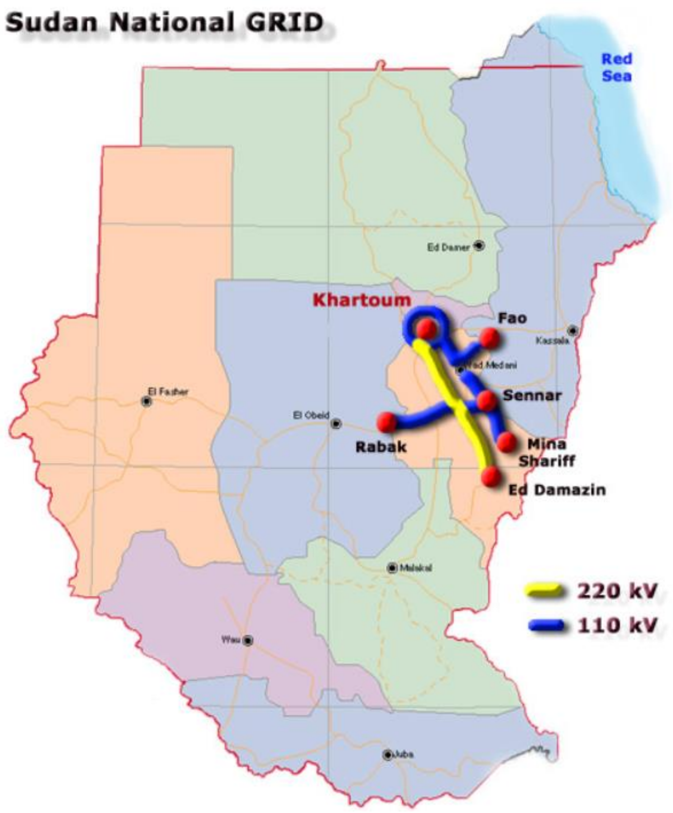


Source: Sudanese Energy Summary

3.6 The National Electricity Corporation (NEC)

The National Electricity Corporation (NEC) is a state-owned electricity company in Sudan. It is a statutory corporation under the Ministry of Energy and Mining (ME&M). The company is responsible of electricity generation, transmission and distribution in the country. The company owns and operates hydro, diesel, steam, gas and combined cycle power stations. In addition, there are many thermal power stations for the isolated areas. The company is undertaking various development projects which include construction of new power infrastructures as well as up-gradation of the existing system. The company was formed in 1982 and is headquartered at Khartoum, Sudan. The national grid network distributes the generated power within the different states of the country by transmission network owned and operate by the Sudanese Electricity Company of 1,000 km and 6,000 km for 500 kV and 220 kV. Figure (8) below is showing the national grid in the country's map and highlighting the 220 kV lines and 110 kV lines.

Fig (7): Sudan's National Grid, 220kV and 110kV lines



3.7 Electricity Demand and Consumption

Electricity Demand at the electric utility is the amount of electrical power that has to be generated at any allowed time and it is a term which represents the rate of electricity that has been consumed and it is measuring unit is kilowatts (kW). Demand charge basically is influenced by the Power Factor which is a measure of efficiency usage of electrical power, for example when the used equipment uses energy in inefficient way it will show a low power factor that needs more generation capacity from the electricity utility to cover the need [42].

Electricity Consumption is the amount of electricity that has been consumed over a period of time and it is measuring unite is kilowatts hour(kWh). Electricity consumption calculation is based on time of use pricing, which is depending on the time of the day, the season of the year and the peak times as general which is varying during the day hours and the seasons of the year in which the consumption is totally different in summer from winter and at 6 am from 6 pm [43].

Capacity Factor is defined as the actual electricity production divided by the maximum possible output of electricity generated from a power plant over a fixed period of time. Capacity factor is not constant; it depends on the type of power plant. The equation below describes the capacity factor, when T is representing the time period [44].

$$Capacity\ factor = \frac{(actual\ energy\ produced\ or\ supplied\ in\ time\ T)}{maximum\ plant\ rating \times T}$$

This ratio contains two variables and they can be significantly different. The variation in capacity factor is due to the fact that the generators do not operate at the full capacity, the variation is based on maintenance issues, weather conditions such as wind and sun availability for wind energy production and solar energy respectively and the cost of generation fuel. The capacity factor of renewable energy resources as a utility-scale solar or wind facility is significantly less than a baseload plants which they used fuel like coal, nuclear, hydro or natural gas, which they are operate continuously, unlike the variable resources of renewable energy facilities [45].

3.8 Electricity Generation

The power production cost in Sudan is marginally higher compared to the average cost of power production in Africa. Sudan average cost production is 0.19$ per kWh which is slightly more than the subsidizing Sub-Saharan production which is about 0.18$ per kWh. The Government is substituting the production cost partially, in 2003 and 2004 the subsidies was about 60 million dollars, and the end user is paying less than the half of the production cost.

A large report from NEC declaring the financial losses in spite of the received subsides from the government. In 2003 and 2004 the utility had lost 12 million dollars each year as a result of selling the electricity by 0.02 $ and 0.03 $ per unit of electricity. Hidden costs caused economic losses in NEC around 500 million dollars in 2008. The major problem is under-pricing, in which the 0.09 $ per kWh tariff is covering only 50 percent of the required of production which is 0.18$. Despite the Government subsidies the under-pricing contributed to add 380 million dollars to the NEC losses in 2008, in which the network losses were approximated by 22 percent. The network losses had contributed 106 million dollars to the NEC's financial losses in 2008. Hidden cost as a share of utility revenue dropped from 175 percent on NEC revenue in 2003 to 96 percent in 2008, this is linked to the significant reduction in network losses, which were 35 percent and it reduced to 22 percent in 2008. Tariffs have risen slightly without keeping pace with the rising cost of production, however, a 60 percent of expansion of power production sold at a loss which led to inflate the hidden cost in 2003 from 306 million dollars to 484 million dollars in 2008, this led to severe drop in GDP from 2.2 percent in 2003 to 1.5 percent of GDP in 2008 [46]. In figure (9), the analysis of hidden cost at NEC from 2003 to 2008 as a result of under-pricing and unaccounted losses is showed.

Fig (8): Hidden Cost of Losses of Sudan's National Grid

Source: Derived from Briceño-Garmendia, Smits, and Foster (2009) using data from World Bank (2007) and Sudan Central Bureau of Statistics handbooks.

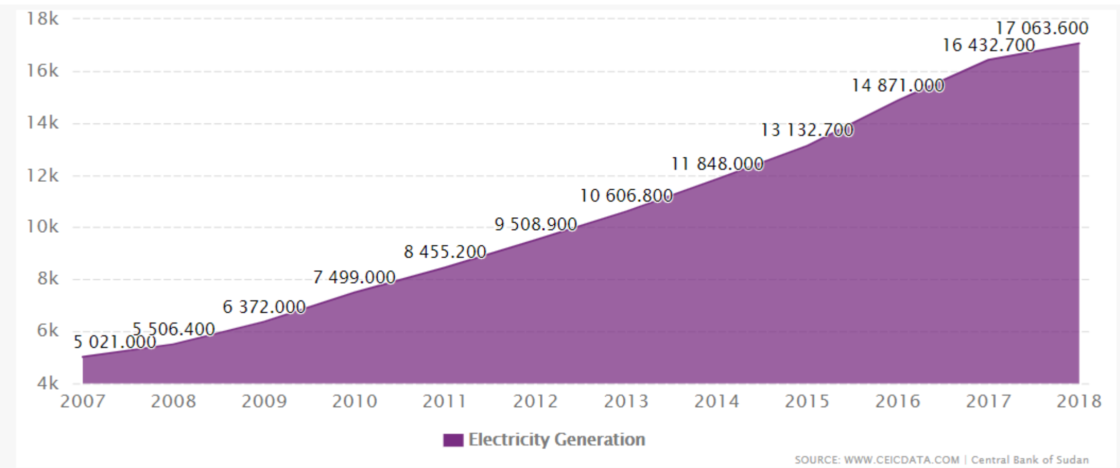
Electricity generation and consumption in Sudan is varying over the years, the Central Bank of Sudan is actively reporting the electricity data in the country in yearly base and it is categorized under Global Database's of Sudan from the latest updated in 22nd of July 2019.

3.8.1 Electricity generation

Electricity Generation in Sudan is continues increasing from the recorded data at the Central Bank of Sudan and its observation. The generation amount in December 2018 recorded as 17,063.600 GWh which is higher than the previous year records of 2017 as 16,432.700 GWh. The yearly update of the generation data is from 1992 till 2018 with 27 observations and averaging of 4,124.400 GWh in December 1992. The high generation all time data is in 2018 with a mount of 17,063.600 GWh and the lowest was in 1995 with only 994.000 GWh. The following figure (table 3) is showing a summary of the generated electricity in the period of 1992 to 2018, highlighting the minimum amount and the maximum and the associated year. [52].

Figure (9) below is illustrating the electricity generation in Sudan from 2007 to 2018 and the amount of each year in GWh.

Figure (9): Sudan Electricity Generation 2018



Source: Sudan Central Bank

3.8.2 Thermal Generation and Hydro Power Generation

Sudan mainly depends on thermal power plants and hydroelectric power plants in generating electricity in the country. The thermal power generation divided into four categories which are compounded circle, Diesel, Steam and Gas.

3.8.2.1 Compounded cycle

In 2017, compounded circle generated 1,325.100 GWh while the amount in 2016 was higher as 1,586.700 GWh, the highest data recorded was in 2008 as 2,340.350 GWh and the lowest was in 2011 as 210.200 GWh after the separation of South Sudan and became independent country [52].

3.8.2.2 Diesel power plants

Diesel generation in 2016 and 2017 was almost equally with slight increase from 330.100GWh in 2016 to 344.300 GWh, the highest generation amount was in 2008 441.900 GWh while the lowest was in 2007 as 140.000 GWh [52].

3.8.2.3 Gas power plants

Gas power plants generation increased during 2017 to 297.000 Gwh while it was 102.300 GWh in 2016, the highest generation amount recorded was in 2004 by 1,255.800 GWh while the lowest production recorded in 2015 as 0.000 GWh. [52].

3.8.2.4 Steam power plants

In 2017, steam power plants reported data was 4,228.300 GWh, this amount decreased from 4,360.500 GWh in the previous year 2016 as the highest amount and the lowest was in 2010 about 473.300 GWh [52].

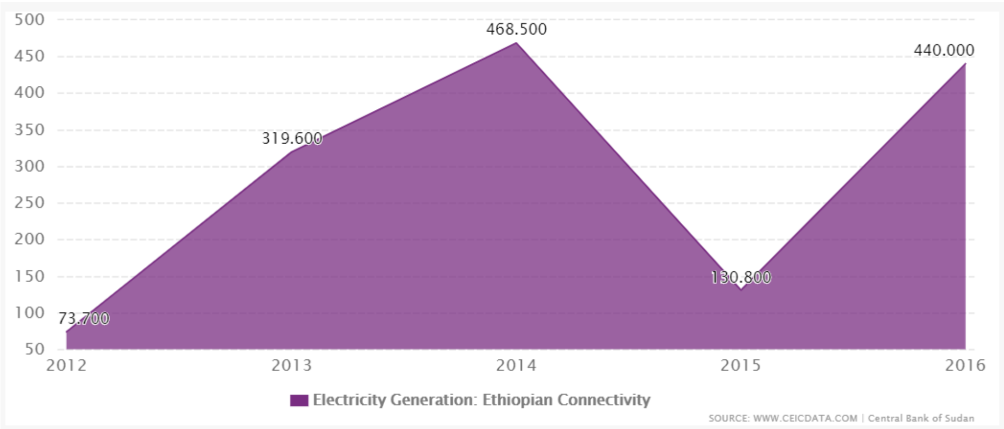
3.8.2.5 Hydroelectric power plants

Hydro power plants are the second main resource of electricity generation in Sudan, the country has a good number of dams in which they are connected to the national grid, the newest is Merowe dam with installed capacity of 1,250 MW and annual generation 5.5TWh, the dam joined the network in 2009. The reported hydropower data and its percentage in 2015 was 64.5% decreasing from 78.35% in 2014. The highest generation amount recorded in 2010 82.7% and the lowest was in 2oo8 by only 26.6% [52] [53].

3.8.2.6 Ethiopian electricity's connectivity

In order to meet the electricity demand in Sudan an agreement of sharing power from Ethiopian Electric Power Corporation (EEPCo) to Sudan was made, the corporation started from 2012. In December 2017 the Ethiopian connectivity data reported as 891.100 GWh, this amount rose from the previous year recorded in December of 2016 of 440.000GWh. The yearly updated data recorded the averaging from December 2012 to December 2017 was 379.800 GWh based on 6 observations. The electricity amount of 2017 was the highest as 891.100 GWh and the lowest was in 2012 with amount of 73.700 GWh. Figure (10) is showing the amount of the electricity that have been imported from the Ethiopian Electricity Power Corporation from 2012 to 2017. [52]

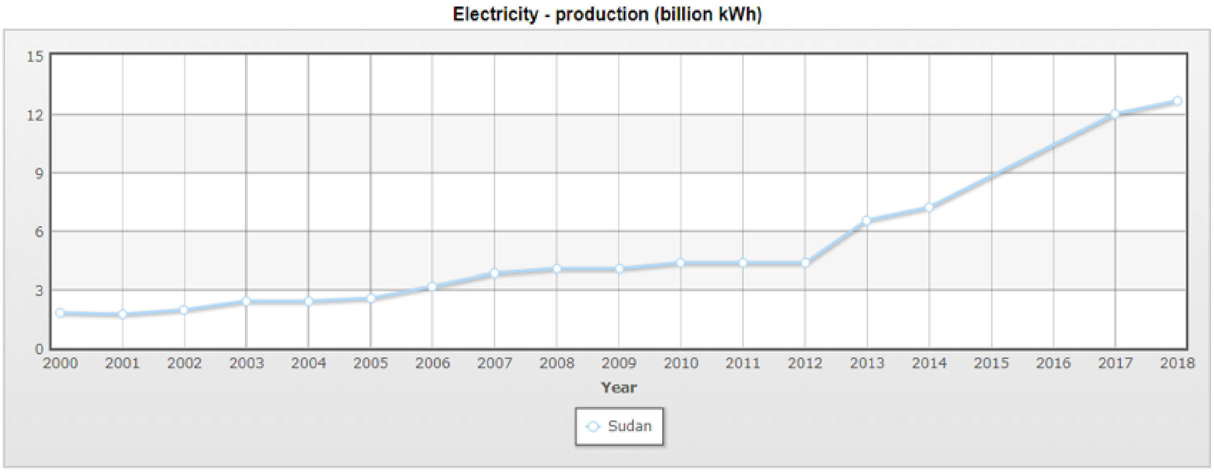
Figure (10): Sudan Electricity Generation, Ethiopian Connectivity 2016



Source: Sudan Central Bank

Sudan's Electricity production through the years from 2000 to 2018 summarized below in figure (11), the amount is calculated in billion kWh (GWH).

Fig (11): Sudan’s electricity production timeline 2000-2018



Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2017	2018
Sudan	1.82	1.76	1.97	2.39	2.39	2.58	3.17	3.85	4.04	4.04	4.34	4.34	4.32	6.51	7.19	12	12.69

3.9 Electricity Consumption

The Central Bank of Sudan reported the actual amount of electricity that has been consumed since the year 1990 till 2018, the data reported for the year 2018 in December was 14,719 GWh with a notice of increase from the previous year records amount of 12,984 GWh for December 2017. Sudanese electricity data is updated yearly, from 1990 to 2018 the averaging is 2,494.900 GWh as a result of 29 observations. During the period between 1990 and 2018 the data reached the highest amount of 14,719.000 GWh in 2018 and the lowest recorded as 724.000GWh in 1995. [16]

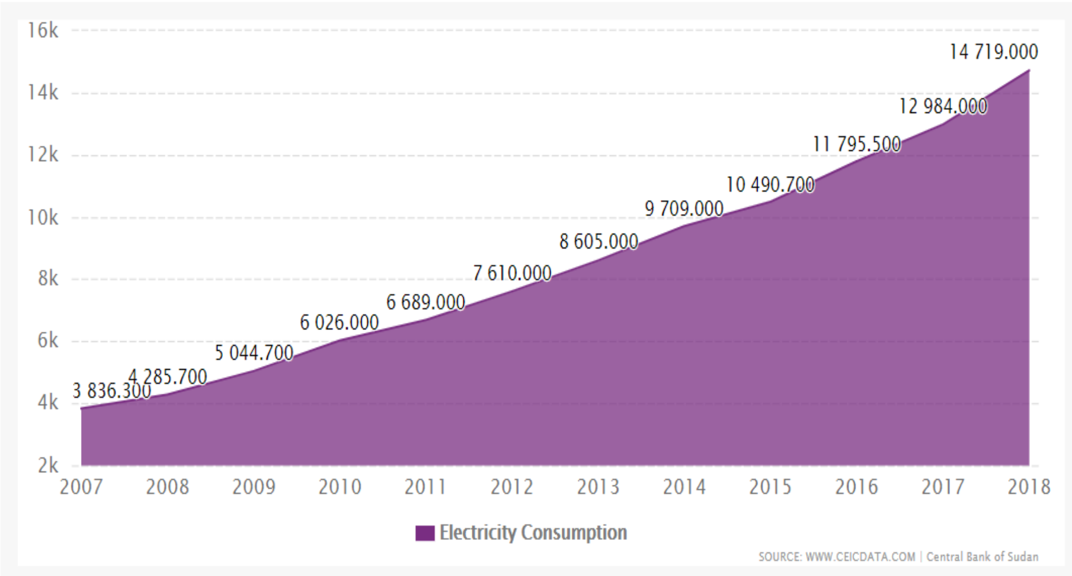
Figure (table 3) is showing the minimum, maximum amount during the period of the records in GWh in yearly base from 1990 – 2018.

Table (4): Electricity Consumption, Maximum and Minimum

Last	Previous	Min	Max	Unit	Frequency	Range
▲14,719.000	▲12,984.000	724.000	14,719.000	GWh	Yearly	1990 - 2018
2018	2017	1995	2018			Updated on 22 Jul 2019

Figure (12) is showing a chart of the electricity consumption for each year from 2007 to 2018 and the amount of the electricity that been consumed and the increasing in the amount during the years till 2018.

Figure (12): Sudan Electricity Consumption 2007 - 2018



Source: Sudan Central Bank

3.9.1 Electricity consumption per capita

In 2014, the electricity per capita was reported at 190.221kWh, this amount in continues increase each year. From 1971 to 2014the averaging amount was 46.390k kWh. The lowest data recoded was in 1971 with only 26.080kWh. The per capita has increased from 2014 and reached to 275kWh in 2017 [53] [54].

3.10 Electric Power Transmission and Distribution Losses

Losses in Electric power sector is remarkable during the transmission and distribution, in 2014 the losses reached 14.3% of the output, but this amount reduced from 22.9% in 2013. In 1997 the losses recorded as 36.8% as the highest and the lowest was in 1984 as 3.2%. [16]

3.10.1 Electrical power losses in Sudan

Losses of power in electrical system is referred to the difference between the generated quantity of power at the source and the consumed power at the consumer's side, from this aspect the need to of losses reduction in transmission and distribution is arises. Three major causes of distribution losses are technical losses caused by internal factors while the non-technical are caused by external factors and Administrative losses [55].

The total losses in any electrical system could be represent in a simple equation as:

$$\mathbf{NTL = G\text{-}TL\text{-}ADL}$$

Where, **NTL** is Non-Technical Losses, **G** is the generation, TL is Technical Losses and **ADL** is Administrative losses.

3.10.2 Technical losses

In power system technical losses referred to incurred losses by physical properties of components in the power system infrastructure. The technical losses are a result of energy wasting in the conductors and other equipment that used for transmission, sub-transmission and distribution of the power, and they are inherent in the power system.

3.10.3 Non-technical losses

The non-technical losses (NTL) are result of an external action out the power system, or they are caused by loads and conditions which the technical losses computation failed to take into consideration. Non-technical losses are difficult to be measured, and the reason is these losses are not accounted by the system operators and there is no recorded information about them [56].

Some of the NTL causes can be summarized [56], including:

- Tapping (hooking) in LT lines.
- Tampering with meters to insure the meter recorded a lower consumption reading.

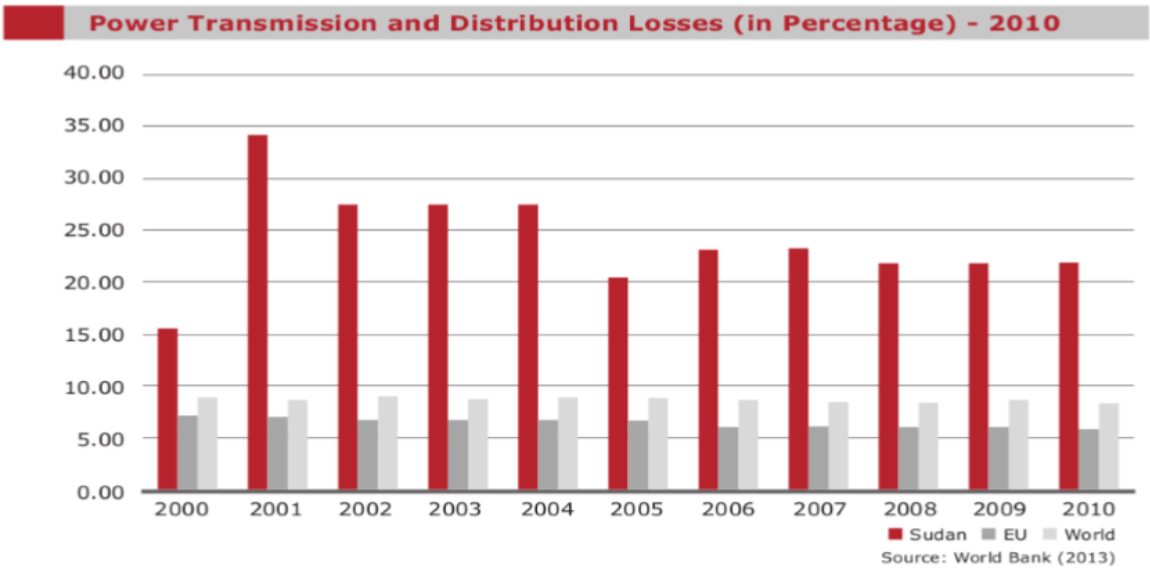
- Stealing by passing the meter or otherwise making illegal connection.
- Errors in accounting and record keeping that distort technical information.
- Errors in technical losses computation.
- Non-payment by customers.
- By just ignoring unpaid bills.

3.10.4 Administrative losses

The administrative losses include all the component and equipment of distribution system network losses that considered for the electric energy that used by the distribution utility in the associated operation of the network of distribution. Another part of administrative losses is, offices, substations, warehouses and workshops and other important electrical loads [56].

The following chart is showing the transmission and distribution losses in Sudan compared to the Emirates United and the world. Sudan has the highest percentage of losses during the period from 2000 till 2010.

Fig (13): Power Transmission and Distribution Losses 2010



Source: World Bank 2013

3.11 Khartoum The Capital of Sudan

3.11.1 History and background of Khartoum

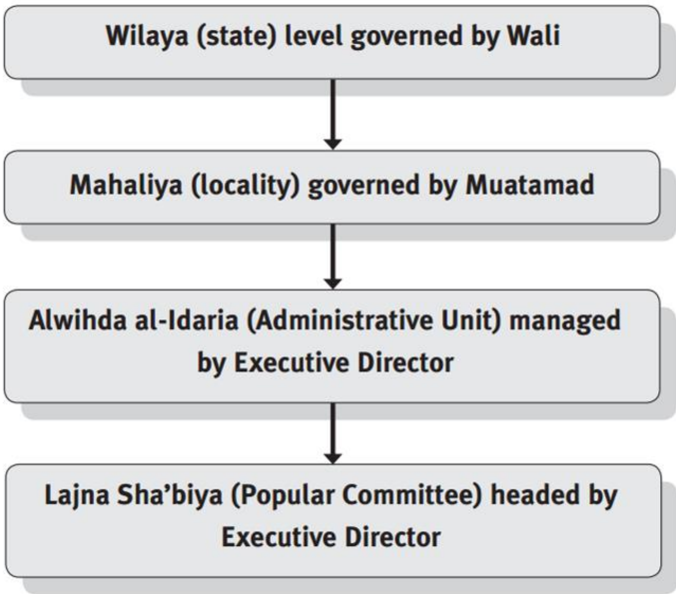
In 1821, Khartoum was first settled by Ibrahim Pasha, Mohammed Ali Pasha the ruler of Egypt at that time. Khartoum established approximately 24 Km north of the ancient City of Soba, it was originally founded for military post, but had grew to be a major trade hub and a key part of the slave trade. Khartoum became part of the Caliphate of Omdurman in 1881 – 1885 following a revolt that overthrow the previous regime. Khartoum became a part of the British Empire in 1898 when the British seized control of Sudan, and after Sudan's independence in 1956 Khartoum became the capital of the country. Khartoum city is the largest city in Sudan, lies along the left bank of the Blue Nile, and forms a huge triangle from which the name tri-capital came from. Khartoum, Bahri (Khartoum North) and Omdurman the three cities form the national capital of the Republic of Sudan. Khartoum vertex at the confluence (known locally as Moqran) of the two Niles, on the west side the White Nile and the Blue Nile on the east side. The population of the tri-capital is around 7,688,858 populous, 5,694,211 of them are living in urban areas while 1,974,647 living in cities areas [47].

3.11.2 Role of the capital Khartoum and formal local government

As the political capital of Sudan, Khartoum is home to offices and residences of Sudan's highest government officials. Both the bicameral parliament and the nation's highest courts are based in Khartoum. The city also contains Sudan's top educational institutions and the headquarters of the country's financial institutions and banks [12]. The structured of formal local government in Khartoum is in top down representation varying on four different levels, the Wilaya (State) is the highest authority and headed by Wali (Governor), and it is the main power of the sub-national level. The second level is Al Mahaliya (Locality) and its headed by Moatamad (Commissioner), in Khartoum state there are seven Localities in the different three cities of the capital, namely they are: in Khartoum city, Khartoum and Jabel Awlia, in Khartoum Nort; Bahri and Sharq-Alnil, in Omdurman; Karari and Umbadda. The third level is Al-wihda Al-idaria (Adminstartive Unit), in this level the government administration deals directly with communities. In this level, each Mahaliya contain numbers of rural and urban administrative unites, and each administrative unites has an elected council. The fourth and the last level is the Lajna Al-Sha'byia (Popular committee), this body is for elected volunteers in order to administers the neighborhood and help with local affairs [57].

Figure (14) shows the fourth level of the formal local government structure of the capital Khartoum.

Figure (14): Khartoum's Formal Local Government Structure

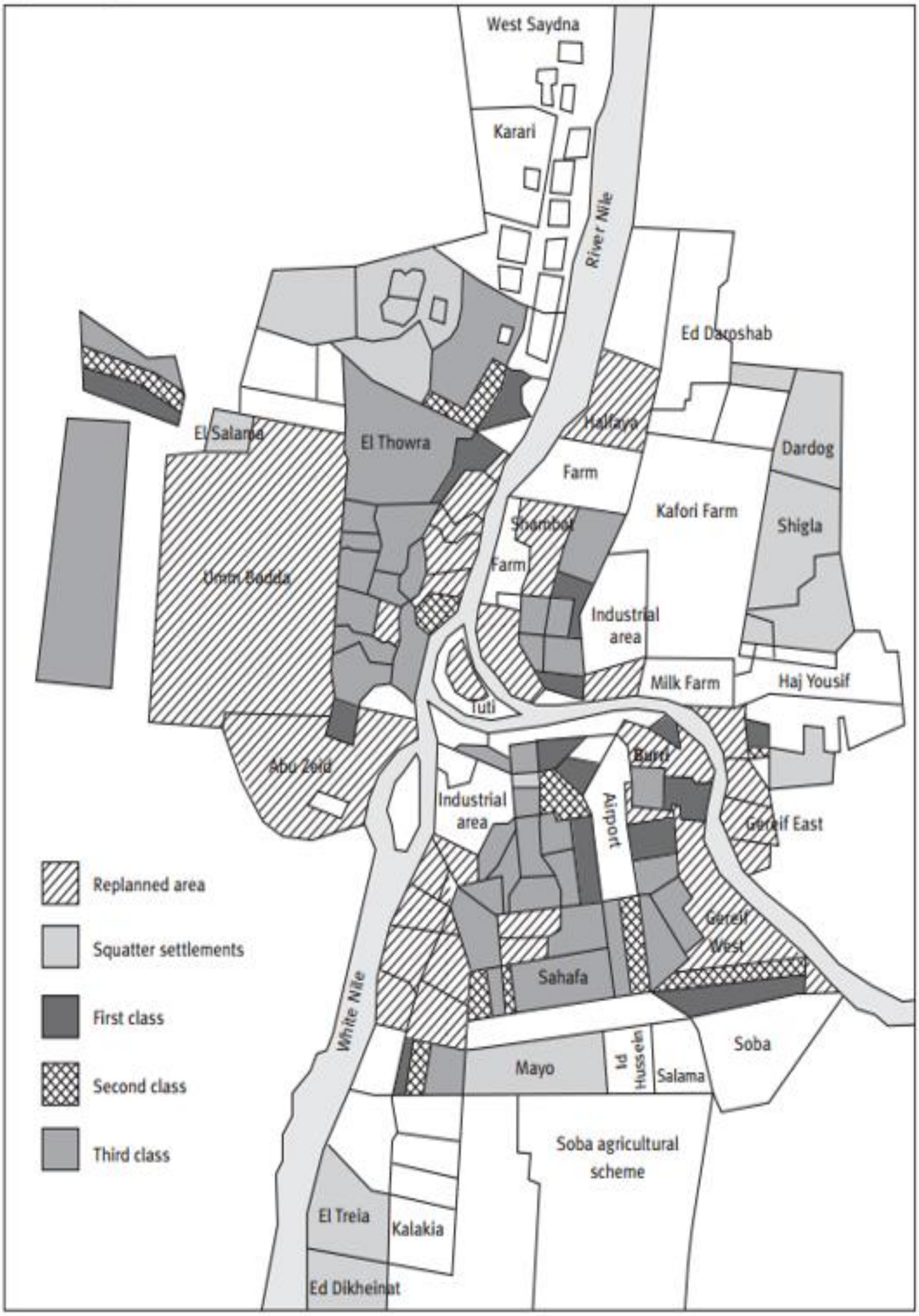


3.11.3 Settlement patterns in Khartoum

Khartoum settlement patterns have been influenced by many factors as; political, family and tribal factors. Particular areas in the city have been associated by specific workforce; for example, military and civil servant, industrial labor and so on. The city had significant expand over the three last decades and the settlement patterns had changed as well [57].

Figure (15) showing Khartoum's map and its different cities and localities, highlighting as well the different types of settlements that are leveled in different classes as first class, second class, third class, re-planned areas and squatter settlements.

Figure (15): Khartoum's Settlements map



3.11.4 Urbanization

Is a term to define the increase in number of people living in towns and cities, and it is occurring as a reason of people movement from rural areas to urban areas which results in direct growth in the population size of the urban areas and extension on urban areas as well. The changes on population size lead to other major changes in community such as: changes in economic activities, changes in land use and culture. Urbanization is associated with a remarkable economic and social transformations, for example, communities living in urban areas are linked with high level of education and literacy, greater access to social services, better health services, lower fertility and longer life expectancy. The unplanned urbanization growth has disadvantages that occurs in term of poor infrastructures such as housing, health services, water and sanitations, transportation, food security and stable electricity supply specially in developing countries in Africa and Asia [51]. Urbanization is about 55% of the world population and continuing to grow in 2018 based on World Bank data**.** Rapid expansion of city borders, driven by increases in population and infrastructure development, leads to the expansion of city borders that spread out and swallow up neighboring urban areas to form mega-cities. Currently, Africa and Asia has the highest rate of urbanization level all over the world. Another term is Peri-Urban areas, are areas that immediately around the main city boarders and characterized as more quickly growing than the main city itself, they are in transition period from countryside areas into cities often with undeveloped infrastructure, poor health and sanitation services and mainly depend on the main city infrastructures and resources. The absence of clear boundaries between the city and peri-urban areas make it difficult to assess the size of towns by their actual population or geographical area.

Comparing to the rest of Sudanese cities, Khartoum the capital is special mixture of wealth and poverty, demographic density and infrastructure; simply Khartoum is a microcosm of contradictions that mark the whole Sudan. Khartoum is the largest city in Sudan with population of **7,668,858 people**, it is located at the meeting of the River Nile (Blue Nile and White Nile) and it is ranked as the six populous city in Africa after Lagos(Nigeria), Cairo(Egypt), Johannesburg (South Africa), Kinshasa (DRC), Luanda(Angola) [14].

Drivers of urbanization

In the first twentieth century Khartoum offered a huge economic and educational opportunity for rural areas people and the number was accelerating after the independence of the country together with the left of the free movement restrictions law allowing a great number of South Sudanese to move to the center of Sudan, Khartoum. Another reason is that since the 1970th the population growth of Khartoum was largely driven by internal displacements. Natural disasters as famine and severe drought in the 1970th and 1980th in the west and east regions including Dar fur and Kordofan result in arrival of great numbers to the city. During the civil war era between South and North millions of South Sudanese flew to Khartoum to seek refuge. From 2002 till now a remarkable number of people from Dar fur came to Khartoum as well. Sudan has received influx of refuge numbers from different countries, such as Ethiopia and Eretria, the majority of the m made their way to Khartoum, in 2007 UNHCR estimated the number of refuge seeking asylum in Khartoum around 31,900, while the Somalian refuges number is increasing as well [57].

To summarize generally the main reasons of urbanization in two points that cover all above as:

1- Natural Increase in Population, increasing of developing countries population is a direct reason of urbanization growing level.

2- Migration of Rural to Urban, in developing countries, urbanization usually occurs as a result of people movement from villages to settle in cities and towns in order to improve their standard of living. This migration is influenced by many factor for example economic growth and development and it may also be a reason of conflict and social disruption. It is driven by pull factors that attract people to urban areas and push factors that drive people away from the countryside [51].

3.12 Sudan's Economy Brief

Sudan has been a victim of social conflict, civil war and separation, in 2011, the South Sudan separated into new independent country after a historical referendum, by this secession Sudan had lost three-quarters of its oil production. The main driver of Sudan's GDP was the oil production sector since 1999. The economy witnessed a great boom in one decade after the oil production exportation, high oil prices and the significant inflow of the foreign currency and foreign direct investment. Sudan has been struggling since the secession of South Sudan which was the main reason of Sudan economic shock, Sudan has been trying to fill the gap of oil production and the loss of the foreign support by other products but another interruption came along in 2012 when it lost the oil transit fees. The ongoing conflicts in Southern Kordofan, Blue Nile state and Darfur, the lack of the most basic infrastructure in large areas and many other factors kept the close to half of the population below or at poverty line.

Sudan was subjected to comprehensively sanction from USA, which was one of the economy drainages for more than twenty years before were lifted in October 2017. Sudan is planning to develop other non-oil sources of revenues, such as gold mining, agriculture while adopting austerity program to cut off the extra expenditures. Sudan is the largest Gum Arabic exporter in the world with percentage of 75 -80% of the world's total output [58].

Figure (16) is showing Sudan's economy status from the middle of year 1985 to year 2018, showing the different time periods of economy oscillations the years of South Sudan secession effects.

Figure (16): Sudan's Economy 1985 – 2018

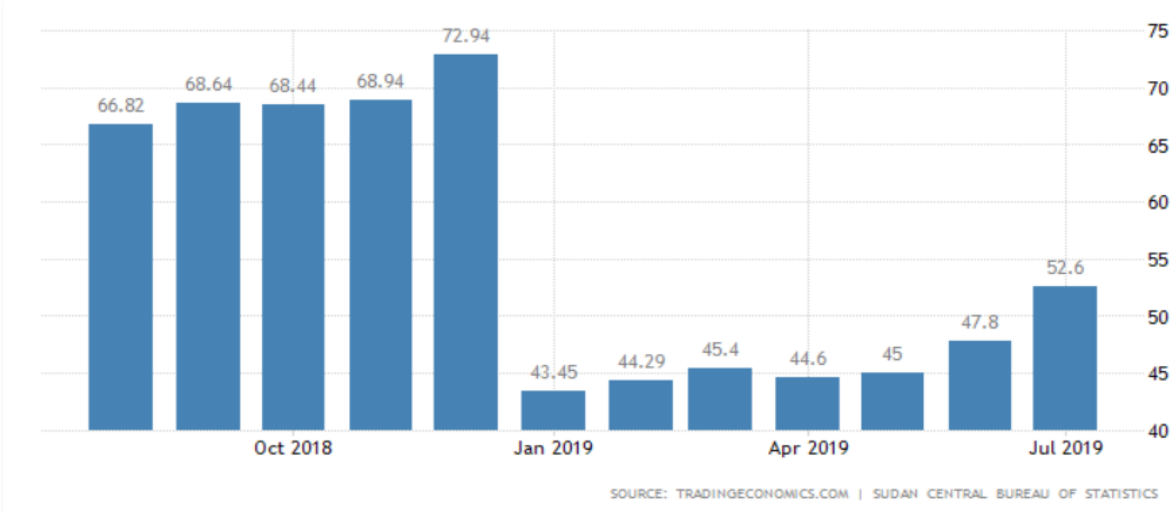
Source: IMF

3.13 Inflation rate in Sudan

Sudan has been suffering from inflation rate for many years, and some of industrial sectors are subjected to serious structural and institutional deficiencies, the currency risk has heightened in 2018 after the repeated devaluations due to the shortage of hard currency in the country. Due to the poor governance, weak rule of law rigid labor markets and the inefficient regulatory regime have affect the economic diversification and created a large informal economy all over the country [59]. In July 2019, the inflation rate was recorded as 52.60%, and the average inflation rate in Sudan since 1971 to 2018 is 32.79%, the highest was 181.50% that's was in 1993 and the lowest was in 1979 recorded as -1% [60].

Figure (17) is showing the recent inflation rate of years 2018 and 2019, the highest recorded in December 2018 with 72.94% while it dropped to 43.45% in January 2019, the following months experienced gradual increasing form January till July which recorded as 52.6%.

Figure (17): Inflation Rate in Sudan



CHAPTER FOUR

4 RESEARCH METHODOLOGY

Different methodologies have been applied to achieve the objectives of this research. The methodology comprises 5 phases, namely; 1. Preparation/Desk study, 2. Data Collection, 3. Data Preparation, 4. Modelling, and 5. Reporting. The preparation phase comprises of literatures study that relate to the topic and fieldwork preparation. Data collection phase comprises of field survey activities in collecting the required data from the community and electricity ministry's offices. These data were used in the description and modelling of the study area. The Data preparation phase comprises of the processing of the data collected into a final product that can be used for the further analysis. The modelling phase consist of building and running a model that represent the study area using a software (VENSIM). The last phase deals with reporting whole the research activities and the results.

4.1 Preparation

This phase is about the review of literatures related the topic of interest and the preparation for data collection. Literature review was carried out to develop the methodology for this research and to obtain research knowledge. This was done along the research process. The literature review was mostly about electricity demand supply gap and electricity access, system dynamic in energy system and more specifically the application of VENSIM software in energy system studies. The VENSIM software was studied in-depth to understand its operation and to know how to apply it to the case of the electricity system. In addition to this, statistical packages like Microsoft Excel were studied to obtain knowledge on how they are used in processing data. The last step was preparation for data collection. Available reports and journals on the topic were collected and studied to get an idea of the required data, available data, where to obtain the data and how to obtain the data.

4.2 Research Design and Data Collection

In this study, a social survey was conducted, whereby a cross-sectional research design was used in which data from respondents was collected in different points whereby both purposive and cross-sectional data collection approach were adopted. Both survey and interview were used. The survey consists of numerous questions socially, economically and other information related to the research topic, interviews were carried out with some of the electricity ministry representatives. Some data were collected from the ministry documents and others from online data archives.

4.3 Research Instruments

In order to collect data from respondents in study area, a semi-structured questionnaire was developed and distributed to the respondents. Broadly, the questionnaire covered various aspects such as access to the national grid electricity, electricity prices, level of income, living standards, renewable energy technologies in Sudan.

4.4 Data Collection Techniques

Both primary and secondary data were collected based on the study field survey. Primary data mainly were collected using structured questionnaires with open and closed-ended questions and the checklist for key informants. Secondary data was obtained through a review of relevant documents including published and unpublished information/data were collected from different sources from individual, private and public offices. Several literatures were visited and important information related to the study was collected according to the need of relevant data.

4.5 Data Processing and Analysis

In this study, data collected were analyzed using descriptive statistics, qualitative and quantitative methods. Descriptive statistics such as percentage and frequency were used to analyze respondents' demographic and socio-economic characteristics.

4.6 Limitation of the Study

The researcher was affected by resources, time, political instability, and long distances to the targeted communities during data collection among other challenges.

The researcher faced a challenge of long distances to penetrate into the center of the capital Khartoum areas. No public means of transport are available due to the scarce of the fuel that made people of Sudan to initiate the revaluation against the ruling regime. To achieve the objectives of the study, it required a great deal of transport facilitation which was not at hand at the time of data collection. Therefore, the researcher bore extra costs which were not planned for.

Since most of the data was collected in critical situation of the country instability the willingness to answer the questions was medium and needed great effort for convincing, during data collection, it was hard for some respondents to open up and give the required information. Some potential respondents were not cooperative enough to allow the researcher interview them. To overcome this challenge, the researcher hired two students, each one in a city and third person the researcher to cover the three cities of the capital Khartoum and to make use of the short time for data collection.

The researcher always sought for consent from respondents of their willingness to participate in the filling of the questionnaire and interviews and assured them of the anonymity and confidentiality of their responses. Respondents were made aware that the information provided would be used for academic purpose only, and that there would be no disclosure of the information to anyone whatsoever.

Lack of resources was a serious constraint of the research process because it involved many expenses ranging from printing and high cost of transportation among others. All these had a direct influence on the span of data collection, thereby forcing the researcher to adjust the work plan.

4.7 Ethical Considerations

Ethical considerations were highly observed before, during and after the study. The researcher obtained an authorization letter from the university to carry out the study. Before the interviews and administering of the questionnaires were held, the researcher explained the prime objective of the study to the potential respondents. Informed consent was sought from all the respondents and local authorities to be involved in the process, and only those willing participated. The participants were assured of confidentiality and anonymity of the information provided, only to be used for academic purposes whatsoever. The researcher also ensured that the respondents' name was not included on the questionnaires as it would intimidate the respondents about their identity and privacy.

4.8 System Dynamics Modelling

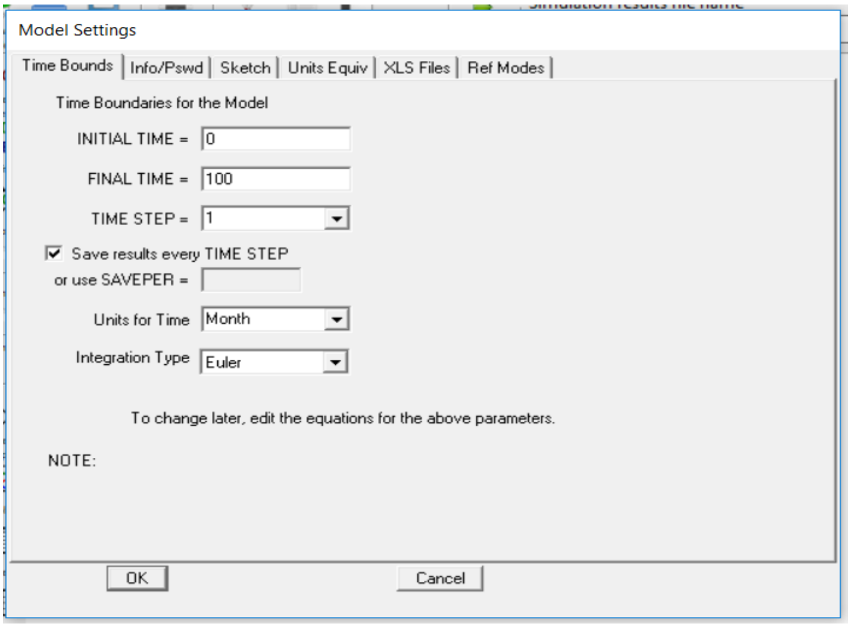
In this part a models of system dynamics were used, System dynamics is a methodology which was developed at MIT in 1950s. Computer simulation models are used to develop models that enable better understanding of complex systems and their dynamic behavior under a given set of conditions or scenarios so that to avoid potential negative consequences or prepare for them. in this research the dynamic behavior of the system is assumed to be a result of interconnected web of feedback loops. Feedback loops will illustrate the connection between variables of the different subsystems of the electricity system. Two types of loops were developed: positive (also known as reinforcing) and negative (also known as balancing). Positive feedback loops enhance or amplify the feedback of information. Negative feedback loops are goal seeking and tend to resist change in the system.

Based on the consultation of energy stakeholders in Sudan through semi-structured interviews for electricity ministry representative personal. Information from different sectors such as academia, government and private sector were collected to identify the barriers that challenge the expansion of electrification in Sudan, and the drivers that possibly promote the electricity gap bridging in Sudan as well as identifying measures that could help overcoming the barriers. Depending on the qualitative analysis for the electricity demand-supply gap, measures and motivations during early stage of this research, the system dynamic methodology was found to be the useful approach for building an integrated dynamic model, which provided computer-based modeling approach to help understanding the dynamics of the complex interaction of electricity sector in Sudan with two main domain of sustainability namely, Social and economic impacts.

4.9 Modelling

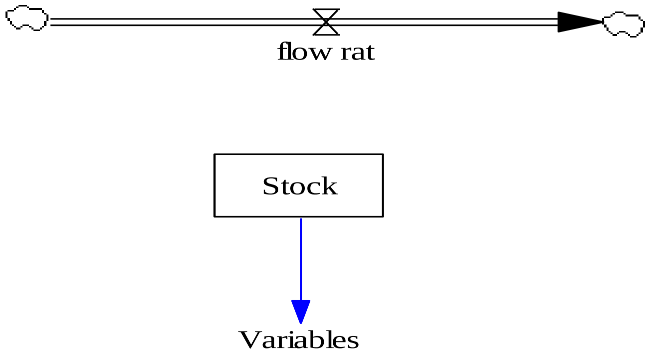
The first window pop up as model settings for the new model, the window is specifying the initial time, final time, time step, units for time in which were filled with the appropriate information, by pressing the OK bottom the model is well set and ready to start. Figure (18) showing the model settings as how it looks in the software.

Figure (18): Modelling Settings Window, VENSIM



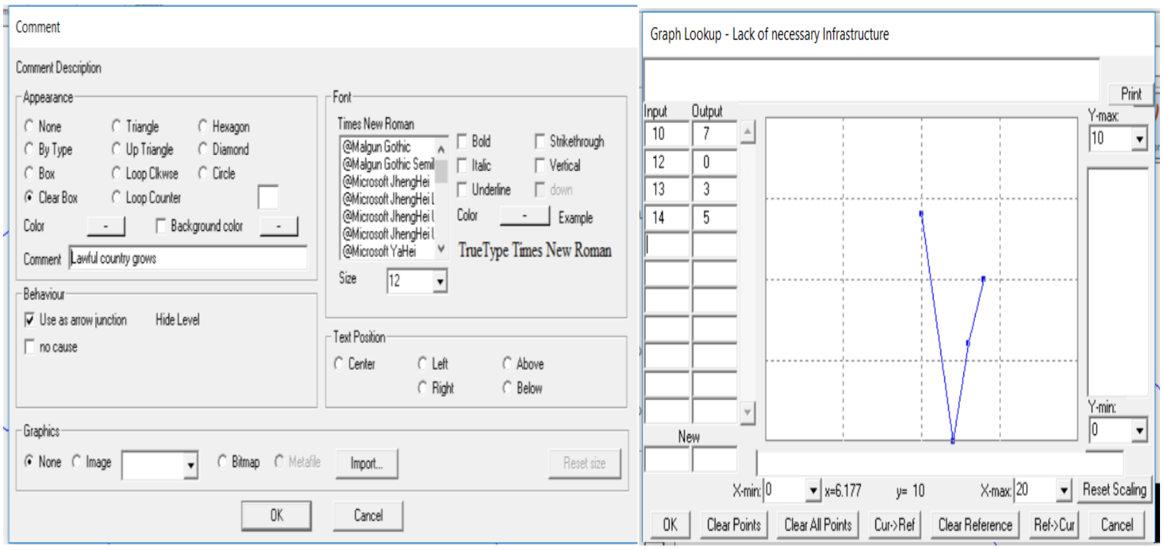
Variables, stocks, flow rate and the arrow for the linking placed on the tool bar at the top of the main box environment in which the whole modelling process take place. Figure (19) shows the flow rate, the stock sample and the variable respectively and the arrow with link between the stock and the variable.

Figure (19): Flow, Stock and Variable



Loops characteristics (the of left figure (20)) on how the loop has been formed, clock wise, circle, diamond hexagon shape etc. In the comment box is used for commenting or adding information to the loop. The right figure, which specified for lookup, which they are variables with different values in order to be represented in graph form as showed in the figure below.

Figure (20): Loops and lookup



Electricity subsystems were formed by the above mentioned features in VENSIM software, the interconnection between variables, loops, stacks were highlighted for the explanation.

4.10 Reporting Phase

This is the final phase of the research. This involves the interpretation of the whole research process and outcomes into information. This phase is very important as it involves documentation of the research to communicate the outcome to the public.

CHAPTER FIVE

5 RESULTS AND DISCUSSION

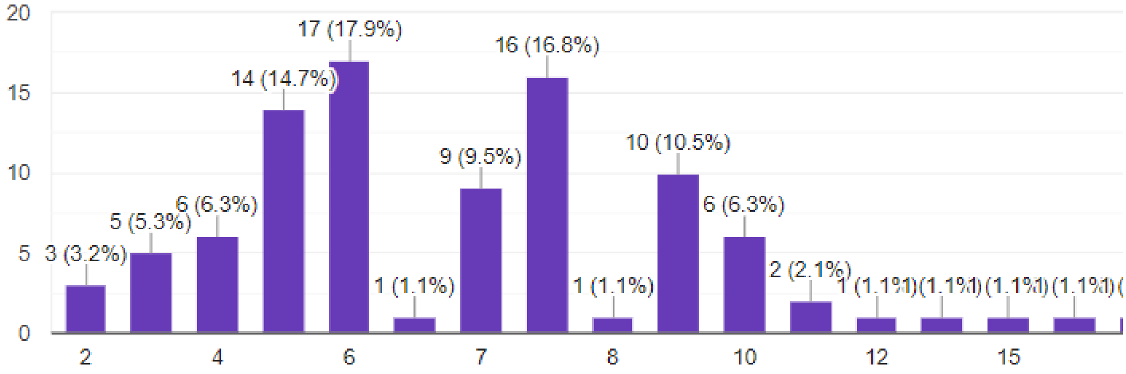
5.1 Demographic and Socio-economic Characteristics of Respondents

The study used different responses from various areas in the capital Khartoum, from the three cities of the capital and considered the various representation of settlements areas. The summary of 102 responses from people living in the capital Khartoum in which it population around 7,668,858 populous and it's the 52nd most populous national capital. Most the respondents are falling in the country side region in peri-urbanized areas and the around the extended area of the capital. Some questions were not answered based on the absence of the general knowledge or information. The respondent's results will be discussed and analyze based on the collected data from the survey and the information from the electricity ministry offices.

5.1.1 Family members number

The study shows that the answers varied from 2 persons up to 15 persons per a family, the statistics from the study shows the percentages as 17.9% are the families whom having 6 members, compared to the historical data in Sudan demography the number of family members reduced, followed by 8 persons per family with percentage of 16.8%, 5 persons per family with percentage of 14.7%, 9 persons per family with percentage of 10.5%, 7 persons per family with percentage of 9% and 2 persons per family with only 3,2% and small representation of big families as 11, 12, 15 members family they got the lowest percentage which is less than 1,4%. The life expectancy in Sudan is about 72 years, it may consider as another reason of the medium number of the families' members as 6 persons. The following figure (21) is showing the families members numbers in percentages.

Figure (21): The number of family members, Source: primary data



5.1.2 Electricity access from the national grid

In this study, the oldest answer was 1965 and the newest in 2016. In 2007 the responds showed is the year of highest percentage for citizen to join the national grid with 10.7% while in 2000 the percentage is 8.3% followed by 2009 with percentage of 6.2% and in 2016 is only 1%.

5.1.3 Average income per capita

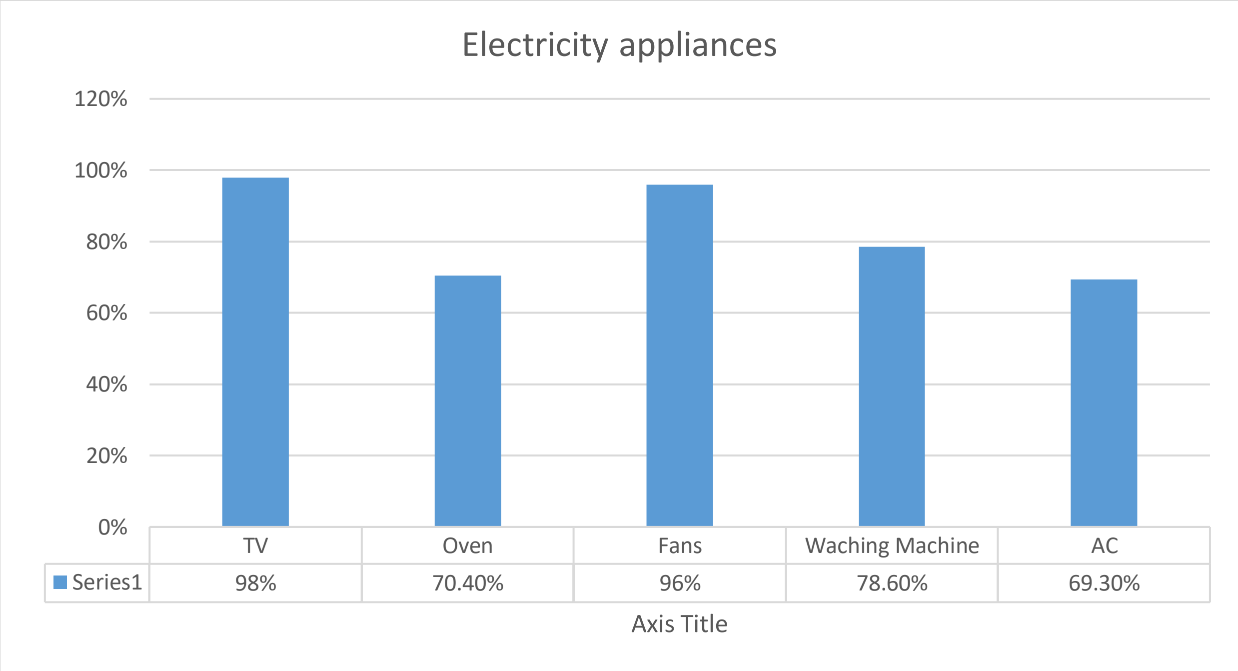
Sudan is falls in lower middle income country**,** from the study, the average income is about between 22 – 110.92 dollar per month which is labor class in the country from varies sectors and it represents about 15%, about 7%of the respondents are falling in the lowest income class which they earn less than 22 dollars per month, high medium class respondents earn between 155 – 443 dollars per month represent 12%of the study statistics and the lower medium class represent 9% and earn 110 – 133 dollars per month.

5.1.4 Electricity appliances

The main goal from the electric appliances in the survey is to classify the citizens in different Multi-tiers, by highlighting the type of the appliances and the load required in order to determine the electricity consumption for every social class and settlements in the capital Khartoum. In the study, almost all the respondents having entertaining and communication devices, Television device has gotten the highest percentage in the appliances data about 98%, followed by the air fans with percentage of 96% of the total respondents, washing machines recorded 78.6% while the Ovens and microwaves about 70.4%, the lowest percentage the study showed is Air Conditioning devices with percentage of 69.3%. Figure

(22) is showing the different appliances and their percentages in the electricity appliances chart below.

Figure (22): The electrical Appliances, Source: primary data



5.1.5 Multi-tiers framework

The multi-tier approach was developed in 2013 within the Sustainable Energy for All Initiative (SE4ALL), measuring energy access based on the performance of the energy supply. The main aim of the framework is to monitor and evaluate energy access by following a multidimensional approach and this by measuring energy access using Mutli-tiers spectrum which is ranging from tire (0) means there is no access to energy to tier (5) the highest level of access. Table (4) is showing the Multi-tier matrix for Access to household electricity services, and identifying the tasks that done by the energy in every tier from tier 0 to tier 5 [61].

Table (4): Multi-tiers Framework.

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Tier Criteria	Not applicable	Task lighting, Phone charging	General lighting, Television, Fan (if needed)	Tier 2 AND Any medium-power appliances	Tier 3 AND Any high-power appliances	Tier 4 AND Any very high power appliances

The framework has three type of thresholds, technological, economics and physical. The technological thresholds include the capacity and the duration in order to determine how the households are affected by the electricity supply. Physical thresholds are containing the reliability and the quality dimensions to examine the physical access of electricity for each household. The economic threshold is about the affordability of electricity and its impact on household expenditures. Table (5) is showing framework matrix and the three thresholds associated to the five tires and the assigned electrical load for each tire **[62].**

Table (5): Multi-tier Framework Matrix

<table>
<tr><th></th><th>Tier 0</th><th>Tier 1</th><th>Tier 2</th><th>Tier 3</th><th>Tier 4</th><th>Tier 5</th></tr>
<tr><td>Capacity</td><td>No electricity</td><td>1-50W</td><td>50-500W</td><td>500-2000W</td><td colspan="2">>2000W</td></tr>
<tr><td>Duration</td><td><4hrs</td><td colspan="2">4-8hrs</td><td>8-16hrs</td><td>16-22hrs</td><td>>22hrs</td></tr>
<tr><td>Reliability</td><td colspan="4">Unscheduled outages</td><td colspan="2">No unscheduled outages</td></tr>
<tr><td>Quality</td><td colspan="3">Low quality</td><td colspan="3">Good quality</td></tr>
<tr><td>Affordability</td><td colspan="2">Not affordable</td><td colspan="4">Affordable</td></tr>
<tr><td>Legality</td><td colspan="3">Not legal</td><td colspan="3">Legal</td></tr>
<tr><td>Health & Safety</td><td colspan="4">Not convenient</td><td colspan="2">Convenient</td></tr>
</table>

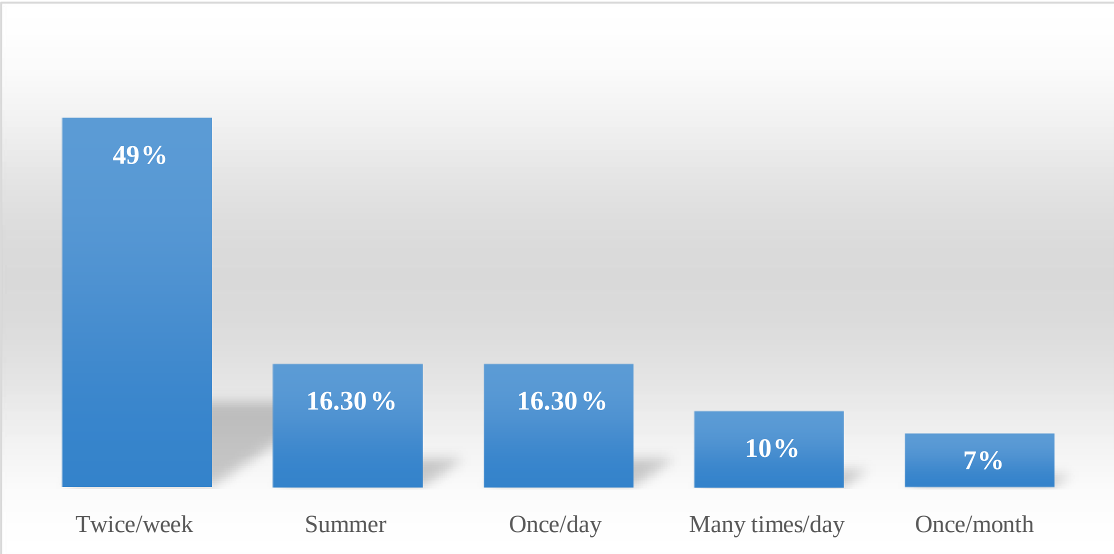
Relating to the Multi-tier framework, the study found that the majority of the respondents falls in the last three tiers, tier (3), (4) and (5) based on the load consumed by the appliances and the fulfilment of the seven dimensions of the framework matrix. The capacity associated to each tier are 500-2000W for tier (3) and for tier (4), (5) $\geq$ 2000W. The duration for all tiers is very high, only disturbed by the random cuts off and the unscheduled outage, and the quality is good in tier three and above, affordable and legal access since the main network is the national grid.

5.2 Electricity Prices and Cuts off

5.2.1 Electricity cuts off

Electricity frequent cuts off is varying from area to another in the capital Khartoum, it is depending on different factor, as the peak time, the season of the year in which is very common in summer while is not the same status in winter, some areas the electricity cut off many times per the day, some once per a day and some regions once per a month, for example in Ramadan (Muslims Holy Fasting month) the demand is high, as a result of over load for cooling systems since the country temperature is high. Another factor is the type of settlement and the area of residing, as matter of fact that, people live in the third class category and squatter settlement are experiencing more cuts off than first class and second in which the cuts is more organized in most minimum rate. Figure (23) is illustrating the variation of the cut off during the year.

Figure (23): Electricity Outage



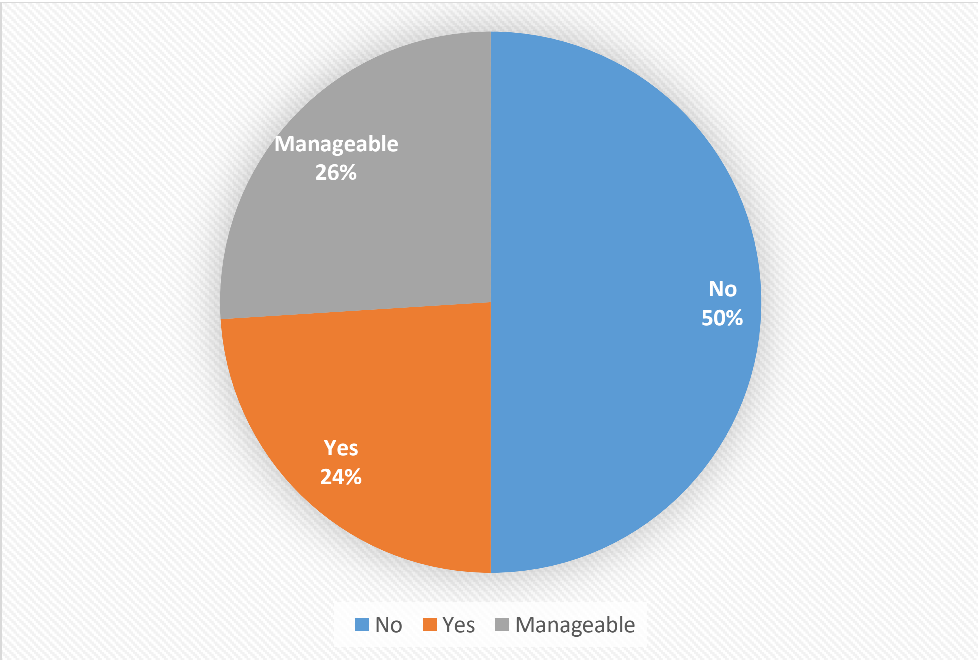
Source: Primary data

5.2.2 Electricity prices

Electricity prices are varying depending on the sectors of use, for example the industrial sector tariff is different from the residential sector and the agriculture sector as well. For this case we are considering only the residential sector with all its categories, the data is showing the half of people finding the price is not affordable, however, 24% of the data confirming that the price is affordable and 25.6% is manageable but no room for any increasing. The Electricity Tariff Facility and the stages of its amendment from 1979 until now for all sectors. As for government subsidies, the average value of production per kilowatt hour of all types of generation is approximately 12 cents of the dollar and is sold to the citizen for less than a cent of the dollar and all of this difference is supported by the state. From the study, 10.9%

of people who respond to the survey are paying 2,22 dollars per month for the electricity, 12% are paying 4.44 dollar and 6.6, 7.6% paying 3.3 dollars, 7.6% are paying 8.87dollars as well, 8.7% are paying 11.09 dollars and 2,8% are paying 22,18 dollars which is the highest. For the affordability of electricity prices, 50% confirmed that the prices are not affordable as a matter of fact that the income per capita is very low, 26% they reserved as the price is manageable but it should not increase more than this, while 24% the confirmed the price is affordable for them. The following chart is showing the numbers of the electricity prices affordability.

Figure (24): The electricity prices Affordability

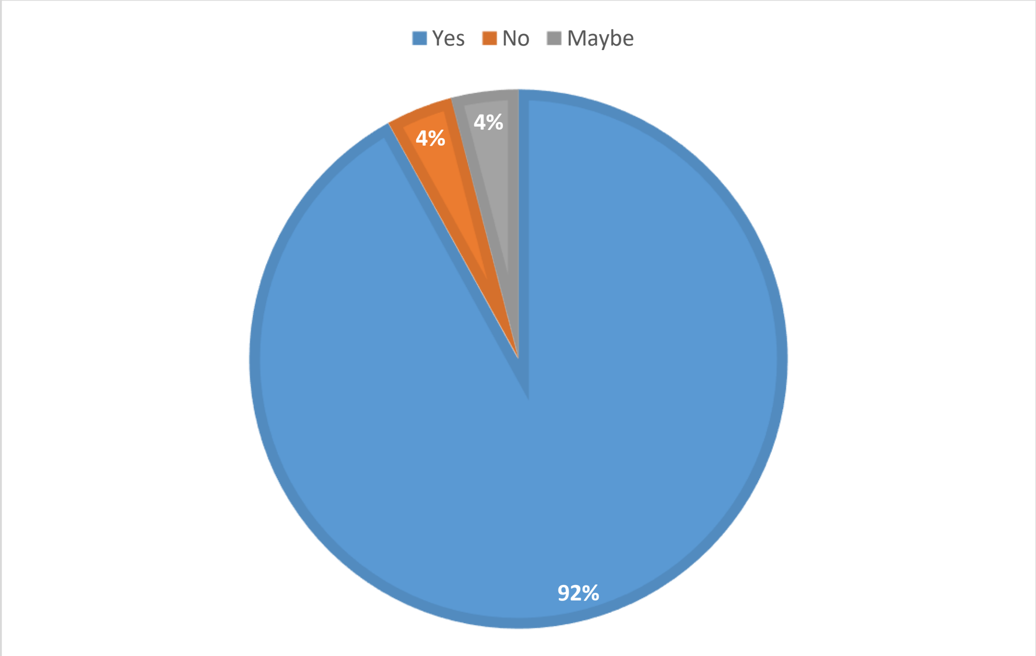


Source: primary data

5.2.3 Social support for future electrification plans

The outstanding fact from the data that, the people are willing to participate in any program or initiative that aim to increase the electrification rate in the country whether by paying a certain amount of money to help the process and to make it quicker to reach the uncovered areas by electricity while 4% are against any effort to be targeted to increase the electrification rate and the argument is that this topic should be covered by the government not citizens and some other personal reasons. The data showing 92% of people are willing to support the electrification procedure.

Figure (25): The electrification support



Source: primary data

5.3 Electricity Tariffs

Sudan's electricity tariffs facility and the stages of its amendment from 1979 until the day for all sectors is available, For the residential sector, the focused of this study the following table showing the electricity tariffs in the period from 1997 to 2016, the fluctuating in the production cost is recorded based on the consumption loud by the different categories of household ranging from 1 kW to more than 501 kW. The consequences of the unstable prices of fuel made the change on production cost through the different years, for example, comparing the first category in which the load is from 1 – 100kW in 1997 was 0.05 Sudanese pound, while in 2016 the price for the same category is tripled to 0.15 Sudanese pound. Despite of the remarkable increase of the subsidies the situation is still not significant good, as a result of the devalue of the Sudanese currency, the increase of the subsidy is faced by the low value of the currency and other fees subjected on the citizens. Table (6) is showing the residential sector feed in tariffs in the period of 1997 to 2016.

Table (6): The electricity Tariff for Residential

<table>
<tr><th>Residential Sector Tariffs</th><th>1997</th><th>1998</th><th>1999</th><th>2000</th><th>2001</th><th>2002-2003</th><th>2004</th><th>2005-2008</th><th>2009-2011</th><th>2012-2015</th><th>2016</th></tr>
<tr><td>Household 1- 100kW</td><td>0.05</td><td>0.05</td><td rowspan="3">0.10</td><td rowspan="3">0.12</td><td rowspan="3">0.14</td><td rowspan="2">0.17</td><td rowspan="2">0.17</td><td rowspan="2">0.20</td><td rowspan="2">0.15</td><td rowspan="2">0.15</td><td>0.15</td></tr>
<tr><td>Household 101200kW</td><td>0.07</td><td>0.07</td><td>0.26</td></tr>
<tr><td>Household 201-300kW</td><td>0.10</td><td>0.10</td><td>0.22</td><td>0.26</td><td>0.26</td><td>0.26</td><td>0.26</td><td>0.32</td></tr>
<tr><td>Household 301-500kW</td><td>0.14</td><td>0.14</td><td>0.14</td><td>0.17</td><td>0.20</td><td rowspan="2">0.25</td><td rowspan="2">0.26</td><td rowspan="2">0.26</td><td rowspan="2">0.26</td><td rowspan="2">0.26</td><td>0.52</td></tr>
<tr><td>Household 501 kW - up</td><td>0.14</td><td>0.14</td><td>0.16</td><td>0.18</td><td>0.23</td><td>0.85</td></tr>
</table>

5.4 Challenges Faced by the Continues Electricity Cuts Off

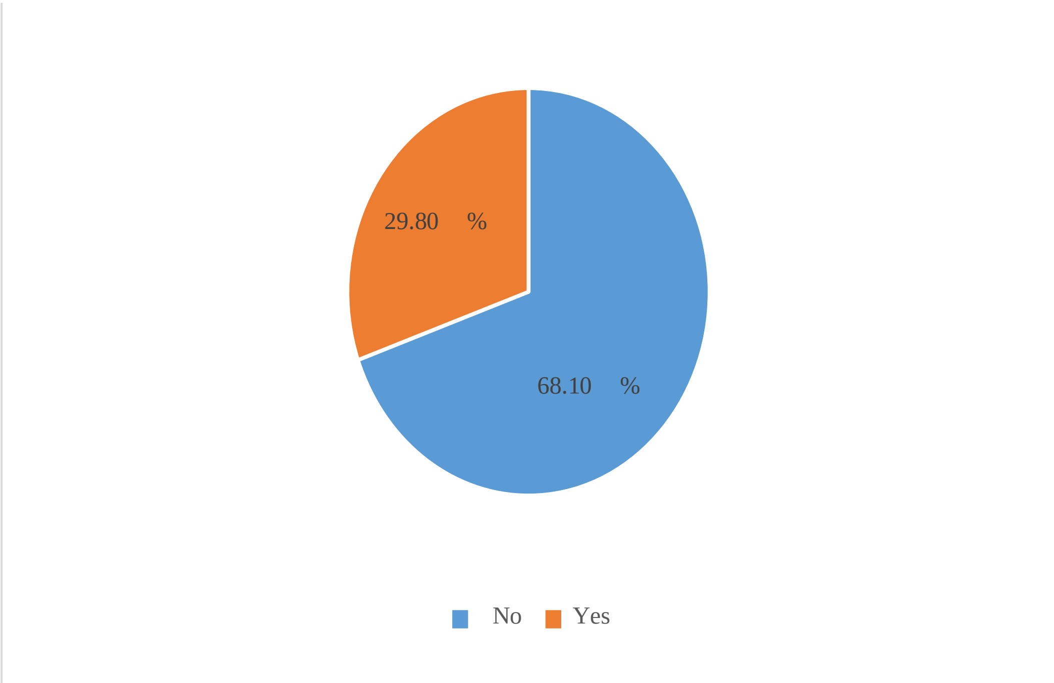
From the study, the main challenges can be summarized in social aspects, health, economically and affect in the education process as well. Sudan's temperature is high, the absence of the electricity is subjecting all the citizen to overheat and some people having health issues in which they affected the most. Economically, the random cuts off of electricity had damaged a significant number of different electricity devices, due to the variance of the electricity intensity. In addition to the local food security, the food cannot be saved without cooling system and fridges. Water supply is depending on electrical generator in many household, the cuts off is affecting the water supply as well. Academically and the low level of the productivity due to dependency of the teaching sources on electricity supply and for the research level. In term of development the limitation of productivity and the loss of opportunities compared to developed societies.

5.5 Green Energy

Sudan has different resources for no-carbon energy, and has the highest potential of solar energy in all north Africa countries. The study is providing information on how the citizen in Khartoum will accept the energy transition from fossil to renewables resources.

From the data, only 29.8% they have information about the green energy, free carbon energy and renewable energy concepts, while 68% they confirmed that they do not have good information about it but they know the main idea behind it and it is a natural source of energy. The pie chart below is showing the respondents ideas about the green energy concept.

Figure (26): Green Energy Knowledge



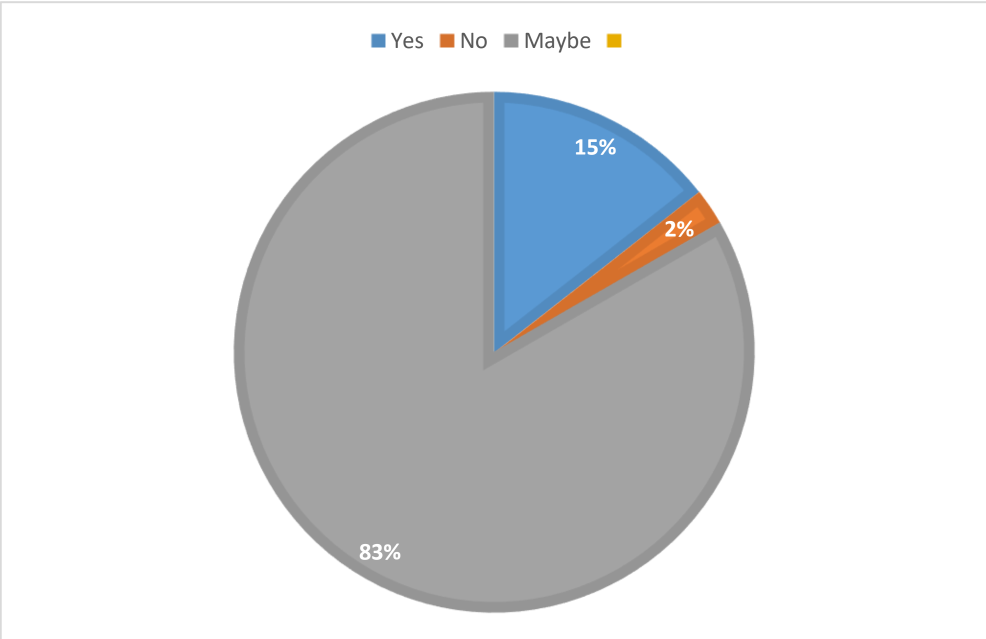
Source: primary data

5.5.1 Electricity from renewables

In the study, a significant number of the respondents are willing to adopt renewable energy resources for electricity generation, heating cooking, irrigation and all different renewables available for the citizen.

The number of people who are willing to have electricity from Renewable sources is quite high, especially people in peri-urbanized areas for the fact that comparing the cost of networks grid extension to the new renewable technology initial cost is cheaper and affordable. 83.5% of people are interested in electricity from green source and motivated to have it. Fig (27) showing the percentage of people who said yes to the green technology and the ones who are not interested, and the rejection reasons were falling in lack of some information about the new technology as they expressed.

Figure (27): The Interest Percentage of Accepting Renewable Energy

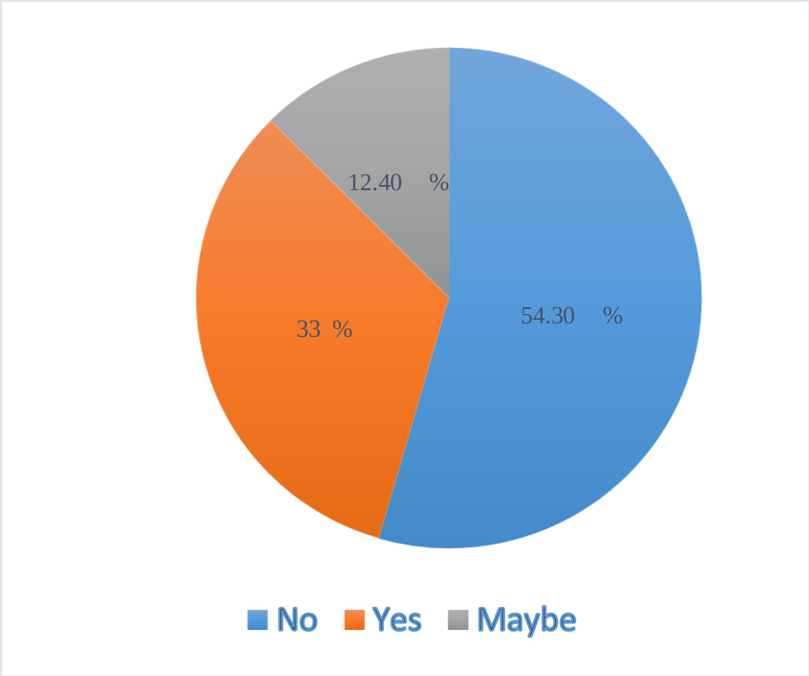


Source: primary data

5.5.2 Renewable energy prices

As a result of the fact that the citizens do not have good knowledge and the absence of the awareness about the green energy, they are not willing to pay extra price for electricity from Renewables, in which it is more expensive due to the high initial cost of the technology and the absence of government subsidies compared to the power plants that are using fossil fuel, which is highly subsidized by the government. The following chart showing the variation of the responses about the electricity from renewables prices, only 33% of the people are willing to pay extra price in order to mitigate the climate change challenges as a result of the fossil fuel burning during the energy production process and usage, whoever, 54% of the people they are not willing to pay extra and the reason is the affordability of the fossil fuel type and considering the financial status for the people in the country where as almost half of the country are living at or below the poverty line (Chapter 3, Sudan's Economy brief), in which any possible extra expenses are totally rejected.

Figure (28): Renewable Energy price acceptability

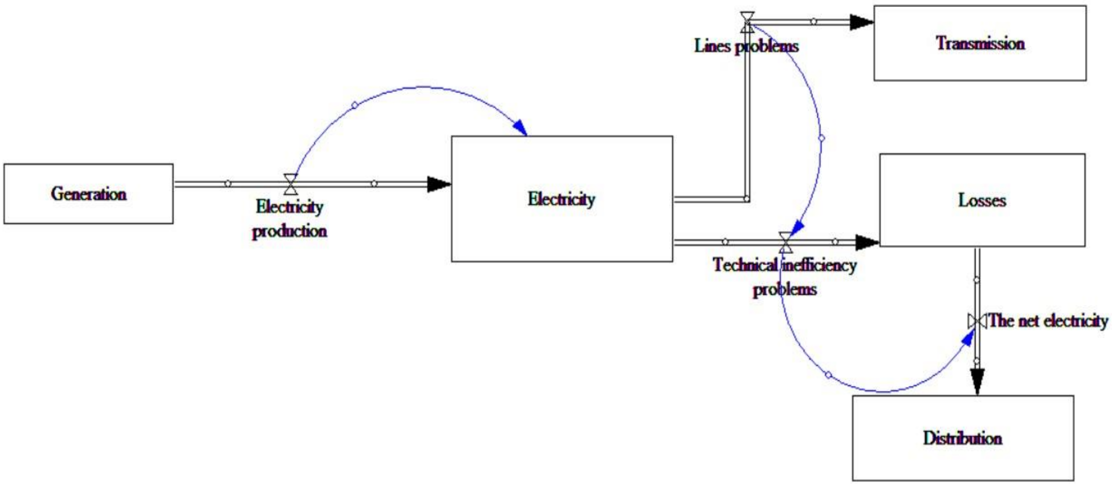


Source: primary data

5.6 System Dynamic Approach of Electricity System

The environment of electricity is influenced by many factors such as historical, political and physical condition, economic of the country when the institutional structure is obtained by different factors and elements for example such as electricity relates laws, policies and organizational elements. The electricity institutional structure contains electricity law, electricity policies, governance and management and it is defined by the political and economic qualities which they can influence the effectiveness of the electricity sector as a result of their capability to promote the effective and efficient transformation of the electricity sector. Figure (29) is showing the electricity as stock, increasing by the inflow of the generation and decreases by losses in transmission and distribution [63].

Figure (29): Electricity System



System dynamic is a simulation-based approach, it studies the relationships between various variable and create good understanding of the system. This technique is for complex systems like energy and analysis of their dynamism. SD is one of the most appropriate approaches in energy, it makes a domestic energy model with consideration of different characteristics of the assigned country. Electricity generation system is considered as a comprehensive dynamic model to be analyzed and obtain results of different scenarios and policies. Advantages of using SD are simulation-based models, high level of flexibility to tolerate the complexity of energy systems [64].

The following SD model is a comprehensive model which is taken all the relevant subsystems of electricity supply system into account. The results of the model are evaluated based on different economical, technical and environmental criteria. The model will be based on the interconnection of three main sectors: Electricity (capacity and power demand), Demography and Economy represented by the GDP. The SD model is based on analyzing the data of historical evolution and present situation of electricity consumption in Sudan as well as the relations between electricity consumption and its influencing factors. The state of the electricity system, since electricity is a nonmaterial commodity, the stock is increased by inflow - electricity generation, investment and financial flow; while the outflow decreases it by transmission, distribution, losses and thefts.

Defining subsystems by dividing the main system into five sub-systems, to study the different variables and to identify the interaction in the variables level and the sub-systems level, namely they are:

1- Electricity demand system depends on main variables (GDP, electricity demand intensity , effect of technology development (TD), the effect of demand side management (DSM) and the effect of tariff on the electricity demand of different sectors.

2- Electricity Generation Subsystem, the main variables are: Capital Constraint, the considered power provision methods, power plants efficiency, Depreciation, Private sector share in power generation.

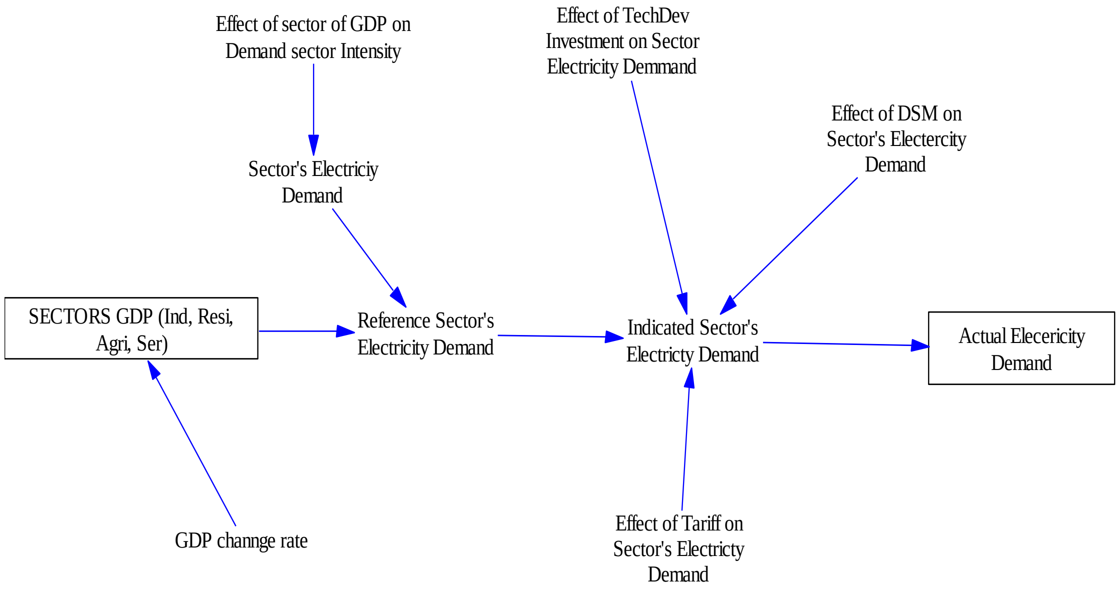
3- Technology Subsystem, Thermal power plants, Hydro power plants, etc

4- Price/Tariffs Subsystem, the main variables are: The tariff adjustment rate, the unit price of electricity considering generated and imported electricity and the inflation rate,

5- Environment Subsystem

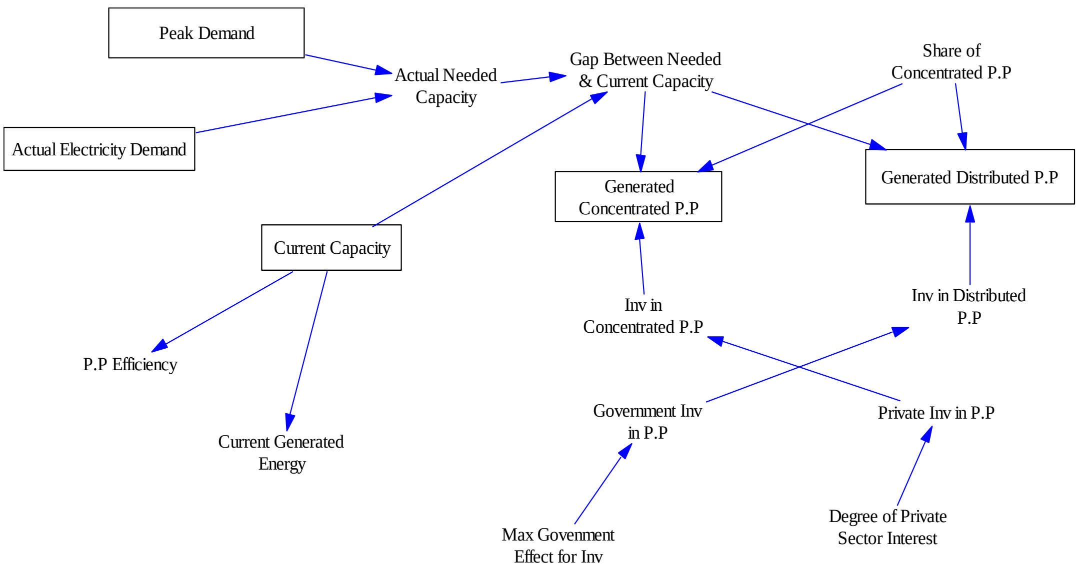
5.6.1 Electricity demand subsystem

The main variables in electricity demand subsystem are: exogenous variables in this model namely are Gross Domestic Production (GDP), inflation rate and the technology change which makes a remarkable effect on the behaviors of the electricity supply system, GDP is an index which shows the amounts of production in different economies sectors. The amount of energy consumption (electricity) has a straight relation with GDP. Due to this relation, GDP has been considered as an important variable to analyze the future demand of electricity. Electricity Demand Intensity is the other main variable in the demand subsystem shows the amount of electricity that is been consumed to obtain one unit of the GDP of the sector. It is obvious that, the lower amount of Demand intensity is an indicator of the higher degree of electricity energy efficiency. This model contains the amounts of demand intensity in different sectors included Residential, industrial, service and agricultural. In addition to the mentioned variables, there are three significant variables are, the effect of demand side management (DSM), the effect of technology development (TD), and the effect of tariff on the electricity demand of different sectors. These three variables have a significant effect on the amount of electricity peak demand which is the last main variable in this subsystem. Figure (30) the Demand Sub-systems and its variables.



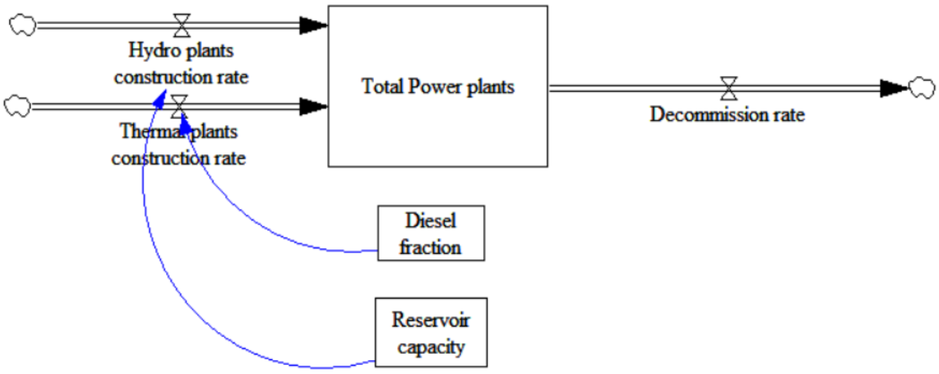
5.6.2 Electricity generation subsystem

There different variables for the generation sub-system, the main variables of the electricity generation subsystem can be summarized as, Concentrated Generation (CG), Distributed Generators (DG), energy importing (EI) and Demand Side Management (DSM). Capital Constrain is the amount of investment and it is one of the important variables in the electricity generation subsystem. Some of the required electricity generation capacities are not fully accessible due to the capital constraint and decrease the reliability of power generation. Power Plants Efficiency is very effective variable in power generation subsystem that shows the amount of time which the power plant is used in the year. The fact of higher degrees of power plant efficiency cause a lower amounts of new electricity generation capacities. The Private Sector share in Power Generation has some limitation concerning the government investment in new power plants capacity and the low productivity. So far, the participation of Sudanese private sector in power generation is not significant. However, in coming years, the increasing demand and the lack of government financial resources will enforce the government sector to give more roles and new polices to the private sector. Figure (31) Electricity Generation Subsystem.



The life time for every power plant in the system is represented in the following figure (32), the stock of the total power plants it is fed by the different power plant technology, for the hydro power plant is affected by the variable of the reservoir capacity while the thermal power plant is depending on the fuel price in which it is represented here by the diesel fraction, the outflow is the decommission and decommission rate.

Figure (32) Power plants life cycle.



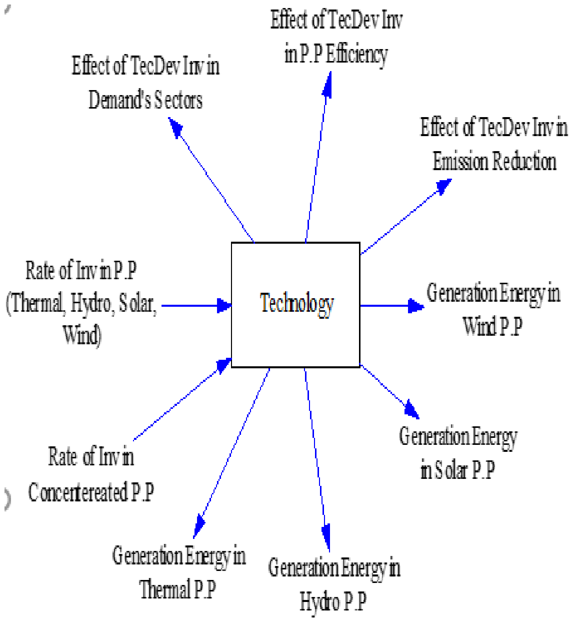
5.6.3 Technology subsystem

Defining the role of different technologies in the power generation technologies is one of the important variables in this technology subsystem. In this model the thermal, Hydro, Wind and solar based power plants are considered as the most appropriate options in Khartoum Sudan, the amounts of investment in different technology development programs such as demand reduction and optimization, pollution and emission reduction and increasing power plants efficiencies are the other important variables. Figure (A) shows the technology subsystem.

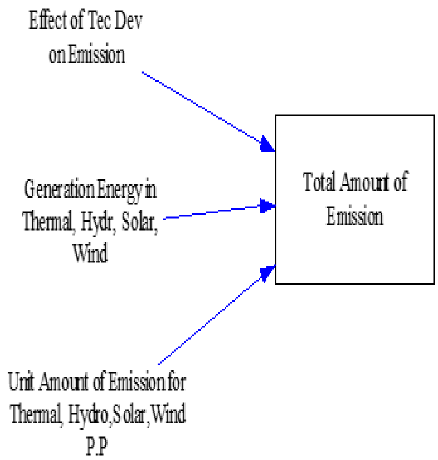
5.6.4 Environment subsystem

The environment subsystem is dealing with the environmental aspects of electricity generation system. The effect of technology development programs on the pollution reduction, and the share of different technologies in power generation programs and the effect of different policies on the demand reduction by sectors are the most important variables in this subsystem. Figure (33) is showing the Environment Subsystem.

Figure (33): Technology subsystem (A) and Environment subsystem (B)



(A)

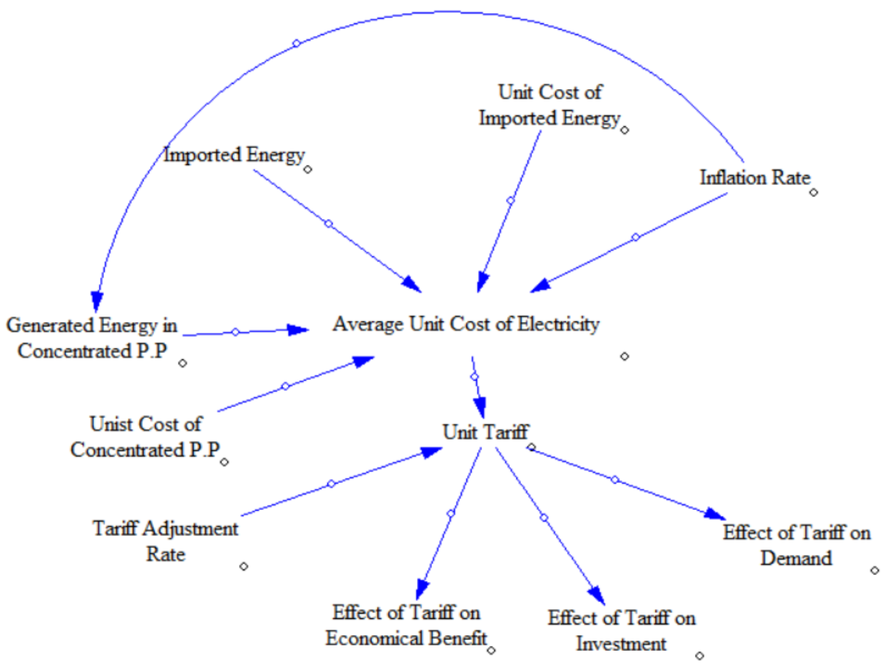


(B)

5.6.5 Price and Tariff Subsystem

The importance of price and tariff subsystem is to determine the unit price and tariff for the electricity by each sector and analyzing the effect of different variables in the other subsystems. The exogenous variable of this subsystem are tariff adjustment rate, the unit price of electricity considering all of generated and imported electricity and the inflation rate. Another effect on unit tariff of power has on the amounts of demand, profit and investment. Figure (34) presents the main variables and their relations in the price/tariff subsystem.

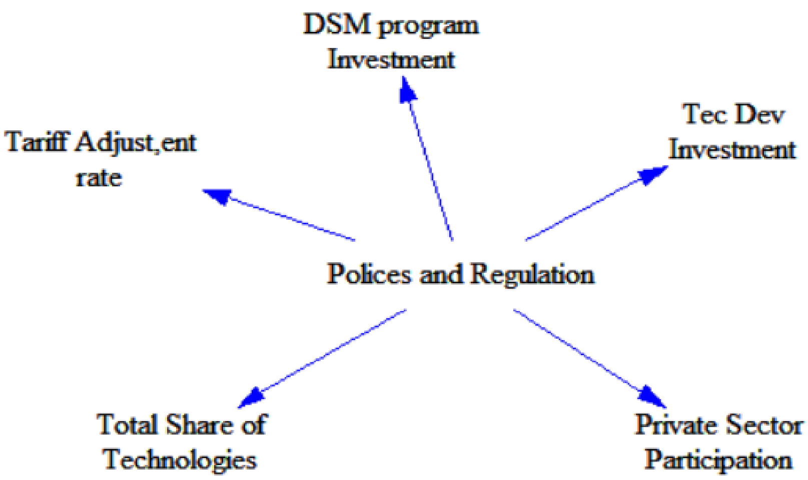
Figure (34): Price and Tariff subsystem.



5.6.6 Policies and regulation

In the polices and regulation subsystem, the endogenous variables are the variables which have regulatory aspect, they are the tariff adjustment rate, the amount of investment on demand side management and technology development, the degree of privatization (amount of private sector participation) and the shares of different technologies in power generation are the main regulatory variables. Figure (35) is showing the main variables that influence the regulatory subsystem.

Figure (35): Polices and Regulation subsystem



5.7 Externalities in Electricity System

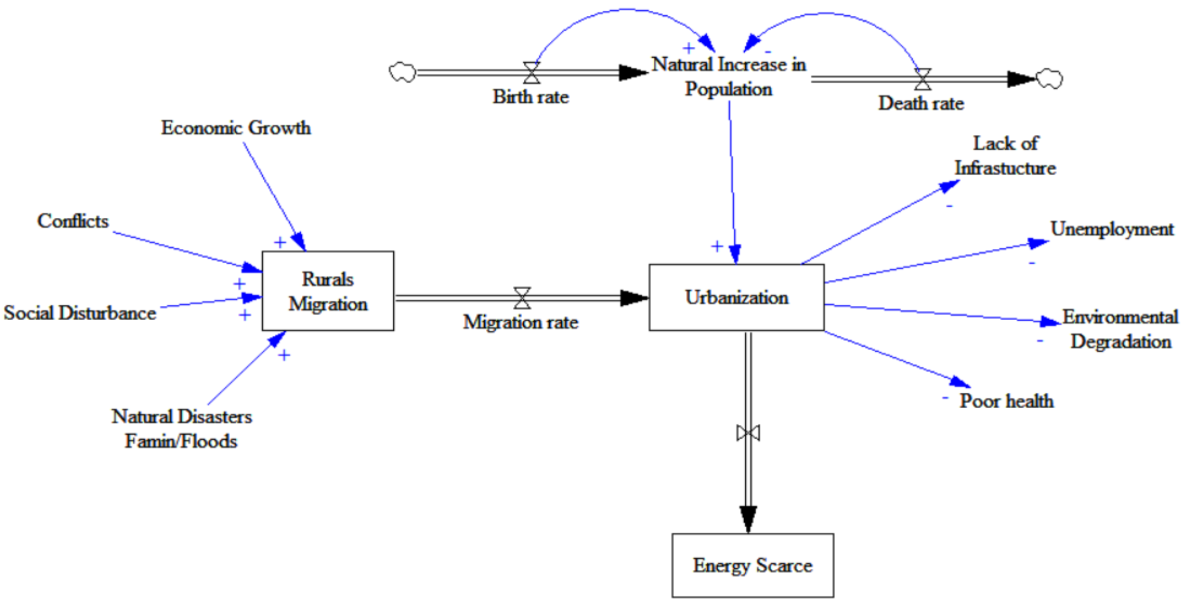
Electricity system is subjected to different externalities that affect the supply of electricity for each sector,

Price increase, exploding urbanization, resources shortages, and the most recent threat of the climate change are some of the externalities. Urbanization and increasing demand form the available generating capacity together with the market instructor are important to forecast the future demand.

5.7.1 Urbanization

Urbanization creates increasing pressure on energy supply and the natural environment. The main variables that affect the urbanization are the natural increase of population and the rural migration and its causes. The urbanization affects all of the infrastructure of the origin place, high rate of unemployment, environmental deration and poor health care due to the overpopulation concentrating in a limited area. Figure (36) shows the urbanization, it causes and effects.

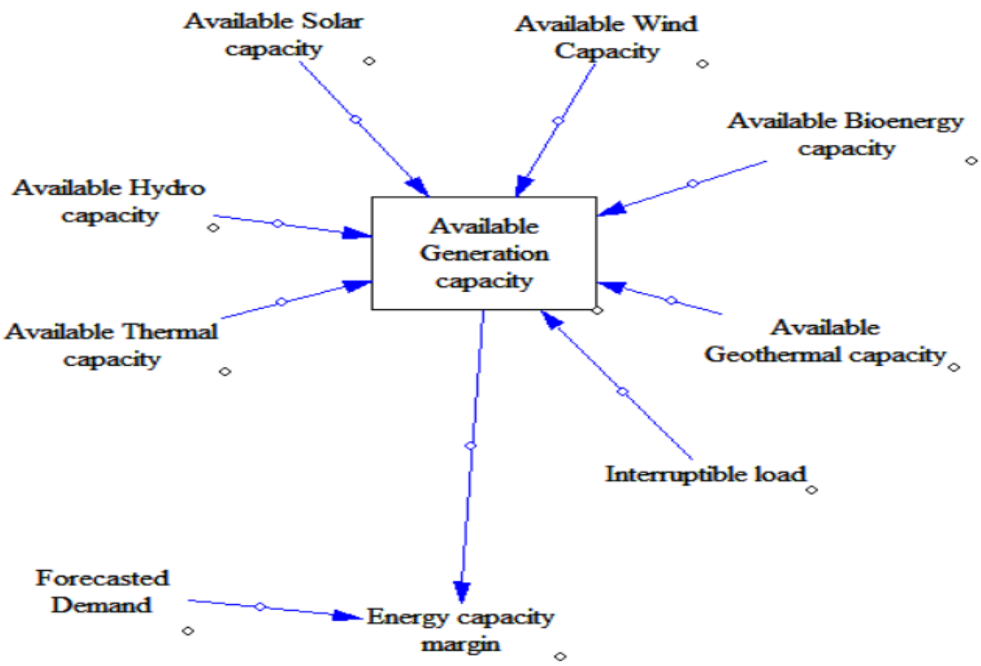
Figure (36): Urbanization



5.7.2 Available generation capacity

There main variables of the available generation capacity are the different power plants technologies and the interruptible load by various causes in addition to the energy capacity which has a direct link from the available generation capacity and effected by the forecasted demand. Figure (37) illustrate the available generation capacity and the variables**.**

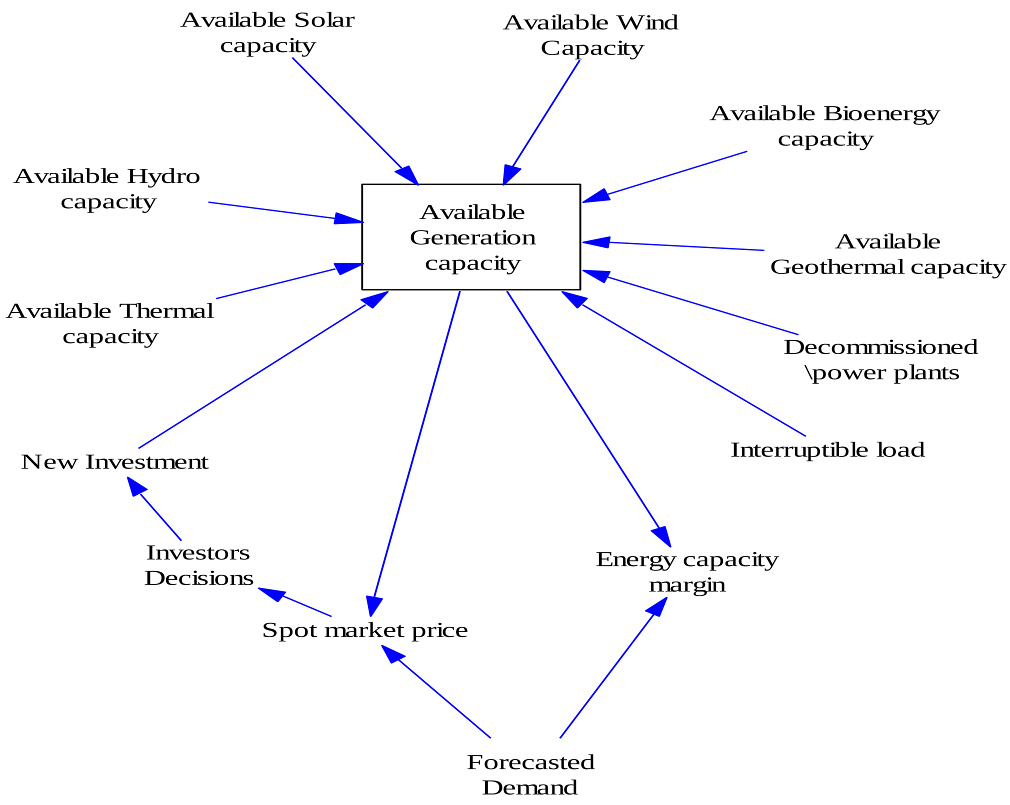
Figure (37): Available Generation Capacity



5.7.3 Market Instructure

In order to meet the future demand, the forecasted demand capacity is needed, the forecasting is depending on the energy capacity margin, the market price and the new investment with the investors decisions in which the price is affecting. The different technologies of the power plants are variables of the available generation capacity. Figure (38) shows the interaction between the generation capacity, the demand and the spot market price.

Figure (38): Market Instructure



5.8 Electricity System Summary

Bridging the Electricity Demand-Supply Gap

In order to solve the electricity demand-supply gap the need for understanding the causes of this gap is highly important. The main causes of electricity demand-supply gap are technical in term inefficiency of electricity production, transmission and distribution, socially as the high level of urbanization in the capital Khartoum and the fast growing communities surrounding the area.

To bridge the demand-supply gap by adding generation capacity alone is not the best solution; efforts should be met in demand side as well, and demand side solution will not solve the issues of the supply side. Long and short solutions should be adopted to face the gap. Understanding the relationships between electricity and the physical parameter is the key to highlight the main causes of the issue and solve it individually in order to repair the main system of the electricity.

Khartoum reinforcement plan is one of the solution that the government is working on it to fulfill the need of the electricity in the capital as well as to increase the electrification rate in the country and increase the area covered by the national grid. The program is to inject new line of 110/33/11kV at Aldiar Al-Qateria and railway, another line of 220/110/33KV at Al-Sunt. The second aim of the plan is to add extension of existing four 220/110KV substations at Al-Ezergab, Al-Shajara, Kuku and AL-Iziba, extension of existing three 220KV at AL-Kabashi, Jabal Awlia and Eid Babkir and extension of existing 110KV substation at Faroug.

A regular maintenance for the power plants it will increase the efficiency of the production and safe the wasted energy due to the inefficiency of the production, transmission and distribution phases.

Encouraging the investment in the energy sector and limit the monopoly based functioning through new attractive policies and provide all the subsides needed.

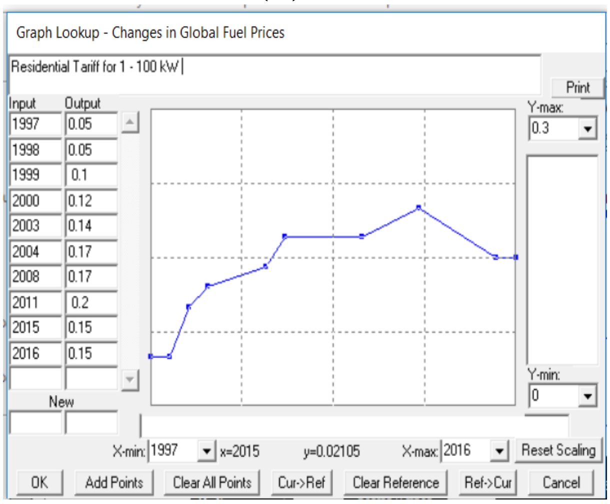
Adopting energy decentralization as one of the main solution of the electricity demand-supply gap, by avoiding extra expenses for grid expansion and make use of the area resources, hybrid systems are efficient and practical solution as well.

Introducing Demand Side Management to the different sector to participate on electricity efficiency.

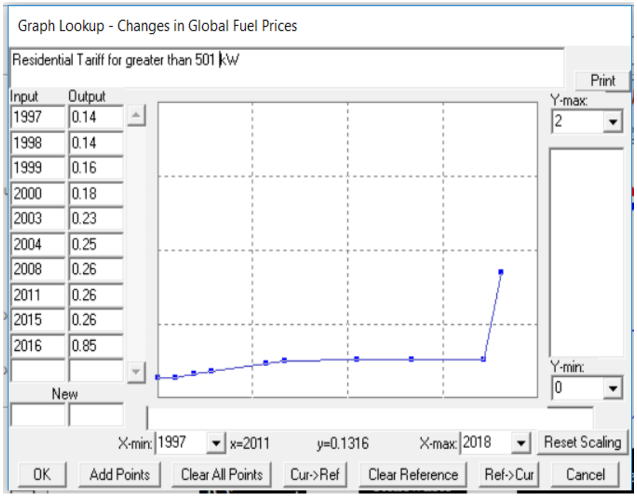
Inform long-term policies on the tariffs to stablaize the supply for good time period, to enable the population to afford the electricity pricesand services, below in the residential tariff figure show the fulctuated behavior of the tariff changing from 1997 to 2016, from VENSIM software modelling, the first graph (A) is showing the different tariff values for the first level of residential sector which is 1 -100kW, the second graph (B) is howing the last level of residential sector with load greater than 501kW.

Figure (39): Residential Tariffs 1997-2016.

(A)



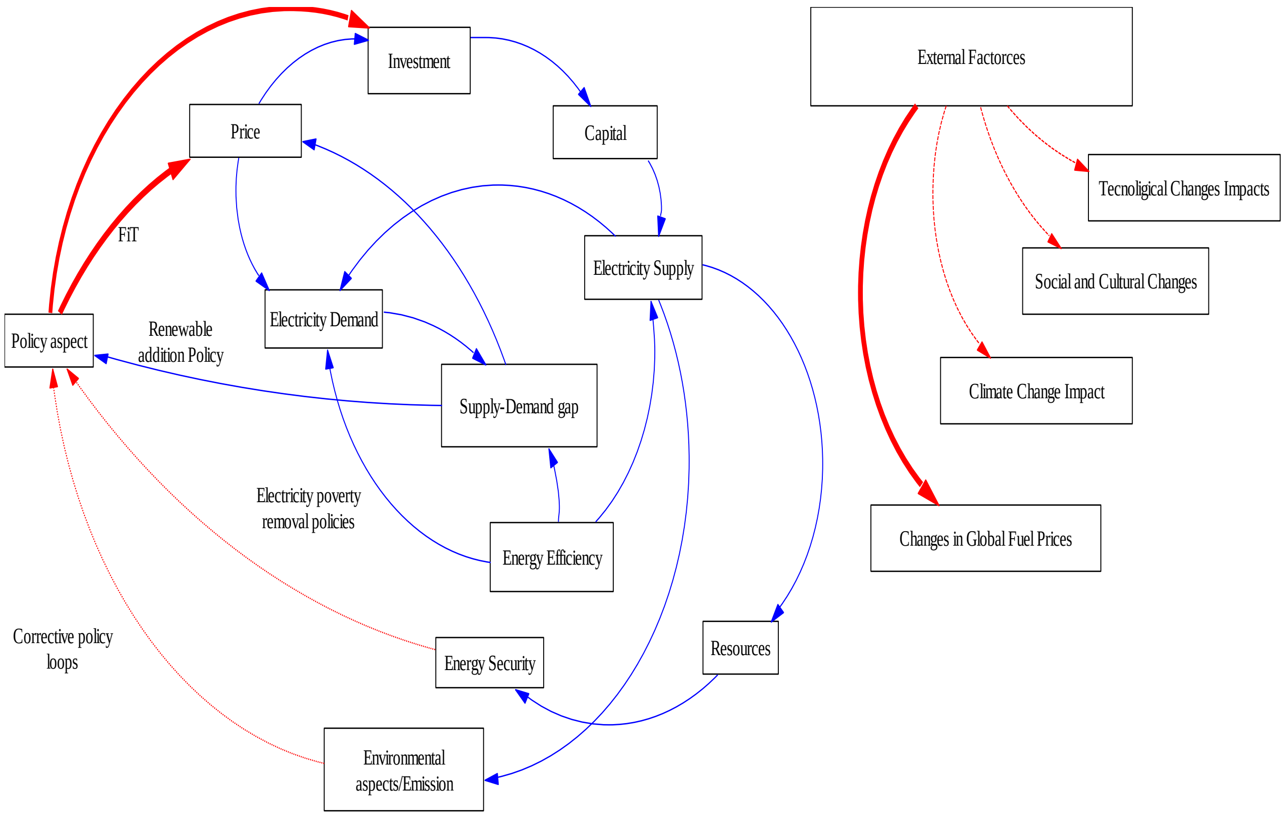
(B)



Finally, for electricity demand-supply gap bridging the first step is to highlight and understand the interconnection of the different sectors and subsystems, taking in consideration all linear and nonlinear relationships between the variables, and estimate the uncertain factors as a matter of fact that the energy system is subjected to different types of difficulties as a result of the energy systems growth in size and system complexity and the dynamic complexity that was inherent from the system should be well identified.

Factors influencing demand-supply (variables) internal and external of the electricity system, such as economic growth, status of energy resources (reserves), industrial activity, propensity for investment, societal development, customer pressure, and technological supply, price, capital and polices, in the following figure the electricity demand-supply gap were modeled together with all the highly affecting factors and variables in electricity system, the casual loop is illustrating the relationships of the demand-supply gap with the internal levels and the external factors. This causal loop is summarizing the different subsystems of the electricity system which they have been discussed in this study.

Figure (40): Casual Loop Diagram of the Demand-Supply Gap



CHAPTER SIX

6 POLICES, CONCLUSION AND RECOMMENDATION

6.1 Policies

The absolute purpose of modeling is to design improved policies in order to improve the behaviors of the system. Modeling helps the level of understanding the flaws in existing policies or lack of it. After significant analysis, validation and scenario generation the model helps in understanding the impacts of different variables on policy formulation. The variation in the GDP growth rate request for more electricity demand. This causes increase the gap between demand and supply. By increasing electricity generation decides the reduction in demand-supply gap. What level of generation increase is sustainable can help taking a policy on generation planning? Model is the best to help in analyzing electricity demand deficit.

By power of system dynamics, the dynamic behavior of the entire electricity generation, transmission and distribution system is linked to one crucial variable which is the GDP growth rate.

Policies are made to achieve the role in meeting the dual challenge of supplying the efficient electricity to the country which in needs to grow and prosper. Policy makers must understand the evolution of renewable energy policies in order to increase the cost competitive for renewables technologies like solar and wind.

Policy makers have options to take the power system towards sustainability by using regulations and properly implement it, since renewables are the most available source of energy, in spite of the high initial cost, but this issue should be solved by adding good rate of subsides to be more attractive than the conventional sources.

6.2 Limitations and future research directions of the study

Every modeling exercise would have its own limitations; the results have to be interpreted keeping these facts in consideration. Some of the limitations have been on account of lack of data. Like electricity demand reporting data has not been available. By having all the related data for demand and supply, different scenarios could be extracted and from them various options of policies would obtained. Some qualitative factors like social acceptance, political uncertainty, international co-operation etc have not been considered in this model. This study is for grid connected power, since Sudan has not installed renewables technologies for the mean time. Meanwhile, Further study could be done with additional distributed generation power plants also considering long term plan.

6.3 Conclusion

This study used descriptive statistics to analyse social economic characteristics of respondents and System Dynamic modelling was used to determine the factors influencing electricity system in details, and the adoption of clean and green Energy to increase the electrification rate with continuous electricity supply for the residential sector.

In this study, the Multi-tiers approach was used to identify the influencing factors on electricity supply in the residential sector by identifying the types of the electrical appliances and the duration of the electricity and the affordability for various areas in the capital Khartoum. The following explanatory variables namely, household income, household head occupation, access to information, area of residing, electricity prices, green energy, renewable energy prices were discussed in details by the respondents.

The results of study indicated that income level, is medium and low level, the majority of the citizens are living far from the capital's centre, the electricity prices are not affordable for significant number of the citizens, increasing of electricity cuts off in different seasons.

The results from study also revealed that over 80% of the respondents are willing to adopt the renewable energy technologies and the socio-economic benefits that support sustainable development in their communities and contributed positively in different projects such as access to modern energy service, helping other researchers in feasibility study for the area.

The results indicated that Urbanization is one of the main reasons of the electricity demand-supply gap, due to the fact that the peri-urban areas are counted as an extended settlements of the capital Khartoum, transmission and distribution losses are contributing in the electricity demand-supply gap and the inefficient generating process at the very old national grid facilities.

The study showed the economic impact on the electricity sector because it has a direct effect on the electricity plan in terms of extension networks and the addition of new generation to meet the increasing demand for electricity by providing the necessary money to implement the required development projects in the electricity sector.

The study revealed the significant usage of system dynamics approach in energy systems, the successful analysis for the interactions among the subsystems and their variables.

6.4 Recommendations

The following are the recommendations suggested as far as the study is concerned:

- Considering the possible relationship between adoption of renewable energy technologies and their benefits, there have been efforts driven by policy for the public to increase the adoption, though at a very low rate. However, many types of solar cells for electricity generation have found their way to the market. Therefore, the government should embark on standardization of the solar cells available on the market to measure their actual efficiency so as to make necessary improvements and label them according to their efficiency. This process will help the customers to have enough information prior to the buying of these cells, thus increasing energy access and stability.

- In order to increase the level of investment in the energy sector, the government and the policy makers should facilitate the access to bank loans, national and international funding. As the results indicated that the problem of the centralization of the electricity supply through the national grid in which it is covering only the center of the country, government should encourage the decentralization for the energy supply and provide the technical support for some new hybrid system for the large scale as the isolated communities.
- Separation the electricity supply per sector to balance the demand load and to reduce the peak time of the grid and to avoid the frequent cuts offs as a result of the over load consumption.
- The government should introduce the demand side management program all over the country and provide well-structured polices to support the program.
- Adopting energy audit strategies to increase the efficiency of all appliances and machines.
- Encouraging the micro-economic project across the country to enhance the GDP/capita and to speed the development of the various areas.

7 REFERENCES

1- *International Energy Agency (IEA, World Bank, 2018).*

2- *The World Bank Annual Report (Santos Report 2018, World Bank 2018).*

3- *The World Bank Annual Report, 2016 (World Bank, 2016).*

4- *Alam, Kango & Singh, 2016.*

5- *Huang and Wang, 2011.*

6- *Evaluation of Moving Average Model and Autoregressive Moving Average Model (ARMA) for Prediction of Industrial Electricity Consumption in Nigeria (Essien and Igweonu, 2014; Sambo, 2008).*

7- Electricity Supply and National Transformation Agenda: The Nigeria Experience, 1980-2012, (Ohwofasa and Kumapayi, 2013).

8- Asley-Edison International Limites [GB], Power Quality in Sudan https://www.ashleyedisonuk.com/world-voltages/africa/voltage-sudan-913/

9- Ley, 2017, Bauwens, 2016.

10- Energy Access Outlook 2017, Energy Access Outlook 2017.

11- Power People Planet https://www.cleancookingalliance.org/binarydata/RESOURCE/file/000/000/389-1.pdf

12- World Bank reports, Addressing the access gap ESMAP 2002; IEG 2008

13- Energy Sector Management Assistance Program, https://www.esmap.org 2007a

14- Africa energy future: Alternative scenarios and their implications for sustainable development strategies Author links open overlay panel Nadia S.Ouedraogo

15- African big nuclear ambition https://www.iol.co.za/business-report/economy/africas-big-nuclear-ambitions-lure-russia-2019026

16- The World Bank Annual Report, (World Bank, 2013).

17- *International Energy Agency Report, (IEA, 2014).*

18- *Energy Policy, (Eberhard et al.2008).*

19- *Energy Economics. Springer, Bhattacharyya,Subhes C(2011).*

20- *Transmission expansion for Renewable Energy* *https://dokumen.tips/documents/transmission-expansion-for-renewable-energy-expansion-for-renewable-energy-scale-up.html*

21- *EM. Empowering Africa, the importance to face energy poverty* *http://www.fondazionepopoli.org/wp-content/uploads/2013/10/Em-Powering_Africa.pdf*

22- *Addressing the Electricity Access Gap, the annual NAEE/IEE International Conference Nigeria, 2015*

23- *Energy in Sudan – Wikipedia.pdf-Adobe Reader*

24- *Struggles for Electrical Power Supply in Sudan and South Sudan.* *https://www.researchgate.net/publication/322924929_Struggles_for_Electrical_Power_Supply_in_Sudan_and_South_Sudan [accessed Aug 10 2019].*

25- *OEC*

https://oec.world/en/visualize/tree_map/hs92/import/sdn/show/2709/2017/

26- *Solar Energy Potential in Sudan, (Omer, A.M., 2015, p.253).*

27- *Wind Energy Resource in Sudan,* *https://www.researchgate.net/publication/227421152_On_the_wind_energy_resources_of_Sudan*

28- *Sudan Access to Electricity, https://tradingeconomics.com/sudan/access-to-electricity-percent-of-population-wb-data.html*

29- *Modelling of Sudan's Energy Supply, Transformation, and Demand (Rabah, A.A., et al., 2016, p.5).*

30- *Geothermal Energy in Sudan,29699wdgeothermal_energy_in_sudan_0(Nationmaster, 2017),*

31- *(Hassan Hussein, W.I., 2013, p. 32).*

32- *Sudan Energy 2019, CIA World Factbook https://theodora.com/wfbcurrent/sudan/sudan_energy.html*

33- *Sudan, Country Profile 2018, Electricity installed capacity index mundi, https://www.indexmundi.com/sudan/electricity_installed_generating_capacity.html*

34- *Sudan energy consumption ,https://www.worlddata.info/africa/sudan/energy-consumption.php*

35- *Electricity demand and consumption https://lucidconnects.com/library/blog/electricity-demand-vs-consumption*

36- *Understanding electricity consumption, demand, http://www.gridpoint.com/understanding-electric-consumption-demand-charges/*

37- *Capacity factor https://circuitglobe.com/capacity-factor.html*

38- *Energy, Capacity factor http://www.nmppenergy.org/feature/capacity_factor*

39- *AICD-Sudan- country report*

40- *Populationstat, https://populationstat.com/sudan/khartoum*

41- *WorldAtlas, Sudan profile https://www.worldatlas.com/articles/what-is-the-capital-of-sudan.html*

42- *The Open University[GB], Urbanization https://www.open.edu/openlearncreate/mod/oucontent/view.php?id=79940&printable=1*

43- *Largest cities in Africa https://www.top10hq.com/the-top-10-largest-cities-in-africa-2018/*

44- *Sudan Energy profile, electricity generation, consumption https://www.ceicdata.com/en/sudan/electricity-generation-and-consumption/electricity-consumption*
45- *IEA Statistics © OECD/IEA 2014 (http://www.iea.org/stats/index.asp)*

46- *Electricity consumption per capita map* ***https://www.indexmundi.com/map/?v=81000***

47- *Sudan's electrical power transmission and distribution losses, July 2013*

48- *City limits: Urbanization vulnerabity in Sudan, Khartoum case study, June 2011 [Urbanization of Khartoum]*

49- *The World factbook, Sudan, Africa https://www.cia.gov/library/publications/the-world-factbook/geos/su.html*

50- *Heritage, Sudan index https://www.heritage.org/index/country/sudan.*

51- *Sudan Inflation rate data https://tradingeconomics.com/sudan/inflation-cpi*

52- *Global tracking frame work for measuring energy access https://energypedia.info/wiki/Global_Tracking_Framework_for_Measuring_Energy_Access#Access_to_Electricity*
53- *Clean cooking alliance, https://www.cleancookingalliance.org/binary-data/RESOURCE/file/000/000/359-1.pdf*
54- *Institutional Quality and electricity supply growth in a developing country m case of Nigeria*
55- *https://pdfs.semanticscholar.org/429d/d1cb1303acbd81a2aaba79f3b263eaff2ec2.pdf*

56- *Application of system dynamics in electricity supply systems*
https://www.systemdynamics.org/assets/conferences/2012/proceed/papers/P1008.pdf

8 APPENDIX

Appendix one: Questionnaire

Interviews questions

This part for the institutions and the general concerned bodies for the technical information and data of the electricity sector in Sudan/Khartoum.

1- What are the main sources of electricity generation?

2- What is the exact installed capacity of electricity generation for Khartoum, when and by whom?

3- What are the portion of electricity sources in the city?

4- Is there a national energy plan or long term development plan?

5- How the increasing in oil prices affecting the electricity price and are there subsides?

6- How the general demand recorded and in which time scale?

7- What is the last 10 years' electricity demand percentage?

8- What are the challenges that facing the stable supply for the city?

9- When were blackouts, how often, where and why?

10- What are the critical factors that have direct impact on the electricity supply?

11- What is the short term/long term road map of the electricity?

12- Is there any future plan to overcome the urbanization effect in electricity sector or the balance between national and urban plan?

13- What is the level of community participation in the electrification action projects?

14- To what extent does a social and economic policies impact the country?

Questionnaire for the Community of Khartoum

The survey covered the people who live in the tri-capital Khartoum (Khartoum, Bahri and Omdurman), which means is considering the center of the capital and its neighborhood as extended areas around the city.

1- What is the number of your family members?

2- Do you have the following: Air conditioner, fridge, TV, microwave, fan, ….?
3- For how many years you connected to the national grid?
4- Where are you living, center of the city/country side?
5- How often the electricity goes off?
6- What is your average per capita income?
7- Does the electricity price affordable for you and how much is it?
8- Do you own a genet? solar panel? or SHS?
9- Did you buy it in a lone?
10- Does your job/work/activity need electricity?
11- What are the challenges that you have faced as a result of electricity cuts off or any economic loss than you had experienced?
12- To what extend does the electricity issue affect your social activities or did you missed any important interaction?
13- Do you know what the Green Energy term stand for?
14- Are you willing to have electricity from green resources and carbon free?
15- Are you willing to pay higher price for green electricity?
16- Are you willing to be part of any project aiming to bridge the electricity gap?
17- Can we use your data our study, anonymously?

Appendix 2: Research grant monthly usage

Month	Activities	Local Cost	Cost/USD
March	Internet Purchase	3,570 DZ	30 USD
April			
	Visa Travel Insurance Internet	Travel Internet charges Sub Total	100 USD 65 USD 30 USD 195 USD
May	Travel to Sudan Stationaries Printing Services Spiral/book Binding Field transport Research assistances	102,199 DZ 2,928 Sud pounds 6,397 Sud pounds 2, 252 Sud pound 20,293 Sud pound 6, 757 Sud pound	854.50 USD 65 USD 142 USD 50 USD 374 + 72 = 446 USD 2 * 75 = 150 USD

	Internet, Algeria **Internet, Sudan** **Travel to Germany** **Transport from Frankfurt to** **Wurzburg**	**3,570 DZ** **2,477 Sud pound** **30,932 DZ** **44 Euros** **Sub-total**	**30 USD** **55 USD** **258.6 USD** **51.6 USD** **2,102 USD**
June	**Data visualization** **Internet charges** **Data analyzing** **Printing** **Spiral binding**	**54 Euro** **8,84 Euro** **17.68 Euro**	**14 + 40 = 54 Euro** **54*1.119 = 60 USD** **10 USD** **20 USD**

		Sub total	**90 USD**

Grand Total = 1,304.7 USD

***Without flights**