UNIVERSITY OF RWANDA

COLLEGE OF SCIENCE AND TECHNOLOGY

DEVELOPMENT OF AN OPTIMIZATION MODEL FOR MINIMIZING THE LEVELIZED COST OF ELECTRICITY

By

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

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Date

CERTIFICATION

This thesis has been submitted for examination with my approval as University Supervisor.

Dr. Alice IKUZWE SUPERVISOR	Date

DEDICATION

To God Almighty for his unconditional love, and
To my family, parents, siblings and friends for your support,
This work is dedicated.

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It would have been impossible to conduct this research without the guidance and support from various people and institutions. Hence, I would like to express my gratitude to them. First, I thank God for keeping me healthy throughout my studies and during the conduct of the present research. Also, I would like to thank the African Centre of Excellence Energy for Sustainable Development(ACEESD) for giving me the opportunity to do a Master of Science degree in Renewable Energy at the University of Rwanda(UR). To the UR and ACEESD staff members who have supported me during my studies, I say thank you!

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List of Abbreviations

SNEL	Société Nationale d' Electriciteé
NST-1	National strategies for transformation
EDPRSII	Economic Development and Poverty Reduction Strategy
MW	Mega Watt
ESSP	Energy Sector Strategies Plan
REP	National Energy Policy
SDGs	Sustainable Development Goals
REP	Renewable energy program
RES	Rural Electrification strategy
EARP	Electricity Access Roll Program
NEP	National Electrification Plan
LCDP	Least cost Development Plan
NBP	National Biomass Programmer
GDP	Gross Domestic Product
RWF	Rwanda Francs
kVA	Kilo volt Ampere
GDP	Gross Domestic Product
UNDP	UN human development report
REG	Rwanda energy group
RURA	Rwanda Utilities Regulation Authorities
USD	United State Dollars
kWh	Kilo watt Hour
EH	Energy Hub
TOU	Time-Of-Use
BESS	Battery Energy System Storage
PV	photovoltaic

FC	Fuel Cell
DC	Direct Current
MILP	Mixed-Integer Linear Programming
DSO	Distribution System Operator
HOA	Heap Optimization Algorithm
OPF	Optimal Power Flow
EC	Electricity Net Consumption
EG	Electricity Net Generation
CPI	Consumer Price Index
EP	Electricity Prices
IVA	Industry Value Added
FP	Average Crude oil Prices
NPC	Net Present Cost
EV	Electron Volt
GA	Genetic Algorithm
NLP	Non-linear programming
EAC	East African Community
$	Dollar
%	Percentage

ABSTRACT

The world has changed substantially over the past century, partly thanks to increased access to energy, an essential factor of social and economic development. Also, various sources of energy have been used. Some are known to be both non renewable and environment unfriendly, while others are commended and recommended for being renewable and for their ability to sustain the environment. The latter category includes energy sources such as hydropower, solar, and methane gaz. As the availability of electricity increases and energy sources diversified, however, the production and access costs in some parts of the world, including Rwanda, are too high for the great parts of the population to afford and/or use it. In such case, efforts to explore the means of reducing electricity costs are necessary in order to increase access and therefore ensure universal access to electricity. One of those means is to develop optimization models to minimize levelized cost of electricity (LCOE). The present thesis reports on a study that involved the development and simulation of a mathematical model to minimize LCOE. The model was developed and tested using Matlab tool. The study also used a questionnaire to collect qualitative and quantitative data on Rwandan electricity users' perceptions and experiences of using electricity in their households. Analysis of the questionnaire data indicated that Rwandans perceived electricity costs to be so high that even those who were connected to the grid used electricity at a very limited scale. Moreover, the simulation outcomes of the developed model demonstrated that the model can identify the best generation capacity variables and minimize LCOE. The optimization results indicated that the involved parameters could help achieve LCOE and to achieve the optimization generation capacity variables from renewable energy sources available in Rwanda. Implications and recommendations are drawn for the relevant energy sector stakeholders.

Chapter 1
INTRODUCTION

1.1 Background

The world has significantly evolved due to energy access, which is a critical factor in social and economic development, and necessary for economic success. The utilization of energy has enabled people to raise their standards of living. In 2021, 38% of the world's electricity was generated from clean sources, while 36% came from coal [1]. The global energy crisis, exacerbated by the war between Russian and Ukraine since 2022, severely hampered efforts to increase electricity access. Since the start of the ward, the population without access to electricity worldwide increased to approximately 760 million, up by about 6 million compared to previous years. Four out of every five people without access now reside in Sub-Saharan Africa, where this setback was primarily concentrated[1] .

Over the past few decades, there has been a gradual global increase in the percentage of individuals with access to electricity. Currently, over 90% of the global population has access, up from less than 80% in 2000. This indicates that approximately one in ten people worldwide still lack access to electricity [2].

In the East Africa, a region where Rwanda is, the International Energy Agency (IEA) notes that the region has significant potential for renewable energy production[3], owing to its excellent geothermal and solar resources [?]. Rwanda, located in this region, shares similar energy sources. The EAC's power generation and accessibility statistics are illustrated in the tableau below [2].

Table 1.1: Summary of the Status of EAC Power Sectors and potential energy resources

Country	**Generation capacity(MW)**	**Electr. Access %**
Kenya	2819	76.49
Uganda	1346	42.1
Burundi	39	11.74
Tanzania	1605.86	39.9
South Soudan	570	7.2
Rwanda	311.1	74.4

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[1] https://tinyurl.com/29rzy6ax

[2] https://tinyurl.com/48m68ak2

1.1.1 Rwanda's energy situation

Within Rwanda, energy is recognized as vital in people's lives because it supports all other sectors of the economy and development. Since 1959, electricity in Rwanda has been primarily supplied by the Ntaruka hydropower plant, with a generation capacity of 11.25 MW, and an oil thermal plant, both connected to the national grid [4]. Another significant source of electricity has been the Rusizi I hydropower plant, co-owned by Rwanda, Burundi, and the Democratic Republic of Congo (DRC), and operated by the Société Nationale d'Electricité (SNEL), with a generation capacity of 16.1 MW. Electrogaz, established in 1976, was the only electricity supplier on the national grid [5]. Notably, 90% of the electricity was supplied by the Ntaruka hydropower plant.

From 1969 to 1985, three new hydropower plants were installed: Mukungwa I with 12 MW, Gihira with 1.8 MW, and Gisenyi with 1.7 MW. However, from 2000 to 2007, the country experienced a shortage of electricity due to decreased water levels, attributed to reduced precipitation and increased demand from human activities [4].

Between 1989 and 2005, there was significant growth in the energy sector, marked by the installation of various new plants. This included the Jabana thermal power plant with a 7.8 MW capacity, and the addition of 16.1 MW from Mururu I and Mururu II, along with 2 MW from Gatuna [3]. By 2009, the total installed capacity for hydropower plants was 41.25 MW, and for thermal power plants, it was 14.5 MW.

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[3] https://tinyurl.com/mpm6h2vd

Table 1.2: The growth of power plants and generation capacity

No	Plant Name	Generation capacity(MW)	Year	Type of technology
1	Murunda	0.1	2010	Hydro
2	Rukarara I	9	2010	Hydro
3	Rugezi	2.6	2011	Hydro
4	Keya	2.2	2011	Hydro
5	Nyamyotsi I	0.1	2011	Hydro
6	Nyamyotsi II	0.1	2011	Hydro
7	Agatobwe	0.39	2010	Hydro
8	Mutobo	0.2	2009	Hydro
9	Nkora	0.68	2011	Hydro
10	Cyimbili	0.3	2011	Hydro
11	Gaseke	0.5	2017	Hydro
12	Mazimeru	0.5	2012	Hydro
13	JAnja	0.2	2012	Hydro
14	Gashashi	0.28	2013	Hydro
15	Nyabahanga I	0.2	2012	Hydro
16	Nshili I	0.4	2012	Hydro
17	Rwaza Muko	2.6	2018	Hydro
18	Musarara	0.4	2013	Hydro
19	Mukungwa II	3.6	2013	Hydro
20	Rukarara II	2.2	2013	Hydro
21	Nyirabuhombohombo	0.68	2013	Hydro
22	Giciye I	4	2013	Hydro
23	Giciye II	4	2016	Hydro
24	Giciye III	9.8	2020	Hydro
25	Rukarara Mushishito	5	2019	Hydro
26	Rugabagaba	0.45	2019	Hydro
27	Nyirantaruka	1.84	2020	Hydro
28	Kigasa	0.27	2020	Hydro
29	Mukungwa MHPP	0.02	2020	Hydro
30	SO Energy	30	2017	Diesel
31	Gishoma	15	2020	Peat
32	Hakana	70	2020	Peat
33	Kivuwatt phase I	26.19	2020	Methane
34	Gigawatt	8.5	2013	Solar
35	Nasho solar	3.3	2017	Solar
36	Gatuna	2	2016	Import

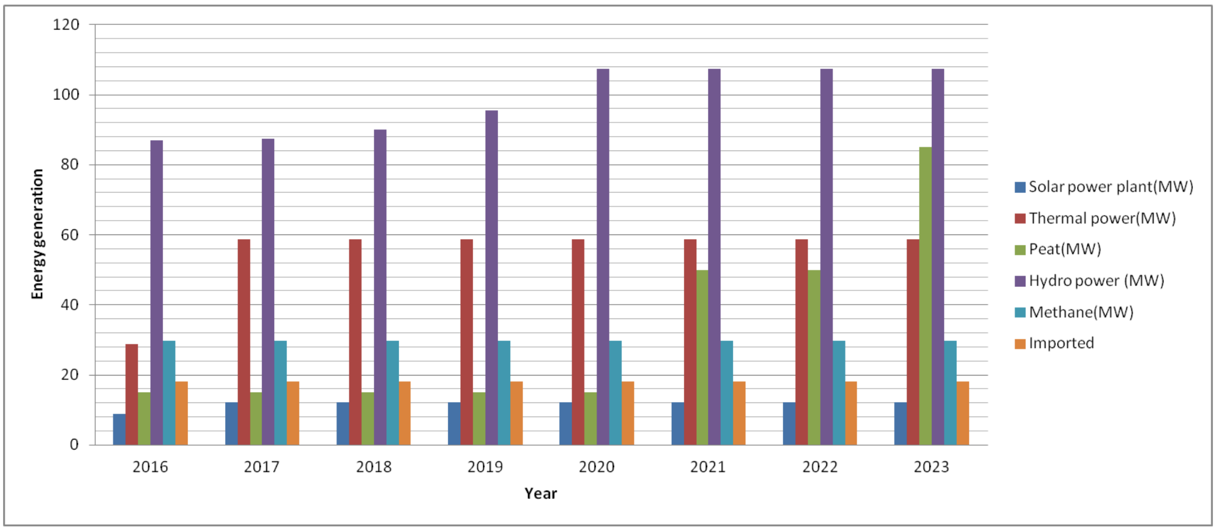

Figure 1.1: Energy generation growth

The electricity access grew rapidly from 29.37% in 2016 to 74.4% in September 2023 where 54.19% were connected to the grid network and 20.21% got electricity through off-grid systems (mainly solar)[4]. Figure 1.2 shows the electricity accessibility growth in Rwanda since 2013.

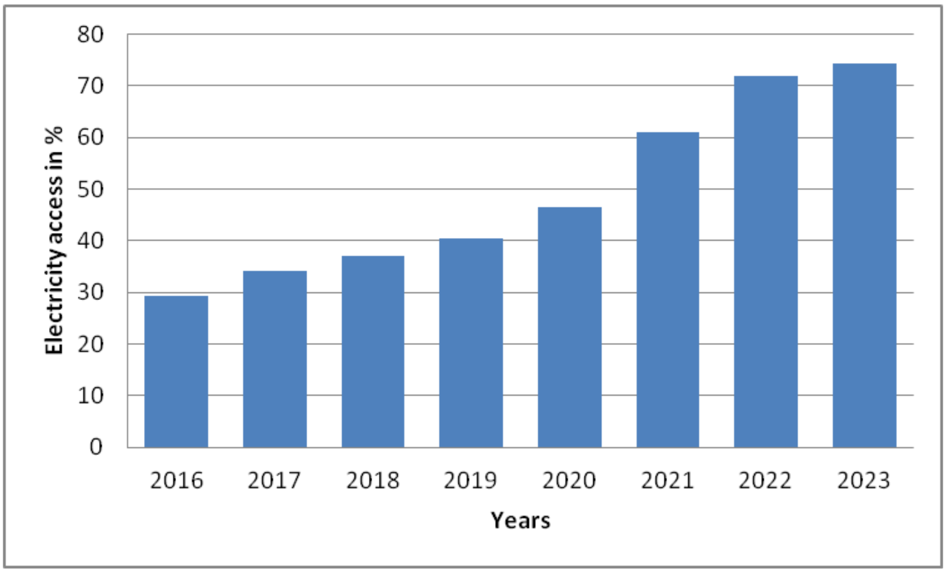

Figure 1.2: Electricity accessibility growth

1.1.2 Sources of renewable energy in Rwanda

Rwanda's geographical location is advantageous due to the variety of energy sources available within the country. Renewable energy, defined as energy generated from natural and persistent environmental flows [6], can also be described as energy derived from limitless sources [7]. The primary source of power generation in Rwanda is hydropower, contributing 107.328 MW, which corresponds to 34% of the country's power generation [8]. Solar power plants, benefiting from high irradiation levels between 4-6 kWh/m^2/day [9], contribute an installation capacity of 12.05 MW from three on-grid solar plants [10].

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[4] https://www.reg.rw/what-we-do/access/

Methane gas, another significant energy resource, is abundantly available in Rwanda from Lake Kivu (under the KivuWatt Project by the African Development Bank Group) [5]. The Kivu Watt project was commissioned following a substantial power deficit in Rwanda between 2011 and 2013, which was temporarily addressed with costly and high carbon diesel generation [11][12]. Currently, the methane power plant has a generation capacity of 29.8 MW [8]. Additionally, Rwanda imports 18.1 MW of electricity from renewable sources. The total renewable energy installation capacity in Rwanda is 149.168 MW, plus the 18.1 MW imported, totaling 167.268 MW. This renewable energy generation capacity accounts for 47.94% of the total generation capacity of 311.1 MW.

The figure below illustrates the available sources of energy in Rwanda.

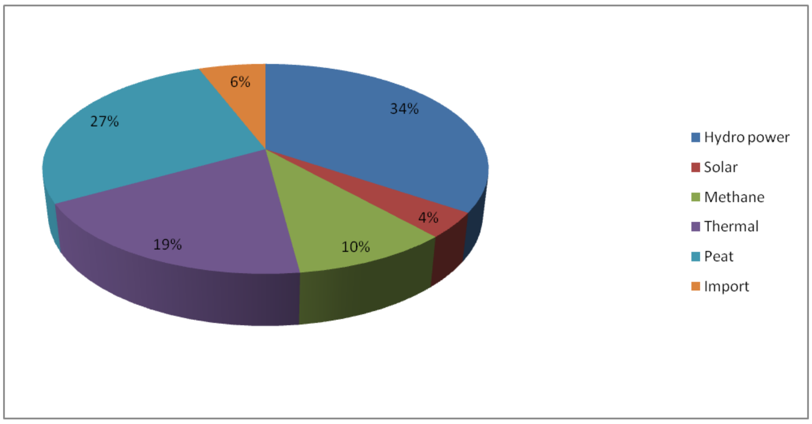

Figure 1.3: Energy generation mix 2023

1.1.3 Energy demand and supply in Rwanda

In a grid system, energy generated is directly fed into the electrical grid, allowing for immediate credit. Currently in Rwanda, various sources of energy, both renewable and non-renewable such as hydro energy, solar energy, peat energy, methane energy, and diesel energy are connected to the grid. The current peak electricity demand is 184.08 MW [13], while the total power supply is 311.1 MW [14]. Renewable energy sources, including hydro, solar, and methane gas, contribute 47.97% of the total power generation, equivalent to 149.15 MW.

Rwanda has set a target to achieve an energy mix of 556 MW by 2024, with the goal of 100% electricity access, where 70% will be on-grid and 30% off-grid [15].

Figure 1.4 illustrates the projected Energy Mix for 2024 [6].

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[5] https://tinyurl.com/sa7msvk6

[6] https://www.reg.rw/what-we-do/generation/

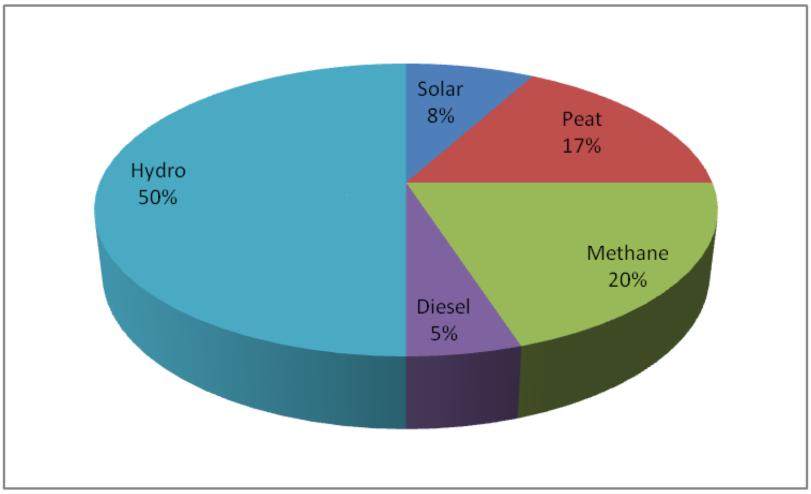

Figure 1.4: Energy Mix 2024

1.1.4 Rwanda's energy policies

As an important pillar of Rwanda's socioeconomic development, the energy sector has been prioritized in the country's strategic policies. For example, the National Strategy for Transformation (NST-1) outlines goals for the energy sector from 2017 to 2024 [16]. NST-1 replaced the Economic Development and Poverty Reduction Strategy (EDPRSII), which comprised four pillars: Economic Transformation, Rural Development, Accountable Governance, and Productivity and Youth, ensuring sustainability from 2013 to 2018. EDPRSII aimed to implement Rwanda's Vision for 2020 [17].

The Energy Sector Strategies Plan (ESSP) deals with achieving national goals in energy sectors, such as well-functioning energy efficiency and ensuring the effective delivery of energy sector goals. It guides the National Energy Policy (REP) and translates targets into practical strategies to realise medium-term targets, demand balance, policy gaps assessment in the sector, least cost development, electrification development, biomass energy strategy, and energy efficiency strategy plan development [18]. NST-1 incorporates long-term, visionary regional, and global commitments by embracing the Sustainable Development Goals [16]. The Sustainable Development Goals (SDGs) comprise 17 goals established as part of the Millennium Development Goals [19]. Among these, Affordable and Clean Energy, Sustainable Cities and Communities, and Climate Action are linked to the energy sector. ESSP supports implementing these goals by making energy affordable and clean, aiming to achieve universal access to electricity by 2030. The nearest goal, to be achieved with ESSP's help, is universal energy access by 2024, with a projected generation mix of 78% renewable energy resources [18].

Rwanda's energy policies outline the country's objectives to realise through the Vision 2050 and NST-1. Vision 2050 replaced Vision 2020 [20]. The policies and strategies of the energy sector include Sustainable Energy for All, Scaling up Renewable Energy Program (REP) Investment Plan, Rural Electrification Strategy (RES), Electricity Access Roll Program (EARP), National Electrification Plan (NEP), Energy Efficiency Strategy, Rwanda Master Plan, Least Cost Development Plan (LCDP), Grid Code, Management Prescriptions for the Development of Lake Kivu Gas Resources, Peat Resource for Generation, Simplified Licensing Procedure, Biomass Energy Strategy, National Biomass Programmer (NBP), Downstream Petroleum Strategy, Electricity Law of Rwanda, PPP Law, Radiation Protection Law, Renewable Energy, and

Energy Efficiency Law [21][17]. The main mission of Rwanda's energy sector is to provide sufficient, safe, reliable, efficient, affordable, sustainable, and environment friendly energy services to the population and all economic sectors [18].

1.1.5 Energy Prices

The electricity tariff in Rwanda varies according to consumption time. During peak hours, the price increases, and it decreases during off-peak hours[7].

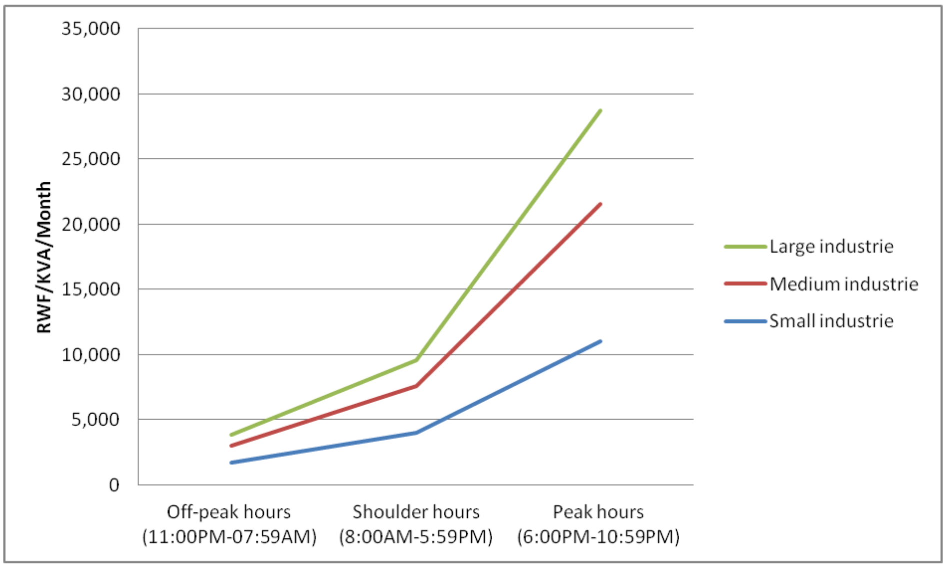

Figure 1.5: Energy Price during off-peak and peak hours.

A report indicates that the current tariff for electricity is 249 RWF/KWh for residential and 255 RWF/KWh for non-residential. From 2013 to 2018, the residential electricity tariff was 134 RWF/KWh, and the industrial tariff had a time-of-day structure as follows:

- 126 RWF between 7 AM and 5 PM
- 168 RWF between 5 PM and 11 PM
- 96 RwF between 11 PM to 7 AM

The purpose of the time-of-day tariff is to encourage electricity consumers, including industries, to change their electricity usage to off-peak times. In 2000, the electricity tariff was 42 RWF per kWh, which increased to 110 RWF per kWh from 2006 to 2016[22][23].

In 2020, the electricity tariff was reviewed and new tariffs were based on the amount of electricity consumed. Hence, customers categories were created and new tariffs were accordingly [13] as shown in Table 1.4 and Table 1.5.

1.2 Statement of the Problem

Energy generation connected to the grid and their capacity from different sources of energy are as follows: Hydropower with 107.328 MW (34%), solar energy 12.05 MW (4%), Methane Gas with 29.8 MW (10%),

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[7] https://tinyurl.com/4yxa2dmd

Table 1.4: Electricity tariff according to the customer categories

Customer categories	**Consumption block**	**RWF/kWh**
`Residential`	`[0-15] per month (kWh)`	89
`Residential`	`[15-50] per month (kWh)`	212
`Residential`	`>50 per month (kWh)`	249
`Non-residential`	`[0-100] per month (kWh)`	227
`Non-residential`	`[>100] per month (kWh)`	255
`Water Treatment`	`All consumed kWh`	126
`Telecom towers`	`All consumed units kWh`	201
`Hotels`	`All consumed kWh`	157
`Health Facilities`	`All consumed kWh`	186
`Broadcasters`	`All consumed kWh`	192
`Commercial centers`	`All consumed kWh`	179
`Small industries`	`< 22,000 kWh/Year All`	134
`Medium Industries`	`22,000-660,000 kWh/Year All`	103
`Large Industries`	`> 660,000 kWh/Year All`	94

Table 1.5: Peak and off peak electricity tariff

Customer categories	Energy charge(RWF/kWh)	Off-peak hours (11:00PM-07:59AM)in (RWF/kVA/month)	Shoulder hours (8:00AM-5:59PM) in (RWF/kVA/month)	Peak hours (6:00PM-10:59PM in (RWF/kVA/month)
Small	134	1,691	4,008	11,017
Medium	103	1,292	3,588	10,514
Large	94	886	2,004	7,184

peat with 85 MW (27%), Thermal power plant with 58.8MW (19%) and Imported energy installation capacity of 18.1MW (6%) [21]. Overall, the sector has experienced a substantial increase in energy production over the past 12 years[24], growing from 97MW in 2010 to 311.1 MW in 2023 [25]. Household access to electricity increased remarkably from 10% in 2010 to 65.7% in July 2023, with 47.6% on the grid and 18.1% off-grid, mainly solar [26]. The current access targets are for 100% of households in Rwanda to have access to reliable and sustainable electricity by 2024. It is expected that 70% of Rwandan households will access electricity through the grid while 30% will use off-grid solutions. The target is to increase electricity generation capacity to 556 MW by 2024 [27], which would help realize the government's goal of ensuring 100% access to reliable and sustainable electricity.

Nevertheless, once the 100% universal access goal has been achieved, a significant proportion of the population might not afford electricity at the current cost due to low income. The most recent data from the World Bank show that Rwanda's GDP per capita was USD 966.3 in 2022 [8]. Also, according to a recent UN human development report (UNDP, 2021), Rwanda is still considered a poor country, ranking 160th out of 189 countries, with 55.5% of Rwanda's population living under the UN poverty line (PPP USD 1.90 a day) [9]. A large proportion of Rwanda's population (83.4%) resides in rural regions and are mainly subsistence farmers. About 69% of the adult rural population work on farms, while more than 70%

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[8] https://data.worldbank.org/country/rwanda

[9] http://hdr.undp.org/en/2020-

of households depend on subsistence farming [28].

Table 1.7: EAC Energy Resources Potentials and GDP

Country	**Generation capacity(MW)**	**Electricity price$ per kWh**	**Electr. Access %**	**GDP($)**
Kenya	2819	0.174	76.49	2082
Uganda	1346	0.172	42.1	883.9
Burundi	39	0.062	11.74	274
Tanzania	1605.86	0.092	39.9	1099.3
South Soudan	570	0.008	7.2	1071.8
Rwanda	311.1	0.209	74.4	966.3

Rwanda has the highest electricity cost per household in the East African region (EA) [10]. In 2022, the average cost of electricity per household in Rwanda ranged between 0.20 and 0.26 for every kilowatt-hour, higher than the prices in other EA countries as shown in Table 1.6. The electricity cost for a Rwandan household would be 3.12 per day, which is 93.6 per month. Given the poverty indicators described above, this would make electricity far less affordable for many low-income families in Rwanda. The generation capacity for the countries in the same region is high, like Kenya with 2819 MW, a GDP of 2082, and an accessibility of 78.46%[29]. In contrast, Rwanda has a generation capacity of 311.1 MW, a GDP of less than 1000, and 65.7% accessibility. Based on these numbers of generation capacity and the low GDP, there is a risk of a mismatch between the rates of electricity generation and consumption. More specifically, if the electricity generation increases as planned and the electricity cost doesn't decrease, the generated electricity will not be consumed unless there is an unlikely exponential increase in the GDP and households' income in the next year or so. To investigate this issue further, a preliminary data collection survey were conducted in April 2023 to find out about electricity use in 100 households in Rwanda.

The survey was conducted on 100 households with electricity. The survey revealed that 75% of the surveyed households used electricity for lighting, radio, and television only, and consumed between 10,000 RWF and 30,000 RWF per month. The survey participants also said if the price decreased, they would use other devices like cookers and washing machines. Moreover, 20% of participants used electricity for lighting only and consumed between 2000 RWF and 5000 RWF per month. Interestingly, only 5% of participants reported using electrical cookers and washing machines, consuming between 50,000 RWF and 100,000 RWF per month. All participants said electricity was very expensive and it limited their use of some devices. Following this situation, efforts to design more efficient solutions to reduce the cost of electricity are required. This study is set to develop an optimization model for minimizing the electricity costs.

1.3 Justification of the study

The findings from the present study will be useful to various stakeholders of the energy sector, including policy makers, advocacy groups and Rwandans in general. The optimization model developed will be important to researchers in the energy sector, regulators, and policymakers for setting policies to reduce electricity costs. The model may also help researchers and academicians in related research to improve their work. The implementation of the developed model may help decrease the electricity cost, which in turn, is expected to increase the electricity consumption in Rwanda, leading to the economic growth of the

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[10] https://tinyurl.com/yckuer8y

country.

1.4 Objective

1.4.1 Main Objective

The present study sought to develop an optimization model for decreasing the levelized cost of electricity (LCOE).

1.4.2 Specific Objectives

More specifically, the study aimed to:

- Collect data on the perception of the households regarding the current price of electricity.
- Develop a mathematical model (optimization model) to minimize levelized cost of electricity.
- Test the effectiveness of the developed model with different scenarios.

1.5 Research question

Consistent with the above objectives, the stud's main question was ”What can be done to reduce levelized cost of electricity and increase accessibility with reliable availability?”. Associated with this question, three specific research questions were as follows:

- What are the perceptions of Rwandan householder about the electricity cost?
- What are the key facts that impact the electricity price ?
- How can optimization be used to reduce levelized cost of electricity and increase accessibility with reliable availability ?

1.6 Scope of study

An optimization model was created to decrease the levelized cost of electricity. The model encompassed renewable energy sources connected to the grid in Rwanda. For on-grid data collection, all data of renewable energy generated are used to test the model. The renewable energy mix includes a Hydro power plant, solar power plant, and Methane.

1.7 Expected outcomes

- Expect an Optimization model that can be used to optimize electricity cost.
- The development of an article in the field for the visibility and for solving the challenges of the studied problem.

Chapter 2

LITERATURE REVIEW

The literature on optimization models for minimising levelized cost of electricity is reviewed in this chapter. Comprehending the optimization process and its impact on energy costs and sustainable development is beneficial. As a result, many theories, frameworks, and models are examined. The main topics covered in this chapter, aside from the introduction, are the following: electricity cost and optimization model.

2.1 Electricity cost

One of the most essential aspects of contemporary life is electricity, a potent source of energy. Numerous policies have been put in place to monitor energy performance utilities and set prices because electricity is a key factor of the nation's economy. Different user classes are taken into account when determining the cost of electricity. Residential and non-residential buildings, hotels, medical facilities, broadcasters, commercial data centres, industries, and water treatment and pumping stations are among the frequent users or clients.

As stated by Rwanda Utilities Regulation Authorities (RURA), 26,653,064 kWh of electricity were supplied to the country's grid in full in 2022[13]. The 24.20% of RURA's total electricity sales were to water pumping stations, water treatment plants, broadcasters, healthcare facilities, telecom towers, hotels, and commercial data centres. The 23.8% went to non-residential customers, 31.7% to industries, and 20.21% to residential customers. Rwanda has 184.08 MW of peak demand[1]. Comparatively speaking to other East African nations, Rwanda has expensive electricity costs.

The cost of electricity has been the subject of additional study. In their study, [15], Nyaga et al. (2021) reported that the domestic electricity tariffs for 2021 were \$0.2/kWh in Rwanda, \$0.15/kWh in Tanzania, \$0.15/kWh in Kenya, and \$0.21 /kWh in Uganda; for the industries, the tariffs were \$0.11/kWh in Rwanda, \$0.1 /kWh in Uganda, \$0.071 /kWh in Kenya, and \$0.067 /kWh in Tanzania. In another study, Byrne et al. [30] made a comparison between Rwanda's the Gross Domestic Product (GDP) and that of East Africa, whose GDP is higher per capita.Rwanda has \$822.3, Tanzania has \$1099.3, Uganda has \$883.9, and Kenya has the highest GDP per capita \$2081.8[2]. In a 2017 study, Thanhtung HAL at el. [31] used GAMS to mimimize electricity costs for a residential area in China. Their study found that, compared to other scenarios, the overall energy costs decreased thanks to the substantial decrease of the gas and electricity that was bought from utilities. Also, they demonstrate how the model works with the characteristics of household loads. Improvements to the EH model are still needed to account for the uncertainties of a distributed generation and load.

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[1] https://www.reg.rw/customer-service/tariffs/

[2] https://tinyurl.com/43vrcwsz

Likewise, using MATLAB/Simulink as the data analysis tool in their study in Alegria, Belfedhal et al. [32] created a Power management plan. The structure's efficacy was then demonstrated using the simulation's results, which highlighted its many benefits and demonstrated that it could function effectively in both landed and/or grid-connected operation modes.The utilization of multiple storage methods increased the energy storage capacity.

In their study in Turkey, Mustafa et al. [33] used a multiple ab/dq transformer to calculate power differentiation values. The authors found that the suggested approach offered grid-side power balancing and could help to eliminate the negative and zero sequence components in grid-side currents.

In Iran, Mansouri et al. [34] used GAMS minimize the total operating cost and maximize consumer's comfort index. Their simulation results indicated that when the Distribution System Operator(DSO) could reconfigure the system, the deviation from the optimal scheduling of micro grids would be substantially lower than in fixed system configuration. In another study in Egypt, Shaheen et el. [35] aimed to optimize the fuel cost of the conventional generators under the system limitations and they used optimal power flow(OPF)methodology. They reported that the fuel cost decreased by 4% for the base case OPF. They also found that the HOA could reduce 0.7-9% in the daily costs compared with GA results. Hence, they recommended the use of HOA method in future power system simulations research.

In another research study in Algeria, Mokhtara et al. [36] used Matlab to lower the building energy consumption and, subsequently, to meet the load demand at the lowest cost. They found that, in comparison to PV modules, the small-scale WT investment cost was still very high and that the efficacy of the recommended strategy, which can reduce building energy consumption, limited component oversizing, and addressed the demand-supply mismatch issue.

In their study in Montenegro [37], Dragasevic et al. examined the factors influencing electricity costs in low-income nations. They examined various variables, including losses in the distribution and transmission systems, and the supplier and promotion fees among other factors. They examined five essential components of an electricity bill, namely, load factor, power factor, energy consumption, demand, and electricity metering [3]. They also examined the criteria that could cause change in the electrical market structure to quantify the influence of specific elements on the determination of electricity prices. They found that the first category of the examined characteristics, only the active energy requirement significantly predicted the price of power (excluding the costs of electricity generation). Moreover, the cost of producing active energy, which explained the biggest portion of the total cost of electricity production, was the one that caused this outcome.

In another study in five EA countries [29] Mburamatare, used panel data analysis and comparative analysis to find the extent of the impact of the International Average Crude Oil Prices (FP), Electricity Net Consumption (EC), Electricity Net Generation (EG), Electricity Transmission and Distribution Losses (Losses), Consumer Price Index (CPI), and Industry Value Added (IVA) electricity costs (ECs). The study findings rejected the null hypothesis that the variables were not co-integrated at a significance level of 1%. Consequently, they concluded that each variable had along-term link. 91% of the differences in power costs could be attributed to the independent variables, according to the estimation results for the FMOLS and DOLS coefficients. Furthermore, every variable that was examined was statistically significant at the 1% level, with the exception of EC, which was only statistically significant for DOLS at the 2% level.The results demonstrated a long-term inverse relationship between fuel prices, power prices, and the production

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[3] https://tinyurl.com/yc7ex4f4

of electricity.

In their study in Rwanda [38], Uwisengeyimana et al. found that Rwanda had a comparatively higher electricity cost than other nations in EA region, and yet it consumed incredibly a smaller amount on average. This issue can be resolved by achieving better investment coordination and integrated planning, implementing 70% electrification, and giving large electrical consumers more priority.

In another study in Rwanda published in 2022 [15], Bisaga and Bridget found tat only 0.4% of Rwandans used electricity as their primary cooking fuel and that Rwandans thought that Electricity was ‘too expensive for cooking. The electricity cost was relatively high at a domestic rate per kWh of RWF 255 ($0.25) for users 100kWh per month.

Similarly, utilising the GAMS tool in their study, Chemouni et al. reported a problematic surge in electricity generation in Rwanda and that the country's electricity consumption remained expensive despite the country's substantial subsidy [39]. For instance, while in 2016 the government invested US$57 million to lower costs by more than 37% of ”real” electricity costs; tariffs remained significantly higher compared to the rest of EA countries, and Rwanda ranked 12th in Africa. The government's drive to build more power plants has resulted in higher electricity prices. Residential electricity rates were $0.10 in 2004 (in 2018 prices); in 2018, however, they were $0.21.5. High tariffs have always existed.According to a 2010 electricity study, Rwanda has the highest rates in the area, five cents more per kWh than Uganda, which comes in second (Economic Consulting Associates, 2010).

A their review, Andersen et al. demonstrated the emergence of regional energy markets, which would facilitate countries' capacity and energy generation planning and enhance reliability. They found that some nations, like Ethiopia, had begun to export energy while others, like Rwanda, were not able to do so because their electricity was too expensive to do so.[40].

In another 2023 study, Guan et al. identified and analyzed the causes of high price of electricity for households in China and how to handle the issues.[41]. They linked an extensive household expenditure database with a worldwide multi-regional input-output database to estimate rising energy costs and demonstrated that life would be complicated for households due to the rising electricity price.

In another study on managing energy in households [42], Qais et al. used Random Integer Search Optimization (RISO) which is a algorithm used to reduce cost of electricity. They reported that the load reduced with the planned time and the energy cost reduced by 25%.

In Australia, a study by Anazi et al. used a load-tracking technique and HOMER to model the photovoltaic system with battery storage to deliver the necessary load and decrease the need for fossil fuels and high investment costs” [43]. As a consequence, 56% of the necessary load was met by renewable energy sources, but they reported that there was still a room for improvement to lower energy costs.

2.2 Optimisation model

2.2.1 Definition

Although there are various definitions of optimization model, Herbst et al.'s (2012) definition is the one that is most frequently cited. They defined an optimization model as a type of energy model that seeks to identify the best combination of technological options to achieve a particular goal while minimizing expenditures while maintaining fixed pricing and equilibrium levels of demand[44]. The country's future energy supply and demand are projected using the optimization model, which also examines various energy conditions such as economic development activities, energy pricing, population growth, and simulation.

2.2.2 Research conducted

Researchers have used various design models and sizing strategies for managing electricity costs. I in one study in USA Moradia aimed to reduce petrol emissions, increase the efficiency of energy utilization, and lower system fuel costs by scheduling the generation of energy resources hourly for the following day [45]. To achieve this goal, the author modeled the generated emission costs as a constrained single-objective optimization problem.

In Spain, Dufo-López et al., wanted to reduce the net present costs of electricity in Spain[46]. They used generic algorithm as an optimization method, taking into account a sophisticated battery model and a precise estimate of the net present cost.

In the Kingdom of Saudi Arabia, Hamanah, used a Lightning Search Algorithm to lower the annual energy cost [47]. Using Matlab in simulation and the algorithm, they obtained the best cost value of a hybrid power system. The annual capacity cost, wind, number of photovoltaic panels, diesel generator capacity with electricity cost, and fuel cost were used to decide variables. As a result, renewable energy was confirmed to be the potential of the proposed approach to be the cheapest.

In another Saudi Arabian study, To design a hybrid PV-renewable energy system with objective functions of minimizing life costs and power supply loss probability, Mohammeda et al. (2022) [48], through, GAMS used an exact method that is integrated into the developed model for its solution. Their study indicated the possibility of integrating a fuel cell, hydrogen tank storage, and electrolyzer with a renewable energy system. Yet, because of the high initial cost, the energy produced was still expensive.
In Hong Kong, Nallapaneni et al. used HOMER software achieved an affordable HREM setup. Their model's outcomes offered wide-ranging workable alternatives[49]. The optimum solution was chosen using a sensitivity analysis from the four optimized finding the four optimized findings, the optimum solution was chosen using a sensitivity analysis. Their study found the PV + DG + BESS-based HREM to be most cost-effective design for the particular site. The essential SDG7 criteria were also mapped onto the final, optimal solutions. In another study in China, Nsengimana et al. [50] designed, analysed, and compared three schematic models and compared:a grid-connected system with PV and battery, and two off-grid system with PV-battery diesel and PV-battery only. The grid-connected system met the load demand on the lowest LCOE of \$0.0645 /kWh and the NPC of \$22,155 US, according to the results. They found the cost of electricity to be four times less than what the country's current electricity tariff was at the time of data collection and analysis. Additional advantages of the system model include the 97.6% excess PV microgrid energy produced and the 92.5% grid sales. This system met the load requirement of 7.5% with a low energy purchase of 2.4% from the grid. The model also had a positive impact on the weather thanks to its high rate of PV microgrid usage to supply the load demand. Also, because of the model's ability sell

the extra power generated during the sunny season and off-peak hours, it had a greater economic impact.

Trinh et al.'s 2021 study [51] concentrated on developing a DER control strategy for low-voltage DC micro-grids in order to maximise the use of RESs like photovoltaic (PV) plants, reduce operating costs, and control the distribution voltage through intelligent EV charging and discharging scheduling.To reduce overall operating costs, the suggested method promoted EV charging at low electricity prices and discharging at high electricity prices when operating costs, and keep the distribution voltage within a reasonable range through intelligent EV charging and discharging schedules. To reduce overall operation costs, the suggested method promoted EV charging at low electricity costs and discharging at high electricity costs when operating normally. However, in the event of an undervoltage issue, EVs were discharged to make up for the voltage drop.Additionally, to meet the departure SoC level that the EV owner had requested, the constraints of the connected EVs were taken into account. In two case studies, the suggested method was contrasted with a traditional approach. The suggested approach is less expensive to run than the traditional method, as the simulation results are numerically confirmed.

Through simulation using Matlab in their study in France in 2022, Gbadega and colleagues evaluated the issue of energy management [52]. They found that the energy cost in the environment's smart grid is lower in scenario 1 than in scenario 2 through the formulation of the convex optimization problem.

Kehbila et al. conducted a review of the literature on the decarbonization based on grid electricity supply and renewable penetration in Kenya [53]. They used the Low Emissions Analysis Platform (LEAP) as a tool. The review indicated that Energy consumption would be affected by the Kenyan government policies for greenhouse gas emission.

In a Japanese study, Mulumba et al., in Matlab, estimated the optimal size of the proposed Hybrid Renewable Energy System (HRES), using a multi-objective optimization modeling approach, considering the Levelized Cost of Electricity (LCOE) and reliability energy index of self-reliance (EISR)) of the system as the main objective function [54]. The findings showed that the suggested off-grid HRES was reliable and could satisfy the load requirement under all local meteorological circumstances. In addition, when used in conjunction with a flywheel storage system, a hybrid energy storage system (HESS) made a potential improvement in battery storage capacity of 858 kWh per year.

By creating a spatial analysis tool specifically designed for Kenya called Renewable for the Rural Electrification of Kenya(RE, RU, KE), a study by Girona et al. in 2019 analyzed the Kenyan national road map for rural electrification and support a systematic scaling-up of access to electricity for off-grid areas at the time. [55]. Results from the RE-RU-KE model highlighted the necessity for an update to the national policy and a methodical up scaling of renewable energy sources to electrify off-grid locations. The program also identified chances for household solar energy to quicken universal access to basic electricity. In contrast to the master plan, RE-RU-KE's least-cost analysis revealed that a decentralized renewable energy systems would be a better option for remote locations, since, indeed, a low level of energy use doesn't warrant significant investments in grid expansion.

2.2.3 Optimization Tools

The present study's main purpose was to developing an optimization model for minimizing levelized cost of electricity. Because of various system of generation, testing and analysis of mathematical model is complicated. In the next section, I discuss some of tools that have been for similar purposes in previous research studies. The discussed tools are computer-based tools for optimization, analysis,feasibility in term of economic are requisite, namely HOMER, iHOGA, HYBRID 2, Excel, and MATLAB. [56] etc.

2.2.3.1 HOMER

The Hybrid Optimisation Model for Electric Renewables (HOMER) was developed in USA in 1993[57]. However, it allows for the minimization of the Net Present Cost (NPC) by only one objective function. Hence, it is not considered a hybrid system based on the levelized cost of energy. Instead, it creates optimal system configurations graphs based on NPC. Additionally, it does not account for hourly variability[58]. For example, using HOMER to lower the LCOE, Abdulrahim et al. found that even with the battery cost impacting the overall system cost, the LCOE was less than the cost of energy [59].

2.2.3.2 iHOGA

A software program called iHOGA (Improved Hybrid Optimisation by Genetic Algorithm) was created in Spain. Ten kWh is the average daily total load that iHOGA can assimilate metering, probability analysis, and sensitivity analysis are not allowed. Moreover, it only needs Windows XP or Vista to function online[56].

2.2.3.3 HYBRID 2

HYBRID 2 has was also developed in USA in 1996. Although this software program lacks versatility and has limited access to parameters, it does provide a library of different resource data files [60].

2.2.3.4 Excel

Excel has been developed by Menoufia University, Egypt Excel has limitation on the ability to incorporate more variables at the same time due to its character of two dimensional, It is not considered as able for data analysis, optimization, or budget preparation. Excel has more challenges [61].

2.2.3.5 Matlab

Matlab has been developed at Wuhan University of Technology, China. Matlab is a great tool mostly popular used by scientist, engineers and industries in modeling and simulation. It has many advantages include Accessibility with high level of programming which make it reliable; Coding Environment which make it to provide Integrated Development Environment and facilitate programming for multiple fields; and applicable. Data analysis, method development, model creation, and application development are all done in MATLAB. Matlab is able to analyze data, test and energy balance[62].

No	Author	Title	Year	Objective	Funding
1	Mburamatare Daniel1	An empirical evaluation of the factors influencing electricity prices in East Africa:Rwanda, Uganda, Tanzania, Burundi, and Kenya's panel data experience.	2023	In order to determine the degree to which factors such as industry value added (IVA), international average crude oil prices(FP), consumer price index (CPI), electricity transmission and distribution losses (Losses), electricity net consumption(EC), electricity net generation (EG), and consumer price index(CPI) could affect electricity prices (EP), a panel data analysis of five East African countries was conducted.	At the 1% significance level, the test results reject the null hypothesis that there is no cointegration of the variables. They concluded that all variables had a long-term relationship as a result. The results of estimating the FMOLS and DOLS coefficients showed that the independent variables account for 91% of the variation in electricity prices..

No	Author	Title	Year	Objective	Funding
2	Zdenka Dragasev Et al.	examining the variables that affect how much electricity costs in developing nations' deregulated markets.	2021	Determine and examine the parameters that may result in a modification of the structure of the electricity market to assess the influence of specific factors on the formation of the price of electricity.	The study's findings, which have also been supported by the majority of other studies, indicate that, of the first group of factors examined (the costs of generating electricity), only the active energy criterion has a significant effect on the price of electricity. This outcome is explained by the fact that the majority of the total cost of producing electricity is incurred in the generation of active energy. The price of electricity is not significantly affected by other factors in this group, network capacity utilization, or transmission system losses.
3	Jean de Dieu Uwisengeyimana Et al,	Rwanda's Present State of Renewable Energy Resources Overview.	2016	The high cost of electricity is one of the many issues the study highlights. Rwanda has very low average consumption volumes and a comparatively high cost of electricity when compared to other countries in the region.	This issue can be resolved by implementing more integrated planning and coordination for investments, implementing 70% energy access, and electrifying more areas. It also helps to prioritize large electricity users.

No	Author	Title	Year	Objective	Funding
4	Hadis Moradia Et al	Energy management and optimisation of a stand-alone hybrid microgrid with a battery storage system	2018	The primary goals are to reduce petrol emissions, lower system fuel costs, and increase energy utilization efficiency by scheduling the generation of energy resources for the following day's hour.	When the MG has access to a battery storage system under the second policy that is being suggested, the obtained results demonstrate a significant reduction in system total cost and produced emissions. Simulation results show that the suggested technique for microgrid energy planning and implementation is both feasible and effective.
5	Rodolfo Dufo-López et al	Off-grid hybrid renewable energy system optimization using thermoelectric generators	2019	The goal was to reduce net present value.	The technique has been used to optimize two instances of off-grid, low-consumption households (in Norway and Cambodia). The best option for Norway includes a thermoelectric generator, which costs €8 per watt. The acquisition cost of the thermoelectric generator in Cambodia needs to be lowered by 25% to be a part of the ideal system.

No	Author	Title	Year	Objective	Funding
6	Phi-Hai Trinh Et al	The Most Effective Control Method for Dispersed Energy Resources in a DC Microgrid for Voltage Regulation and Energy Cost Reduction	2021	Concentrate on developing a DER control strategy for low-voltage DC microgrids in order to maximise the use of RESs like photovoltaic (PV) plants, reduce operating costs, and keep the distribution voltage within a reasonable range through intelligent EV charging and discharging scheduling.	In two case studies, the suggested method was contrasted with a traditional approach. The suggested approach is less expensive to run than the traditional method, as the simulation results are numerically confirmed.
7	Thanhtung HAL at el.	"Using solar energy and BESS in energy hub modeling to reduce residential energy costs"	2017	the objective was to minimize total energy expenses.	As a result, the characteristics of the electricity and gas power purchased from utilities alter significantly, resulting in lower total energy costs than in other situations. They also show that the model is suitable for household loads characteristics. The EH model still needs to be improved. To take a scattered generation and load uncertainty into account
8	Belfedhal et al.	Examining a hybrid renewable energy system connected to the grid	2019	The goal is to highlight the management of power flow among the grid, the HRES, and the varying load demand.	By the Matlab simulation, The results of the simulation were then used to illustrate the effectiveness of the structure, which offered notable advantages and could operate well in both landed and/or grid-connected operation modes.

No	Author	Title	Year	Objective	Funding
9	Mustafa et al	”A modified energy management plan to facilitate grid-interfaced photovoltaic/fuel cell system phase balancing.”	2021	Enhancing energy management for a hybrid photovoltaic/fuel cell (PVPV)/energy system with unbalanced, sensitive loads was the aim.	They find that the recommended method eliminates the negative and zero sequence components of grid-side currents and provides grid-side power balancing.
10	S.A Mansouri et al	A sustainable framework for multi-micro grid energy management in automated distribution networks by considering smart homes and high penetration of renewable energy resources	2022	The objective was the minimization of the total operating cost and maximization of the consumer’s comfort index. GAMS has been used as tool	The simulation results show that in the cases the Distribution System Operator(DSO) can reconfigure the system, the deviation from the optimal scheduling of micro grids would be considerably lower than the cases with fixed system configuration.
11	MOHAMED A. M. SHAHEEN At el	Utilising the HEAP Optimisation Algorithm to Solve the Optimal Power Flow Problem with Renewable Energy Resources (HOA)	2021	The objective was to optimize the cost of fuel of the conventional generators under the system limitations and they used optimal power flow(OPF)methodology.	For the base case OPF, they led to a 4% reduction in fuel costs. In the meantime, compared to the GA results, the HOA has shown a percentage decrease in the daily costs of 0.7-9%) across the various scenarios.

No	Author	Title	Year	Objective	Funding
12	Charafeddine Mokhtara	The best design of off-grid hybrid renewable energy systems for residential electrification in arid climates requires integrated supply and demand energy management.	2020	They used Matlab to achieve their goal of lowering building energy consumption to meet load demand at the lowest feasible cost.	The findings show that, in comparison to PV modules, the small-scale WT investment cost is still very high. The results of this study demonstrate the efficacy of the recommended strategy, which can reduce building energy consumption, limit component oversizing, and address the demand-supply mismatch issue.
13	Iwona Bisaga	Modern Energy, Cooking Service wrote a Policy and market review"	2022	The goal of this study was to analyze the use of electricity for Rwanda population.	As a result, Currently 0.4% of Rwandans use electricity as their primary cooking fuel and the challenge was Electricity commonly perceived as 'too expensive for cooking. A relatively high cost of grid electricity a domestic rate per kWh stands at RWF 255 ($0.25) for users 100kWh per month.

No	Author	Title	Year	Objective	Funding
14	Chemouni, B. Et al	The contradictions of an aspiring developmental state: energy boom and bureaucratic independence in Rwanda by using GAMS Tool	2020	The goal was to investigate the cost of electricity	The government's drive to build more power plants has resulted in higher electricity prices. Residential electricity rates were \$0.10 in 2004 (in 2018 prices); in 2018, however, they were \$0.21.5. High tariffs have always existed. According to a 2010 electricity study, Rwanda has the highest rates in the area, five cents more per kWh than Uganda, which is in second place (Economic Consulting Associates, 2010).
15	Andersen et al.	the paradox of overcapacity in African energy sectors	2023	The goal was to investigate the cost of electricity	They demonstrate the emergence of regional energy markets, which will facilitate countries' capacity and energy generation planning and enhance reliability. He added that some nations, like Ethiopia, have begun to export energy while others, like Rwanda, won't be able to do so because of their expensive electricity.

No	Author	Title	Year	Objective	Funding
16	Yuru Guan et al	Burden of the global energy price crisis on households	2023	The objective of study was to identify and analyze the general cause of high price of electricity for households and how to handle the issues.	they linked an extensive household expenditure database with a worldwide multi-regional input-output database to estimate rising energy costs and demonstrate that the life will be complicate for households due to the electricity price rising.
17	Mohammed Qais et al	Optimal Comfortable Load Schedule for Home Energy Management Including Photovoltaic and Battery Systems	2023	The objective of the study was to minimize the energy cost The government concern was zero energy structures because lessen the residential sector's imprint.They used Random Integer Search Optimization (RISO) which is a algorithm used to reduce cost of electricity.	As result, the load reduced with the planned time and the energy cost reduced by 25%.
18	Abeer Abdullah Al Anazi et al	The Grid-Connected PV Power Plant: A Technical, Economic, and Environmental Analysis and Comparison of Various Scenarios	2022	In this study, a load-tracking technique and HOMER has been used to model the photovoltaic system with battery storage to deliver the necessary load and decrease the need for fossil fuels and high investment costs.	As a consequence, 56% of the necessary load was met by renewable energy sources, but there is still room for improvement in his studies regarding lowering energy costs.
19	Hadis Moradia et al	Energy management and optimisation of a stand-alone hybrid microgrid with a battery storage system	2018	Planning the generation of energy resources hourly for the following day has the primary goals of reducing petrol emissions, increasing the efficiency of energy utilization, and lowering system fuel costs.	The system's goal is to minimize operating and generated emission costs by modeling it as a constrained single-objective optimization problem.

No	Author	Title	Year	Objective	Funding
20	Rodolfo Dufo-López et al	Off-Grid Hybrid Renewable Systems Optimization with Thermometric Generators	2019	The goal was to reduce net present costs. The optimization of this type of system took into account a sophisticated battery model and a precise estimate of the net present cost. Genetic algorithms have been used to optimize two situations of off-grid, low-consumption households.	In the case of Norway, a thermoelectric generator is a component of the ideal solution. The acquisition cost of the thermoelectric generator in Cambodia needs to be cut by 25% to be a member of the ideal system.
21	W. M. Hamanah et al	A Lightning Search Algorithm-Based Hybrid PV, Wind, Battery, and Diesel System's Ideal Sizing	2020	The goal of the study was to minimize the annual cost of energy. By the use of Matlab in simulation and the algorithm.	they obtained the best cost value of a hybrid power system. The annual capacity cost, wind, number of photovoltaic panels, diesel generator capacity with electricity cost, and fuel cost are used to decide variables. As a result, renewable energy was confirmed to be the potential of the proposed approach to be the cheapest.
22	AwsanMohammeda Et al	A mixed integer linear programming multi-objective optimisation model for hybrid photovoltaic-hydrogen storage system sizing	2022	The objective was to minimize life costs and loss probability of power supply using the GAMS program	The results demonstrated that it is possible to integrate a fuel cell, hydrogen tank storage, and electrolyzer with a renewable energy system; however, because of the high initial cost, the energy produced is still expensive..

No	Author	Title	Year	Objective	Funding
23	Manoj Kumar Nallapaneni et al	In the framework of SDG7, a Hybrid Renewable Energy Microgrid for a Residential Community: A Techno-Economic and Environmental Viewpoint	2019	The analysis was completed using the HOMER software tool, and an affordable HREM setup that was affordable was achieved. The model's outcomes offered a wide range of workable alternatives	The outcomes showed that the most cost-effective design for the particular site was a PV + DG + BESS-based HREM. The outcomes showed that the most cost-effective design for the particular site was a PV + DG + BESS-based HREM. The essential SDG7 criteria were also mapped onto the final, optimal solutions.
24	Cyprien Nsengimana Et al	A comparative study was conducted on a feasible, affordable, and dependable photovoltaic micro grid for residential use in Rwanda.	2020	Three designed schematic models were analysed and compared in this study. The two other models are the off-grid system with PV-battery diesel and PV-battery only. The first model is the grid-connected system with PV and battery.	According to the findings, the grid-connected system used HOMER to meet the load demand at the lowest LCOE of \$0.0645/kWh and the NPC of \$22,155.
25	Phi-Hai Trinh Et al	The Most effective control method for dispersed energy resources in a DC Micro-grid for Voltage Regulation and energy cost reduction	2021	Concentrate on developing a DER control strategy for low-voltage DC micro-grids to maximize the use of RESs like photovoltaic (PV) plants, reduce operating costs, and keep the distribution voltage within a reasonable range through intelligent scheduling of EV charging and discharging.	In two case studies, the suggested method was contrasted with a traditional approach. The numerical verification of the simulation results showed that the suggested method is less expensive to operate than the traditional method.

No	Author	Title	Year	Objective	Funding
26	Peter Anuoluwapo Gbadega et al	Primal dual interior point algorithm for electricity cost minimization in a presume-based smart grid environment: A convex optimization approach	2022	.Through simulation using Matlab, the study's goal was to evaluate the issue of energy management	They discover that the energy cost in the environment's smart grid is lower in scenario 1 than in scenario 2 through the formulation of the convex optimization problem.
27	Anderson Gwanyebit Kehbila et al	Assessing transition pathways to low-carbon electricity generation in Kenya: A hybrid approach using back-casting, socio-technical scenarios, and energy system modeling	2022	The objective was to fill the gap of Kenya literature review in decarbonization based on grid electricity supply and renewable penetration. They used the Low Emissions Analysis Platform (LEAP) as a tool	As a result, Energy consumption will be affected by the Kenya government policy, Least Cost Power Development Plan, and other policies adopted for greenhouse gas emission.
28	Alphonce Ngila Mulumba et al	Techno-economic analysis and dynamic power simulation of a hybrid solar, wind,battery and flywheel system for off-grid power supply in remote areas in Kenya	2023	The objective was an optimal size of the proposed Hybrid Renewable Energy System (HRES) is estimated, using a multi objective optimization modeling approach, taking into account the Levelized Cost of Electricity (LCOE) and reliability energy index of self-reliance (EISR)) of the system	he findings showed that the suggested off-grid HRES is very reliable and can satisfy the load requirement under all local meteorological circumstances. In addition, when used in conjunction with a flywheel storage system, a hybrid energy storage system (HESS) realized a potential annual improvement in battery storage capacity of 858 kWh.

No	Author	Title	Year	Objective	Funding
29	Magda Moner Girona et al	Decentralized rural electrification in Kenya: Speeding up universal energy access	2019	This study aims was to analyze the current national road map for rural electrification and support a systematic scaling-up of access to electricity for off-grid areas.	The RE-RU-KE model was results to highlight the necessity for an update to the national policy and a methodical up scaling of renewable energy sources to electrify off-grid locations. The program also identifies chances for solar home systems to quicken universal access to basic electricity. In contrast to the master plan, RE-RU-KE's least-cost analysis reveals a preference for decentralized renewable energy systems in remote locations, which is even more pronounced when the low level of consumption doesn't warrant significant investments in grid expansion.

No	Author	Title	Year	Objective	Funding
30	Ituru et al	Towards 100% Renewable Energy Cities and Regions for Climate Change Mitigation in Kenya	2018	The goal was to create a precise and palatable forecast of future electricity consumption in order to create the best strategy for power expansion.	As result, the rise in residential consumption as well as the expansion of the manufacturing and industrial sectors are both contributing to the increased demand for power and multiple connections. The government implemented a time-of-use tariff to encourage manufacturers to take advantage of off-peak production times.
31	Aminu Bugaje et al	Electric Two-Wheeler Vehicle Integration into Rural Off-Grid Photovoltaic System in Kenya	2021	The goal was to electricity two wheeler vehicle to reduce air pollution greenhouse gas emission. By the use of Matlab/ Simulink tool.	The findings demonstrate that while keeping the PV and battery capacities for both systems at 30 kW and 104 kWh, respectively, the system with the Non-linear programming(NLP) algorithm was able to reduce the yearly energy deficit for the system without NLP optimization from 376 to 1 kWh.

No	Author	Title	Year	Objective	Funding
32	Fabian Eze et al	Technical and Economic Feasibility Assessment of Hybrid Renewable Energy System at Kenyan Institutional Building: A Case Study	2022	The objective was to find the best hybrid renewable energy system that can provide the school with dependable and inexpensive power	They discover that by using HOMER in simulation, the system has lowered the amount of power purchased from the grid by around 77 percent and the cost of electricity by about 84 percent. The same configuration was produced by the sensitivity analysis of nine sensitivity instances, except the exception of those in which the sizes and costs of some components were altered.
33	Tabitha N. Karanja et al	Finding and assessing the most economical technological solutions to enhance Kenya's rural electricity access	2019	.This study, which is based on a geographic information system, attempts to identify and evaluate low-cost technological possibilities for increasing access to power in rural Kenya.	According to the research, these technologies may possibly reach 2.1 million households, raising the national electrification rate by 28 percentage points to 94 percent from the present estimate of 66 percent.

No	Author	Title	Year	Objective	Funding
34	Ahmad Alzahrani et al	Energy Management and Optimization of a Standalone Renewable Energy System in Rural Areas of the Najran Province	2023	The objective of the study is on a standalone microgrid's ideal design and techno-economic analysis for a small residential neighborhood in Sharurah City, Saudi Arabia. For the best design of microgrids and energy management employing intelligence-based control mechanisms between generation and load, respectively, HOMER Pro and MATLAB/Simulink have been employed.	When compared to generation through a base system (0.38 SAR/kWh) and a diesel generator, the price of power acquired from the optimized microgrid system is 0.18 SAR/kWh, which is relatively cheap. Using MATLAB/Simulink, a simulation of the optimized system was modeled and validated. The results collected demonstrate the system's resilience to changes in load demand and weather circumstances

Chapter 3
METHODOLOGY

3.1 Introduction

The present chapter delineates the assorted research methods and techniques employed, elucidates the selected methodology while expounding on the rationale behind their use. It delineates the procedures implemented for the accumulation, analysis, and interpretation of data to address the posed research queries. The chapter further explicates the realization and fulfillment of the study's objective, which is the development of a optimization model to at lower the levelized cost of electricity .

3.2 Research strategies

In recent times, a plethora of researchers have gravitated towards a mixed-methods methodology. This approach aims to mitigate the limitations inherent in purely quantitative or qualitative methods. Specifically, this study focuses on the Adoption of Renewable Energy Technologies (RETs) utilizing a mixed-method framework, as delineated in the subsequent figure. The research process encompasses six critical steps: defining the research problem, conducting a comprehensive review of related literature, developing an optimization model (Mathematical model) for collecting data and integrating it into the model developed through the Matlab tool, analyzing results and engaging in discussion, and ultimately, composing and submitting the thesis. Consequently, the research utilizes a multifaceted approach comprising a literature review, an examination of methods and tools previously employed by other researchers, and the utilization of data procured from the Rwanda Energy Group (REG). Additionally, it involves an evaluation of potential sources for an energy mix, such as hydro power plants, solar plants, and methane. Matlab is employed for optimizing the model.

3.2.1 Research methods

The present study used mixed methods research approach, incorporating both qualitative and quantitative methodologies. A questionnaire was developed to collect data on electricity users' perceptions and experience of using different sources of electricity. The questionnaire comprised open-ended and close-ended questions. The data from qualitative component were represented by the non-numerical format. Concurrently, a comprehensive literature review was conducted to accumulate relevant data, serving as an additional qualitative element. In contrast, the quantitative aspect involved the collection of numerical data. The integration of these methodologies facilitated a comprehensive approach to addressing the research questions [63].

3.2.1.1 Survey

The survey, detailed in Appendix 6.1 was designed to gather preliminary data for the perception of residential electricity users. The questionnaire format is selected for its efficacy in offering energy generation companies a spectrum of response options. It allows respondents to choose from a set of provided answers, while also enabling them to provide open-ended responses. Participants are assured that the information gathered is for academic purposes only and will be kept confidential.

1. Solar photovoltaic A solar module is comprised of a set of solar cells, and several modules connected together form a solar array. Multiple arrays linked together constitute a solar system. In general, initial cost per capacity generation cost between \$7500\$ and\$10,000 per 5 kW. It means between 1.5\$ to 2\$ per watt [1]. The solar lifetime range between 20 and 30 years [2] The LCOE average for solar is \$0.049 per kWh[64]. Solar pv power factor varies between 10 to 25%[3].

    (a) Investment cost

    The investment cost for solar systems varies according to their energy generation capacity. The investment cost (Is) is calculated as follows:

    $$I_s = C_s * X_s \tag{3.1}$$

    Where

    - Is is the investment cost
    - Cs is the cost of the panel
    - Xs is the solar generation Capacity

    (b) Operation and Maintenance cost (OM)

    The OM cost can be estimated as 2 to 2.5% of the investment cost per year [65]

2. According to the IRENA report [66],the initial cost for:

    - Small Hydropower Plant (less than 10 MW): can range from \$1,300 to \$8,000 per installed kilowatt (kW). The variation depends on factors such as site accessibility, environmental impact assessment, and civil works.The power factor(PF) varie between 25 to 90%
    - Large Hydropower Plant (greater than 10 MW): can be significantly higher, ranging from \$1,050 to \$7,650 per kW and the power factor varie between 20 to 95%[66].

    The global levelised cost of electricity (LCOE) is\$ 0.061 /kWh [64].

    (a) Investment cost

    The investment cost for hydro power plants varies depending on site-specific challenges, including transportation difficulties due to road conditions, the length of pipes and tunnels, and geological differences[67]. The investment cost (Ih) is calculated as follows:

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[1] https://tinyurl.com/mrywwwhr
[2] https://www.energysage.com/solar-panels/
[3] https://tinyurl.com/4hu554kf

$$Ih = Ch * Xh \tag{3.2}$$

Where:

- Ih is the investment cost of the hydro power plant
- Ch is the initial cost of hydro power. It is the cost per installed kilowatt, which includes all the expenses associated with designing, constructing, and commissioning the power plant[67].
- Xh is the Hydro power plant generation capacity

(b) OM cost The primary components of OM costs include machine maintenance, replacement of damaged parts, insurance, and staff payments (salaries). The lifespan of hydro power plants typically ranges from 20 to 40 years, with 30 years often used as an estimation in financial calculations. There are two major types of maintenance: preventive maintenance and breakdown maintenance. Annually, operation and maintenance costs account for 2–5% of the investment cost [68].

3. Methane power plant:
Methane (CH4) is a primary product of organic matter (OM) decomposition in freshwater environments [12]. The methane initial cost varies between \$ 2,000 to \$4,000 per kW [4] The methane gas power plant is connected to the grid. The average LCOE for methane technology is \$0.061 per kWh .The power factor range from 40 to 60% [64]. The lifetime for methane varie between 20 t0 30 years[5]

1. Investment cost

   The investment cost (Im)[69] is calculated as:

$$I_m = C_m * X_m \tag{3.3}$$

   Where

   - I_m is methane power plant investment cost
   - C_m is the methane power plant initial cost
   - X_m is the methane generation capacity

2. OM cost

   The OM cost for methane-based power generation ranges between 2% to 5% of the investment cost[64].

The Diesel LCOE in Rwanda is \$0.135 per kWh[50]. The average LCOE in Rwanda is between \$0.06 per MW and \$ 0.1 per MW [6]

The discount rate r is 5%[70]

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[4] https://tinyurl.com/4fjswjpr

[5] https://www.iea.org/

[6] https://tinyurl.com/dvxdzwfn

3.3 Optimization model

The optimization system process is on the figure below

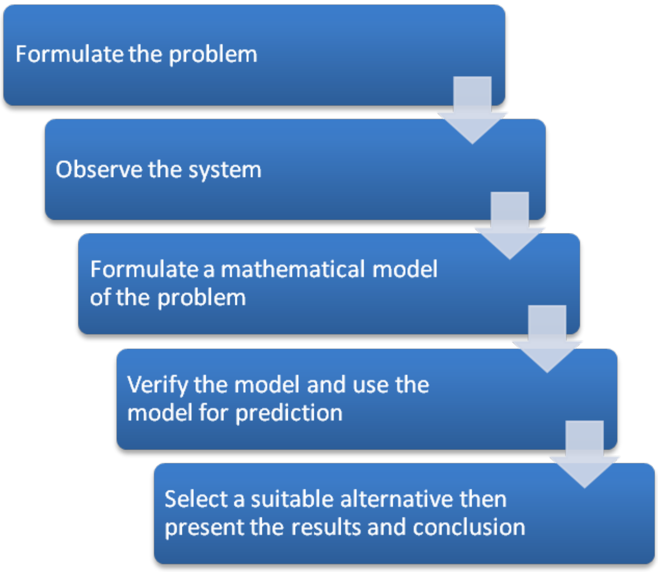


Figure 3.1: Optimization system process

3.3.1 Research problem

As mentioned earlier, this study aimed to address the problem of high electricity costs in Rwanda by developing and testing an optimization model for minimizing the LCOE. The average net present cost of producing power over a generator's lifetime is measured by the LCOE. It serves as a consistent foundation for comparing various electricity generation techniques and is employed in investment planning [71].

3.3.2 Mathematical model formulation

The formulation of the mathematical (optimization) model aims to minimize the LCOE. This model comprises three main components: design variables, the objective function, and constraints. The nature of the mathematical model is contingent on the structure of the objective function, constraints, and boundaries.

3.3.2.1 Design Variables

The yearly generation capacities of each renewable energy source are the problem's design variables. expressed as Xi(t), in which 'i' denotes the energy source, which can range from 1 to 'n': 'n' represents energy sources total number. 'n' in our model is 3. 't' represents time, from 1 to 'T,': 'T' represents the evaluation duration. This time frame, 'T,' for our model is three years. Each source's generation capacity is represented by Xi.In this case, Xi can represent the generation capacity of solar Xs, hydro power Xh, or methane Xm.

3.3.2.2 Objective function

The model's objective is to lower the LCOE.

The mathematical model is:

$$minf(x) = \sum_{t=1}^{T}\sum_{i=1}^{n} \frac{C_i * X_i + \frac{S_i * C_i * X_i * k_i * O_y i}{(1+r)^t}}{\frac{X_i * PF_i * k_i * O_y i}{(1+r)^t}} \tag{3.4}$$

Where

- C_i is initial cost for i source
- Xi(t) The generation capacities per source i of renewable energy in year t.
- S_I is the % multiplied to the investment cost to get operation and maintenance cost.
- PFi is power factor for i source
- ki is generation hours per year
- $O_y i$ Operating years

In general the Investment cost is the product of generation capacity and the initial cost[69]. Then

$$I_i = C_i * X_i \tag{3.5}$$

and

$$OM_i = S * C_i * X_i \tag{3.6}$$

$$E_i(t) = X_i * PF_i * k_i * O_y i \tag{3.7}$$

Where

- Ii : Investment cost of i source ($)
- $OMi(t)$: Operation and Maintenance cost of i source at time t ($)
- r=Discount rate
- T=Evaluation period
- $Ei(t)$ is generation capacity of source i at time t(MW)

3.3.2.3 Constraints

The objective function is constrained by energy balance generation capacity. The supply balance constraints aims to meet the demand.

$$\sum_{t=1}^{T}\sum_{i=1}^{n} Xi(t) \geq Ea \tag{3.8}$$

Where

- Ea :Energy generation capacity target in period T(MW)

The generation capacity target per year is schedule as follow:

1. First year constraint:
$$\sum_{t=1}^{T}\sum_{i=1}^{n} Xi(t) \geq 50\% Ea \tag{3.9}$$
The 50% Ea denoted by tg1 is energy share target for the first year.
2. second year constraint:
$$\sum_{t=1}^{T}\sum_{i=1}^{n} Xi(t) \geq 25\% Ea \tag{3.10}$$
The 25% Ea denoted by tg2 is energy share target for the second year.
3. Third year constraint:
$$\sum_{t=1}^{T}\sum_{i=1}^{n} Xi(t) \geq 25\% Ea \tag{3.11}$$
The 25%Ea denoted by tg3 is energy share target for the second year.

The target share by source tgi for mix energy are:

1. The first year is scheduled as
    - Target share of solar tgs for first year is 20 % tg1
    - Target share of hydro tgh for first year is 50 % tg1
    - Target share of methane tgm for first year is 30 % tg1
2. The second year is scheduled as
    - Target share of solar tgs for second year is 20 % tg2
    - Target share of hydro tgh for second year is 50 % tg2
    - Target share of methane tgm for second year is 30 % tg2
3. The third year is scheduled as
    - Target share of solar tgs for third year is 20 % tg3
    - Target share of hydro tgh for third year is 50 % tg3
    - Target share of methane tgm for third year is 30 % tg3

3.3.2.4 Boundaries

The boundaries of the model is
$0 \leq$Xi(t) $\leq tgi(t)$
Therefore the bounaries for solar , hydro and methane are:

- $0 \leq$Xs(t) $\leq tgs(t)$

- 0 ≤Xh(t) ≤ $tgh(t)$
- 0≤ Xm(t)≤$tgm(t)$

Where

- $Xs(t)$ represents the generation capacity of solar at time t
- $Xh(t)$ represents the generation capacity of hydro at time t
- $Xm(t)$ represents the generation capacity of methane at time t
- tg represents the targeted generation capacity at time t
- tgi represents the targeted generation capacity per source at time t

3.3.3 Solution methodology

Constrained fmincon, a Matlab tool, is used to solve the optimisation model for minimising the levelized cost of electricity problem. The model is a nonlinear programming problem whereby the solver offers a solution to problems of the form:

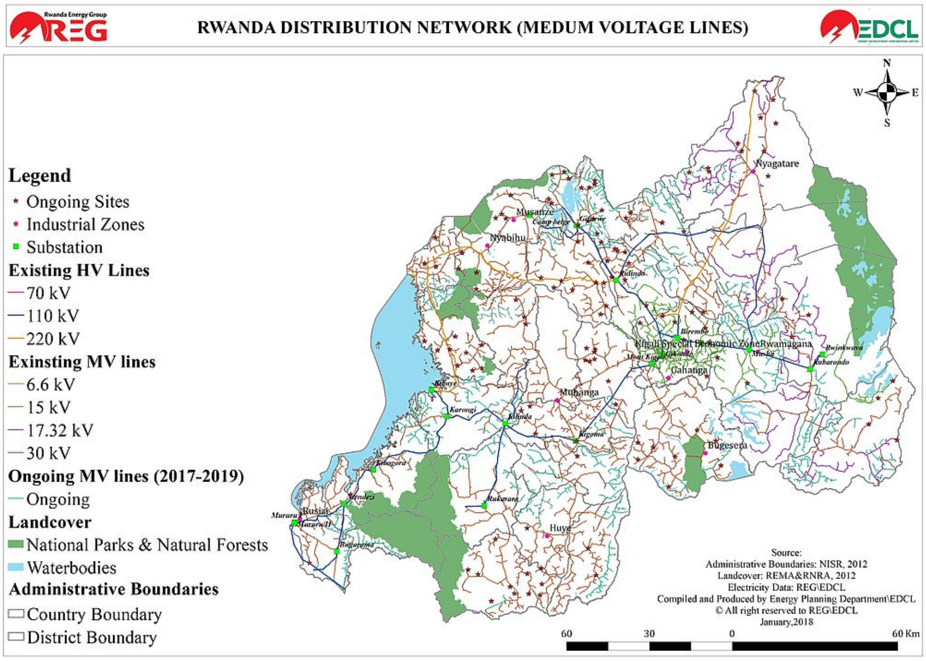
$$minf^T X \ such \ that \begin{cases} c(x) \leq 0 \\ ceq = 0 \\ A.x \leq b \ inequality \ linear \ constraint, \\ lb \leq Xi \leq ub \ variables \ bounds, \end{cases} \tag{3.12}$$

Chapter 4
CASE STUDY

The case study is situated in Rwanda, encompassing a comprehensive survey and interview methodology implemented across different regions of the nation to gather essential data. Additionally, this section outlines various modeling techniques employed. Notably, the Matlab software was utilized for inputting the energy mix of available renewable resources, subsequently facilitating the generation of an optimized system configuration.

4.1 Study area and Sampling technique

Rwanda has set an ambitious target of achieving 100% electricity accessibility for its population and increase generation capacity up to 556 MW by 2024. In light of this objective, the study encompasses all regions of Rwanda, focusing on the population's concerns regarding electricity pricing. The primary aim of this study was not to generalize the findings but to explore the effectiveness of electricity cost management for Rwandan households, particularly by integrating of various renewable energy sources available in the country.



1

Figure 4.1: Rwanda Electricity Transmission Network and Distribution

4.2 Electricity users

The 2022 population survey indicated that Rwanda's population was 13,246,394 including approximately 3 million households.By June 2023;65.7% of Rwandan households had achieved electrification, with 47.6% connected to the national grid and 18.1% relying on off-grid solutions,predominantly solar energy [26]. Rwanda aims to escalate electricity access to 100% and increase its generation capacity to 556 MW by 2024. This study primarily focuses on residential customers consuming over 50 kWh per month, who are charged 249 RWF per kWh, as detailed in Table 1.4. The table elucidates varied pricing tiers based on consumer electricity usage. It is observed that higher consumption leads to increased costs, potentially deterring usage due to the escalated electricity prices. Achieving the ambitious one-month target appears challenging, and even upon realization, the high pricing may limit the consumption of the generated power by residential customers.

4.3 Energy target

This research examines the augmentation of renewable energy to 100% by 2026, over a three-year period (T). The generation mix incorporates three primary sources: hydro power (50%), methane gas (25%), and solar energy (25%) [72]. Figure 4.2 presents the detailed breakdown of each energy source's contribution.

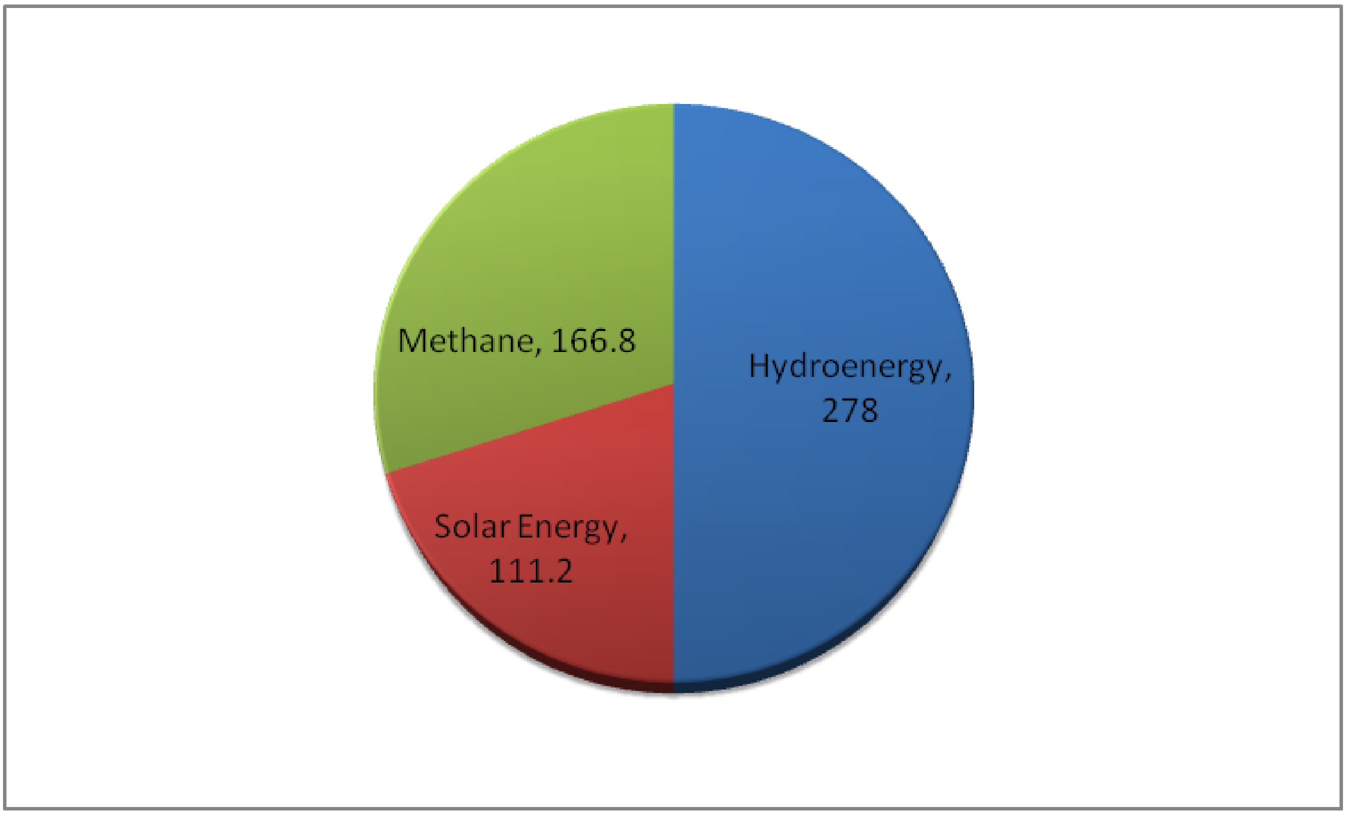


Figure 4.2: Renewable energy increase

4.3.1 Calculation

Using Rwanda's variety of renewable energy sources, this study aims to assist the nation in reaching its 2026 target of producing 556 MW with the current 311.1 MW of generation capacity. 244.9 MW, represented by Ea, are required to reach the goal. This study predicts that in three years, 244.9 MW will be produced. According to the schedule, the share installation target for each year is 50% Ea(tg1), or 122.45 MW in the first year, 25% Ea(tg2), or 61.225 MW in the second year, and 25% Ea(tg3), or 61.225 MW in the third year.

By contrasting the present LCOE with the computed LCOE, we can select the best possible solution for the issue. Reducing the LCOE is the goal function. Chapter 3 goes into detail about the LCOE parameter. The time of day and variations in the climate affect some of the parameters. Based on the lowest global horizontal irradiation in Rwanda, which ranges from 4.2 to 5.8 kWh/m2, the generation hours per day (k) parameter for solar energy is, on average, 5 hours [2]. The generation hours per day for methane and hydro are 24 hours[17]. The energy source mix have the share target per source per year as following

1. First year
   The energy capacity to achieve is at least 122.45 MW which correspond to 50% Ea(tg1) of required generation in 3 years. The target share per source for first year are:
   - Target share of Solar for first year(tgs) is 20 % of tg1 which correspond to 24.49 MW .
   - Target share of hydro power for first year(tgh) is 20 % of tg1 which correspond to 61.225 MW .
   - Target share of Solar for first year(tgm) is 30 % of tg1 which correspond to 36.735 MW .
2. Second Year The energy capacity to achieve is at least 61.225 MW which correspond to 25% Ea(tg2) of required generation in 3 years. The target share per source for second year are
   - Target share of Solar for second year(tgs) is 20 % of tg2 which correspond to 12.245 MW .
   - Target share of hydro power for second year(tgh) is 50 % of tg2 which correspond to 61.225 MW .
   - Target share of Solar for second year(tgm) is 30 % of tg2 which correspond to 18.3675 MW .
3. Third Year The energy capacity to achieve is at least 61.225 MW which correspond to 25% Ea(tg3) of required generation in 3 years. The target share per source for second year are
   - Target share of Solar for Third year(tgs) is 20 % of tg3 which correspond to 12.245 MW .
   - Target share of hydro power for Third year(tgh) is 50 % of tg3 which correspond to 61.225 MW .
   - Target share of Solar for Third year(tgm) is 30 % of tg3 which correspond to 18.3675 MW .

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[2] https://tinyurl.com/4recj2ta

Chapter 5
RESULTS AND SIMULATION

5.1 Introduction

The present chapter presents the study's outcome, which fulfills its goal of creating a model that minimizes LCOE. The primary data collection highlights how customers and homeowners view the present cost of electricity, regardless of grid systems. Rwanda has access to hydro power, solar photovoltaic, and methane power as renewable energy sources. Interviews were conducted with a variety of Rwandan energy industry participants, including end users and residential consumers as well as government agencies. Microsoft Excel was employed in the analysis of data.

5.2 Matlab Tool

Utilizing an optimization model that has been developed to lower the electricity cost, Matlab software assists in modeling the data and analyzing the results. Matlab is a fantastic modeling and simulation tool that scientists, engineers, and industry primarily use. Among its many benefits are its high degree of programming accessibility, which makes it dependable; its coding environment, which offers an Integrated Development Environment and makes programming for various fields easier; and its applicability. MATLAB is used for data analysis, method development, model creation, and application development. Compared to spreadsheets or traditional programming languages, the built-in math functions, language, and tools allow one to explore various options and arrive at a solution more quickly [62]. Matlab can test, analyze, and balance energy.

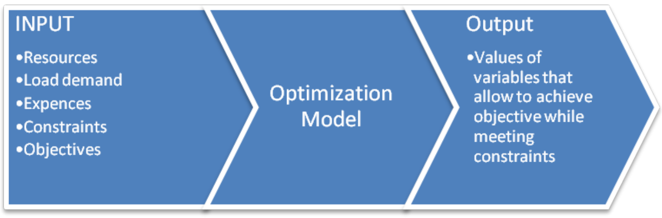

Figure 5.1: Schematic representation of Matlab software

A document review provided the data utilized in the simulation to validate the models developed . The references listed in Chapter 3 are where the model parameters (Ci,PF, si, ki, and Oyi,r) are found. The data are shown in Table 5.1. Below there is table of all data required.

Table 5.1: Renewable energy data

Source of energy	Initial cost($ /MW)	Target share generation capacity per period T$/MW per year	Power factor(PF) in%	Target share generation capacityper source i per year 1	Target share generation capacityper source i per year 2 (MW)	Target share generation capacityper source i per year 3
Solar	1,500,000	50% Ea	1	20% tg1	20% tg2	20% tg3
Hydro	1,500,000	25% Ea	1	50% tg1	50% tg2	50% tg3
Methane	2,000,000	25% Ea	1	30% tg1	30 % tg2	30% tg3

5.3 Results analysis

The analysis of the preliminary data helped to answer the first research question. Microsoft Excel was used for this purpose. The Matlab tool was used for modeling and analyzing the data collected in relation to the remaining two research questions. By the use of Matlab, the function for minimizing LCOE and their constraint was used to find the value of Xi. The energy target to meet is shown in Figure 4.2.

The end users of on-grid electricity are located in all areas of the country. The majority of residential users charge their phones and use electricity for lighting. Large families with low levels of education make up the majority of the households; they rely on small businesses, including small-scale farming and agriculture for subsistence. Such users have very limited monthly income and limited ability to buy electricity at exorbitant prices. The only options available to residential electricity users are electrical devices because of the high cost of electricity.

Also, the simulation using Matlab gives the following findings as shown in Table 5.3.

Table 5.3: Simulation findings

Period	**Variables by source of energy (MWh)**	**Algorithm**

`Year 1`	`Xs 24.4800`
	`Xh 61.2000`
	`Xm 36.7200`
		'interior-point'

`Year 2`	`Xs 12.2400`
	`Xh 30.6000`
	`Xm 18.3600`
		'interior-point'

`Year 3`	`Xs 12.2400`
	`Xh 30.6000`
	`Xm 18.3600`
		'interior-point'

	`fval 2.5070e+03`	in $ /MWh
	`Exitflag`	1

The Matlab tool used 'interior point' algorithm to find optimal values of the energy generation variables, Xi. Fmincon is the program that was used to solve the model. This study set out to generate 244.9 MW in three years by utilizing hydro-power, methane, and solar power. The total power generated in three years was 244.9 MW, with hydro-power producing 122.45 MW, methane-producing 73.47 MW , and solar power producing 48.98 MW.The study aims to minimise LCOE. The fval result is \$ 2.5070e+03 per MWh.

5.4 Discussion

In three years, the target of generating more than 244.9 MW while minimizing LCOE was achieved. 149.15 MW of the 311.1 MW of current generation capacity comes from renewable energy sources. 29.8 MW comes from methane power, 107.3 MW from hydropower, and 12.05 MW from solar photovoltaics. In three years, 48.98 MW of solar power, 122.45 MW of hydropower, and 73.47 MW of methane power can be generated. In this study, the target set a three-year target of 244.9 MW of renewable energy. To achieve this target, LCOE must be minimised and 48.98 MW of solar PV, 122.45 MW of hydropower, and 73.47 MW of methane power installed.

5.5 Sensitivity analysis

The sensitivity analysis for an optimization model that was designed to lower the LCOE is shown here. The created model will be crucial for analyzing the cost of electricity. Electricity cost is dependent on several factors, such as the generation of power from various sources . Every source has different costs for investments, operations, lifetime, power factor, and generation capacity in addition to costs per unit of energy produced. The time frame T used for this investigation is three years. Three types of renewable energy were used in the mix: methane power generation, hydropower, and solar electricity. In Chapter 3, the constructed model's principal element is displayed.

The investment cost, which was determined by taking the starting cost of each energy source, C_i, and the system's OM cost of the system for the duration of its whole life O_y, generation hours per day ki, as well as the power factor (PF), discount rate (r), and period (T), were entered into Matlab. The generation hours per day (ki) varies with source of energy, climate and location. In the case of Rwanda, solar generation hours per day average is 5 hours per day. General data from document reviews are used for model testing. This paradigm can be applied to various situations in accordance with the goal and resources that are available.

The findings indicate that at the current generation capacity of 311.2 MW, PF of 1 and r neglected, with a target of generating 244.9 MW in the next three years, the optimised generation capacity for solar, hydro, and methane in the first year would be 24.48 MW, 61.2 MM and 36.72 MW, respectively, while the first target is 122.45 MW.The target for the second year is 61.225 MW. For the second year, the optimised generation capacities for solar, hydro, and methane would be 12.24 MW, 30.6 MW, and 18.36 MW, respectively. The optimised generation capacity for solar, hydro, and methane would be 12.24 MW, 30.6 MW, and 18.36 MW, respectively, with the third-year share target of 61.225 MW.

The figure 5.2 below show the generation capacity per source per year.

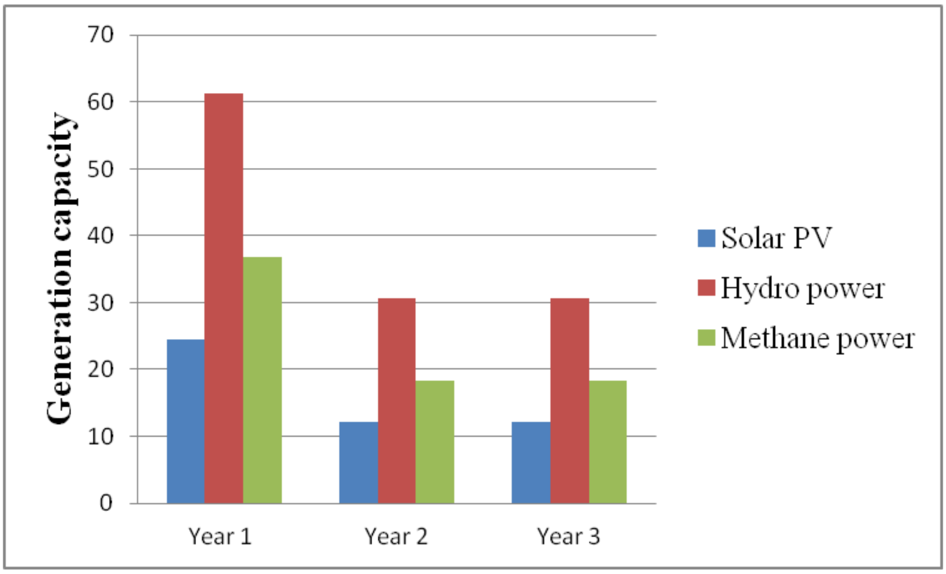

Figure 5.2: Generation capacity per year per source

When the target generation capacity is changed to 200 MW, the share targets for the first, second, and third years change to 40 % Ea, which corresponds to 80 MW, 35 % Ea, which corresponds to 70 MW, and 25% Ea, which corresponds to 50 MW, respectively, over the same three-year period. Furthermore, if the first-year share targets for solar, hydro, and methane change to 35% tg1 equivalent to 28 MW for both solar and hydro, and 30% tg1 equivalent to 24 MW for methane. If the goals for the second year's share targets for solar, hydro, and methane change to, respectively, 35% tg2 corresponding to 24.5 MW for solar and hydro then 30% tg2 corresponding to 21 MW for methane. Also in the event that the share targets for solar, hydro, and methane change to 35% tg3 equivalent to 17.5 MW, 17.5 MW for solar and hydro then 30% tg3 equivalent to 15 MW for methane for the third year, respectively. The findings become as presented table 5.4.

Table 5.4: Simulation findings

Period	**Variables by source of energy (MWh)**	**Algorithm**

`Year 1`	`Xs 28.0000`
	`Xh 28.0000`
	`Xm 24.0000`
		'interior-point'

`Year 2`	`Xs 24.5000`
	`Xh 24.5000`
	`Xm 21.0000`
		'interior-point'

`Year 3`	`Xs 17.5000`
	`Xh 17.5000`
	`Xm 15.0000`
		'interior-point'

	`2.5903e+03`	in $ /MWh
	`Exitflag`	1

If the target generation capacity remains at 244.8 MW,r is 0.08 and the power factors (PF) are considered to be 0.9 for solar, 0.85 for hydro, and 0.8 for methane, the share targets for the first, second, and third years change to 50% each year, which corresponds to 122.4 MW, 25% each year, corresponding to 61.2 MW, and 25% each year, corresponding to 61.2 MW, respectively, over the same three-year period. Furthermore, if the first-year share targets for solar, hydro, and methane change to 20% (24.48 MW) for

solar, 50% (61.2 MW) for hydro, and 30% (36.72 MW) for methane.
In the second year, the share targets for solar, hydro, and methane change to 20% (12.24 MW) for solar, 50% (30.6 MW) for hydro, and 30% (18.36 MW) for methane. In the third year, the targets remain the same as the second year: 20% (12.24 MW) for solar, 50% (30.6 MW) for hydro, and 30% (18.36 MW) for methane.

In the event that the third-year share targets change again to 35% (17.5 MW) for solar and hydro, and 30% (15 MW) for methane, the findings are presented in Table 5.5.

Table 5.5: Simulation findings

Period	**Variables by source of energy (MWh)**	**Algorithm**

`Year 1`	`Xs 24.48`
	`Xh 61.2`
	`Xm 36.72`
		'interior-point'

`Year 2`	`Xs 12.24`
	`Xh 30.6`
	`Xm 18.36`
		'interior-point'

`Year 3`	`Xs 12.24`
	`Xh 30.6`
	`Xm 18.36`
		'interior-point'

	`332.4651`	in $ /MWh
	`Exitflag`	1

The results shows both the LCOE and the optimal generation capacity variables changed as the input did. Also if the generation remain the same and PF,r are considered, the LCOE change immediately With one's own data, this model can be applied to anyone, anywhere.

Chapter 6

CONCLUSION AND RECOMMENDATIONS

The present chapter provides a summary of the present study's findings and draws relevant conclusions and recommendations to the key energy stakeholders in Rwanda, namely policy-makers and regulators, renewable energy companies suppliers, and researchers.

The present study aimed to design and test an optimization model for reducing the LCOE. Hence, the model was developed and simulated. A Matlab tool was utilized in this study to simulate the data and the fmincon program used an algorithm called interior-point.The input parameters were initial cost, target share generation capacity per period T, target share per source i per period T, the target generation capacity Ea, and the power factor PF. The simulation outcomes demonstrated that the developed model can identify the best generation variables and minimize the levelized cost of electricity. The optimization results indicated that the above-mentioned parameters could help achieve LCOE and to achieve the optimization generation capacity variables from renewable energy sources available in Rwanda.

The optimization model presented in the present study has demonstrated the possibility of using environmentally friendly energy sources at a relatively cheaper cost than that of non-renewable sources. It is, therefore recommended to investors and energy supply companies to adopt the model to make their services more efficient and effective in terms of generating and distributing environment-friendly energy at relatively more affordable costs. Policy-makers could also consider supporting the adoption of the model. Meanwhile, this study used data from only three sources of renewable energy and its findings should, therefore be interpreted with awareness of that limitation. A replication research study using more data from all possibly available sources of renewable energy in Rwanda could produce more robust findings to support the model.

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Appendix A
HOUSEHOLDERS QUESTIONNAIRE

Figure A.1: Householders questionnaire