

CRANFIELD UNIVERSITY

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OPTIMISING RESIDENTIAL ELECTRICITY DEMANDS THROUGH
INNOVATIVE DEMAND SIDE MANAGEMENT STRATEGIES IN
NIGERIA

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Cranfield University.

The research described in this thesis is the original work of the author except where indicated by special reference in the text.

It was carried out at the Centre of Energy Systems and Strategy, School of Water, Energy and Environment, Cranfield University under the Supervision of Dr. Chao Long, Dr. Pegah Mirzania and Prof. Phil Hart

This work has not been submitted for another degree or award of another academic or professional institution in the United Kingdom or overseas.

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ABSTRACT

The Nigerian power supply faces significant shortages, resulting in frequent nationwide power outages, load shedding and severe energy crises. The country relies heavily on a centralised energy mix, primarily comprising gas-fired power plants with a capacity of 10.6 Giga Watt (GW) and hydropower with a capacity of 1.9 GW. Despite having a total installed capacity of 12.5 GW, only around 4 GW actually reaches end consumers. This is mainly due to limited transmission infrastructure, inadequate distribution facilities, poor metering, inadequate fuel supply, lack of market competition and inadequate management of energy resources. Innovative demand side management (DSM) strategies are required to optimise electricity demands at customer ends to improve the power supply in Nigeria.

This thesis develops an innovative DSM method of utilising direct load control (DLC), acting as a mandatory operational strategy for regional residential grids, as opposed to traditional approach of load shedding. The proposed DLC method controls residential loads by classifying loads into three different categories: critical, less critical, and non-critical. The evaluating metrics include energy cost savings and comfort levels of residence (i.e., the length of supply of the critical loads). Furthermore, paper-based surveys are used as the quantitative methods to evaluate the understanding, awareness, and attitude of Nigerian households towards DSM under different representative groups. The survey data are also used to model load profiles, to which the DLC is applied to validate the proposed DLC method.

The proposed DLC method was compared with load shedding considering three load shedding scenarios: 1) nobody uses generators during power cut period, 2) running home generators for 4 hours per day during power cut period, and 3) running home generators for 8 hours per day during power cut period. Simulation results showed that, for scenario 1, the proposed DLC method results in a 20% of energy cost saving and a 28% improvement of in comfort level; for scenario 2, the proposed DLC method results in an 87% decrease in household expenditure and a 5% decrease in comfort level, and for scenario 3, the proposed DLC method results in a 93% energy cost saving but a 39% decrease in comfort level.

The study shows that households with the post-paid billing systems are less responsive to the DSM approach. However, the proposed DLC strategy results in higher cost savings on the post-paid billing systems (23%) than the pre-paid billing systems (17%), both compared to the load shedding approach. Households working in the public sector who use the pre-paid billing system have proven to be the most effective target group for implementing DSM. This is

because these households consume 23% more energy on average compared to other representative household groups. This research presents an innovative DLC method designed to enhance power supply in residential grids, providing an alternative to load shedding in developing countries. Additionally, it utilises a methodology that involves gathering data through paper-based surveys to construct electricity demand profiles, establishing a numerical dataset for future DSM studies. The research findings reveal that the proposed DLC method not only lowers energy expenses but also improve overall household comfort and quality of life.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS	i
DECLARATION	ii
ABSTRACT	iii
TABLE OF CONTENTS	v
LIST OF FIGURES	x
LIST OF TABLES	xii
LIST OF ABBREVIATIONS	xiv
PUBLICATIONS.....	xvi
CHAPTER 1.....	17
INTRODUCTION	17
1.1. Background.....	18
1.2. Defining Demand Side Management in the Research Context.....	22
1.2.1 Research Questions.....	23
1.2.2 Research Objectives	23
1.3. Thesis Structure	23
CHAPTER 2.....	25
A REVIEW OF DEMAND SIDE MANAGMENT	25
2.1 Introduction	26
2.2 Overview of Demand Side Management (DSM)	27
2.3. Classification of Demand Side Management (DSM).....	28
2.4. Demand Side Management Programme Mechanism in Developed Countries.....	30

2.4.1 DSM Programmes in the United State (US).....	30
2.4.2. DSM Programme in Australia	34
2.4.3. DSM Programme in United Kingdom	38
2.5. Demand Side Management Programme Mechanism in Developing Countries	44
2.5.1 DSM Programme in India	44
2.5.2 DSM Programme in South Africa.....	46
2.6. Comparison of DSM Programmes in Developed and Developing Countries.	50
2.7. DSM Programme in Nigeria	52
2.7.1 Overview of Nigerian Electricity Market (NEM)	53
2.7.2 Challenges in the Nigeria Electric Power Systems	56
2.7.3 Energy Policy Evolution in Nigeria	58
2.7.4 Energising Nigeria: A Pathway to Sustainable Energy and Economic Growth.....	60
2.8. Chapter Summary and Opportunity for Research.....	62
CHAPTER 3.....	65
RESEARCH METHODOLOGY	65
3.1. Introduction.....	66
3.2. Research Focus	66
3.3 Summary of Research Method.....	66
3.4. Survey Approach	68
3.4.1 Data Collection Methods	69
3.4.2 Survey Area.....	72
3.4.3 Survey Data Analysis	73
3.4.4 Ethics Issues	74

3.5. Analytical Framework and Research Tool	75
3.5.1 Rationale of Using MATLAB over Python and C++	75
3.6. Technical Model.....	76
3.6.1. Objective Function of the Problem.....	77
3.6.2. Constraints of Scheduling Appliances	79
3.6.3 Constraints of Scheduling Appliance with Application Direct Load Control.....	80
3.7 DLC Impact Data Analysis.....	81
3.8 Conclusion.....	82
CHAPTER 4.....	83
SURVEY KEY FINDINGS: AN OVERVIEW OF RESIDENTIAL LOAD PROFILE FOR DEMAND SIDE MANAGEMENT IN NIGERIA	83
4.1. Introduction.....	84
4.2 Unlocking Sustainable Energy Solutions in Developing Nations - A Study of DSM in Nigeria Household.....	84
4.3. Survey Study for Nigeria Residential Demand Profiling	86
4.3.1 Characteristic of Survey Area	86
4.4. Analytic Procedures (Findings and Discussion)	87
4.4.1. Household Information	87
4.5. Energy Bill	91
4.6 Household Appliance Usage.....	95
4.7. Energy Management	98
4.8. Alternative Energy	100
4.9. Conclusion.....	102

CHAPTER 5.....	104
SIMULATION RESULTS: DEVELOPMENT OF ENERGY MANAGEMENT WITH DIRECT LOAD CONTROL IN NIGERIA	104
5.1. Introduction.....	105
5.2. Defining Direct Load Control in the Research Context.	105
5.3. Simulation Results	106
5.3.1 Residential Energy Load Profile	107
5.3.2. Billing System	111
5.4. Conclusion	130
CHAPTER 6.....	132
DISCUSSIONS AND RECOMMENDATIONS.....	132
6.1 Discussion on Limitation of the Research	133
6.1.1 Survey-Based Demand Profiling.....	133
6.1.2 Regional Sensitivity.....	133
6.1.3 Sensitivity Analysis for Generator Operations.....	134
6.2 Discussion on the Impact of DLC on Different Representative Groups	134
6.2.1 Impact of DLC on Household working in the Public Sector.	134
6.2.2 Impact of DLC on Household working in the Private Sector.	135
6.2.3 Impact of DLC on Household who run Businesses.....	136
6.2.4 Impact of DLC on Households who are Students.....	137
6.2.5 Accessing the Effect of DLC on Household that are Retired.....	137
6.3 Recommendation	140
CHAPTER 7.....	144

CONCLUSIONS AND FUTURE WORK	144
7.1 Conclusions	145
7.2 Achievement of Research Objectives.....	145
7.3 Original Contribution to Knowledge.....	147
7.3.1 Knowledge Contribution	147
7.3.2 Contribution to Industrial and Commercial Practices	148
7.4 Opportunities for Future Research.....	148
REFERENCES.....	150
APPENDIX A: PAPER-BASED SURVEY QUESTIONS	179
APPENDIX B: ETHICS APPROVAL LETTER	184
APPENDIX C: MATLAB CODE	185
APPENDIX D: SURVEY RESULT	200
APPENDIX E: HOUSEHOLD DEMAND LOAD PROFILE.....	209

LIST OF FIGURES

Figure 1. 1: Electricity Generation in Nigeria .	19
Figure 1. 2: Structure of the Nigeria Electricity Supply Industry .	19
Figure 1. 3: Pre-Paid Meter.....	21
Figure 1. 4: Post-Paid Bill.....	22
Figure 2. 1: Classification of Demand Side Management	28
Figure 2. 2: Percentage of the Total Peak Demand Savings from DR.	31
Figure 2. 3: An Interconnected Electricity System.....	41
Figure 2. 4: Nigeria National Grid.....	54
Figure 2. 5: Nigeria Electricity Market Industry	55
Figure 2. 6: Capacity Margin (MW).....	57
Figure 3. 1: Research Block Diagram.....	68
Figure 3. 2: Flow Chart of Sequential Data Analysis	69
Figure 3. 3: Map of Nigeria	73
Figure 3. 4: Technical Simulation of DSM.....	77
Figure 3. 5: Block Diagram of DLC	80
Figure 4. 1: Map of Nigeria	87
Figure 4. 2: Occupation of Households	88
Figure 4. 3: Level of Household Education.....	89
Figure 4. 4: Age Group of Households.....	90
Figure 4. 5: Composition of Households	90
Figure 4. 6: Household Electricity Expenditure	92

Figure 4. 7: 2 - 3 Numbers Household Composition	93
Figure 4. 8: 4 - 5 Numbers Household Composition	93
Figure 4. 9: 6 - 7 Numbers Household Composition	94
Figure 4. 10: Household with Degree Level Education.....	94
Figure 4. 11: Household with no Formal Education.....	95
Figure 4. 12: Time of Use of Lightening	95
Figure 4. 13: Time of Use for Air Conditioning.....	96
Figure 4. 14: Relationship Between Air Condition Time of Use and Pre-Paid Billing.....	97
Figure 4. 15: Relationship Between Air Condition Time of Use and Post-Paid Billing	97
Figure 4. 16: Period of Iron Use	98
Figure 4. 17: Energy Saving at Home.....	98
Figure 4. 18: Generator as Alternative Energy Source	99
Figure 4. 19: Willingness to Participate in Energy Management.	100
Figure 4. 20: Participation in Direct Load Control	100
Figure 4. 21: Renewable Energy Resources at Home.....	101
Figure 4. 22: Barrier for your Grid Energy to Renewable Energy	102
 Figure 5. 1: Residential Energy Profile.....	 108
Figure 5. 2: Residential Energy Profile with DLC	108
Figure 5. 3: Comparison of Daytime Energy Profile with and without DLC.....	109
Figure 5. 4: Post-Paid Residential Energy Profile	112
Figure 5. 5: Pre-Paid Residential Energy Profile.....	112
Figure 5. 6: Comparison of Daytime for Pre-paid and Post-paid Billing System	112
Figure 5. 7: Number of Households.....	116

LIST OF TABLES

Table 2. 1: Summary of the PJM and CAISO Electricity Market (NEM) Mechanisms	32
Table 2. 2: The Barriers Hindering the DR Programme and the Recommendation by CASIO for a Properly Configured DR Programme.	33
Table 2. 3: Summary of the Australia National Electricity Market (NEM) Mechanisms	36
Table 2. 4: Ancillary Market in Australia	37
Table 2. 5: Balancing Services in the United Kingdom.....	43
Table 2. 6: DSM Programmes in India	45
Table 2. 7: DR Programmes in South Africa	48
Table 2. 8: EE Programmes in South Africa.....	49
Table 2. 9: Comparison of DSM Programmes.....	52
Table 2. 10: Percent of Electricity Generation.....	54
Table 3. 1: Questionnaire Content	71
Table 3. 2: Residential Time Slot and Price	78
Table 3. 3: Power Information and Working Hour for DLC.	78
Table 4. 1: Correlation Analysis of Household	91
Table 4. 2: Tariff Classification	92
Table 5. 1: Comparison of Energy Consumption with and without DLC	108
Table 5. 2: Cost of Energy for Different Scenario	110
Table 5. 3: Comfort Level of Residence	111
Table 5. 4: Comparison of Daytime for Pre-paid and Post-paid Billing System.....	113
Table 5. 5: Cost of Energy under Various Billing System Scenarios	114
Table 5. 6: Comfort Level of Residence under various Billing System Scenarios.....	115
Table 5. 7: Analysis of Energy Consumption based on Number of Occupant with and without DLC.....	116

Table 5. 8: Average Energy Consumption Savings based on Number of Occupants with DLC	117
Table 5. 9: Cost of Energy for Different Occupant Numbers of a Household	118
Table 5. 10: Comfort Level of Residence for Different Occupant Numbers of a Household	119
Table 5. 11: Comparison on the Energy Consumption with and without for Households working in Different Sectors.....	120
Table 5. 12: Average Energy Consumption Savings with DLC for Households working in Different Sectors.	120
Table 5. 13: Cost of Energy for Households working in Different Sectors.....	122
Table 5. 14: Residence Comfort Level Based on Different Occupation.	123
Table 5.15: Comparison on Energy Consumption with and without DLC Based on Level of Education.	124
Table 5. 16: Average Energy Consumption Savings with DLC for Different Level of Education.	125
Table 5. 17: Cost of Energy for Different Household Scenarios by Educational Backgrounds.	126
Table 5. 18: Residential Comfort Level for Different Scenario by Educational Backgrounds.	127
Table 5. 19: Summary of Cost of Energy across Different Representative Groups.....	128
Table 5. 20: Summary of Comfort Level across Different Representative Groups.....	129

LIST OF ABBREVIATIONS

AC	Air Condition
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
AMI	Advanced Metering Infrastructure
CAISO	California Independent System Operator
DISCOS	Distribution Companies
DLC	Direct Load Control
DNO	Distribution Network Operators
DR	Demand Response
DRA	Demand Response Aggregator
DRM	Demand Response Mechanism
DSM	Demand Side Management
DSR	Demand Side Response
ECN	Electricity Corporation of Nigeria
EE	Energy Efficiency
FCAS	Frequency Control Ancillary Service
GENCO	Generation Companies
GW	Giga-Watts
ISO	Independent System Operators
LED	Light-Emitting Diodes
LS	Load Shedding
LSE	Load Serving Entity

MAP	Meter Asset Provider
MW	Mega-Watts
NEM	Nigerian Electricity Market
NERC	Nigerian Electricity Regulatory Commission
NERSA	National Energy Regulator of South Africa
NESI	Nigerian Electricity Supply Industry
PJM	Pennsylvania-Maryland-New Jersey Interconnection
REA	Renewable Energy Association
SME	Small and Medium Enterprises
SPSS	Statistical Package for the Social Science
STOR	Short-term Operating Reserve
TCN	Transmission Company of Nigeria
UK	United Kingdom
US	United States

PUBLICATIONS

Usman, R.; Mirzania, P.; Alnaser, S.W.; Hart, P.; Long, C. (2022) Systematic Review of Demand-Side Management Strategies in Power Systems of Developed and Developing Countries. *Energies*, 15, 7858. <https://doi.org/10.3390/en15217858>

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Usman, R.; Long, C.; Mirzania, P. (2023) Residential Energy Demand Profiling in Nigeria: A Comprehensive Paper-Based Survey, IET Smart Grid.

CHAPTER 1

INTRODUCTION

Summary:

This chapter establishes the thesis's aim and objectives by introducing the challenges driving the transformation within the Nigerian Electricity Supply Industry and provides an overview of the thesis structure.

1.1. Background

Nigeria, often referred to as the "Giant of Africa," boasts the largest population on the continent and seventh biggest population in the world. The country is one of the world's fastest-growing economies and has faced persistent difficulties in ensuring dependable and sustainable electricity access for its people and industries (Victor, 2017). As of 2022, the country's centralised energy mix is predominantly of thermal (Gas-fired plant) with 10.585 GW and hydropower stations with 1.9368 GW, with energy generation of 32.10-terawatt hour (TWh). Figure 1.1 shows a steady increase in electricity generation in Nigeria from 2000 to 2022. Whilst the current structure has a total installed capacity of 12.522 GW, only about 4 GW reaches last-mile customers.

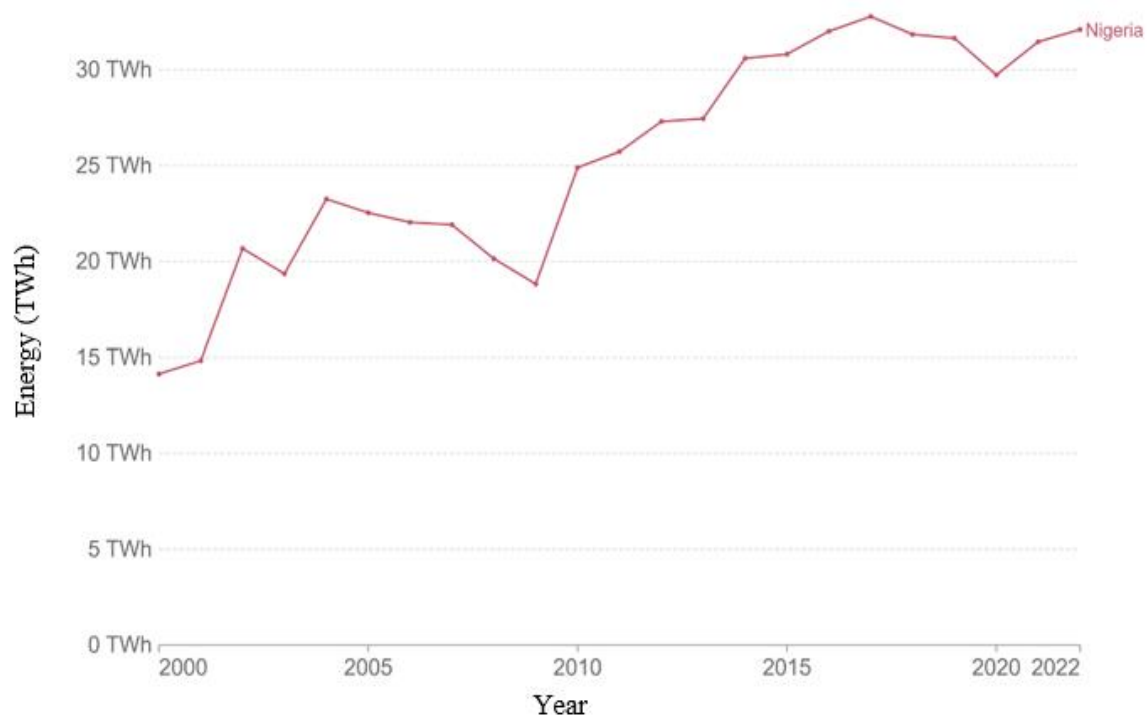


Figure 1. 1: Electricity Generation in Nigeria (Ritchie and Roser, 2023).

Nigeria's electricity system, initially managed by the state-owned Nigerian Electricity Power Authority (NEPA), was transformed into the Power Holding Company of Nigeria (PHCN) before being privatized and unbundled into multiple distribution (DISCOs) and generation companies (GENCOs). Electricity generation, primarily from gas-fired power plants and hydropower stations, is transmitted by the Transmission Company of Nigeria (TCN) to distribution companies. Distribution is handled by 11 privately-owned companies, each serving specific regions and managing electricity supply, billing, and customer service for end-users.

Figure 1.2 shows the structure of the Nigerian Electricity Supply Industry (NESI). NESI embraces a contemporary strategy of privatising government utilities, with the objective of tackling issues related to market inefficiencies, management, and investment obstacles. The electricity supply industry is regulated by the Nigeria Electricity Regulatory Commission (NERC).

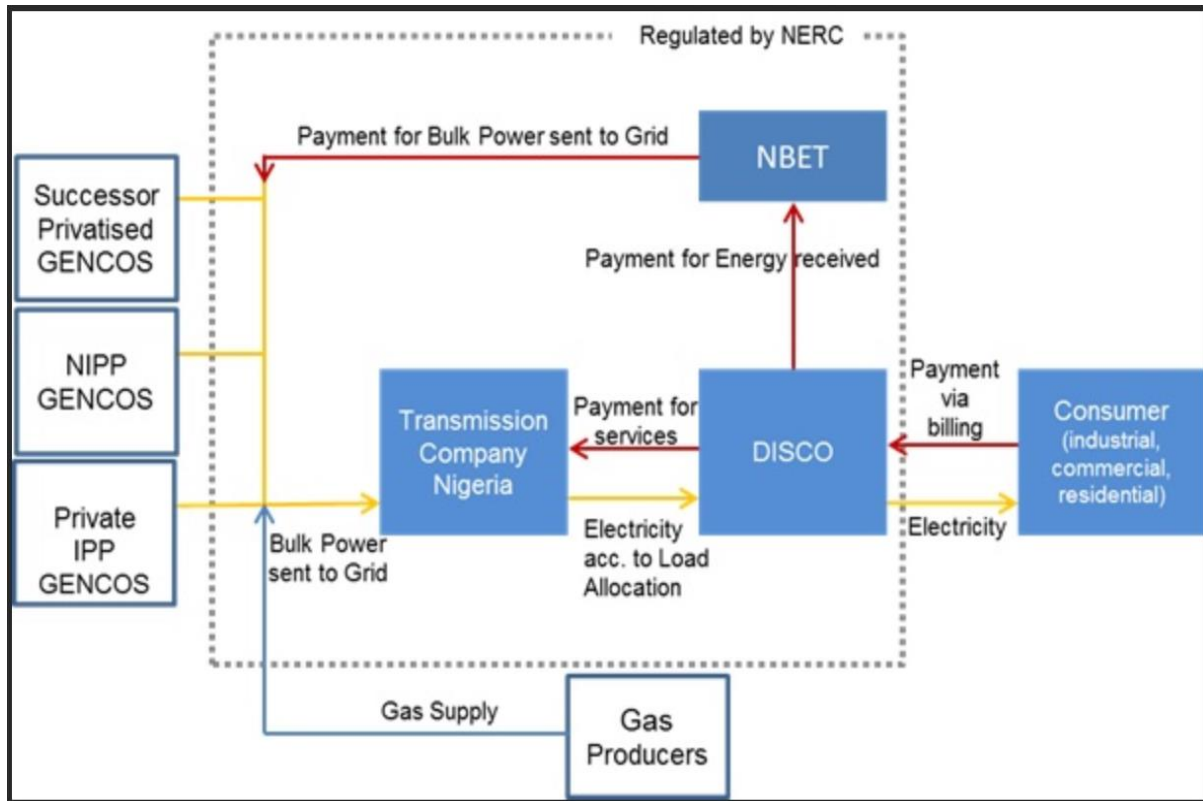


Figure 1. 2: Structure of the Nigeria Electricity Supply Industry (NERC, 2021).

Developing countries face unique challenges in meeting energy needs while pursuing sustainable development goals. Many nations experience rapid population growth, urbanisation, and industrialisation, leading to escalating energy demands (Kaygusuz, 2012a). Despite vast energy resources, the electricity industry faces numerous challenges hindering the growth in meeting the countries energy demand (Onyekwena, Ishaku and Akanonu, 2017). The infrastructure is outdated, and a combination of factors including aging, inadequate maintenance, and suboptimal design have consistently resulted in regular system breakdowns. Consequently, this has led to a rise in load shedding and power outages (The Conversation, 2022). Similarly, there is an insufficient workforce to oversee the infrastructure, coupled with a rising incidence of theft and vandalism targeting grid equipment, further exacerbating power outages. As a result, financial sustainability within the power sector remains a significant challenge, marked by a growing number of bill non-payments and the accumulation of debt,

which in turn obstructs infrastructure maintenance and upgrades (Onyekwena, Ishaku and Akanonu, 2017). In addition to these issues, the electricity sector faces ongoing difficulties stemming from political interferences, inadequate policy enforcement, regulatory obstacles that hamper the attraction of vital investments, and the suboptimal operation of the supply industry, which collectively exacerbate the sector's struggle to provide a dependable power supply (Akanbi, 2022). The energy billing system in Nigeria's electricity supply industry is categorized into two types: prepaid and postpaid. The system faces several challenges, including inaccurate billing, a low number of prepaid meters, infrastructure deficiencies, and revenue collection issues. The prepaid billing system measures electricity consumption using a meter that allows customers to pay for electricity in advance before using it, which helps in better managing their usage and avoiding unexpected bills (see figure 1.3).



Figure 1. 3: Pre-paid Meter

The post-paid billing system allows subscribers to pay for electricity after it has been consumed. In this system, the utility company provides an estimate of energy use over a billing period, usually a month (see figure 1.4), and the subscriber receives a bill based on this estimated consumption. However, the low penetration of prepaid meters means many customers still rely on the postpaid system, which often results in billing inaccuracies and difficulties in revenue collection. Infrastructure deficiencies further complicate the efficient delivery and management of electricity, impacting the overall reliability and sustainability of the system.

 YOLA ELECTRICITY DISTRIBUTION COMPANY YEDC		Bill #: 18244229 
Business Unit:	YELWA	
Service Centre:	YELWA	
11kv Feeder:	11KV ABTT	
33kv Feeder:	33KV YOLA	
Bill Month :	June , 2024	#11,000
DT Name:	ROULOUDELE 1	15-07-24
Customer Account #:	710015087438	P
Account Name:	RILWAN USMAN	11,000
Address:	WURO CHEKKE	
Phone No:		
City:	YOLA	
State	Adamawa	
Sales Rep:		
Meter #:	N/A	
Multiplier:	1.00	
Billing Details:		
Last Payment Date:	20/06/2024	
Last Payment Amt	=N=13,000.00	
ADC	5.53 kwh	
Present Reading:	0	
Previous Reading:	0	
Consumption	166.00 kwh	
Tariff Rate:	=N=63.33	
Tariff Class:	B - NMD	
Status Code	02	
Opening Balance	=N=12,456.84	
Adjustment:	=N=0.00	
Total Payment Amt	=N=13,000.00	
Net Arrears:	=N=-543.16	
Energy Charged:	=N=10,512.78	
Fixed Charge:	=N=0.00	
VAT:	=N=788.46	
Total Due:	=N=10,758.08	
Powered by dotNET e-Business		

Figure 1. 4: Post-paid Bill

Despite these difficulties faced, Nigeria's electricity supply industry continues to play a pivotal role in the country's economic and social development. Several initiatives and strategies are being pursued to transform the sector. This includes the development of renewable energy to diversify the energy mix and reduce the dependence on fossil fuels (REAN, 2020). Upgrading of electricity infrastructure in the transmission and distribution network (TCN, 2022). Strengthening the regulatory framework enabling conducive environment for private investment (NERC, 2023a).

To address these challenges, load shedding is often employed as a short-term measure to cope with the inadequate electricity supply. This concept disrupts industrial production, commercial activities, and service sectors, leading to revenue losses, decreased productivity, and potential business closures. Moreover, it has a detrimental impact on households concerning their comfort, well-being, and education, as vital services such as heating, cooling, and lighting are compromised, (Pahwa et al., 2013; Raghu. C. N et al., 2018). As the world transitions towards sustainable and resilient energy systems, collaborative efforts among policymakers, utilities,

researchers, and stakeholders will be vital in effectively tackling load shedding and ensuring a reliable and uninterrupted electricity supply.

The implementation of Demand Side Management (DSM) is crucial for developing countries like Nigeria to effectively regulate and optimize energy consumption, enhance energy efficiency (EE), and ensure a sustainable and reliable energy supply. DSM can significantly improve the reliability of the electricity supply by reducing peak demand and boosting energy efficiency, which in turn decreases the frequency and duration of power outages. This enhanced reliability not only increases industrial productivity and competitiveness, fostering economic growth, but also reduces energy costs for businesses and consumers, thereby freeing up resources for other investments. Moreover, a more stable power supply improves the quality of life for residents by minimizing disruptions and ensuring the consistent operation of essential household appliances. Despite these benefits, there is a notable shortage of comprehensive studies on the awareness, perception, and attitudes of households in Nigeria regarding DSM.

Moreover, the absence of research on a technical model for carrying out and assessing the impact of DSM in Nigeria presents a significant gap. The development of such a model would provide a structured and data-driven framework for the precise analysis and enhancement of energy consumption, potentially leading to energy cost savings and improved living conditions for residents. Lastly, there is a distinct lack of research that specifically examines the performance and effectiveness of DSM in the Nigerian context.

The desired outcome is a developed, innovative DLC method that not only reduce energy cost but enhances the overall comfort and quality of life for households. This DSM strategy will improve electricity supply to the Nigerian residential sector.

1.2. Defining Demand Side Management in the Research Context

The primary aim of this research is to optimise residential electricity demands by developing an innovative DSM strategy, which simultaneously addresses Nigeria's electricity challenges and improve electricity supply to the residential sector addressing the following research questions and objectives:

1.2.1 Research Questions

This work has the following research questions:

1. What Demand Side Management (DSM) strategies will work in a developing country like Nigeria, and what are their corresponding performances?
2. What type of DSM strategy and DSM method should be adopted, and to what extent can these DSM strategies reduce energy bills?
3. What level of awareness does the end customer have regarding DSM, and how to implement end customers' awareness and reactions into the DSM strategies in developing countries?

1.2.2 Research Objectives

This work has the following research objectives:

1. To develop a DSM strategy for the distribution system by critically evaluating the literature on the state of the network grid (technical and non-technical challenges) and state of the art methods for DSM.
2. To evaluate and analyse residential customers' understanding, awareness, attitude, perspective, and willingness to adapt DSM programme via paper-based survey.
3. To develop a technical model to evaluate the effect of implementing direct load control of DSM and identify areas of improving DSM strategies considering the customers awareness and reactions.
4. To explore and analyse energy consumption patterns and responsiveness on DSM strategies among various representative groups of residential customers and formulate a DSM Strategy for Nigeria.

1.3. Thesis Structure

The remainder of this thesis is arranged as follows: -

Chapter 2 provides an overview of DSM initiatives to identifying the key factors contributing to an efficient power system in some selected developed countries. It also provides an overview of DSM programmes in some selected developing countries, evaluating the role and importance of DSM initiatives in the electricity market. The chapter also reviews the technical and non-technical challenges of the Nigerian electricity supply industry.

Chapter 3 provides the methodology employed in this thesis. It begins by outlining the focus and potential scope of the research, followed by the strategy and methodological approaches taken to address the research questions. Details of the survey used are outlined, along with the software used for the simulation and data analysis.

Chapter 4 presents the empirical findings from the paper-based survey. This chapter shows residential customers' perspectives, awareness, and acceptance of DSM. Furthermore, this chapter presents Nigerian households' understanding of DSM, energy management and strategies for deploying these strategies at home. It also identifies factors that are hampering the penetration of DSM in Nigeria.

Chapter 5 presents energy consumption pattern in Nigeria's residential sector and also delves into the results of implementing DLC in terms of energy cost savings and comfort level improvement compared to the load shedding approach. This chapter also presents the results of implementing DLC in different representative groups of residents, including households with pre-paid and post-paid billing systems, with different education background, and with different occupations.

Chapter 6 presents the limitations of the research and recommendations for the formulation strategies and the deployment of DSM in Nigeria.

Chapter 7 presents conclusion of the thesis and summarises the main findings of the research. It also describes potential future research topics based on the work carried out.

CHAPTER 2

A REVIEW OF DEMAND SIDE MANAGEMENT

Summary:

This chapter provides an overview of DSM initiatives to identify the key factors contributing to an efficient power system in developing countries, such as the U.S., Australia, and the UK. It also provides an overview of Indian, South African, and Nigerian DSM programmes as examples of developing countries, to critically evaluate the role and importance of DSM initiatives in the electricity market. Furthermore, this chapter reviews the challenges of power systems in Nigeria and summarises the research gaps.

2.1 Introduction

Electricity plays a vital role in the economic, social and political development of a country, serving as the cornerstone of modern society (Dada, 2014a; Oseni, 2011). The increment in the standard of living, industrialisation, and other sectors (such as health, education) is significantly influenced by the limitation of adequate energy supply (Oseni, 2011; Usman and Gidado, 2017). Different studies have correlated the relationship between the role energy consumption plays in the economic, social, and technological growth of a country (Ozturk, 2010). The quest for electrical vitality is increasing exponentially, and the accessible assets are exhausting at an alarming rate. Subsequently, it is imperative to adequately manage the energy sources, enhancing the use and curtailing the production cost (Khan et al., 2016). For years developing countries have been forecast for growth of energy demand, increased fossil fuel use with associated emission of greenhouse, with low-income households driving the rise in energy consumption (Wolfram, Shelef and Gertler, 2012). The energy consumption in developing countries is set to increase by 3% annually from 46% to 58% between 2004 and 2040 (IEA, 2015). Despite its abundant natural resources, Nigeria's energy potential has not translated into sufficient power supply, as the country lags behind in electric power consumption per capita, with only 145kWh, compared to other African nations like South Africa with 4198kWh, Egypt with 1683kWh, Namibia with 1653kWh, and Botswana with 1816kWh (The World Bank, 2014). As reported by the World Resource Institute, a substantial 61.4% of global greenhouse gas (GHG) emissions are attributed to energy-related activities. Historical data has consistently shown that the majority of these emissions originate from developing countries (Sadorsky, 2010). Air pollutants associated with solid fuel use have become of great concern to environmentalists and policymakers in Sub-Saharan African, this energy source is responsible for 4000 premature death per day (IEA, 2006). The Intergovernmental Panel on Climate Change (IPCC) emphasizes that the existing climate conditions, compounded by the economic challenges posed by the recent global pandemic (COVID-19), underscore the growing urgency of shifting towards low-carbon energy systems. As part of this transition, renewable energy sources are projected to play a pivotal role, with estimates suggesting they could provide approximately 70-80% of the world's electricity needs by the year 2050 (IPCC, 2021). The increasing electricity demand, driven by economic factors and policy initiatives, has propelled an annual 3% growth in global renewable energy consumption between 2018 and 2050. This trend positions renewable energy as the foremost primary energy source, even though fossil fuels still play a significant role in meeting current energy demands worldwide (Energy

Information Administration, 2019). The potential of renewable energy in developing countries has placed it in a crucial position in the energy transition with a projected double increase in electricity demand (IEA, 2019). The African renewable energy initiative (AREI) was launched at COP21 with a pledge to mobilise the continent to generate 300GW from renewable energy by 2030 and to provide a new and additional renewable energy capacity of 10GW in 2020 (Keho, 2016). The distinct orientation of top-down and single-direction energy flow has presented challenges with the increasing number of renewable resources, thereby requiring sophisticated real-time control of distributed energy resources. DSM presents an alternative solution in balancing demand and supply (Warren, 2014).

Most research worked focused on consumers in industrialized or developed economies with few studies undertaken on alternative schemes for consumers in developing economies. This study fills the gap by reviewing DSM policies, experiences and hindrances in developed countries, and assessing the potentials and requirements of the role DSM could play in the electricity industry in Nigeria.

2.2 Overview of Demand Side Management (DSM)

DSM was introduced in the 1980s by the Electric Power Research Institute to change load shapes and patterns of energy consumption to improve reliability, monitoring, and deferring investment. DSM places customers in the middle of the decision-making process to decide how and when electricity is utilized (Behrangrad, 2015a; Gelazanskas and Gamage, 2014). The evolution of the electricity market has further evolved DSM (Eissa, 2011). The definition of DSM in the literature is broad, but the overall goal of DSM is to reduce the energy demand by shifting consumption patterns on the customer side. According to Warren (Warren, 2014) "*DSM refers to technologies, actions and programmes on the demand-side of energy metres that seek to manage or decrease energy consumption, in order to reduce total energy system expenditures or contribute to the achievement of policy objectives such as emissions reduction or balancing supply and demand.*" According to Lampropoulos (Lampropoulos et al., 2013) DSM involves a holistic set of management functions closely associated with guiding and regulating demand-side initiatives, including tasks such as programme planning, evaluation, execution, and ongoing supervision. Strbac (Strbac, 2008) define DSM in terms of consumers' response to changes in price and shifting of load for on to off-peak periods.

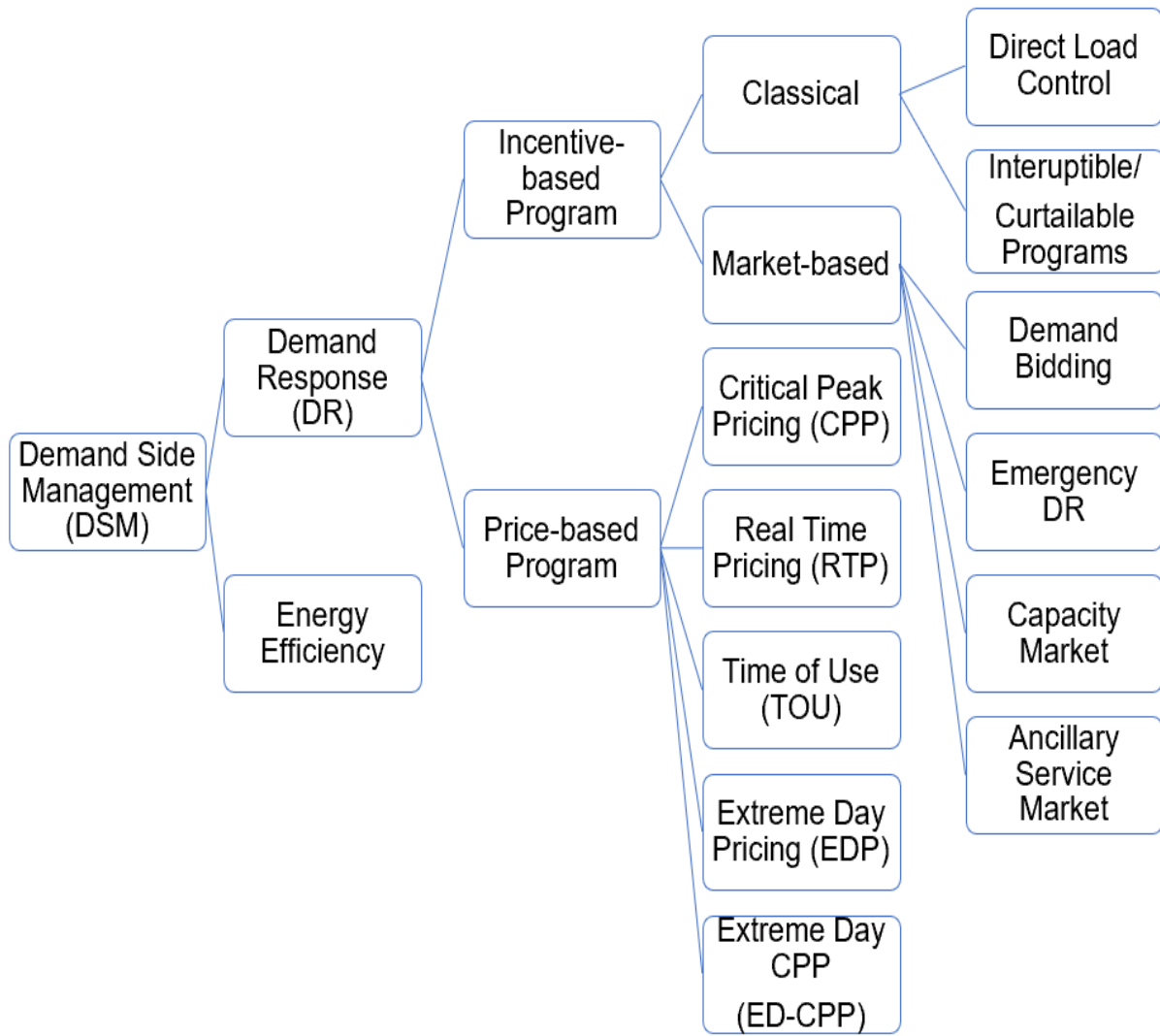


Figure 2. 1: Classification of Demand Side Management (Albadi and El-Saadany, 2007)

2.3. Classification of Demand Side Management (DSM)

The literature categorised DSM into two classifications (see Figure 2.1) (Albadi and El-Saadany, 2007):

- i) Demand response (DR) provides the platform for end-users to alter load consumption patterns in response to a price change of electricity over a period there by reducing the overall peak of the system.
- ii) Energy Efficiency emphasizes persuading consumers to utilize the efficient product as a means of reducing demand (Albadi and El-Saadany, 2007; Behrangrad, 2015a; Palensky and Dietrich, 2011).

DR programmes are divided into incentive-based and price-based (Behrangrad, 2015a). In the incentive-based programme, classical programme customers receive bill credit or discount rate for participating in the programmes while market-based customers receive a reward for load

reduction. Price based programme are utilized to flatten the demand curve by providing high prices during peak periods and lower prices during the off-peak period (Albadi and El-Saadany, 2007).

Incentive-based DR a proactive and time-critical method for effectively managing electricity demand. Such programmes entail swift and direct reductions in electricity consumption when there is a high demand or grid instability. This programmes such as DLC, is a strategy used by utilities and grid to remotely control specific appliances in residential, commercial, or industrial settings to enhance grid reliability, cost savings and promote energy sustainability(Fell et al., 2015; Garniwa and Wardana, 2019; Li, Chiu and Sun, 2017). Interruptible or curtailable service represents an alternative form of incentive-driven DR, primarily utilized within the industrial and large-scale commercial sectors to effectively reduce electricity consumption. This approach involves the establishment of a bilateral contract outlining specific terms, including the duration and the maximum allowable hours per activation (Li, Chiu and Sun, 2017). Other programmes are emergency DR is designed to handle unforeseen and extreme grid circumstances, such as supply deficiencies or unanticipated equipment breakdowns (Liu et al., 2023). The capacity market guarantees the reliability of electricity supply by providing compensation for dependable capacity sources, in addition to their earnings from electricity sales, thus ensuring the availability of energy when needed while in the concept of demand bidding consumers indicates the will to reduce demand in exchange for benefit (Abedrabbob and Al-Fagih, 2023). Ancillary market is a segment that provides essential support through frequency regulation, voltage support and reserve capacity thereby ensuring grid stability and reliability (Behrangrad, 2015b).

Price-based DR is a price-based strategy that focuses on utilising dynamic price signals to impact consumers activities and achieving load management. This programme furnishes consumers with real time data, empowering them to make knowledgeable choices regarding when and how to utilise electricity. Time of use (TOU) is one concept of price-based DR which entails adjusting electricity rates according to distinct time segments throughout the day, usually categorized into peak, off-peak, and shoulder periods. During peak hours, consumers face higher rates, while lower rates apply during off-peak hours (Chang and Wu, 2020). Real-time pricing provides consumers with electricity rates that vary every few hours based on market conditions. This focuses on large customers allowing them to adjust energy usage pattern to take advantage of lower rates. This approach entails the continuous monitoring of price data and adjusting accordingly (Bakare et al., 2023a). Critical peak pricing sometimes

referred as contingencies pricing, is a strategy that allow utilities to charge more for energy during hottest summers days or periods of peak consumption(Kanakadhurga and Prabakaran, 2022), while extreme day price is a mandatory commitment to reduce load with penalties. Utility companies charge higher rate for energy on days when demand is exceptionally high (Asst Professor and Joseph Asst Professor, 2015).

This provides a comprehensive grasp of both incentive-based and price-based DR approaches, accentuating the essential mechanisms and strategies within the different categories, such as bill credits, time-of-use and real-time pricing, DLC, and ancillary markets, underscoring their significance in effectively controlling electricity demand and safeguarding grid stability.

2.4. Demand Side Management Programme Mechanism in Developed Countries

2.4.1 DSM Programmes in the United State (US)

The Electricity Supply sector in the United States is complex and diverse, with a combination of energy sources, a mix of regulated and competitive markets, and ongoing efforts to transition towards cleaner and more sustainable energy generation. It consists of several interconnected entities that work together to ensure the reliable supply of electricity to consumers. These generators can be privately owned companies, publicly owned utilities, or cooperative entities. In addition to the aforementioned entities, there are other stakeholders and organizations that play important roles within the USA Electric Supply Sector. These include regional transmission organizations (RTOs) and independent system operators (ISOs), which manage the operation of the transmission system, ensure grid reliability, and facilitate competitive wholesale electricity markets. RTOs and ISOs, such as the California Independent System Operator (CAISO) and the Pennsylvania-Maryland-New Jersey Interconnection (PJM), coordinate the movement of electricity across multiple states and manage the dispatch of generation resources to meet demand (EIA, 2021). The structure and organisation of the US Electric Supply industry vary across different regions with some states having deregulated or restructured their electricity markets, allowing for competition among electricity suppliers, while others maintain a vertically integrated utility model where a single utility handles all aspects of electricity generation, transmission, and distribution.

Utilities in the US have played a pivotal role in advancing EE and DR programmes, with a primary focus on EE, which represents the most extensive aspect of DSM. Between 2014 and 2017, these American utilities made substantial investments of \$5.9 billion, \$6.2 billion, and

\$5.9 billion, respectively. These investments led to increased energy savings, rising from 26.5 million MWh to 29.9 million MWh during the mentioned years. These initiatives included providing customer incentives like complimentary or low-cost energy audits for both residential and commercial properties, offering free or discounted energy-efficient light bulbs, and providing rebates for the purchase of energy-efficient appliances, among other measures (EIA, 2019). According to Mordor (Mordor, 2020), approximately 9.5 million customers are enrolled in different DR programmes, contributing to nearly 10% of the total electricity demand, resulting in substantial reductions in peak demand savings across utilities as illustrated in Figure 2.2.

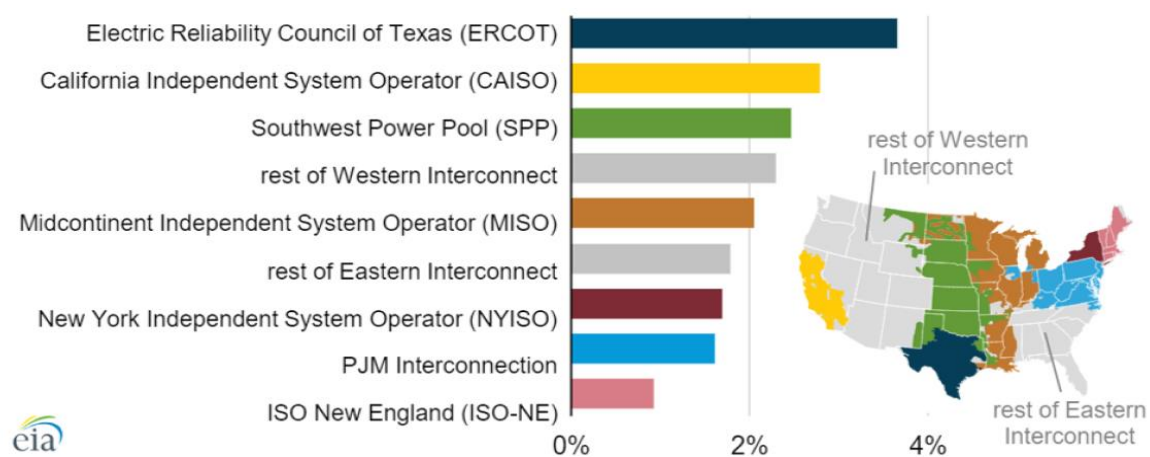


Figure 2. 2: Percentage of the Total Peak Demand Savings from DR (EIA-861, 2020).

The Pennsylvania-Maryland-New Jersey Interconnection (PJM), which serves as a mid-Atlantic grid operator overseeing wholesale electricity distribution, holds the distinction of being the largest power market in the United States. It operates across 13 states and the District of Columbia. The California Independent System Operator (CAISO) comes in as the second largest and most technologically advanced power grid on a global scale, providing its services to California, the most populous U.S. state with a population of 39.512 million (CA, 2020). In light of the state's ambitious energy policy to achieve carbon-free electricity by 2024 (BBC, 2018), a formidable challenge has emerged in managing the growing share of solar and wind energy sources, is turning to DR and EE as the bedrock to meet this challenge and establish the groundwork for a stable, cleaner, and environmentally sustainable electricity grid (CAISO - MO, 2020). DR plays a crucial part in PJM and CAISO market. The different array of market products operated by both PJM and CAISO is shown in Table 2.1(CAISO-MO, 2023; PJM-MO, 2020)

Table 2. 1: Summary of the PJM and CAISO Electricity Market (NEM) Mechanisms

Services	Function
Energy Market	This secures electricity to meet customer demand in real-time while providing the avenue for using locational marginal pricing (LMP) to voluntarily reduce consumption.
Day Ahead Scheduling Reserve Market	An offer-based energy market that provides an additional 30 minute30-minute reserve for energy generation and demand resources.
Capacity Market	Ensures the security of electricity supply by offering payment for dependable sources of capacity, along with their electricity revenues, to ensure they serve energy when required.
Synchronized Reserve Market	Auxiliary service provides an opportunity for a competitive development for the demand reduction response via investment in infrastructure, enabling fast response within 10 mins to maintain grid reliability due to unexpected disruptions either through load reduction or increased generation.
Regulation Reserve Market	Utilizes DR in adjusting generation to maintain frequency, enabling grid operators to balance supply and demand for a safe and reliable power system.
Load Curtailment service	Through intermediate agents, customers are compensated for energy reduction when requested by utilities during high power prices or when the grid reliability is being threatened

The California government in an effort to boost the DR programme in the residential sector ran a study to advance the DR programme with the goal to (i) Evaluate the effect of different timing and messaging, (ii) To assess diverse financial incentive mechanisms, (iii) To evaluate the current baseline methodology and the effect on customer electricity conservation, and (iv) To forestall the effect of time of use rate based on the project team research findings (Newsom, 2020). The regulatory reform has ushered fresh prospects for DR such as the DR auction mechanism (DRAM). DRAM aims to address areas where electric reliability could be in jeopardy. Its primary objective is the complete integration of DR resources into the CAISO market, allowing residential sectors to directly participate in the CAISO market, and exploring the potential for third-party resource contributions outside the confines of a structured utility programme (Chamberlin, 2017). CAISO identified the challenges hindering the success of DR programmes and proffers roadmaps in achieving a successfully configured DR programme

(See table 2.2). Eliminating these obstacles will enhance the integration of DR and EE, positioning them as crucial, dependable, and foreseeable assets that will underpin a resilient and environmentally friendly electrical power system.

Table 2. 2: The Barriers Hindering the DR Programme and the Recommendation by CASIO for a Properly Configured DR Programme.

Mechanism	Challenges	Recommendation
Market	Some Programmes were poorly aligned with the market while the capacity market limits the price	load shaping by maximizing the potential of DR and Energy Efficiency
Regulatory	Disconnection of policy implementation between utility companies with state and federal regulators	Resource sufficiency focuses on supply-side resources.
Customer participation	- Underestimation of customer behaviour by utilities and regulators - Underrating the market complexity	Independent system operator's process to optimize the use of resources in the supply side DR
Infrastructure & technology	Coordination of Scheduling, the level of transmission requirements for participating load in the market	Monitoring system for useful feedback on the process
Operations and settlements	- Reduce peak power purchases in the wholesale market. - Training of personnel in different DSM programmes	

The introduction of the state's green new normal initiative, focusing on fossil-free energy aims to elevate the current 36% share of fossil-free electricity generation to 60% by 2030 and ultimately achieve 100% by 2045 (CAISO-Renewable, 2021). The California state set targets and continuous dependence on renewable energy has increased the challenge for CAISO to ensure a reliable power supply in periods of intense heat which often causes a spike in power demand (CAISO-Green, 2016; WSJ, 2020). In August 2020, a comprehensive analysis was conducted in response to the rotating electricity outages, and it revealed that issues related to resource adequacy, planning processes, and certain market practices were the primary contributors to the problem. This highlights the necessity of reevaluating strategies to ensure a higher level of reliability and to avoid the recurrence of such events in the future (CEC-Report, 2021). The event has provided for a \$100m expansion of infrastructure which increases the

load reduction capacity from 100MW to 550MW over three years. The investment encompasses the distribution of intelligent thermostats for shifting air-conditioning loads and wireless smart plugs that allow for remote control of appliances, turning them on and off as needed (ST. John, 2021).

2.4.2. DSM Programme in Australia

The Electricity Supply Industry in Australia is diverse and characterised by a mix of energy sources, a liberalized market, and efforts to transition towards cleaner energy generation. The structure of the Australian Electric Supply Sector can be described as follows:

1. **Generation:** Electricity in Australia is primarily generated through various sources such as coal, natural gas, renewable energy (including wind, solar, hydro, and biomass), and nuclear power. There are both public and private companies involved in electricity generation (AEMC, 2023)
2. **Transmission:** The transmission network in Australia is responsible for carrying electricity from the generation facilities to distribution networks and major substations. This network is regulated and operated by several transmission network service providers (TNSPs) across different regions in the country (AEMO-MO, 2010).
3. **Distribution:** This delivers electricity from the transmission network to end-users, including residential, commercial, and industrial consumers. Distribution network service providers (DNSPs) are responsible for operating and maintaining the distribution infrastructure within specific geographic regions (AEMO-MO, 2010).
4. **Retail:** Retailers in the Australian Electric Supply Sector are responsible for selling electricity to end-consumers. They purchase electricity from the wholesale market and then sell it to residential, commercial, and industrial customers. Retailers compete in the market, offering different pricing plans and services to consumers (AEMC-ES, 2020).
5. **Market Operator:** The Australian Energy Market Operator (AEMO) plays a crucial role in the Australian Electric Supply Sector. It operates the wholesale electricity market, manages power system operations, and ensures the reliable and secure supply of electricity across the country. AEMO facilitates the balancing of electricity supply and demand, manages market settlements, and coordinates the dispatch of electricity generation (AEMO-EM, 2020).

6. **Market Regulator:** The Australian Energy Market Commission (AEMC) is responsible for developing and reviewing the rules and regulations that govern the electricity market in Australia. The AEMC oversees the market design and regulatory framework to promote competition, efficiency, and reliability in the electricity sector. It conducts inquiries, provides policy advice, and makes rule changes to support the long-term interests of consumers (AEMC, 2023).
7. **Government Entities:** Various government entities at the national and state levels also play a significant role in the Australian Electric Supply Sector. They set energy policy, establish targets for renewable energy generation, provide financial incentives for renewable projects, and regulate environmental standards and emissions reduction measures. Additionally, state-owned entities may own and operate electricity generation, transmission, and distribution assets in some regions (AG, 2023).

The Australian Energy Regulator (AER) is the regulatory body responsible for monitoring and enforcing regulations in the electricity industry. It sets the rules for network businesses, including transmission and distribution companies, and regulates wholesale and retail markets to ensure fair competition and protect consumer interests (AER, 2023). The Energy Regulator works with the Australian Energy Market Commission (AEMC), Australian Energy Market Operator (AEMO), Clean Energy Regulator (CER), and state-level regulatory authorities collectively to monitor market operations, enforce regulations, promote competition, and support the transition to cleaner and more sustainable energy sources (AUCE, 2023).

The Australian National Electricity Market (NEM) is operated by the AEMO across Victoria, Queensland, New South Wales, South Australia, Australian Capital Territory, and Tasmania (AEMO-EM, 2020). With a population of 25,764,830 (Worldometer-Australia, 2021). The electricity market operates as a spot market, emphasising real-time balancing of demand and supply through a centrally coordinated dispatch system. Market participants submit daily offers at 5-minute intervals, with a market price cap set at AUD12,500 per megawatt-hour (MWh). A customer has a choice to purchase energy from AEMO or a retailer with access to the spot market (AEMO-MO, 2010). ARENA (Australia Renewable Energy Agency) and AEMO have joined forces to oversee ten pilot DR initiatives valued at AUD35.7 million, expected to generate 200 megawatts (MW) of capacity in the regions of Victoria, South Australia, and New South Wales. This incentive-driven programme's primary objective is to curtail electricity usage when reserves reach critical levels and illustrate the potential of DR during scorching

summer heatwaves (ARENA, 2017). In spite of these initiatives, Australia remains less advanced in implementing DR for balancing mechanisms compared to the majority of European and North American countries (Deign, 2020). The Australia National Electricity Market (NEM) comprises two markets (see table 3):

- (a) Competitive wholesale markets (AEMC-LD, 2020; AEMC-SM, 2020; AEMO-AS, 2020).
- (b) Regulated monopoly network is a framework for the electricity sector (AEMC-ES, 2020; AEMC-NR, 2020).

Table 2. 3: Summary of the Australia National Electricity Market (NEM) Mechanisms

Market Class	Market Mechanism	Definition
Competitive wholesale markets	The spot market	• Reflects electricity consumption. • is a tool of AEMO matching supply from power stations in real-time consumption. • Through spot price change, it determines whether the generator output is ramped up or turned down.
	The contract market	• Is a central dispatch engine that selects and delivers energy from generators that offer the lowest price at 5 minutes intervals
	The ancillary service market	• Is engaged with AEMO for ensuring that the power system operation runs safely and efficiently. • Controls critical technical power system architecture such as frequency, voltage, network loading, and system restart processes through the market ancillary service agreement.
Regulated monopoly network		• This provides a framework for the electricity sector. • Determines the charges for service rendered by utilities. • Manages risk of monopoly pricing. • Creates a stable atmosphere for investment

AEMO facilitates customer access to the market for reducing energy consumption through a demand response mechanism (DRM) and ancillary services. The DRM empowers end-users to receive compensation for their DR actions in the spot market via a DR aggregator (DRA).

Initially, this mechanism is primarily designed to assist commercial and industrial users with an annual consumption of 100MWh per year. However, future adaptations are expected to extend participation to end-users (demand response loads) through the DRA (AEMO-DRM, 2013). AEMO operates eight separate ancillary markets (AEMO-AS, 2020), these ancillary service markets are categorised into three functions as shown in Table 2.4 (AEMO-AS, 2020; AEMO-MO, 2010; AEMO-NEM, 2015).

Table 2. 4: Ancillary Market in Australia

Ancillary Markets	Control	Control Mechanism
Frequency Control	Regulation	- Automatic generation control (AGC)
Ancillary Services (FCAS)		
Network Control	Contingency	- Generator governor responds by opening and
Ancillary Services		closing the turbine steam valve altering the output
(NCAS)		- Load shedding
		- Rapid generation of a generator when frequency
System Restart		relay detects low frequency.
Ancillary Services		- Rapid unit unloading of a generator at a high
(SRAS)		frequency

The Alcoa aluminium smelter in western Victoria demonstrated the capacity of DR by temporarily reducing its energy consumption for 100 minutes during a period of elevated temperatures. This proactive measure released 400 megawatts of electricity, effectively averting the need for grid load shedding, and highlighting the significant potential of DR in managing energy demand (ARENAWIRE, 2019). Meridian Energy, the retailer, as part of the DR trail, runs a mobile phone user-operated DR phone application. Participants will receive a notification from the app when power spikes up, requesting them to alter energy consumption. This system is to save 5MW a year (ARENAWIRE-PS, 2017). Furthermore, customers participating in the DR programme, including interruptible tariffs, spot pass-through, and scheduled loads, face varying levels of risk and transaction costs that are challenging for many commercial and industrial users to effectively handle. The policy, regulation, design, and competition in the past have amounted to the high cost of electricity, making it unaffordable to consumers and businesses (AEMO-DRM, 2013). The report (ACCC, 2018), and AEMC's draft rule reform for the energy market, scheduled for implementation in 2022, is designed to bring

down electricity costs. This reform empowers large commercial and industrial energy users, working through DRA, to enter the wholesale market by offering demand reductions. This increased competition is expected to result in lower prices for customers and improved efficiency in the power system. Additionally, the restructuring of the ancillary market allows DRAs to participate in FCAS using individual or aggregated loads, independently of the retailer, effectively removing control from the retailers (AEMC-DRM, 2019).

The ongoing expansion of renewable energy sources and the AEMO Integrated System Plan of 2020 underscore the demand for 6-19 GW of energy storage capacity by 2035 within the energy market. In response to this need, ARENA has engaged in various energy storage initiatives, including the AUD777 million Kidston hydro facility boasting a 250MW capacity. This energy storage infrastructure is designed to offer 8-hour storage capabilities, guaranteeing the reliability of energy supply and enhancing the security of power systems (ARENA-Kidston PHES, 2021). Another facility is the AUD30 million, 30MW/ 8MWh grid-connected battery energy storage for commercial renewable integration (ESCRI). This phase two programme seeks to provide storage assistance to renewable energy generation during instances of generation deficits, power outages, and the rapid provision of frequency response to stabilize the electricity grid. This is especially important as the deployment of additional renewable sources continues to grow (ARENA-ESCRI, 2021). Similarly, a AUD13.03million project with the aim to conduct trials on the deployment of 600MW PHES using underground coal mining voids as a cost reduction alternative compared to traditional PHES (ARENA-Coal PHES, 2021). Furthermore, project MATCH (Monitoring and Analysis Toolbox for Compliance in a High DER Future) is focused on investigating the response of distributed energy resources during disturbances, with the goal of furnishing AEMO with tools for effectively handling DER responses to disturbances and implementing necessary adjustments for FCAS associated with real-time DER generation. (ARENA-Project MATCH, 2021).

2.4.3. DSM Programme in United Kingdom

The United Kingdom's Electricity Supply Industry has undergone significant changes in recent years, driven by a combination of policy objectives, technological advancements, and environmental concerns. The industry has been evolving towards a more sustainable, low-carbon, and decentralised system. The structure of the UK Electric Supply Sector is composed of various entities and stakeholders involved in the generation, transmission, distribution, and supply of electricity as shown in figure 2.3. This sector has evolved over time, with changes in

regulation, privatisation, and the emergence of renewable energy sources. This is an overview of the structure of the UK Electric Supply Sector

1. **Generation Companies:** The UK Electric Supply Sector consists of several electricity generation companies that produce electricity from various sources, including fossil fuels, nuclear power, and renewable energy. These companies include EDF Energy, Centrica, Scottish Power, and RWE (Npower) (Ofgem, 2023)
2. **Transmission System Operator (TSO):** The TSO in the UK is the National Grid Electricity Transmission. It operates the high-voltage transmission network, ensuring reliable and secure transmission of electricity across the country (Ofgem Transmission, 2021).
3. **Distribution Network Operators (DNOs):** The UK has several DNOs responsible for operating and maintaining the regional electricity distribution networks. Examples of DNOs include UK Power Networks, Northern Powergrid, Western Power Distribution, and Scottish and Southern Electricity Networks (Ofgem Distribution, 2005)
4. **Independent System Operator (ISO):** The ISO in the UK is National Grid Electricity System Operator (ESO). It is responsible for balancing electricity supply and demand in real-time and maintaining system stability.
5. **Energy Suppliers:** Energy suppliers purchase electricity from generation companies or through the wholesale market and supply it to end consumers. These suppliers can be the "Big Six" energy companies, including British Gas, E.ON, EDF Energy, npower, Scottish Power, and SSE, as well as smaller independent suppliers
6. **Regulators:** The regulatory framework for the UK Electric Supply Sector is overseen by several regulatory bodies. Ofgem (Office of Gas and Electricity Markets) is the primary regulator responsible for promoting competition, protecting consumer interests, and ensuring the efficient operation of the electricity market (Ofgem, 2023).
7. **Market Operator:** The Electricity Market Reform (EMR) established the Low Carbon Contracts Company (LCCC) and the Electricity Settlements Company (ESC) as market operators. LCCC manages contracts for low-carbon electricity generators, while ESC is responsible for administering payments and settlements between market participants (Gov, 2023).

8. **Renewable Energy Generators:** The UK Electric Supply Sector has witnessed a significant increase in renewable energy generation. Renewable energy generators, such as wind farms, solar parks, and hydroelectric power plants, contribute to the electricity mix. Companies like Ørsted, Scottish and Southern Energy Renewables, and Vattenfall are active players in the renewable energy sector (Ofgem, 2023).
9. **Demand-Side Response Providers:** Demand-Side Response (DSR) providers enable consumers to adjust their electricity demand in response to price signals or grid requirements. These providers offer services such as load shifting, demand management, and energy storage solutions to support grid stability and optimise electricity usage (NGESO-DSR, 2020; NIC, 2023).
10. **Marketplaces and Exchanges:** The UK Electric Supply Sector includes marketplaces and exchanges where electricity is traded. The main market for electricity trading is the Day-Ahead Market, where suppliers and generators submit bids and offers for the next day's electricity supply. The Balancing Mechanism allows for real-time adjustments to balance electricity supply and demand(NGESO-DSR, 2020).
11. **Industry Associations:** There are various industry associations in the UK Electric Supply Sector that represent the interests of different stakeholders. For example, Energy UK is a trade association that represents energy suppliers, while the Renewable Energy Association (REA) represents renewable energy generators and promotes their interests (Energy UK, 2023).
12. **Government Departments:** Government departments play a crucial role in shaping the policies and regulations of the UK Electric Supply Sector. The Department for Business, Energy and Industrial Strategy (BEIS) is responsible for energy policy formulation, while the Office for Low Emission Vehicles (OLEV) focuses on promoting electric vehicle adoption and charging infrastructure (BEIS, 2023; LWV, 2023).

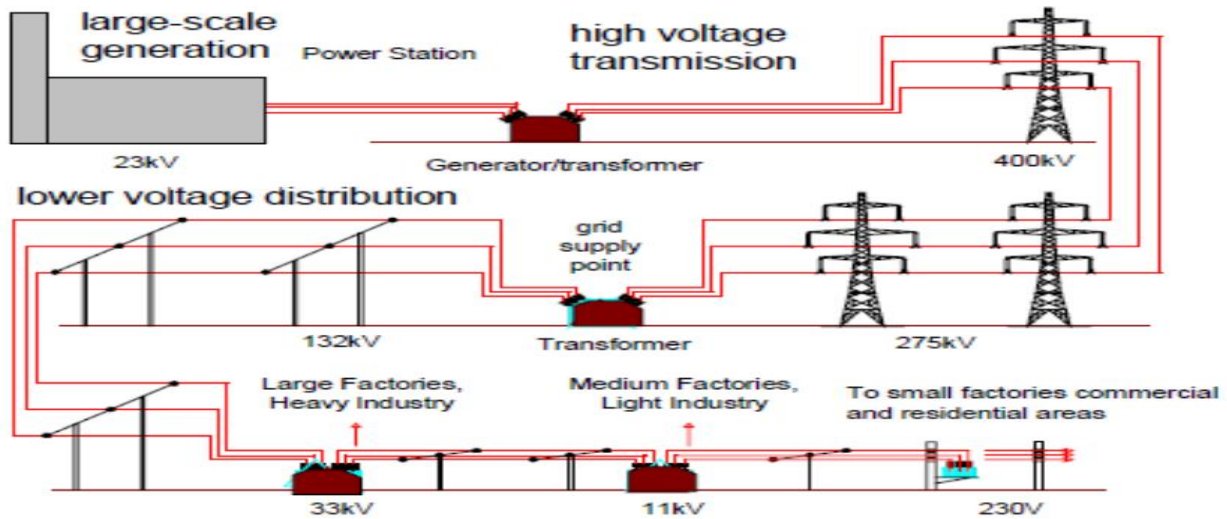


Figure 2. 3: An Interconnected Electricity System

The UK more than most other European countries provides different DR markets. These DR programs mark a significant shift in how the electricity market operates, transitioning from a traditional one-way approach to a system where consumers actively engage in controlling their energy usage by flexibly adjusting their demand. This initiative plays a crucial role in maintaining grid stability by aiding in power balance through ancillary services (Lau et al., 2015). Residential electricity consumption in the UK constitutes a significant one-third of the total electricity demand, with a substantial peak demand of 40%. This growing peak demand puts increasing pressure on the grid, leading to a mismatch between supply and demand and, consequently, a notable rise in energy costs (Palmer and Cooper, 2013). The National grid electricity system operator oversees the balancing mechanism, ensuring the creation of a resilient and flexible electricity system by collaborating with suppliers, generators, traders, and the wholesale electricity market (see Table 2.5)(Centrica, 2020). Prominent services contracted by the system operator are frequency response service, fast reserve, STOR and time use of tariff (Lau et al., 2015). Flexitricity, acting as a commercial aggregator, presents businesses with revenue-boosting prospects by enabling their participation in the STOR service. This service entails either generating a minimum of 3 MW of power or curbing energy demand within 4 hours of receiving instructions from the National Operator for a sustainable 2-hour duration. It also plays a vital role in frequency response services, mitigating frequency drops during significant power generation reductions. Additionally, Flexitricity engages in the Triad program, focusing on peak power demand during three half-hour periods within the months of November to February across the grid. (Flexitricity, 2020), with case studies of Royal United Hospital in Bath (Flexitricity-RBH, 2020) and Thamesway Central Milton Keynes

(Flexitricity-Thameswey, 2020). Another example is (Centrica, 2020), which provided EE solutions such as LED lighting, automatic doors, pipe insulation for Durham Country council at three facilities, providing a 34% energy reduction, saving 380kWh which translates to a GBP44,000 cost reduction (Centrica-DCC, 2020). Time of use programme such as Octopus Agile and Octopus Go and Go Tariff have played a significant role in shifting energy use to off-peak while providing the customer with the opportunity to save (Energy-stats, 2021).

The need for flexibility is increasing as more renewable power generation capacity has grown in the UK to 47% of its capacity in 2020, eclipsing fossil fuel (Ambrose, 2020). The UK boasts the world's largest offshore wind capacity, but the inconsistent wind speeds pose a significant challenge. To address this variability, the government has taken measures to eliminate obstacles hindering the development of extensive battery storage facilities for storing energy generated from wind and solar sources. The new legislation has lifted restrictions on storage capacities, allowing for installations above 50MW in England and 350MW in Wales. This strategic move is projected to result in savings of up to GBP 40 billion for the UK's energy system by 2050 (DBEI-Battery Storage, 2020). The policy change has also paved the way for a GBP10 million liquid air energy storage facility in Greater Manchester. This project, with a capacity of 50 MW/250 MWh, is anticipated to become one of Europe's most extensive energy storage facilities. It will provide electricity to 200,000 homes and offer longer-lasting performance compared to conventional lithium batteries, thus contributing to the UK's goals of delivering clean, dependable, and cost-effective energy storage for the national grid (Smart Energy, 2020).

This work offers a comprehensive examination of DSM initiatives in the United States, Australia, and the United Kingdom, aiming to assess the feasibility of implementing DSM. Through comparative analysis, it becomes evident that these developed nations have made substantial strides in DSM adoption, with the U.S. meeting 10% of its electricity demand through DSM, the UK showcasing flexibility from industrial and commercial end-users totalling 2300 megawatts (MW), and Australia surpassing contracted capacity in various trial projects, exceeding 200 megawatts (MW). Additionally, the study highlights impediments to full exploitation of DSM's potential, including issues such as programme-market misalignment, disconnect between operators and regulators in policy implementation, underestimation of market complexities, overlooking customer behaviour in DSM programmes, and a lack of proper personnel training to operate diverse DSM initiatives effectively.

Table 2. 5: Balancing Services in the United Kingdom (Mirzania et al., 2019; NGESO-BS, 2020).

Class of Services	Major Service Stream	Functions
Frequency response service	Firm frequency response, Mandatory response services, Dynamic containment, Auction trail,	These services are designed to manage the real-time balance between system demand and total generation to maintain frequency control of $\pm 1\%$ of 50Hz
Reserve revenue	Fast reserve, Short-term operating reserve (STOR), Demand turn up, Super SEL, BM start up Replacement reserve	These services provide additional power source services enabling the system operator to source extra power by increased generation or demand reduction.
System security	Interstrip, System operator to system operator (SO to SO), Black start, Transmission constraints management & maximum generation	Provides different balancing services by buying or selling electricity in the balancing mechanism or trading and entering contracts, it provides a control mechanism in an event of a fault in the system
Trading	Forward trading via bilateral agreements & Contract enactment	System operator utilises the service to provide security of supply and attain balancing requirements at minimum cost through trade between the operator and other counterparties.
Demand side response	Large industrial and commercial customers, small to medium enterprise & aggregator	Energy users are provided with a financial incentive to turn up, turn down or shift demand in real-time in response to signal from the National grid at peak demand or system stresses.
Reactive power services	Obligatory reactive power service (ORPS), Enhanced reactive power service (ERPS)	The provision of reactive power required and contingencies for the system

2.5. Demand Side Management Programme Mechanism in Developing Countries

2.5.1 DSM Programme in India

India is globally the third-largest energy consumer, with the fifth-largest electricity grid and third-largest distribution and transmission network with a total installed capacity of 372,693MW of electricity (EIA-India, 2017; MoP-India, 2020). The network faces the challenge of voltage fluctuations, recurrent load shedding, lack of reactive power support, and inefficient metering systems (Mukhopadhyay and Rajput, 2010a). for grid energy requirement in 2019 of 1291010 million units (MU) while only 1284444 is available. Peak demand stands at 183804 MW, and only 182533 MW was able to be met (MoP-India, 2020), for a population of 1,383,234,052 (Worldometer, 2020).

In 2001, the Energy Conservation Act was implemented in India, aiming to decrease energy intensity. The Bureau of Energy Efficiency was entrusted with the task of establishing a regulatory framework for this purpose (MoP-EE, 2020). Energy conservation act offers a mandate for the following schemes to encourage EE and energy conservation:

- 1) Standard and labelling of equipment and appliance: this initiative empowers consumers to make choices that save energy and reduce costs by establishing energy consumption limits and affixing energy performance labels, equipping customers with essential information for making well-informed purchases. Currently, there are 26 appliances and equipment with star ratings under this scheme (BEE-S&L, 2020).
- 2) Energy conversion building codes for commercial buildings (ECBC): this provides a vital means to control the growth of energy consumption in the future, offering cost-saving tools to building occupants and proprietors, given that the building sector constitutes 33% of total energy use. The effective enforcement of this code is expected to yield savings of 125 billion units of electricity by 2030. (Shaurya Bajaj, 2018).

DSM in India is categorised into different aspects as highlighted in table 2.6:

Table 2. 6: DSM Programmes in India (BEE-AgDSM, 2020; BEE-Capacity DISCOMs, 2020; BEE-Municipal, 2020).

Programme	Phase/ Period	No of ULB	Time (Year)	No. of distribution companies	Function
Capacity building	1		2012- 17	34	• Reduce peak power purchases in the wholesale market. • Training of personnel in different DSM programmes
	2		2017- 20	28	• The research on load profile • Training on load management
Municipal	XI XII	/ 175			• To improve energy efficiency in urban local bodies • Potential savings of 120MW
Agriculture	XI				• Increase energy efficiency in the agricultural sector • Increase awareness among end-users

In the small and medium enterprises (SMEs) sector, EE is a critical concern, involving a substantial number of sixty-three million enterprises. The majority of these enterprises currently lack EE, primarily because they rely on outdated and inefficient technologies. As part of their efforts, the Bureau of Energy Efficiency (BEE) undertook an intervention involving 25 SMEs during the XI plan. A comprehensive study was carried out to evaluate the technology gap, create EE manuals, and provide capacity-building initiatives, among other actions. Simultaneously, the second phase is the implementation of 100 technology-proved projects in 5 SME sectors (BEE-SME, 2020). The need for DSM in India cannot be overemphasised, with demand outstripping the capacity and inadequate cash flow by utilities (CTI, 2020). The major hurdles facing DSM implementation include the lack of awareness and knowledge among both utility companies and consumers, cross-subsidies benefiting agricultural and domestic customers, inefficiencies in tariff structures and market organisation. Additionally, utilities' reluctance to encourage EE measures among industrial and commercial customers due to concerns about revenue loss from these high-paying clients, coupled with the absence of penalties for not implementing power factor correction, have hindered the progress of DSM (Mukhopadhyay and Rajput, 2010b). Appropriate policy and programme with legal backing, incentives for DSM investment, proper tariff structure will propel the development of DSM in India (Harish and Kumar, 2014).

The government intends to attain 175GW of renewable energy (100GW from Solar, 10GW from bio-power, 60GW from wind and 5GW from hydropower) by 2022, with projections indicating renewable energy will contribute 20.3% and 24.2% by 2027 (Charles Rajesh Kumar and Majid, 2020). At present, India boasts an installed capacity of 73.74 GW for variable renewable energy (VRE) derived from solar and wind sources, constituting 19.79% of the total installed capacity. According to reports from the national load dispatch agency, the energy mix experiences fluctuations ranging from 6% to 10% over the span of a month. This situation arises due to the absence of adequate energy storage facilities, resulting in all the generated energy being injected into the grid, potentially causing frequency imbalances. This challenge has impeded the expansion of renewable energy and the ability to support grid control by harnessing energy from a mix of thermal and hydropower sources (Samuel, 2020). The expansion of renewable energy faces significant hurdles because the sector heavily depends on private investment and government incentives. The COVID-19 pandemic has presented various financial and logistical challenges, widening the disparity between the current capacity and the desired target (Shekhar et al., 2021).

2.5.2 DSM Programme in South Africa

The South African electricity supply industry is a vertically integrated, publicly owned utility of the South African Government known as Eskom Holding SOC Limited (Eskom). This is regulated by the national electricity regulator of South Africa (NERSA) (Eberhard, 2000), (Mirzania, Balta-Ozkan and Marais, 2020). For a population of 59,978,099 (Worldometer-SA, 2021), South Africa has an installed 48 GW capacity with Eskom supplying 94% to the market, while 6% by municipal power stations and the private sector (Thomson Reuters, 2020). The South Africa Electricity Supply Sector is structured in a way that involves various entities responsible for different aspects of electricity generation, transmission, and distribution. Here is an overview of the structure.

1. Generation: The generation of electricity in South Africa is primarily carried out by Eskom Holdings SOC Limited (Eskom). They operate numerous coal-fired power stations and some hydroelectric and pumped storage facilities (Eskom, 2023). In recent years, efforts have been made to diversify the generation mix and incorporate renewable energy sources through the Renewable Energy Independent Power Producer Procurement (REIPPP) programme (Eskom Generation, 2023; SA REIPPP, 2023).

2. **Transmission:** The transmission of electricity is handled by Eskom through its subsidiary, Eskom Transmission Division, which operates the high-voltage transmission grid across South Africa. The transmission grid connects power stations to distribution networks and significant load centres (Eskom Transmission, 2023).
3. **Distribution:** Electricity distribution in South Africa is managed by various regional electricity distributors, also known as municipalities or metros, operating at the municipal or regional level. These distributors are responsible for operating, maintaining, and developing the electricity distribution networks within their respective jurisdictions (Eskom Generation, 2023). Examples of distribution entities include City Power in Johannesburg, Cape Town Electricity Services in Cape Town, and eThekweni Electricity in Durban.
4. **Regulation:** The Electricity Supply Industry in South Africa is regulated by the National Energy Regulator of South Africa (NERSA), which is an independent regulatory authority. NERSA's role includes setting electricity tariffs, issuing licenses, promoting competition, and ensuring compliance with regulations and standards (NERSA, 2023)

The depletion of the electricity reserve margin has resulted in significant power shortages, necessitating the implementation of balancing mechanisms such as load shedding (Minnaar, Visser and Crafford, 2017; Monyei and Adewumi, 2017). In 2004, NERSA introduced a regulatory policy on EE and DSM, making EE/DSM a prerequisite for obtaining licenses for all electricity distributors. (ESMAP, 2011). A total of 203 across different programmes led to a substantial reduction in evening peak demand, amounting to 409.6 MW, in line with NERSA's projected savings of 379 MW (ESMAP, 2011). Peak demand ranges between six in the morning and midday, and five to nine in the evening (ESKOM-IDM, 2014).

DSM is an integral part of South Africa electricity market with DR programmes driven by the occurrence of constraints on the national power system. These DR programmes are categorised into four as shown in Table 2.7 while EE programmes are highlighted in Table 2.8.

Table 2. 7: DR Programmes in South Africa (Eskom-DR, 2020; Vaughan Smith, 2017).

Programme	Load criteria (MW)	Period (Minutes)	Utility notification period (Minutes)	Function
Non- dispatchable	2			• Mitigating system constraints through load shifting or peak clipping.
Instantaneous	10	10	0.1	• Is a frequency response programme to reduce demand.
Supplemental	0.5	60	30	• Ancillary serves used for demand reduction.
Emergency reverse			10	• Utilises interruptible loads, generator emergency capacity and gas turbine capacity to provide system stability.

Table 2. 8: EE Programmes in South Africa (DOME-Sa, 2005; DOME-SaSP, 2005; Eskom, 2011; Skinner, 2012).

Programme	No of programme	Period	Demand Savings (MW)	Energy Savings (GWh)	Function
Eskom Integrated demand management			0.25		• Incentive to install energy-efficient technology to support demand reduction during peak demand
Standard offer	80	3	32.3	209.6	• Load reduction for industrial/commercial customers ranges from 50kW-5MW
Performance Contracting	12	3		1307	• A medium size scheme for industries of the size of 30GWh
Standard product	1287		50.1	323	• Is a pre-approved rebate for the replacement of equipment such as showerheads, lighting and industrial heat pumps with energy savings ones.
Residential mass roll-out			125		• Is a scheme for the replacement of inefficient technologies with compact fluorescent lamps, light emitting diodes, showerheads, geyser controllers for residential customer

DR and EE's role in the energy market is projected to play a significant part with electricity costs set to increase by 15% from mid-2021. These increases in energy tariffs are the driving force for growth development, decreasing grid reliability based on load shedding. Policy enabling private or distributed generation may encourage businesses to choose to relinquish

expensive grids, thereby eliminating the Eskom revenue stream, further worsening the tariff cost (ESI-Africa, 2020). South Africa is highly reliant on coal with generation of close to 70%, while biofuel 10.7%, crude oil 14.8%, nuclear 2.4%, gas 2.9%, hydroelectric 0.1% and the combination of solar and wind accounts for 0.1% of the energy supply (Colthorpe, 2018). Renewable energy is poised to have a significant impact, as evidenced by the projected total revenue of \$1.3 billion in the energy market for 2019, reflecting a notable compound annual growth rate of 20.3% from 2015 to 2019 (Market Research, 2021). The initiation of the Renewable Energy Independent Power Producer Procurement Programme aims to facilitate the deployment of 17.8 GW of renewable energy sources such as wind, solar, biomass, biogas, and hydropower. This initiative, spanning from 2012 to 2030, is anticipated to decrease the reliance on nuclear and coal as primary energy sources (Walwyn and Brent, 2015). The government has implemented laws to impose penalties on high carbon emitters, including mines and large industrial operators, through the introduction of a new carbon tax. Simultaneously, banks have taken steps to discontinue financing for new coal power stations (ESI- Africa, 2019). To decarbonise the country and meet the energy demand, Eskom has launched 1400MWh solar plus storage and energy storage projects to allow for the greater integration of renewable (Colthorpe, 2018). The approval for the development of a 128 MW integrated facility that combines photovoltaic, wind, and lithium-ion battery storage technology marks it as the most extensive hybrid energy initiative in Africa. This plant is anticipated to supply electricity from 5:00 AM to 9:30 PM, with any surplus energy being stored in the lithium batteries (Caboz, 2021).

2.6. Comparison of DSM Programmes in Developed and Developing Countries.

Many developed countries have introduced a range of DSM programmes, it is feasible to pinpoint key success factors that can serve as relevant components when designing a framework for integrating DSM into Nigeria's energy market. For instance, both the U.S. and Australia have conducted quantitative trials to reduce peak loads through price-based programmes, such as real-time pricing, time-of-use, and critical-peak pricing. These programmes were primarily implemented in the residential, commercial, and industrial sectors of their energy systems, enhancing supply security. In the U.K, a pricing-oriented initiative like Octopus Agile or Octopus Go and Go Faster has been primarily adopted by energy-intensive consumers in the industrial and large-commercial sectors. This approach offers tariff flexibility, thereby enhancing the overall energy management system. In India, price-based tariffs have predominantly been applied in the industrial sector, and there is ongoing consideration for their

implementation in the commercial sector. In South Africa, the industrial and commercial sectors introduced price-based tariffs. However, the fixed operating hours for most commercial customers in the country, typically running from 8 am to 6 pm, may eventually steer them towards a flat-rate tariff structure, as they often lack the flexibility to adjust their energy demand (Cousins, 2020)). There's a proposal to implement a time-of-use programme for residential customers by 2021 (Eskom, 2020).

Incentive-based programmes (e.g., DLC, interruptible/curtailable programmes) have been introduced to residential, commercial, and industrial customers with the aim of load reduction (or increase) during system contingencies, offering discounted bills or credits in return. These programmes follow an aggregator business model and have mainly been adopted in the United States. Presently, incentive-based programmes in the electricity markets of Australia and the UK are primarily accessible to large industrial customers (Monyei and Adewumi, 2017). The findings of this study vividly demonstrate the potential of utilising DLC programmes for load management in a developing nation. Incentive-based programmes are considered the ultimate safeguard in ensuring energy security and power system stability. Interestingly, these programmes have not yet been implemented in South Africa, Nigeria, and India.

EE programmes have revolutionised global energy consumption patterns. Various EE policies and schemes, including fuel economy standards, appliance and equipment EE regulations, and the Energy Star programme, have been implemented in the United States. These policies and programmes have resulted in substantial savings, preventing annual power consumption from being 23% higher. Moreover, EE programmes have generated 2.3 million jobs, constituting 40% of all employment opportunities in the energy sector (EE, 2020). EE policy in Australia has shown a substantial decline in household electricity over the last decades despite increased household equipment in a country with appliances and lighting accounting for 30% and 15%, respectively. UK Energy Efficiency programme (EEC 1 and EEC2) achieved savings of 86.8TWh and 187TWh (Warren, 2014). South Africa and India have significantly invested in the EE programme to reduce peak demand reduction with campaigns aimed at the mass roll-out of CFL bulbs, consequently improving energy management.

A comparison of the level of implementation of these DSM programmes in the abovementioned countries is presented in Table 2.9.

The comparison classified the DSM programme into three categories: i) Price based, ii) Incentive-based and iii) EE programmes. The analysis on the level of implementation for the

different countries is based on categories (e.g., industrial, commercial, and residential sectors). “Majorly implemented” means these countries run different DSM programmes in the three sectors of industrial, commercial, and residential, partly implemented indicate various DSM programmes in two sectors while “Not/negligible implementation” illustrates a non/insignificant number of programmes in any of the sectors. This comparison illustrates the level of implementation of DSM programmes in these countries.

Table 2. 9: Comparison of DSM Programmes

DSM Programme	Example	Developed Countries			Developing Countries		
		US	Australia	UK	India	South Africa	Nigeria
Price-based	Time-of-day/time-of-use pricing	M	M	P	P	P	N
Incentive-based	Direct-load-control	M	P	P	N	N	N
Energy efficiency improvement	Compact fluorescent lamps, LED	M	P	P	P	P	P

M: Majorly Implemented; P: Partly Implemented; N: Not/negligible Implementation

The comparison analysis indicates that various developed countries have successfully implemented diverse DSM programmes, encompassing both price-based and incentive-based strategies, alongside EE initiatives, providing valuable insight and potential success factor that can guide for the development of DSM mechanisms in Nigeria’s energy market, leading to enhanced energy management, security of supply and the prospect of significant cost savings and employment opportunities.

2.7. DSM Programme in Nigeria

Nigeria is Africa's largest populated country, with 206 million people, growing at an average of 2% annually with a United Nations projection of 401.31 and 728 million by 2050 and 2100 respectively (Energypedia, 2019; WPR, 2020). The Sub-Saharan country can boost an estimated reserve of 185 trillion cubic feet of natural gas, 2.75 billion tons of coal, and 35 billion barrels of crude oil (Olaoye et al., 2016).

2.7.1 Overview of Nigerian Electricity Market (NEM)

The Nigeria Electricity supply industry dates to 1886 with two small generators to serve the then commercial capital colony, Lagos. An Act of parliament in 1951 and 1962 respectively created the Electricity Corporation of Nigeria (ECN) to develop and supply electricity and Niger Dams Authority to cater to the dam construction of Kainji on the River Niger (ECN, 2014). The Federal Government of Nigeria (FGN) merged the two companies based on decree no. 24 of 1972 as part of the power industry's evolution to form a unified body known as National Electric Power Authority (NEPA), which was responsible for electricity generation, transmission, and distribution in Nigeria. Figure 2.4 shows the National grid comprising 330 kV and 132 kV. The ongoing challenges in power supply have prompted several modifications, with the most recent one being the Electric Power Sector Reform Act of 2005, commonly referred to as the EPSR Act 2005. This legal framework facilitated the privatisation of the power sector and the establishment of 18 companies, predominantly under private ownership. These entities encompassed the six generation companies (GENCOs), a sole transmission company (TCN), and a 60% stake in the eleven distribution companies (DISCOs). This transition has opened doors for increased private sector engagement in the industry (NESO, 2020). The country has an installed capacity of 10,396MW (thermal 8,457.6MW, and hydropower 1,938.4MW) (NESI, 2020a). The Table 2.10 illustrates the importance of the various energy sources. For comparison, the table shows the average value for the world and Africa.

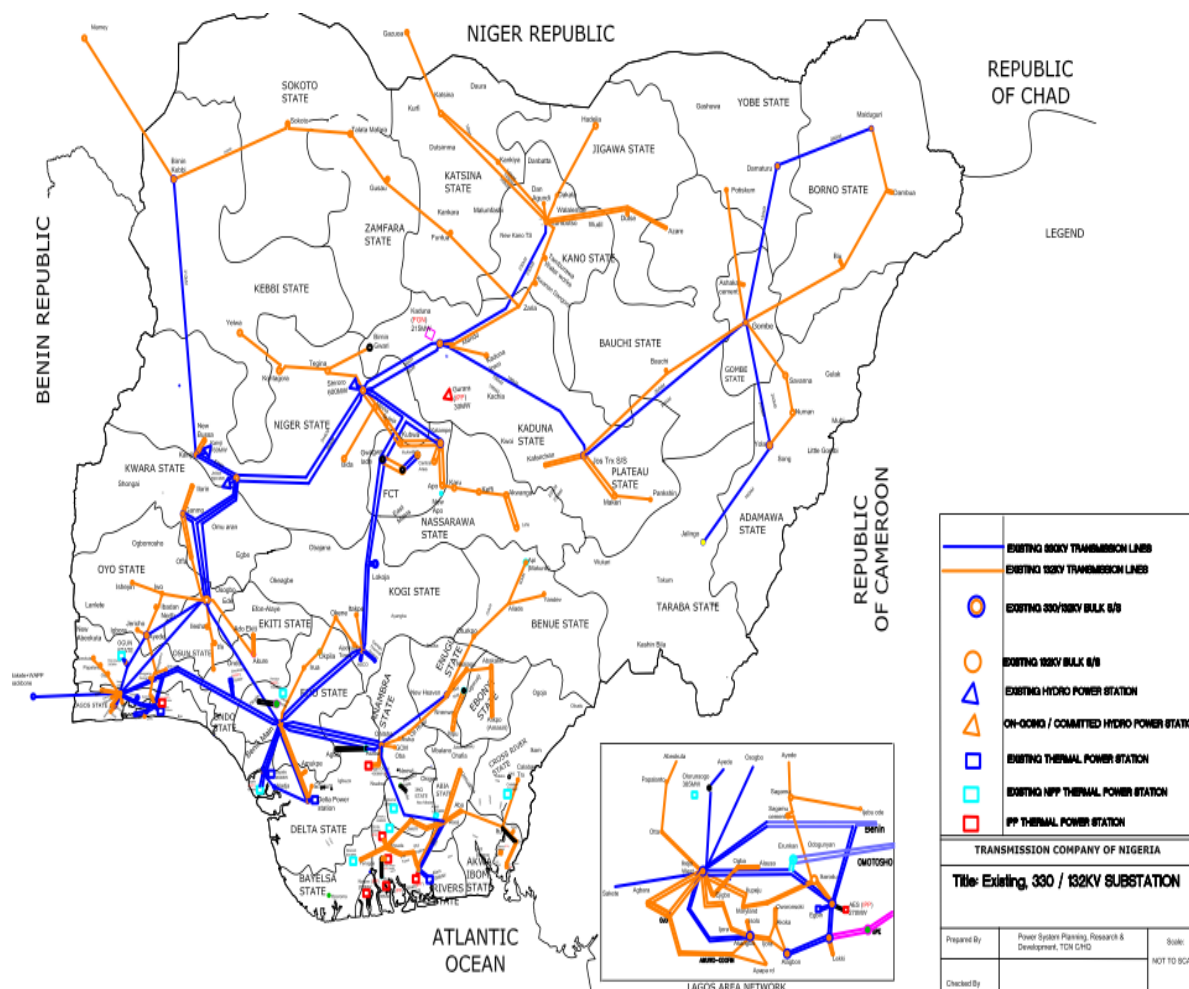


Figure 2. 4: Nigeria National Grid (NESO, 2023)

Table 2. 10: Percent of Electricity Generation (Global Petrol Price, 2020).

Energy Source	Nigeria	Africa	World
Fossil	81.72	79.96	65.81
Wind	0.01	1.1	4.75
Solar	0.08	0.48	1.79
Hydro	18.19	16.09	16.85
Nuclear	0	1.88	10.47
Geothermal	0	0.5	0.33

The Nigerian Electricity Market (NEM) has undergone a substantial transformation in recent years with the objective of enhancing energy security within the country. The structure of the Nigeria electricity market, as depicted in Figure 2.5, has been meticulously designed to promote efficiency, competitiveness, reliability, and transparency in the electricity market. This transformation was structured into Pre-privatisation and Post-privatisation categorised with a four-stage framework: (i) Pre-transitional stage of unbundling of state-owned utility and

privatising of generation and distribution assets, (ii) Transitional phase providing a formalised competition with transactions based on contracts, (iii) Medium stage creates more competition in generation with a centralised balancing mechanism, (iv) Long term stage is the full implementation of competitive wholesale and retail electricity market (NERC, 2020a).

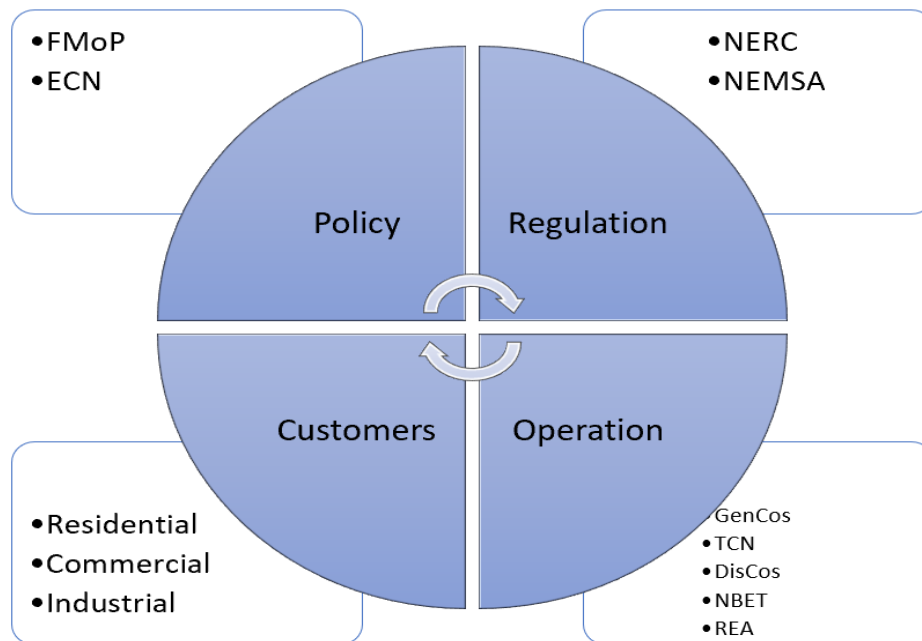


Figure 2. 5: Nigeria Electricity Market Industry

The Nigeria Electricity Supply industry value chain comprises of the following.

1. **Generation Companies (GenCos):** these companies are responsible for the generated electric power in Nigeria (NESI, 2020a)
2. **Transmission Company of Nigeria (TCN):** TCN is the sole transmission system operator in the country. This entity is responsible for bulk transfer of electricity from the different generating companies to the distribution companies (DisCos). Furthermore, it is responsible for operation and maintenance of the national grid infrastructure (TCN, 2020).
3. **Distribution Companies (DisCos):** this company serves as the final stage in the value chain saddled with the responsibility of delivering electric power to the consumer (NESI, 2020b). Examples of DisCos include Abuja Electricity Distribution Company, Eko Electricity Distribution Company, and Ikeja Electric.
4. **Nigeria Bulk Electricity Trading Company Plc (NBET):** is wholly owned by the Federal Government of Nigeria and empowered by industry regulator (NERC) to serve as the

manager of the electricity pool. They are a licensed trader who purchases electricity from generating companies and sell off to the distribution companies (NBET, 2020).

The regulatory institutions withing the Nigeria Electricity Supply industry includes:

1. Ministry of Power (FMoP): they are the arm of Nigeria's federal government responsible for supplying policy guidance for the supply industry (FMP, 2020).
2. Energy Commission of Nigeria (ECN): this agency is mandated to provide strategic design and harmonization of national policies in Energy(ECN, 2020).
3. Nigerian Electricity Regulatory Commission (NERC): this an arm of federal government established as an independent regulatory body, empowered to set tariff, issue licenses, and regulate the activities of market operators such as regulating the generation, transmission, and distribution (NERC, 2020b).
4. Nigerian Electricity Management Services Agency (NEMSA): the agency is established to inspect, test techniques, and certify all classifications of electrical installations, electrical meters, and instruments to ensure efficient, reliable, and sustainable delivery of electric power supply (NEMSA, 2020)
5. Rural Electricity Agency (REA): this agency is designated to encourage, support, and deliver rural electrification programmes via the involvement of the public and private sector promoting grid and off-grid development (REA, 2020).

2.7.2 Challenges in the Nigeria Electric Power Systems

The difficulty of achieving energy security is vividly depicted in Figure 2.6. Data collected over nine months in 2018 reveals that the available energy fluctuated between 3,700 and 4,100MW, despite a system capacity ranging between 7,400 and 8,200MW. This fluctuation can be attributed to a combination of factors such as inadequate gas supply, limitation of distribution network, challenges with water management, transmission line capacity limitation, and other associated infrastructure issues (Oseni, 2018). The further decrease can be attributed to factors such as inadequate funding for power stations, insufficient communication infrastructure, ineffective maintenance with delays, low staff morale, outdated equipment and tools, safety concerns, and a lack of operational vehicles (Sambo et al., 2010). Distribution sector has challenges such as inadequate metering, electricity theft, and revenue collection remain significant issues marring the development of the sector (Anon, 2020).

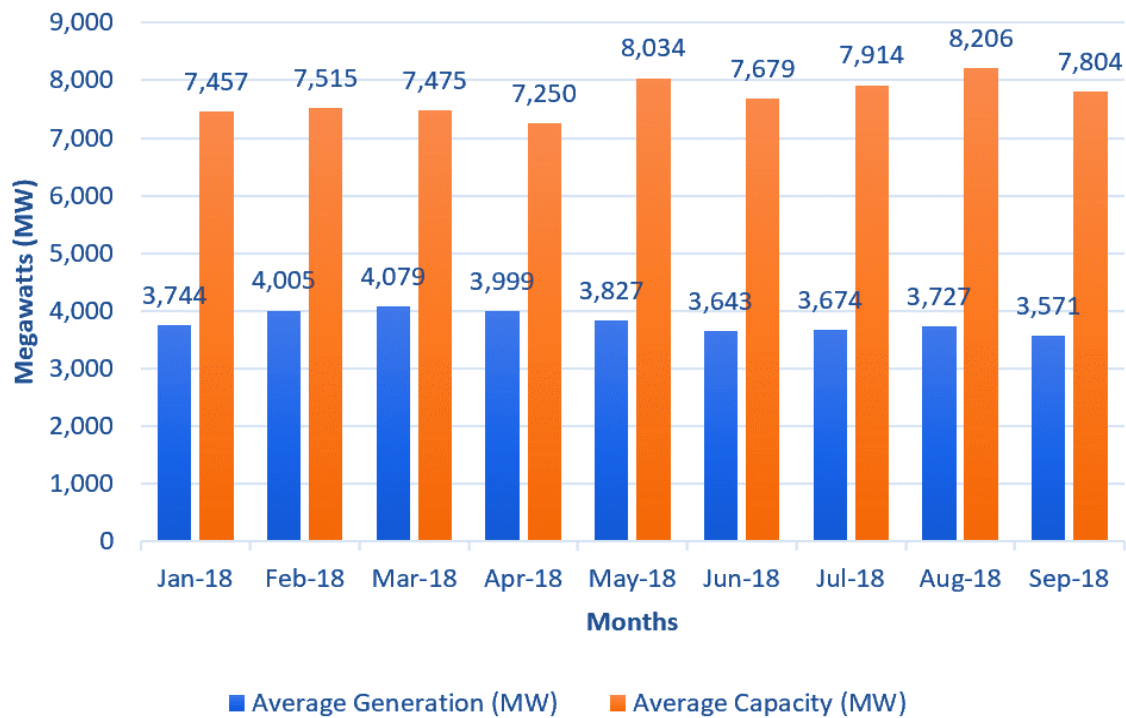


Figure 2. 6: Capacity Margin (MW) (Arowolo and Perez, 2020).

In 2017, The Power Sector Recovery Programme (PSRP) was launched to facilitate the financial and operational turnaround of the sector. The programme includes measures to address tariff shortfalls, improve revenue collection, enhance governance, and strengthen regulatory oversight. It intends to attract private investment and encourage renewable energy development, the government introduced policies such as the Mini-Grids Regulation and the Nigerian Electricity Regulatory Commission Feed-In Tariffs for Renewable Energy Regulations (NERC, 2021). These policies aim to promote off-grid and renewable energy solutions to complement the centralised grid system (Qadir et al., 2021)

In 2019, the Federal Government of Nigeria forged a strategic collaboration with Siemens Power to establish the Nigeria Electrification Roadmap. These initiatives aimed at revamping, enhancing, and extending the power transmission and distribution systems, along with boosting power generation. At the heart of this multifaceted roadmap lies the ambitious plan to implement a state-of-the-art Supervisory Control and Data Acquisition (SCADA) system, complemented by a cutting-edge Energy Management System (EMS). This pivotal component of the roadmap is further supported by the development of requisite telecommunication infrastructure. These combined advancements are poised to usher in a new era in the Nigerian power sector, empowering it with real-time visibility, robust monitoring capabilities, and

highly efficient power dispatching mechanisms (Siemens, 2019). The roadmap is categorized into three-phase:

1. Phase 1 (by 2021): This will concentrate on critical and swift win measures by upgrading the system end to end operating capacity to 7 GW.
2. Phase 2 (by 2023): This stage drives to illuminate the remaining bottlenecks to enable the full utilisation of the existing structure of the generation network and last-mile distribution capacities, bringing the system's operating capacity to 11 GW.
3. Phase 3 (by 2025): The final stage of the agreement includes upgrading and expanding the grid to a capacity of 25GW (Omonfoman, 2019).

2.7.3 Energy Policy Evolution in Nigeria

The National Energy Policy provides amongst others: (i) Promotion of Energy Efficiency and conservation in the industry, (ii) Enlightening of customers on the benefit of improved Energy Efficiency, (iii) The creation of guidelines and regulation of Energy Efficiency within the country, (iv) The policy on utilisation of Energy Efficiency methodology, machinery, and technologies for the construction, agriculture, industry, transport, household and commercial/Service sectors, (v) Development of standards, codes, guidelines on energy conservation (Energy Commission of Nigeria, 2018). Furthermore, NERC has historically promoted energy efficiency at different times through (i) EPSR Act 2005, (ii) Draft National energy master plan in 2006 later revised in 2011, (iii) In 2008, the creation of Energy Efficiency labelling standard for an electrical appliance, equipment, and machinery, (iv) Inter-ministration committee on renewable energy (RE) and Energy Efficiency in 2009, (v) Review of Multi-year tariff order (MYTO) presenting Energy Efficiency as cost migration to consumers (Abdussalam, 2014). NERC has developed two programmes:

- 1) Promoting the use of CFL and LED lighting options is expected to yield substantial advantages. By replacing traditional bulbs with these energy-efficient alternatives, it is projected to result in a considerable decrease in peak electricity demand, estimated to range from 3,000 MW to 4,000 MW. This reduction in peak demand closely aligns with the residential peak demand, with lighting consumption accounting for approximately 60% of this reduction (Chinedum O. Ukabiala, 2014).
- 2) The implementation and distribution of electricity meters through the Meter Asset Provider (MAP) system is established to facilitate the procurement, installation, and upkeep of end-user meters by independent providers authorised by the regulatory

commission (NERC-MAP, 2018). This initiative aims to address the shortfall in metering within the electricity market. The 11 DISCOs have a combined customer base of 8,292,840 but have so far equipped only 3,591,168 customers with meters, resulting in a 43% coverage rate (The Sun, 2019). The Nigerian government has granted a one-year postponement of the 35% import adjustment tax (levy) to facilitate the deployment of three million electricity meters (Leadership, 2020; Sweet Crude, 2020).

The Nigerian national energy efficiency action plan envisions that as awareness grows, the adoption of efficient lighting in households will surge by 40% in 2020 and 100% in 2030. In addition, the high-energy consumption sectors, including transportation, power, and industry, are projected to grow by 20% in 2020 and 50% compared to the baseline, ultimately aiming to reduce distribution losses to less than 10% (NACOP, 2015). The DSM's potential is enormous, particularly with the anticipated surge in electrification due to industrialization. As industrial demand for electricity continues to grow, it is expected to provide a strong foundation for the expansion of demand flexibility, thereby creating a broader scope for DSM to play a more prominent role within the electricity market (Ikpe and Torriti, 2018).

Nigeria possesses abundant conventional energy resources, which have historically accounted for more than 90% of the nation's revenue and served as the primary sources for electricity generation (Aliyu, Dada and Adam, 2015). The availability of ample renewable resources, such as solar, wind, hydroelectric, tidal, and biomass, has been the driving force behind the creation of the Renewable Energy Master Plan (REMP) (Dada, 2014b). The plan seeks to grow the supply of renewable energy by 13% in 2015, 23% in 2025 and 36% by 2030 (IEA-Renewable, 2013). Renewable energy deployment in Nigeria has primarily involved customers installing residential rooftop PV systems. Government initiatives have focused on investing in microgrid systems to provide remote off-grid solutions to rural areas lacking access to the grid.

As part of the government's economic sustainability plan in response to the post-COVID-19 situation, a new off-grid solar connection project is planned to electrify five million communities. This initiative is expected to generate NGN 7 billion (USD 18 million) in additional tax revenue annually, reduce annual import costs by USD 10 million, expand energy access to 25 million people through solar home systems (SHS) or mini-grid connections, enhance local content in the off-grid solar sector, and create 250,000 new jobs in the energy industry (REA-Solar Naija, 2021). The Energizing Economics Initiative is dedicated to implementing off-grid solutions for micro, small, and medium enterprises, including markets,

shopping complexes, and agricultural/industrial clusters. The primary goal is to enhance energy accessibility and foster economic development, with a projected generation of 2,500 job opportunities (REA-EEI, 2021). The Energizing Education Programme (EEP) is an additional project that aims to implement a solar hybrid and/or gas-fired captive power plant with a total capacity of 28.5MW across nine federal universities and one university teaching hospital. As part of this initiative, street lighting will be installed while simultaneously phasing out the use of numerous generators currently in operation (REA-EEP, 2021).

2.7.4 Energising Nigeria: A Pathway to Sustainable Energy and Economic Growth

DSM holds the potential to significantly contribute to bridging the energy security gap in Nigeria. The NERC has articulated a well-structured four-stage transition plan, guiding the energy market's progression from the pre-transitional phase to the transitional, medium-term, and long-term phases (NERC, 2020b). The primary aim was to create a competitive wholesale market with a responsive real-time balancing system. Nonetheless, Nigeria is currently situated in the transitional phase, and the progression toward the medium-term phase has encountered hurdles, primarily due to the lack of a cost-effective tariff structure and political influences. Consequently, load shedding continues to be the predominant approach for maintaining the equilibrium between supply and demand.

Price-based programmes, including Time-of-Use (TOU) and Real-Time Pricing (RTP), are instances of DSM initiatives that employs strategies such as peak clipping to curtail electricity demand during peak periods and valley filling to enhance demand during off-peak periods. These pricing programmes aim to balance and optimise electricity usage by aligning it with rate fluctuations throughout the day. Once Nigeria transitions to the medium-term energy market, a programme similar to this concept could be well-suited for implementation. One notable approach could involve the deployment of smart meters for residential consumers, providing them with access to a tariff structure that varies with time. This model draws parallels with past initiatives like the Economy 7 programme once utilised in the UK. Under this arrangement, electricity costs are higher during daytime hours but become more economical during night-time periods. Additionally, contemporary programmes such as Octopus Agile, Octopus Go, and Go Faster tariff schemes exemplify the diversity of options available. These programmes offer consumers fixed rates for specific time intervals, ensuring price stability, while also presenting competitive flat rates for other periods. This strategic diversification allows consumers to manage their electricity consumption more efficiently while adjusting

their usage patterns. For industrial customers, the load-shifting concept stands out as a compelling strategy. This approach facilitates the migration of energy demand from high-demand on-peak periods to off-peak hours. By doing so, industrial operations can curtail their operational costs, mitigate the impact of high energy prices during peak periods, and eliminate the need for grid load shedding practices. This shift towards load shifting not only optimises energy utilisation but also contributes to the overall stability and reliability of the electrical grid. The introduction of such a programme in Nigeria, aligned with the country's transition to a medium-term energy market, holds the potential to revolutionise energy consumption patterns and bolster energy security while ensuring sustainable development for the nation.

Incentive-based programmes, such as DR with its various components like DLC and interruptible/curtailable load, are strategies rooted in the Demand-Side Management (DSM) approach of load shifting. These programmes empower system operators to manage and control the operation of specific customer equipment in exchange for financial incentives. In the context of Nigeria, DLC presents itself as a more feasible option compared to the interruptible/curtailable load programme, which involves contractual agreements demanding longer curtailment durations and more extended notice periods. One viable concept within the incentive-based programme that could be effectively implemented in Nigeria involves providing continuous power supply to industrial and commercial customers during their regular working hours, typically from 8 am to 6 pm. Concurrently, residential customers could benefit from DLC, which allows them access to a limited amount of electrical capacity. This dual-pronged approach ensures that essential daytime operations of businesses and industries remain uninterrupted, while residential customers can participate in DR programmes, contributing to the overall grid stability and DR. By considering this approach, Nigeria can enhance its energy management strategies, promoting a balance between different customer segments and improving grid reliability through the strategic use of incentive-based programmes like DLC. This concept has the potential to enhance the efficient utilisation of existing networks and mitigate the occurrence of load shedding. In Nigeria, the power utility can consider implementing DLC for residential air conditioners (AC) and water heating, as these are among the highest load-consuming appliances. Additionally, the adoption of a smartphone app, similar to the Australian mobile app Powershop, could be beneficial. This app could notify customers to reduce their energy consumption. Nigeria can also take inspiration from the UK's incentive-based programmes, such as STOR, to manage demand in the industrial and commercial sectors. Distribution companies can incorporate this control strategy to reshape their business portfolio

and reduce operational expenses. EE programmes (e.g., US energy star programme) can provide information that residential consumers can rely on when purchasing energy-efficient products (e.g., ACs, light bulbs, washers, dryers, etc). The Energy Star programme offers valuable insights for industrial and commercial customers to identify cost-effective methods of conserving energy. Nigeria has the potential to incorporate similar EE initiatives. To achieve this, the Nigerian government should bolster awareness campaigns and extend incentive support to residential, commercial, and industrial consumers. These incentives may encompass educational programmes, workshops, and other constructive measures designed to promote EE.

The implementation of the DSM programme in Nigeria would provide benefits such as (i) Reduction in the requirement of generation margin, (ii) Improving distribution network efficiency, (iii) A tool for balancing demand and supply, (iv) Addition revenue stream for both power utilities and end-uses (v) Allowing for the integration of distributed generation.

Additionally, the prospects of DSM would be greatly encouraged and developed through the following policy recommendations:

- (i) Upgrade of infrastructures providing advanced metering, communication, information technology, and control mechanisms.
- (ii) Reform of the electricity market structure by allowing and facilitating DSM strategies.
- (iii) Establishment of a comprehensive policy and regulatory framework to support all DSM programmes.
- (iv) Formulation of incentives to encourage investment in DSM.
- (v) Promotion and enlightenment of the benefit of DSM to consumers.
- (vi) Policymakers' commitment to DSM policies and programmes.
- (vii) Evaluating, reviewing and monitoring the DSM programmes and targets after implementation.

2.8. Chapter Summary and Opportunity for Research

This chapter provides an overview of DSM initiatives, exploring their potential benefits as well as the challenges and obstacles hindering their advancement. With a specific focus on developed nations, it examines how developing countries can draw lessons from their experiences.

The findings reveal that significant advancements and research in DSM have taken place in developed countries like the United States, Australia, and the United Kingdom, where DSM constitutes 10% of the United States' energy demand, the United Kingdom displays substantial flexibility among industrial and commercial customers amounting to 2300 megawatt (MW), and Australia has surpassed contracted capacity in multiple trial projects, exceeding 200 megawatts (MW).

The existing literature underscore the significant economic potential of DSM in developed countries. In the US, DSM programmes has produced increased savings from 26.5 to 29.9 MWh, 34% energy reduction, equal to 380 kWh and resulting in a GBP 44,000 cost reduction at three Durham County Council facilities, while large commercial and industrial energy user businesses in Australia, participating through Demand Response Aggregators (DRA) in the wholesale market, provide demand reductions that lead to lower prices for customers and enhance the overall efficiency of the power system.

The literature indicated that developing nations like South Africa and India have taken steps towards the implementation of certain price-based DSM programmes by actively promoting the adoption of time-of-use pricing schemes. While Nigeria is currently in the early stages of development of DSM, with a primary focus on improving energy efficiency, while additional efforts are being directed toward raising awareness about the importance of responsible energy consumption.

The literature illustrates that DSM evolves according to market needs and it is imperative that Nigeria and developing countries need to take advantage of the experiences of developed electricity markets with mature demand management programmes to build a suitable DSM model for their market.

The work identifies the following gaps:

1. Based on existing literature, the research has observed that the majority of studies have focused on consumers in industrialised or developed economies, with limited research conducted on alternatives solutions for consumers in developing economies. Employing DSM in developing countries will regulate and optimise energy consumption pattens, enhance energy efficiency and ensure a sustainable and reliable energy supply. Innovative DSM strategies are required to optimise electricity demand at customer ends to improve the power supply in developing countries.

2. Based on the existing literature, it is evident that there are no comprehensive studies conducted regarding the awareness, perception, and attitude of households in Nigeria toward DSM.
3. Existing literature has confirmed the absence of research concerning a technical model for assessing the influence of DSM in Nigeria. The presence of a technical model offers a well-organised and data -driven framework for precise analysis and enhancement of energy consumption, which potentially bring energy cost savings and comfort levels or living conditions of residence.
4. There is a lack of research that has specifically examined the extent of performance of DSM in Nigeria.

CHAPTER 3

RESEARCH METHODOLOGY

Summary:

This chapter offers an insight into the research design and methodologies that have been employed for data collection and to address the objectives of this thesis. The research provides an overview of the research tools and analytical framework used for data analysis. The justification for selecting these research methods and analytical frameworks is also presented.

3.1. Introduction

This chapter outlines the research methodologies that have been adopted for this thesis. The first section of this chapter summarises the overall methodology of this project. This is followed by an overview of the survey study area, methods used for data collection, and rationale for selecting the research methods, presenting the questionnaire design, strategy, and ethical issues.

The other part introduces the analytical framework and research tool used for running the simulation.

3.2. Research Focus

This thesis develops an innovative DSM method of utilising DLC, acting as a mandatory operational strategy for regional residential grids, as opposed to traditional approach of load shedding. In contrast to load shedding, the proposed DLC method controls residential loads by classifying loads at every home into three different categories: critical, less critical, and non-critical. The primary focus is on daytime and evaluating metrics are the cost savings and comfort levels of residence, i.e., the length of supply of the loads at homes. Furthermore, paper-based surveys are used as the quantitative methods to evaluate the understanding, awareness, perception, and attitude of Nigerian households towards DSM under different representative groups. The survey data are used to model load profiles, and the DLC is applied to verify the proposed methodology.

3.3 Summary of Research Method

This subsection describes the research strategies that has been adopted in this thesis.

Figure 3.1 shows the research block diagram. The research method is summarised into four stages as listed below:

- I. The first stage comprises data collection, which entails distributing paper-based survey questionnaires to collect the public's perceptions of DSM. The survey data is used to create a load profile for households. This is presented in Chapter 4.
- II. The second stage encompasses the DLC approach, involving controlling of household appliances classified into Critical, Less Critical, and Non-Critical loads according to their criticalness. Through the DLC, the regional network operator is able to control the ON/OFF status of the household appliances

according to the network's availability and appliances' classifications. This is presented in the first half of Chapter 5.

- III. The third stage encompasses an evaluation of the effect of DLC comparing it with the traditional load shedding method. The evaluation metrics include the energy costs and comfort levels of residence. This comparison also considers three load shedding scenarios considering the number of hours (e.g., 0, 4 and 8 hours) that the residences use their home generators. This comparison also considers different billing systems the residences use, employment status, education background and house size of the residence. This is reported in the second half of Chapter 5.
- IV. The fourth stage encompasses an analyses of energy consumption patterns among various representative groups. It also provides the discussion, limitations, and recommend framework for the implementation of DSM in Nigeria. This is conveyed in Chapter 6.

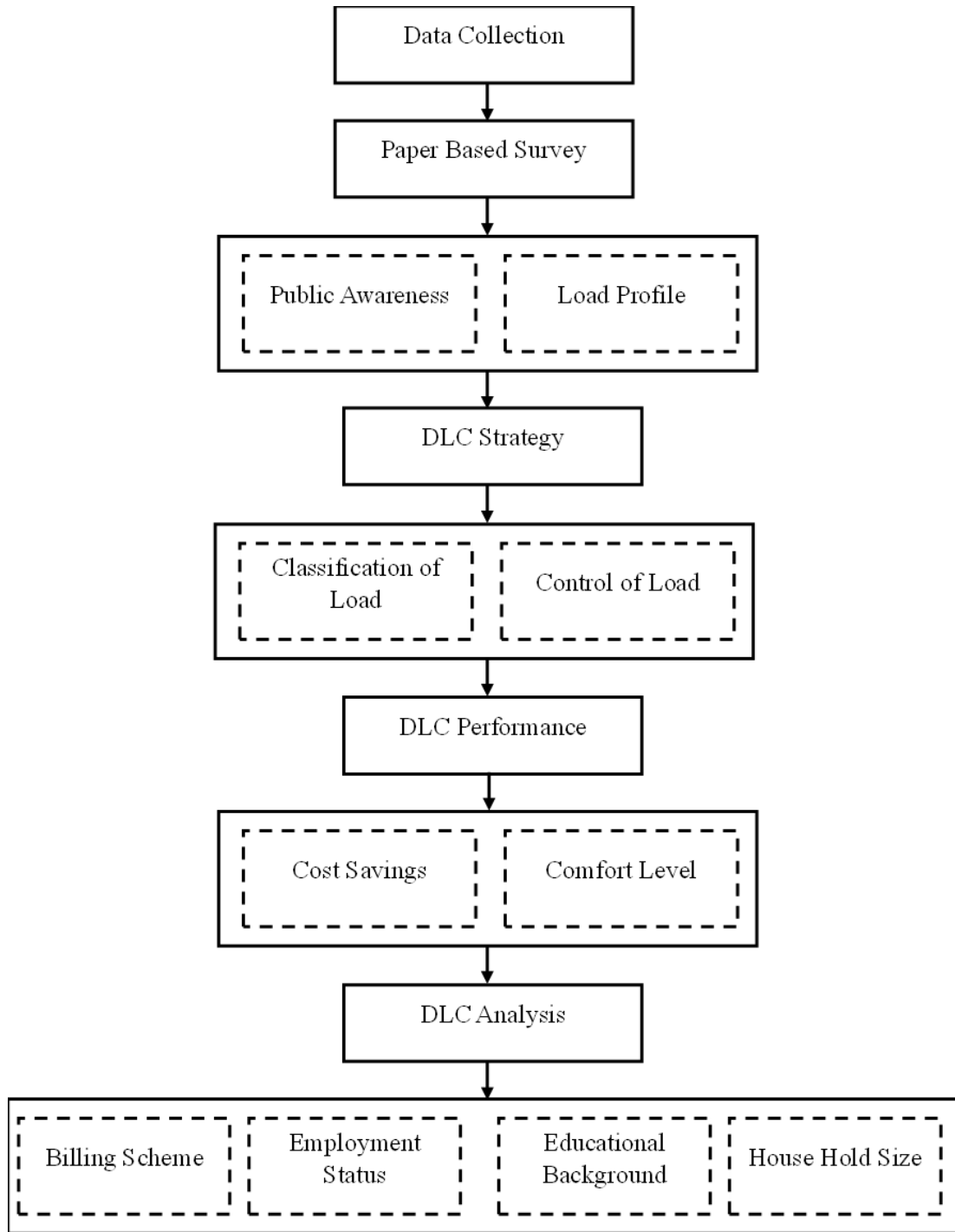


Figure 3. 1: Research Block Diagram

3.4. Survey Approach

In this thesis, a paper-based survey has been employed to quantitatively assess Nigerian household's understanding, awareness, perception, and willingness to participate in DSM programmes. The quantitative analysis in DSM utilises mathematical models and statistical method to understand and predict energy use patterns. As outlined in Figure 3.2 the sequential method employed in this study.

QUANTITATIVE ANALYSIS

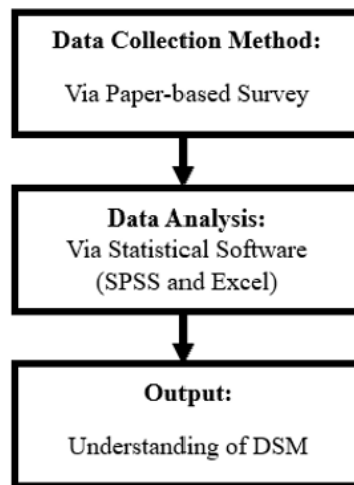


Figure 3. 2: Flow Chart of Sequential Data Analysis

3.4.1 Data Collection Methods

This section provides an overview of data collection methods employed in this thesis.

3.4.1.1 Literature Review

We carried out an exhaustive examination of existing literature to attain a comprehensive grasp of DSM initiatives. This encompassed a critical assessment of the roles and significance of such initiatives in both developed and developing nations. Our literature review drew from various scholarly sources, including esteemed journals like Energy Policy and Energy Research & Social Science, as well as authoritative government documents such as those from the NERC, IEA, and the Ministry of Power.

To maintain the alignment of our research with the latest policies and data, we leveraged Mendeley alerts, which ensured that we received timely notifications about newly published materials to further refine our search and identify the most relevant resources, we employed a carefully curated set of specific keywords. This approach enabled us to stay at the forefront of the most recent developments in our field of study. The following keywords below were used in search for relevant publications:

All in titles

- Demand side management
- Demand response
- Energy efficiency
- Nigerian electricity market
- Renewable energy

- Direct load control

3.4.1.2 Questionnaire Design

The purpose of the questionnaire was to capture respondents' energy use, attitude toward energy conservation and willingness to participate in DSM programmes. The designed questionnaires comprised of 19 questions with both closed and open-ended questions aimed at gathering information on Nigerian households (the questionnaire sample can be found in Appendix A while Table 3.1 shows questionnaire content)

The paper-based survey was conducted between November 2021 to April 2022 across the North-Eastern State of Adamawa State, Nigeria. A total of 600 number of questionnaires was distributed across different area in urban and rural environment of the state in-order to capture diverse number of participants. The research received 396 participants. After filtering out incomplete data, the final count of valid responses for the survey amounted to 380 (63% response rate). Subsequently, for the simulation, after screening for data aligned with the study requirements, a total of 300 household responses were retained.

The survey was classified into five types to cover: i) Demographic information and household information, ii) behavioural and usage, iii) knowledge, awareness and attitude, iv) information related to the purchase of electric appliances, including energy saving techniques, v) willingness to adapt DSM schemes and awareness of utilisation of renewable energy. Table 3.1 below presents Survey Types A-E, summarizing the five key aspects of the survey.

Table 3. 1: Questionnaire Content

Type	Section	Content
A. Demographic Information and Household Information	Household attributes	- Number of households members - Occupation - Education level - Number and age group of children - Type of housing (owned/rented) - Number of rooms - Monthly expenditure on electricity - Electricity billing (pre-paid/post-paid)
B. Behavioural and Usage	Ownership of electric appliances	- Availability and number of appliances - Time of use: Lighting points, water heater, microwave, television, refrigerator, freezer, air condition, water pump and water dispenser (Morning, Afternoon, Evening, or all day) - Frequency of use: Washing machine, iron, and oven (Daily, twice a week, often and never) - Time of use (Morning, afternoon, evening)
C. Knowledge, Awareness and Attitude	Intention/Knowledge of reducing electricity consumption	- Awareness of saving energy techniques - Mode of energy saving technique is practised and locations - Factor influencing behaviour change towards energy use
D. Purchase Decision	Purchase of electric appliances	- Factors influencing purchase decisions - Utilization of energy label information at purchase
E. Energy Management and Environmental Awareness	Energy Management	- Willingness to participate in DLC scheme - Awareness of renewable energy - Availability of renewable energy resources available at home - Barrier to switch to renewable

3.4.1.3 Questionnaire Sampling Strategies and Key Content

The study employed a multifaceted sampling approach, incorporating various settings, including individual households, students' residential areas, mosques, and community centres. Additionally, it engaged retired residents to participant in the research. This approach was aimed to ensure a diverse representation of households, thus enabling a comprehensive understanding of residential energy profiles and households' perception, awareness, and

attitudes towards energy management. The validation of the questionnaire was conducted by the PhD supervisory team to ensure its reliability and effectiveness.

Once the data was collected the Statistical Software Package (SPSS) and excel were used to analyse the quantitative collected data.

3.4.2 Survey Area

The state of Adamawa is one of the six states which lies at latitude 9° 20'N and 12° 30'E in the North-east region of Nigeria, with Yola as the capital. The state shares borders with Borno State to the Northwest, Gombe State to the west, and Taraba state to the southwest, while its eastern border forms part of the national border with the Republic of Cameroon as seen in Figure 3.3. It has a land area of 36,917 square kilometre and a population based on 2006 census of 3,178,950 and a later 2016 forecasted number of 4,248,436 representing a 2.26% of Nigeria's total population (Adebayo et al., 2012; Dibiaezue, 2023). The climate in Adamawa is tropical wet and dry seasons. The wet season spans between April to October while the dry season runs for minimum period of five months ranging from November to March. This cycle is usually very hot with average temperature of 36° C and maximum record temperature is 47° C (Adebayo et al., 2012). The maximum temperature in Nigeria ranges from 31.1° C to 36° C (World Data, 2023). Energy in the city is powered by Yola Electricity distribution company (YEDC, 2023). Energy demand profile is not readily available, but the region has been grappling with electricity supply issues like any other region in the country (The World Bank, 2021; TheCable, 2022).



Figure 3. 3: Map of Nigeria

3.4.3 Survey Data Analysis

The quantitative data collected through the survey is analysed using the software statistical package for the social science (SPSS). SPSS is a powerful tool that students, researchers, various public, private, and nongovernmental organisations utilise. It helps provide insight and understanding of data for analysing consumer behaviour and forecasting (SPSS, 2023). It is a comprehensive and flexible tool that provides rich features. It is user friendly for all forms of statistical analysis needed within the social sciences field ranging from engineering, medical, business, and education. Descriptive statistics will summarise the survey responses, while inferential statistics, such as correlation analysis, will help identify, describe the strength and direction of linear relationship, and association linking or bonding of different variables (Rahman and Muktadir, 2021). The quantitative analyses' findings will be triangulated to provide a comprehensive understanding of residential energy demand patterns in Yola. The implications of the findings will extend beyond Yola and have broader relevance to the Nigerian residential sector. The study's insights can inform policy decisions and urban planning strategies aimed at addressing energy needs and promoting sustainable development in Nigeria

(UNDP, 2021). This thesis utilises correlation analysis to identify relationship, association, linking two variables. Also, cross tab analysis was used to determine relationship between multiple variables.

3.4.3.1 Rationale of using SPSS for Survey data analysis

Residential demand profiling plays a crucial role in understanding consumer behaviour and preferences in the housing sector (Lekshmana et al., 2015). SPSS was chosen as an appropriate tool due to its user-friendly interface, extensive range of statistical techniques, and capacity to efficiently handle moderate-sized datasets (Khan, 2021). It offers flexibility in data manipulation and transformation, enabling researchers to customize their analytical procedures to the specific needs of residential demand profiling research (Anderberg, 2017). models, machine learning, or big data analysis, they often require a higher level of programming expertise. In contrast, SPSS allows researchers to perform robust statistical analysis without the necessity of extensive coding knowledge (Natarajan and Viswanathan, 2021). This research focused on structured survey data to gather insights into housing demands in Nigeria, where patterns vary significantly across regions and socioeconomic factors. SPSS was selected not only for its user-friendly design and proven reliability but also for its ability to address the specific analytical needs of this study.

3.4.4 Ethics Issues

Residential demand profiling research in Nigeria aims to understand the energy consumption patterns and behaviours of households, enabling the development of effective energy management strategies and policies. While conducting such research, it is crucial to uphold ethical standards to protect the rights and well-being of the participants.

This research seeks institutional review board (IRB) approval which have been approved by the Cranfield University Ethics Committee (see Appendix B).

This following are highlights of the key ethical issues that were considered when conducting a survey study for Nigeria's residential demand profiling.

1. Informed Consent

One of the fundamental ethical principles in research is obtaining informed consent from participants. All participants are adequately informed about the purpose, procedures, potential risks, and benefits of the study before participating.

2. Confidentiality and Data Protection

This research involves the collection of sensitive information, including household energy consumption data, demographic details, and potentially personally identifiable information. Participants were assured that their data will be protected and used solely for research purposes. Adequate measures, such as anonymisation and encryption were implemented to protect the participants' privacy.

3. Voluntary Participation and Withdrawal

Participants were explicitly informed that their participation is entirely voluntary, free from coercion or pressure. They were assured that they possess the right to withdraw from the study at any time without incurring any adverse consequences or penalties.

4. Minimisation of Harm and Risk

The questionnaires were thoughtfully designed to mitigate the potential harm or risks to the participants during data collection. Careful consideration was given to the possible impact of the findings on vulnerable participants, with a commitment to ensuring the responsible and unbiased use of the result.

Additionally, all participants were explicitly informed that the information collected would be maintained in strict confidentiality and would not be shared with any third party in a way that could identify them individually. Only research results based on aggregated data are made public, and individual responses will never be disclosed at any stage. Participants have the option to request access to the survey's findings. (see Appendix B).

3.5. Analytical Framework and Research Tool

This section introduces the software MATLAB which was employed to investigate the impact of implementing DLC in the Nigeria electricity supply industry.

3.5.1 Rationale of Using MATLAB over Python and C++

MATLAB is a powerful software tool recognised for its advanced scripting capabilities, which provide exceptional flexibility in data manipulation, visualization, and analysis. This flexibility enables researchers to precisely tailor their analytical processes to align with the specific requirements of their datasets and research objectives, thereby enhancing the accuracy and relevance of their findings (Shaedr, 2015). Although MATLAB may face performance limitations with very large datasets compared to languages like Python or C++, which offer optimized packages or frameworks specifically designed for big data, the size of our dataset is manageable within MATLAB's performance capabilities. For the dataset in question, MATLAB's performance remains adequate without significant drawbacks (Natarajan and

Viswanathan, 2021). Additionally, many DSM studies involve analysing time-series data to understand energy consumption patterns and demand fluctuations. MATLAB provides specialised toolboxes for time-series analysis, facilitating tasks such as forecasting, trend analysis, and seasonality detection, making it particularly suited for research on energy management and analysis (Nagar, 2017; Pedregal, 2019).

3.6. Technical Model

Figure 3.4 provides an overview of employing DSM strategy to assess the energy and cost of residential household in Nigeria.

The data gathered from the paper-survey was employed to construct a residential energy profile. The simulation inputs including number of appliances, time of use (morning, afternoon, evening, and all days), period of use for some selected appliance (daily, twice a week, often and never). The model was designed based on the objective function and constraints, with the simulation run based on a half an hour interval. The result contains:

- The energy profile of each respondent
- Cost of electricity
- Energy profile with the application of DLC
- Bill savings as result of DLC

The analysis of the result was undertaken using Excel software to illustrate the energy profile and impact of DLC in terms of the following:

- Number of households
- Billing system
- Occupation
- Level of education

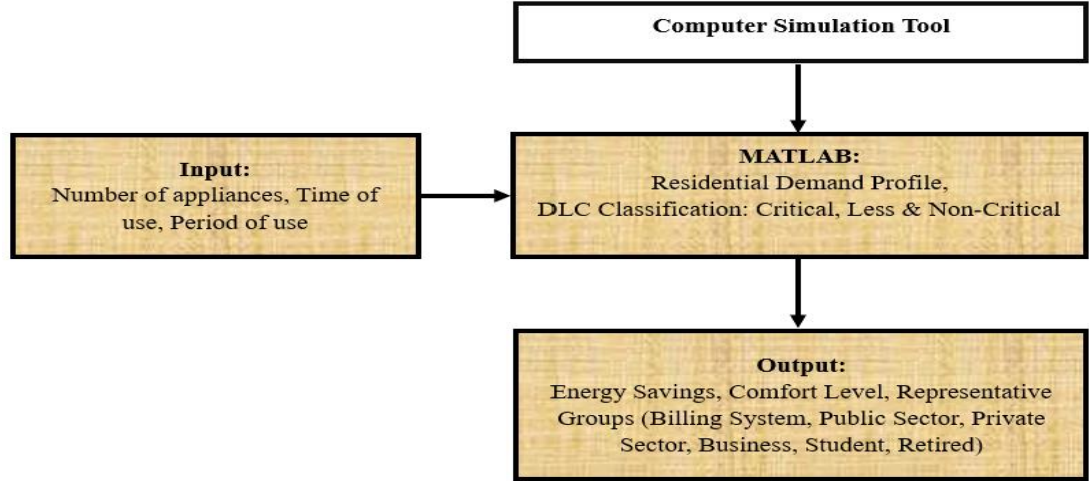


Figure 3. 4: Technical Simulation of DSM

3.6.1. Objective Function of the Problem

The objection function was design to produce the residential energy profile of households in Nigeria. Formulation of linear programming is presented below:

$$\text{Min} \sum_{i \in I} \sum_{k \in K} C_{ik} \cdot v_{ik} \quad (1)$$

Assume binary variable v indicate turning ON

v = represents the appliances

i = represents the time slot

$v_{ik} = 1$; k^{th} appliance is used at i^{th} time slot =0; else

E_K is the energy consumption of k^{th} appliance which consumes energy a single time slot kWh.

$$E_K = P_K \cdot t \quad (2)$$

P_K = Power of k^{th} appliance

t = Working hours of appliances

C_{ik} is the cost of k^{th} appliance.

$$C_{ik} = E_K \cdot r_i \quad (3)$$

r_i = Tariff (₦/kWh)

The tariff prices are given in Table 3.2 for Nigeria. The power values of appliance and the application of the concept of DLC is shown in Table 3.3

Table 3. 2: Residential Time Slot and Price

Tariffs	Time Slots	Price (NGN)
Daytime	06-18	50.01
Nighttime	18-06	50.01

Table 3. 3: Power Information and Working Hour for DLC.

Appliances	v	Power (kW)	DIRECT LOAD CONTROL		LOAD CLASS	CLASSIFICATION
			NIGHT	DAY		
Lighting Point	1	0.01	12	0	N	Non-Critical Load
Fan	2	0.075	2	2	L	Less Critical Load
Air Condition	3	1.5	12	5	C	Critical Load
Television	4	0.2	6	7	C	Critical Load
Refrigerator	5	0.9	12	3	L	Less Critical Load
Freezer	6	0.5	12	3	L	Less Critical Load
Water Dispenser	7	1.3	12	3	L	Less Critical Load
Microwave	8	1.7	0.5	0.5	L	Less Critical Load
Water Heater	9	4	2	0	N	Non-Critical Load
Water Pump	10	0.6	2	0	N	Non-Critical Load
Iron	11	2.5	2	0	N	Non-Critical Load
Washing Machine	12	0.8	3	0	N	Non-Critical Load
Oven	13	2	2	0	N	Non-Critical Load

The thesis classified the DLC scheme load classification into three categories based on the working hours: i) Critical Load, ii) Less Critical Load and iii) Non-Critical Load. “Critical

Load'' denotes appliances that enhance consumers overall comfort and satisfaction, with an expected operating duration of 5 to 7 hours. "Less Critical Load" encompasses useful appliances that, for the purpose of this research, are considered to offer a lower level of convenience to customers, typically operating for durations ranging from 2 to 4 hours in the daytime. "Non-Critical Load" are appliances that see minimal or no use within homes during daytime hours, and for many residential users, these appliances are dispensable during the day, typically operating for less than 2 hours.

3.6.2. Constraints of Scheduling Appliances

Appliances are represented by v and appliances are lighting point, fan, air condition, television, refrigerator, freezer, waster dispenser, microwave, water heater, water pump, iron, washing machine, oven respectively.

The model is designed to provide energy consumption of households, this is based on user determination of time and period of energy use from the data provided by the households in the survey. Constraint 4, 5, 6 & 7 determines the time of use of household, either morning, afternoon, evening, or all of the day for all the appliances.

$$t_m = \sum_{i=6}^{12} v_{ik} ; \forall v = J \quad (4)$$

$$t_f = \sum_{i=6}^{12} v_{ik} ; \forall v = J \quad (5)$$

$$t_e = \sum_{i=12}^6 v_{ik} ; \forall v = J \quad (6)$$

$$t_a = \sum_{i=1}^{24} v_{ik} ; \forall v = J \quad (7)$$

t_m = working time of k^{th} appliance in the morning

t_f = working time of k^{th} appliance in the afternoon

t_e = working time of k^{th} appliance in the evening

t_a = working time of k^{th} appliance in all day

J = serial number of appliances

Furthermore, for appliances such as washing machine, iron and oven which are the appliances which are often not in regular use. Constraint 8, 9, 10 & 11 determines which the appliances that are used daily, twice in a week, often, or never.

$$t_{da} = \sum_{i=1}^{24} v_{ik} ; \forall v = J \quad (8)$$

$$t_t = \sum_{i=6}^{12} v_{ik} ; \forall v = J \quad (9)$$

$$t_o = \sum_{i=1}^{24} v_{ik} ; \forall v = J \quad (10)$$

$$t_n = \sum_{i=1}^{24} v_{ik} ; \forall v = J \quad (11)$$

t_{da} = period of working time of k^{th} appliance on a daily use

t_t = period of working time of k^{th} appliance twice in a week

t_o = period of working time of k^{th} appliance on a weekly basis

$t_n = k^{th}$ appliances are never used

3.6.3 Constraints of Scheduling Appliance with Application Direct Load Control

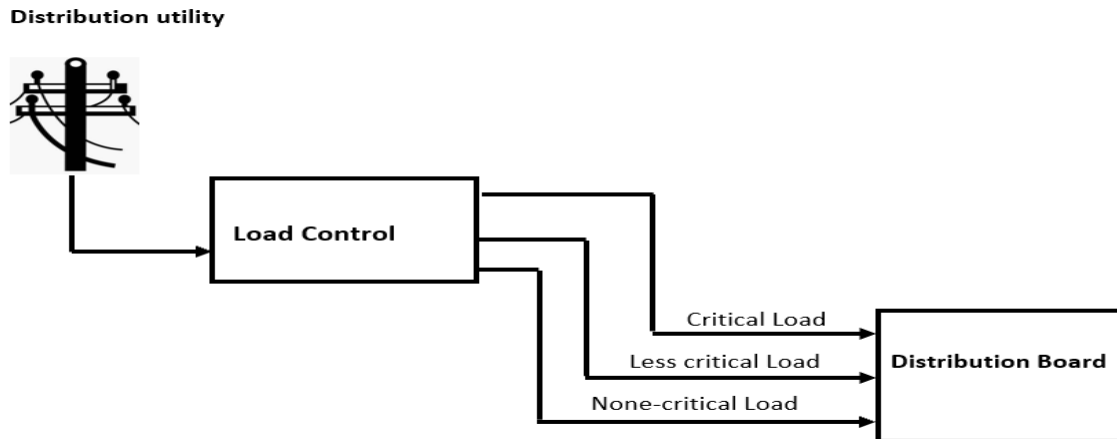


Figure 3. 5: Block Diagram of DLC

The traditional approach to implementing DLC relies on customers voluntarily participating in the programme in exchange for incentives and lower rates.

This thesis introduces a novel and innovative utilisation of DLC, this entails incorporating DLC as a mandatory concept that operates concurrently with the grid, serving as an alternative solution to load shedding. In this research, DLC is approached as an optimisation challenge aimed at minimising daytime energy consumption. When applying DLC (constraint (12)) represents energy consumption from household during the daytime running from 6:00 to 18:00 and (constraint (13)) represents energy consumption by household between the hours of 18:00 to 6:00.

The system employs a remotely controlled switch integrated into the electrical panel (see Figure 3.5), allowing for the switching of loads on or off. This residential load controller is employed to control various load connected to a home distribution board either by the utility company or a third party (aggregator) to curtail energy demand, with appliance activation categorised according to the three categories critical, less critical, and non-critical load, as detailed in Table 3.3.

$$t_d = \sum_{i=6}^{12} v_{ik} \quad ; \quad \forall v = J \quad (12)$$

$$t_n = \sum_{i=6}^{12} v_{ik} \quad ; \quad \forall v = J \quad (13)$$

t_d = working time of k^{th} appliance in the daytime

t_n = working time of k^{th} appliance in the night-time

The MATLAB code is provided in Appendix C.

3.7 DLC Impact Data Analysis

The data analysis focuses on assessing the impact of DLC across various representative groups, using data that captures essential variables such as household energy consumption, billing system type (prepaid or post-paid), household size, education level, and occupational sector.

Households were stratified into five occupational sectors: public sector, private sector, business sector, students, and retirees. Within each stratum, further subdivisions were made based on billing system type, household size, and education level. This methodical approach ensured that the sample accurately reflected the broader population, thereby enabling a nuanced and detailed analysis of how DLC impacts different groups across these pivotal variables.

The Data analysis was conducted using the following technique:

- The analysis used a structured approach to descriptive statistics, summarizing the data by calculating frequency distributions for billing system types within each occupational sector, identifying the central tendency of energy consumption across various sectors and household types, and evaluating the degree of variability in energy consumption both within and across different sectors.
- A comparative analysis was conducted to evaluate the impact of household size and education level on energy consumption within each billing system group. This approach enabled the identification of the demographic factors that have the most significant influence on energy usage.
- Cross-tabulation was employed to identify trends and patterns within the data, enabling an in-depth exploration of the relationships between categorical variables such as billing system type, household size, and education level and their impact on energy consumption.

3.8 Conclusion

This chapter provides an understanding of the data collection techniques utilised in the study, offering an outline of the research methodology and the analytical structure applied for data evaluation. It also explains the rationale behind the reasoning behind the choice of these research methods, analytical frameworks and provides the methodological approach for analysing the impact of DLC in the study.

The next chapter will provide a detailed presentation of the results which have been collected and analysed by the methodology described in this chapter.

CHAPTER 4

SURVEY KEY FINDINGS: AN OVERVIEW OF RESIDENTIAL LOAD PROFILE FOR DEMAND SIDE MANAGEMENT IN NIGERIA

Summary:

This chapter provides survey result of Nigerian households. This presents public perspectives, awareness, acceptance, and potential of implementing demand side management. It also identifies factors that are hampering the increase in the penetration of renewable energy.

4.1. Introduction

This chapter presents the empirical data obtained from the survey conducted in this study, aimed at investigating public perspective, awareness, acceptance, and potential of DSM in addressing the insufficient supply of electricity to the residential sector. This result is based on data gathered from the paper-based survey conducted in the North-Eastern State of Adamawa, in Nigeria. It covers areas such as household attributes, information on different appliance times of use and duration, desires to conserve energy, factors that motivate attitudinal change to energy use, the perception of renewable energy, and prospects for a future lifestyle of customers (see Appendix D).

This chapter serves two primary objectives:

1. To unveil the readiness of households to embrace and engage in various DSM practices if presented as a means to alleviate load shedding.
2. To illustrate that despite considerable awareness of different renewable energy sources, numerous Nigerian households depend on generators as backup in the event of a grid outage. The findings imply that enhancing awareness and reducing costs can play a pivotal role in promoting the use of renewable energy sources.

The following section presents the survey results.

4.2 Unlocking Sustainable Energy Solutions in Developing Nations - A Study of DSM in Nigeria Household

In the face of ever-increasing energy demands and mounting concerns about climate change, the global community has recognised the urgent need for sustainable energy solutions. DSM has emerged as a critical strategy to achieve energy efficiency and mitigate the environmental impact of energy consumption. DSM focuses on optimising energy use by empowering consumers and end-users to actively participate in managing their energy consumption patterns.

DSM encompasses various strategies to alter energy consumption patterns to ensure a more sustainable and efficient energy ecosystem. At its core, DSM seeks to shift the emphasis from traditional supply-driven approaches to fostering consumer-centric practices. This involves implementing policies, incentives, and technologies that encourage consumers to use energy during off-peak hours, reduce overall energy consumption, and adopt energy-efficient technologies (Alasser et al., 2017; Usman et al., 2022).

Thus, the relevance of DSM to developing countries is vital, owing to their peculiar situation. Developing countries face unique challenges in meeting energy needs while pursuing sustainable development goals. Many nations experience rapid population growth, urbanisation, and industrialisation, leading to escalating energy demands (Kaygusuz, 2012b). Despite facing economic constraints and limited access to advanced technologies, developing countries increasingly recognise DSM's potential to address energy poverty and enhance EE (Usman et al., 2022). Consequently, DSM initiatives are gaining traction in these regions as a viable approach to optimising energy consumption and promoting sustainable growth.

Developed countries have been at the forefront of implementing DSM initiatives because they have mature energy infrastructures and greater access to resources. Policymakers in these countries have proactively embraced DSM as a critical component of their energy policies, aiming to reduce carbon emissions and enhance energy security (Strbac, 2008). Innovative technologies, such as smart meters and home automation systems, have played a crucial role in empowering consumers to actively manage their energy usage actively, resulting in reduced peak demand and more stable grids (Khan, 2019; Osório et al., 2019).

The success of DSM initiatives largely depends on the presence of conducive policy and regulatory frameworks. Developing countries, particularly, are exploring policy measures to incentivise DSM adoption among consumers and businesses (Schaffer, 2009). In contrast, developed countries have implemented comprehensive regulatory frameworks that foster stakeholder collaboration and promote innovation (Warren, 2018). Understanding the nuances of these policies can offer valuable lessons to governments worldwide seeking to design effective DSM strategies hence the need to undertake the survey study on DSM.

While DSM holds immense potential, its widespread adoption is challenging. Developing countries need more financial resources to implement DSM, including a lack of technological infrastructure and limited consumer awareness regarding the benefits of energy conservation (Bakare et al., 2023b; Strbac, 2008). On the other hand, developed countries are confronted with the dual challenge of both promoting and incentivising voluntary participation in DSM programmes, and simultaneously addressing potential privacy issues associated with the collection of data from smart devices (Bakare et al., 2023b). By acknowledging and understanding these challenges, policymakers can develop targeted interventions to bolster DSM implementation.

Many studies on household energy consumption were carried out in Nigeria (Diji and Ganiyu, 2013; Isa Shuaibu and Adetunji Babatunde, 2010; Kayode and Nyamapfene, 2011) and little information is available from Nigerian households as regards their understanding, awareness, and acceptance of DSM.

This survey on DSM in developing countries such as Nigeria underscores the significance of DSM in the pursuit of sustainable energy solutions. The primary aim of the study is to obtain residential load profile of households in Nigeria providing data on the living condition of people of different socio-economic classes and understanding the potential and possibility of implementing DSM in the developing country.

4.3. Survey Study for Nigeria Residential Demand Profiling

4.3.1 Characteristic of Survey Area

Adamawa is positioned in the northern region of Nigeria with Yola serving as the capital city. The state shares its borders with Borno State to the northwest, Gombe State to the west, and Taraba State to the southwest. Furthermore, its eastern border forms a segment of the national boundary with the Cameroon Republic (see Figure 4.1). Adamawa State spans across an expanse of 36,917 square kilometres and boast an estimated population of 4,248,436(Adebayo et al., 2012; Dibiaezue, 2023). The climate in Adamawa is characterized by distinct wet and dry seasons. The region encountered high temperature, with average temperature of 36° C and maximum record temperature is 47° C (Adebayo et al., 2012). Yola Electricity distribution company is responsible for supplying power to the city (YEDC, 2023). Energy demand profile is not readily available, but the region has been grappling with electricity supply issues like any other region in the country (The World Bank, 2021; TheCable, 2022).



Figure 4. 1: Map of Nigeria

4.4. Analytic Procedures (Findings and Discussion)

4.4.1. Household Information

The Nigerian National Statistical office states that the total number of households in 2020 is 43.0 million (Helgi Library, 2020; Statista, 2023). The result illustrates that of the 380 respondents the largest number are government officials with 187 participants corresponding to 51.9%, from the total number of 380 (see figure 4.2).

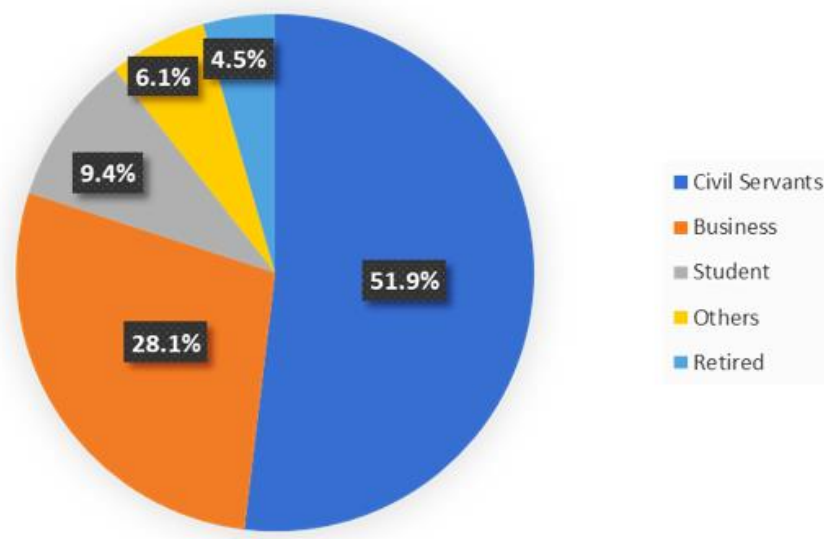


Figure 4. 2: Occupation of Households

The level of education within household is a vital indicator of a country's socio-economic development. Gaining insight into the educational diversity is an essential tool for comprehending societal perspectives. Educational attainment within households varies widely, encompassing individuals with limited or no-formal education to advanced degrees (FMoE, 2023; UNICEF, 2023).

Within the age group of 15-49, the research has established a distinct disparity, with approximately one-third of Nigeria in this demographic lack formal education, in contrast to men with a lower percentage 22%. A total of 14% of women and 13% of men have attended primary education, while 40% of women and 48% of men have attend secondary schools. A smaller proportion of only 11% of women and 17% of men have beyond secondary level. The disparity is evident in the literacy rates in Nigeria which reflect a substantial gap, with almost half of women (47%) and nearly one-quarter of men (28%) classified as illiterate, meaning they cannot read (NDHS, 2018). The level of education is shown in figure 4.3, with 90.2% of participates in the survey having some form of formal education.

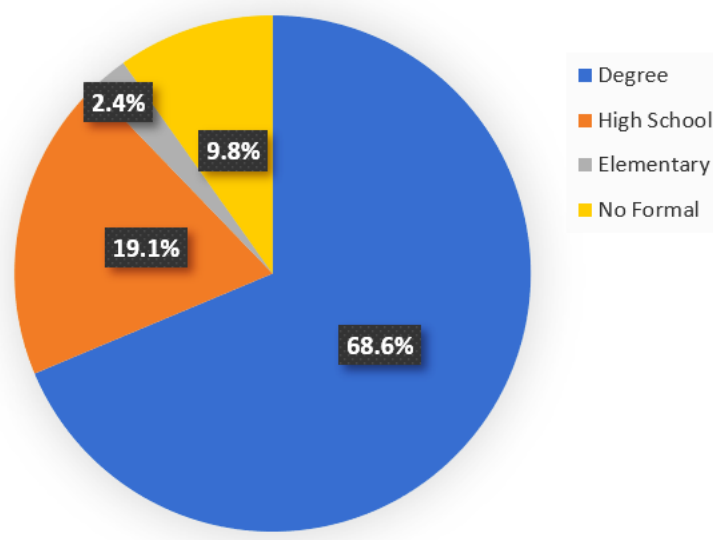


Figure 4. 3: Level of Household Education

The makeup of a Nigerian household mirrors the nation's diverse cultural, social, economic, and demographic traits. Nigeria boasts a mosaic of ethnic groups, each characterised by distinct traditions and values. These multifaceted aspects exert a profound influence on the composition and functioning of households. According to data from 2018 and 2019, Nigerian households averaged between 4.7 and 5.06 members. Additionally, less than one in five households is led by women. (NDHS, 2018; Statista, 2018, 2019). The extended family structure holds a significant role within Nigerian households, extending beyond the nuclear family to encompass members from the extended family. Nigeria's rich cultural tapestry comprises 250 ethnic groups, each with its own distinct customs and traditions. For instance, Yoruba and Igbo cultures emphasise communal living, fostering strong extended family ties, while in contrast, Hausa communities often adhere to a more patriarchal family structure. In numerous households, men traditionally assume the role of primary breadwinners, while women are responsible for managing domestic affairs. Nevertheless, these roles are undergoing transformation, particularly in urban settings, where an increasing number of women are pursuing careers beyond their household duties (Achebe, 1958; Olaitan, 2018; Ugwu, Ifelunni and Onuorah, 2016). Most participants are within the age group of 31 – 60 (see Figure 4.4), while Figure 4.5 below provides insight into the composition of households among the respondents, revealing that a significant majority, accounting for 87%, have fewer than seven children. The number of children within a household serves as an indicator of the family's energy consumption patterns.

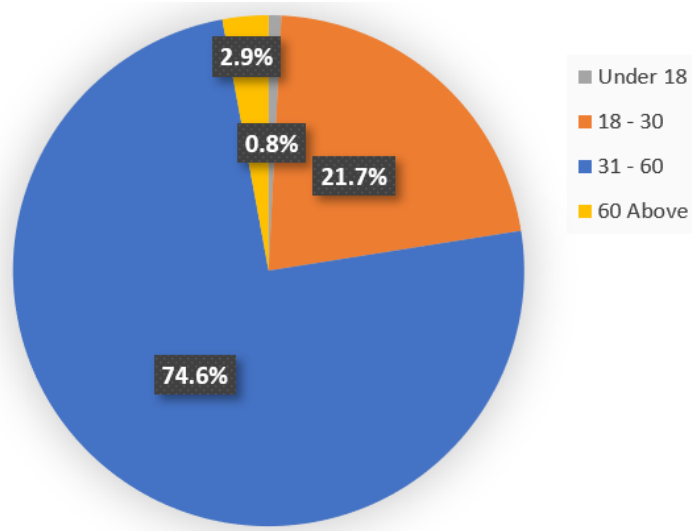


Figure 4. 4: Age Group of Households

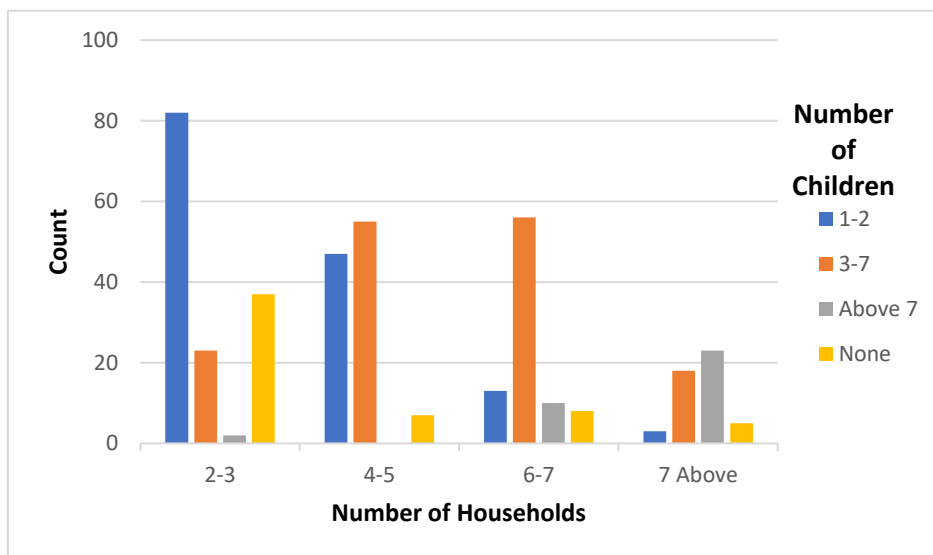


Figure 4. 5: Composition of Households

Table 4.1 shows the analysis that establishes the relationship, association, link, or bonding for the household. This correlation matrix shows the significant relationship between different information of the household data from the survey.

Table 4. 1: Correlation Analysis of Household

	Occupation	Education	Age	Number of Households	Number of Children	Age of Children	Type of Housing	Number of Rooms in the House
Occupation	1							
Education	-.224**	1						
Age	.310**	.063	1					
Number of Households	.095	-.054	.92**	1				
Number of Children	-.062	.015	.111*	.197**	1			
Age of Children	.165**	-.087	.229**	.416**	.487**	1		
Type of Housing	.010	.005	-.046	-.265**	-.068	-.165**	1	
Number of Rooms in the House	.093	-.135**	.153**	.386**	.089	.303*	-.499**	1

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Analysing household composition with a descriptive statistic known as Pearson correlation coefficient (r) describes the strength and direction of the linear relationship between two quantitative variables.

Pearson product correlation of occupation and education was found to be negative correlation and statistically very low ($r=0.224$, $p<0.001$). This shows that an increase occupation does not lead to the level of education. The household result shows that the relationship between number of household and number of children and age of children is respectively positively correlated but statistically low ($r=0.487$, $p<0.001$) and ($r=0.416$, $p<0.001$), this indicates that increase in the number and age of children will lead to increase in the number of households. Therefore, the level of education of household is markedly low or negligible with the other household data.

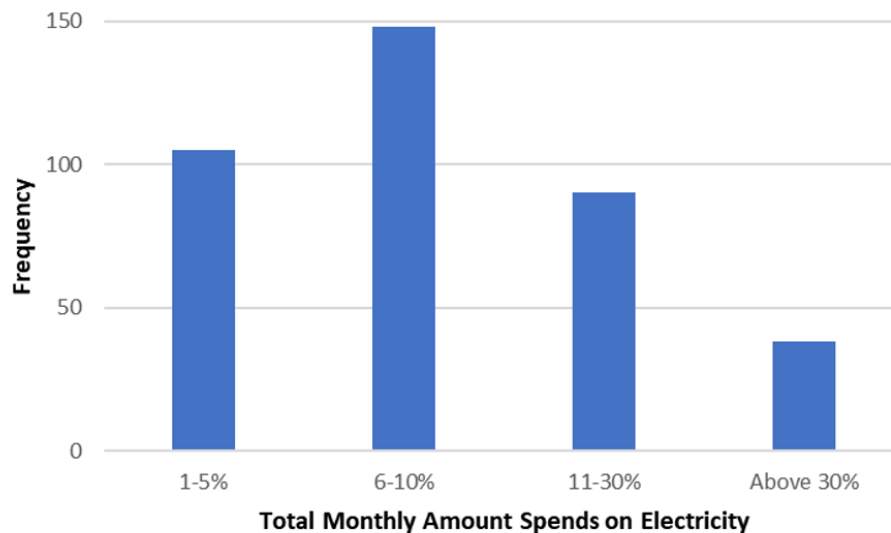
4.5. Energy Bill

The Nigerian electricity supply industry classified end user of electricity into 5 broad tariff classes (see seen in table 4.2 below) (NERC, 2023b). The energy billing system in the Nigeria electricity supply industry is classified into two category, pre-paid and post billing system. Pre-paid billing system is the measure electricity consumed using an electricity meter. In Nigeria, the post-paid billing systems allows subscribers to make power bills after the services is rendered by the utility. This is an estimated billing system where payment for energy consumed may not reflect the actual energy consumed by the end-user (Diji and Ganiyu, 2013).

Table 4. 2: Tariff Classification

	Tariff Class	Description
R	Residential	Customer who utilises his premise as a residence such as house, flat, or multi-storied house
C	Commercial	End users who use their premise for businesses and establishments
I	Industrial	Customers that use his premises for manufacturing goods
A	Special	Customers such as agriculture and agro-allied industries, water boards, religious centres, government research institutes and teaching hospitals, and educational establishment
S	Streetlight	Streetlights

In this survey the 192 (50.5%) respondents are on the prepaid and 188 (49.5%) are on the post billing system. The result shows the 147 (39.2%) spend 6-10% of their income on electricity monthly while 106 (28.27%) and 86 (22.93%) respondents spend 1-5% and 11- 30% monthly in energy in their homes (see Figure 4.6). The results show that with a greater number of households in a residence the power bill on government employee raises to above 10% of their income from 2 -3 household to 4-5 household but some energy management for larger house (see Figure 4.7 – 4.9).

**Figure 4. 6: Household Electricity Expenditure**

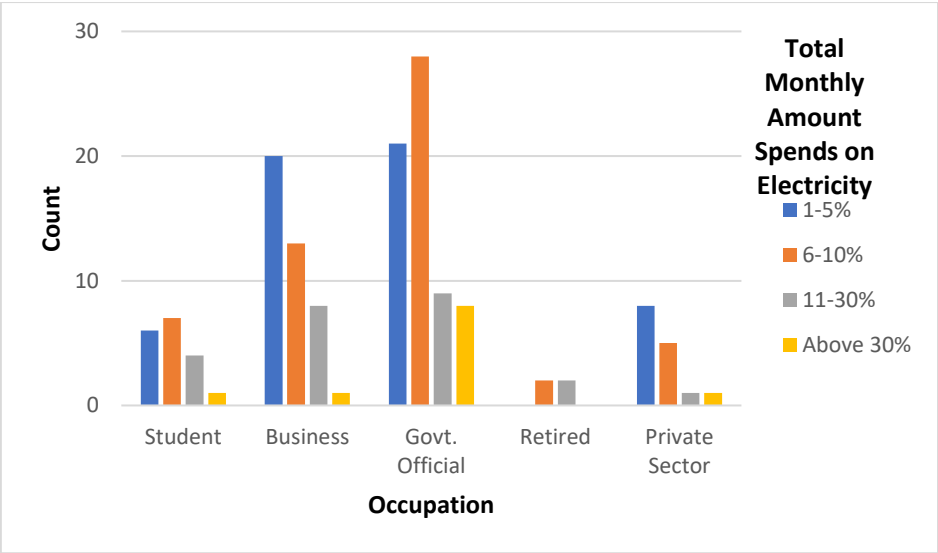


Figure 4. 7: 2 - 3 Numbers Household Composition

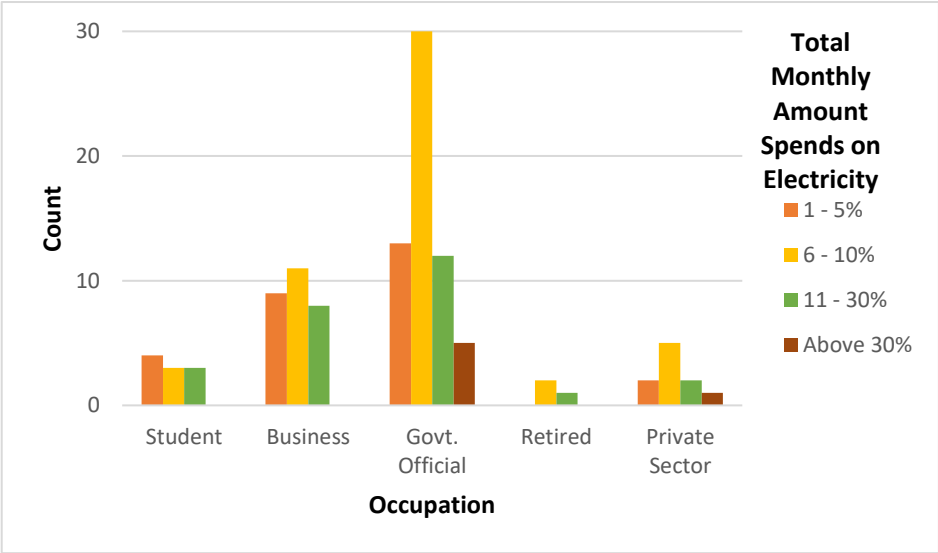


Figure 4. 8: 4 - 5 Numbers Household Composition

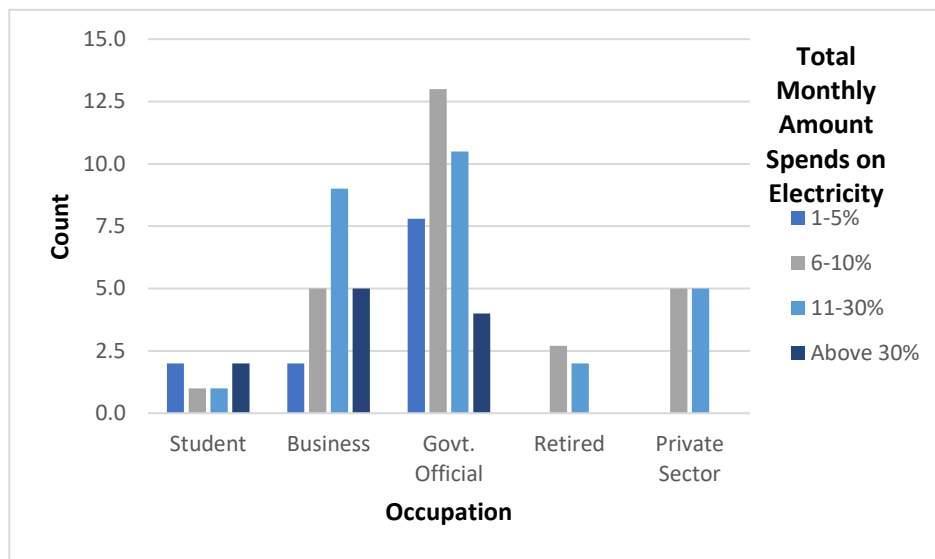


Figure 4. 9: 6 - 7 Numbers Household Composition

Higher levels of education often correlate with a better understanding of the importance of energy conservation, willingness to adopt energy efficient practices, influence of policy and promotion of energy use and management (Bonderud, 2021). An analysis of responses categorized by educational attainment indicates a significant correlation between the level of education and electricity expenditure among government officials. Those with a degree-level education spend approximately 6-10% of their earnings towards electricity costs. Conversely, individuals in the same professional category who lack formal education typically spend a lower percentage of their income on electricity (see Figure 4.10 & 4.11). This indicates that education plays a role in how energy is been utilised, furthermore, it establishes that educated household tend to utilise more appliances in their households creating a tendency to spend more monthly on electricity.

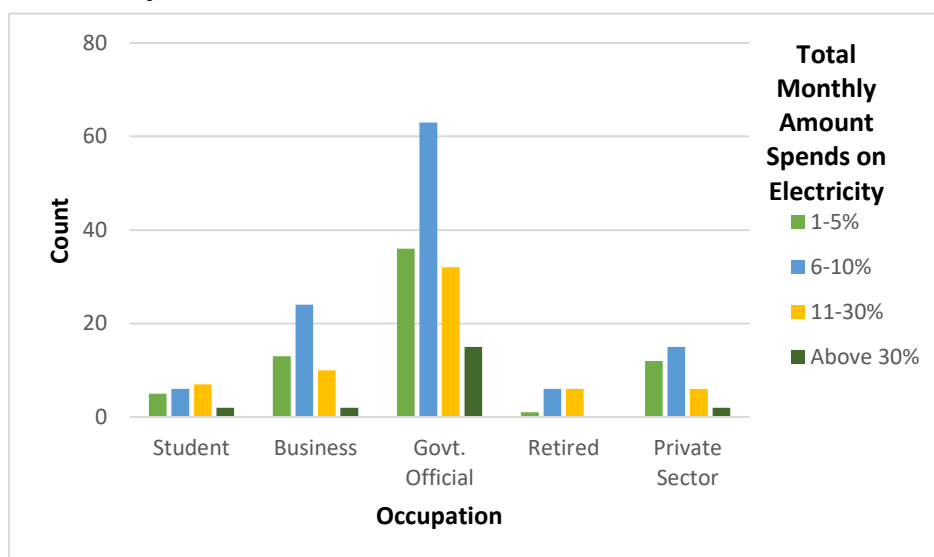


Figure 4. 10: Household with Degree Level Education

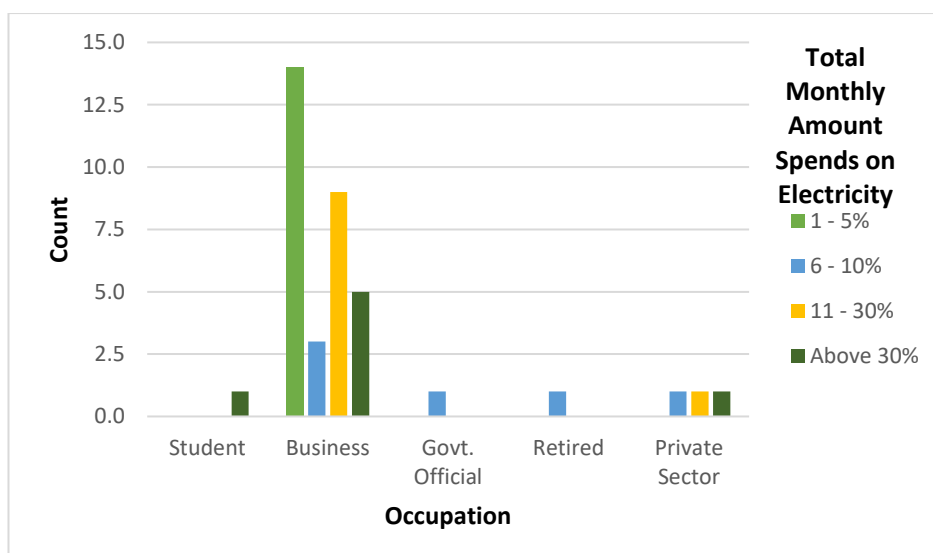


Figure 4. 11: Household with no Formal Education

4.6 Household Appliance Usage

The survey aims to provide a snapshot understanding of typical energy usage profile for majority of electric appliances for a household in North-east region of Nigeria. The data seek to identify the number of appliances for lighting points, water heater, microwave, television, refrigerator, freezer, air condition, water pump and water dispenser. Furthermore, the survey seeks to understand period of use (daily, twice a week, often and never) and time of use (morning, afternoon, evening) for washing machine, iron, and oven. Analysing one of the appliances which is the most frequently used, lightening shown in Figure 4.12 highlights the defect of post-paid billing system as large number of respondents does not apply energy management for an appliance whose utilisation is expected during night-time.

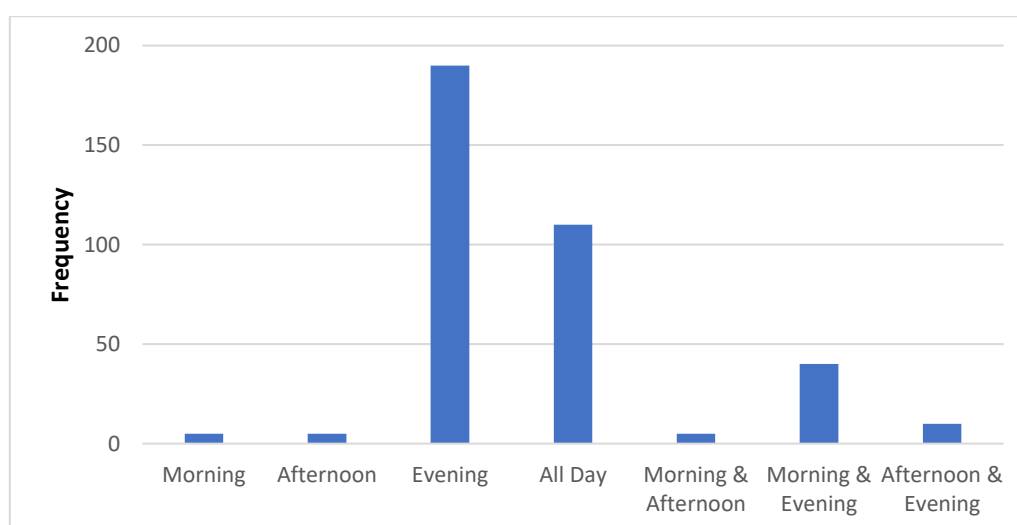


Figure 4. 12: Time of Use of Lightening

Nigeria is a country located near the equator with average temperature ranges between 21°C and 35 °C. The country has two seasons in a year which are dry and wet. The wet season is known as rainy season which falls between April and September while the dry season is a season that experiences midday temperature that can reach 38 °C (Ayantunji and Saleh, 2008; Na-Allah, Ali and Said, 2016). People are turning to AC as a solution to beat surge in temperature. According to International Energy Agency the demand for the increase of AC could raise to 244% by 2050 (Noor, 2023). The result shows that many households use AC in the evening (18:00 – 6:00) and all day (24 hours) (see Figure 4.13), the comparison in terms of the difference billing systems indicates that a larger number of households that run their ACs on a 24-hour bases are household on the post-paid billing system. A Clear indication that the household on post-paid basis have less tendency to run any form of energy management at home. The survey categorised the expenditure on households to either under or above NGN 10,000 on a basis of monthly, quarterly, or random mode of payment mode. For the pre-paid billing system there is no clear difference between how household that spend under or above NGN 10,000 utilised ACs (see Figure 4.14). For the post-paid billing system, a greater number of households spend energy above NGN 10,000 monthly with little effect on the number of households (see Figure 4.15).

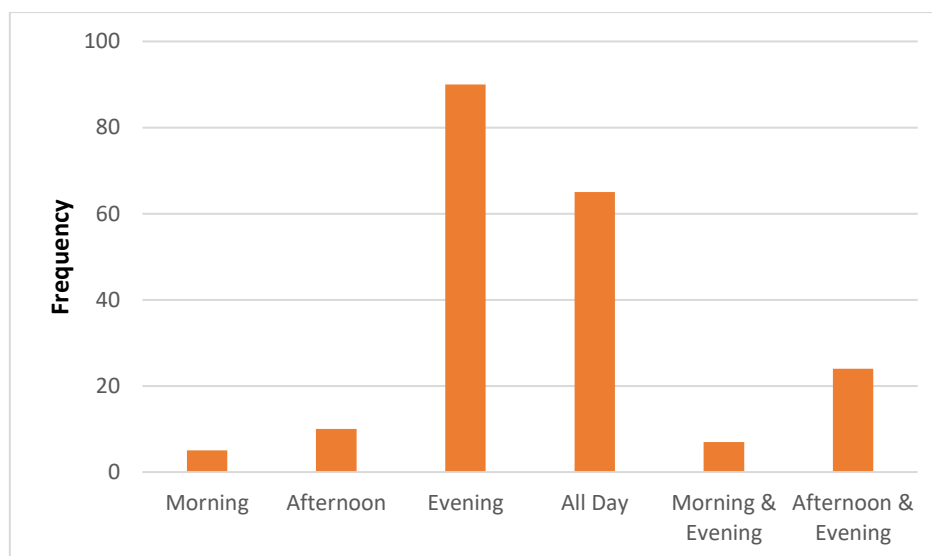


Figure 4. 13: Time of Use for Air Conditioning

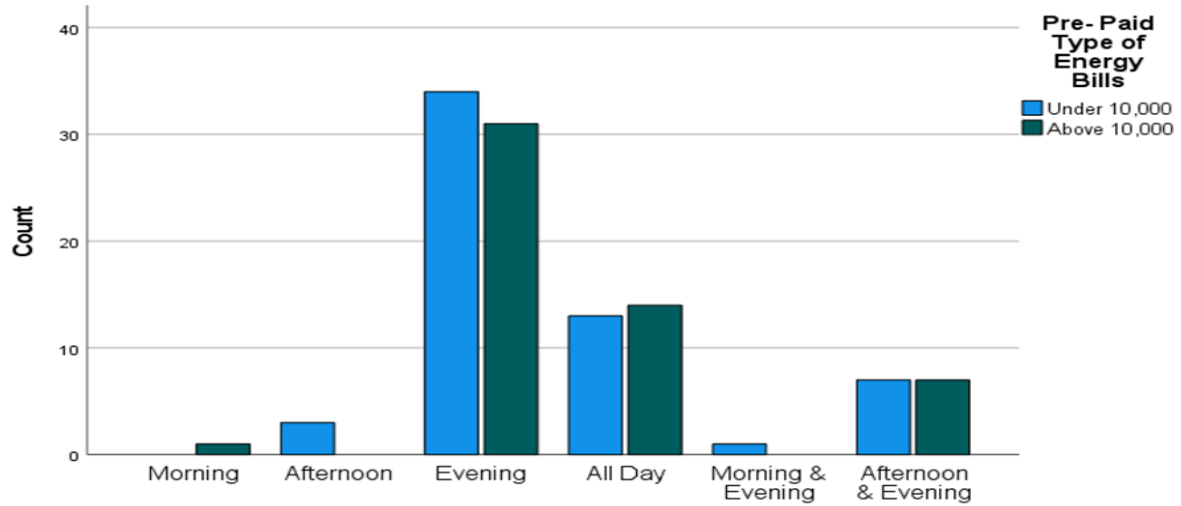


Figure 4. 14: Relationship Between Air Condition Time of Use and Pre-Paid Billing

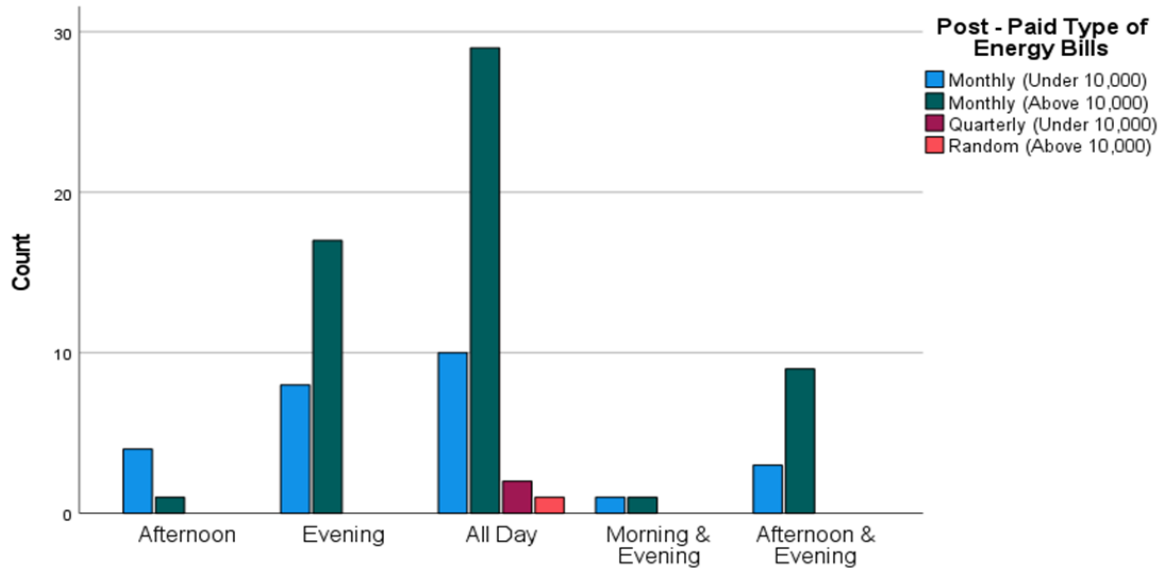


Figure 4. 15: Relationship Between Air Condition Time of Use and Post-Paid Billing

Nigeria being a developing country has appliances such as washing machine, and oven, these are equipments that are often not found in many homes. Iron a device that is essential appliance found in many household (see Figure 4.16). The data clearly indicates that a significant portion of the population utilises this device. When households employ this device during hours of peak energy demand, it poses substantial implications for both load management and DSM strategies.

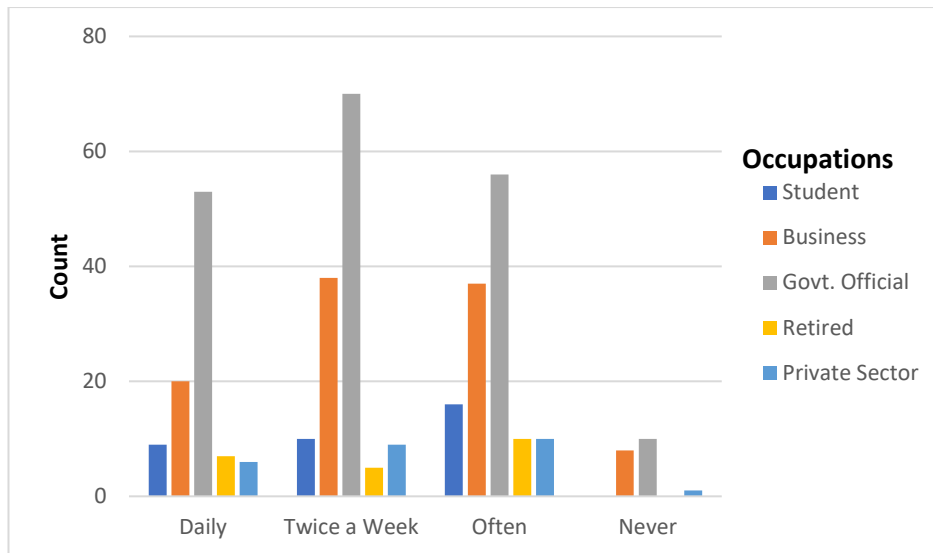


Figure 4. 16: Period of Iron Use

4.7. Energy Management

Nigerian understanding of energy management differs based on the household level of education, access to information, socio-economic status and geographical. Figure 4.17 illustrates that a substantial portion of Nigerian households has put considerable thought into various methods of saving energy at home. 60% of the survey respondents employ some form of energy management, this energy management practice involves the use of energy saving bulbs, switch off light or any appliance when leaving home, using energy saving appliances and change daily habit towards saving energy.

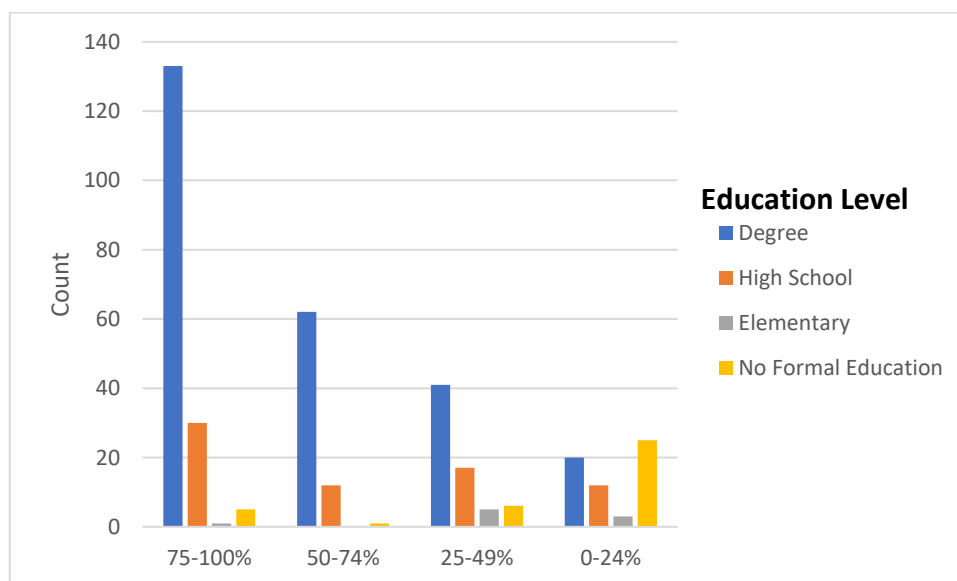


Figure 4. 17: Energy Saving at Home.

it is notable that 82% of households rely on petrol or gas-powered generators as an alternative power source when faced with grid power interruptions (see Figure 4.18). Approximately 40% of households in Nigeria rely on generators to fulfil their electricity needs, incurring an estimated annual cost of \$14 billion due to the absence of a reliable grid power supply (Nnodim, 2022).

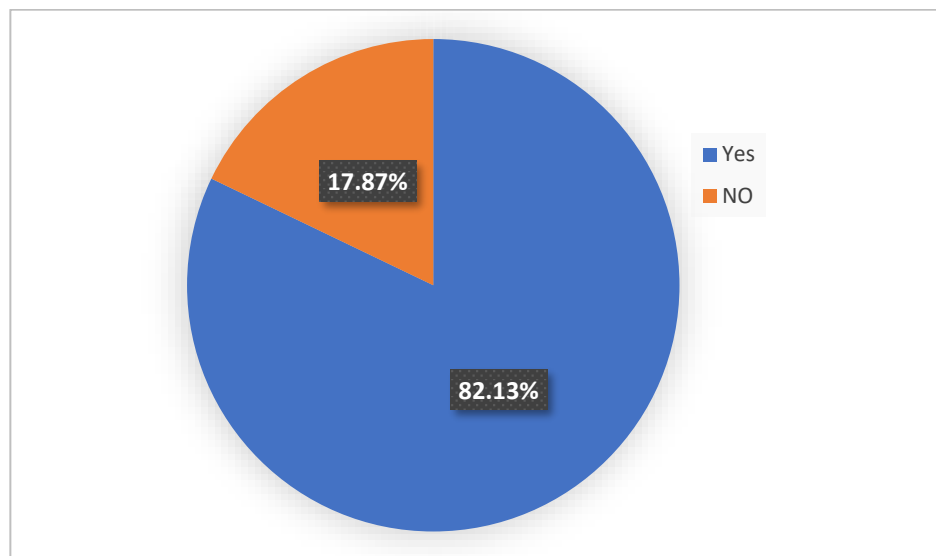


Figure 4. 18: Generator as Alternative Energy Source

Effective energy management can lead to substantial cost savings by decreasing energy consumption. Figure 4.19 demonstrates that 87.04% of respondents are open to participating in an energy management system to assist in load reduction. Furthermore, it indicates that while participants are willing to embrace some form of energy management, there is a 10% decrease in households willing to engage in a DLC scheme. This scheme offers the opportunity to reduce peak energy consumption by directly controlling the operation of appliances during working hours (8:00 – 17:00) in exchange for reduced electricity costs (refer to figure 4.20).

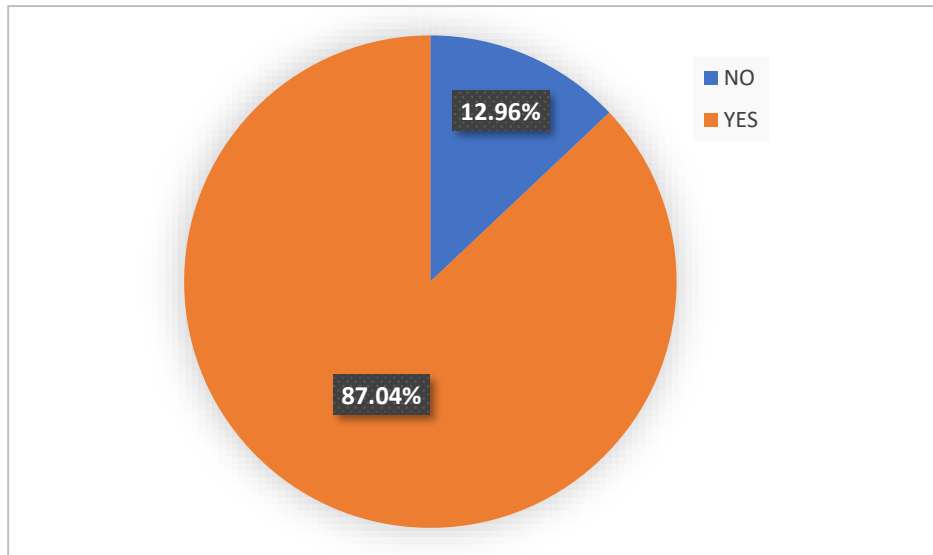


Figure 4. 19: Willingness to Participate in Energy Management.

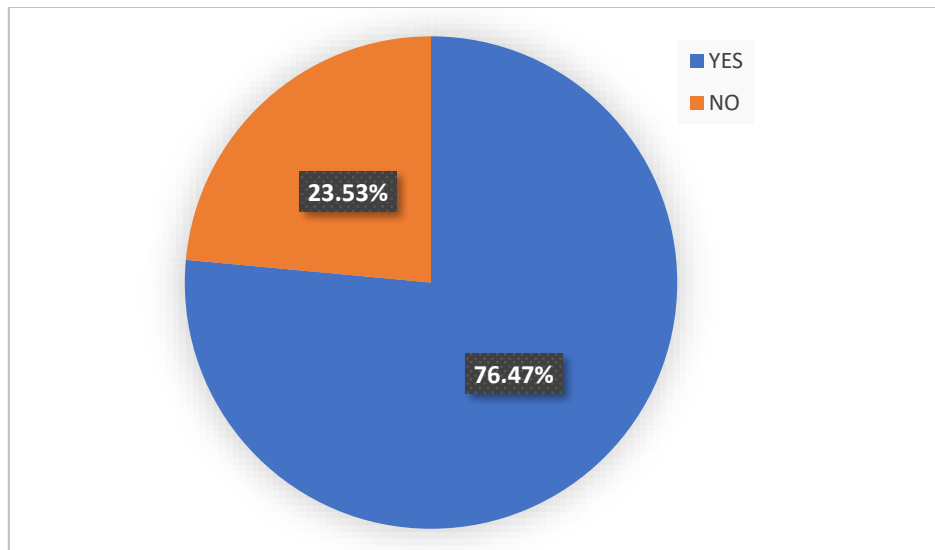


Figure 4. 20: Participation in Direct Load Control

4.8. Alternative Energy

The renewable energy capacity experienced modest growth from 2011 to 2021, reaching a total capacity of 2.16 megawatts (Statista, 2023). Despite a high level of awareness among households regarding various forms of energy management, only 32% of participants have adopted some form of renewable energy. Furthermore, 17% of respondents possess a complete photovoltaic system, which includes solar panels that convert solar energy into usable electrical energy, a battery bank for energy storage, and an inverter that transforms battery-direct current into alternative current. This system contributes to demand response by reducing reliance on

the grid during peak hours. It facilitates load shifting and peak reduction, thereby aiding in the stabilization of the grid during periods of high demand. Concurrently, another 17% of households employ a battery-only system, which does not include the solar panels and inverters that are integral components of a photovoltaic system. This battery-only system switches to battery power when the main supply is interrupted, ensuring that essential appliances continue to run without interruption. The batteries are recharged either through the grid or via a generator (see Figure 4.21). These battery-only systems contribute to demand response in Nigeria by providing backup power to households during grid stress or blackouts.

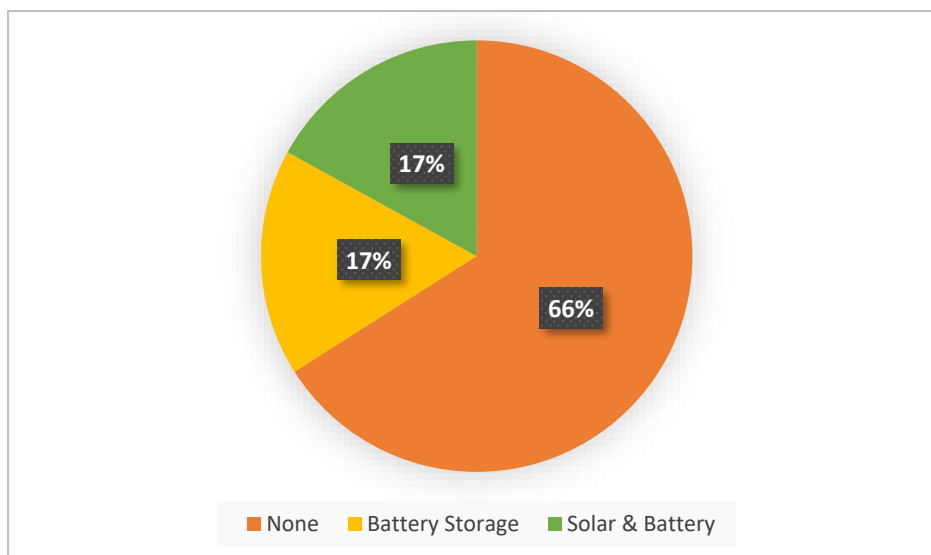


Figure 4. 21: Renewable Energy Resources at Home

When participants were queried about the factors that would drive them to alter their behaviour in order to curtail energy consumption, the findings unmistakably reveal that cost is a primary obstacle hindering the advancement of renewables, with a lack of awareness and limited access serving as additional bottlenecks for households (see Figure 4.22). Several factors, such as the costs linked to renewable energy technologies, subsidies, and government incentives, pose significant obstacles to advancement. Government policies and regulations wield considerable influence when it comes to bolstering the growth of renewable energy. To expedite development, there's a need for both financial resources and the smooth integration of renewable energy sources into the grid infrastructure. Furthermore, the amplification of public support and the rise in demand for clean energy can have a substantial impact on promoting the adoption of these technologies.

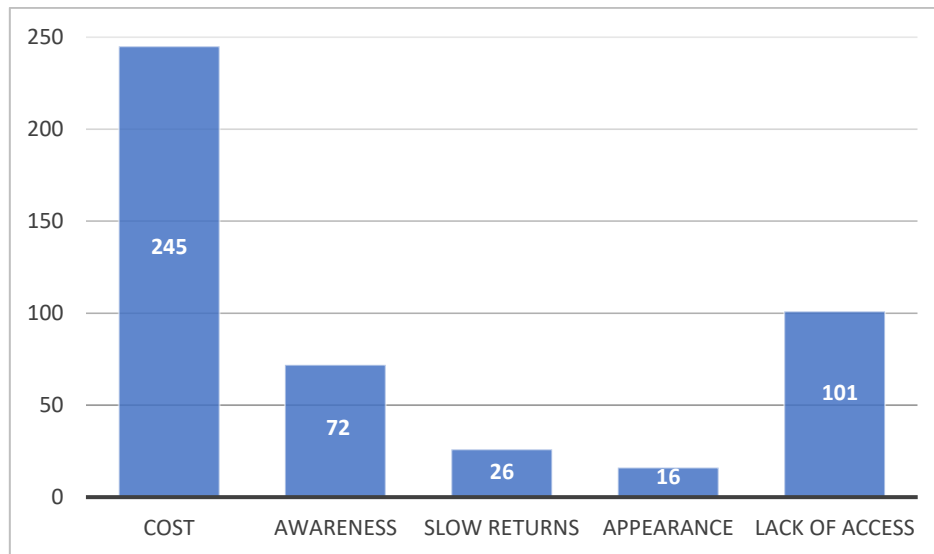


Figure 4. 22: Barrier for your Grid Energy to Renewable Energy

4.9. Conclusion

This chapter have presented an overview of Nigerian households, including their educational backgrounds, occupational statuses, the number and ages of children, types of residences, the count of rooms, and monthly electricity expenditure. The data illustrates that a considerable portion of participants falls within the middle-age category, with around half of them being employed in the public sector. Moreover, a significant proportion of households have received some form of education, and a substantial number of them have fewer than seven children. This comprehensive overview provides valuable insights into the demographic characteristics of the households participating in the study, which are crucial for understanding energy consumption patterns and load profiles. The research demonstrates a significant connection between socio-economic factors, specifically educational level, employment status, and income. These factors play a pivotal role in shaping the individual household load profile.

The survey reveals that a considerable number of households spend a significant portion of their income to cover electricity expenses, particularly among households working in the public sector where this percentage ranges from 6% to 10%. Notably that an almost equal number of households participating in the survey utilise both prepaid and postpaid billing systems. However, the results suggest that those using the postpaid billing system are less inclined to engage in energy management practices, as the electricity billing system is on an estimated basis and not a reflection of energy consumption.

The research reveals that a considerable portion of households incorporate energy-saving measures into their daily routines, such as making use of energy-efficient light bulbs, turning off lights and appliances when they leave their homes, and opting for energy-efficient appliances. Additionally, the survey indicates that a noteworthy proportion of households express a willingness to partake in DSM initiatives like DLC should they be accessible.

In addition, it was observed that only a small fraction of households currently harnesses renewable energy sources within their homes, with the majority relying on generators as backup systems in times of grid outages due to cost considerations and a general lack of awareness about alternative energy solutions.

This study result serves as a compelling testament to the eagerness of Nigerian households to embrace the concept of DSM. It vividly illustrates the transformative impact that DSM can exert on household energy consumption patterns, fostering elevated awareness regarding energy usage. Consequently, this shift will pave the way for a substantial upswing in energy efficiency within these households, promising a more sustainable and environmentally conscious approach to energy consumption. The following chapter evaluates the impact of deploying DLC in Nigerian residential sector.

CHAPTER 5

SIMULATION RESULTS: DEVELOPMENT OF ENERGY MANAGEMENT WITH DIRECT LOAD CONTROL IN NIGERIA

Summary:

This chapter presents the simulation results of the energy consumption patterns within residential households in Nigeria. It investigates the impact of implementing direct load control as a potential solution to address the demand and supply challenges. We examine how socio-economic factors influence energy consumption in households.

5.1. Introduction

This Chapter presents the simulation results developed based on survey findings presented in Chapter 4. With the assistance of the survey conducted in the North-east region of Nigeria, we gained insight into energy usage patterns in residential areas and established a typical residential energy profile of households in Nigeria. Using this data, we simulated the impact of the implementation of DLC and the concept of DSM as an alternative approach to enhancing energy security in the residential sector.

For the simulation, due to insufficient data provided by respondents, we could only utilise 300 responses out of total 396 responses we received. The data covers the number of appliances, time of use of appliances, selected appliance usage period.

Additionally, this chapter provides overview of socio-economic factors such as household income, family structure, and education levels which may influence energy consumption patterns. Understanding these socio-economic determinants that affect household energy consumption is crucial for devising effective energy policies and strategies. Furthermore, it examines the different billing systems as addressing energy consumption in households requires a holistic approach that considers both technological innovation and socio-economic realities to achieve a balanced demand and supply.

5.2. Defining Direct Load Control in the Research Context.

The degree of economic growth and nations industrialisation depends largely on the ability to meet the countries energy demand. Developing countries face the challenge for balancing demand and supply leading to increase blackout and the need for load shedding. Load shedding is a common concept used worldwide as a tool to enable the control and a temporary reduction in electricity supply to enable the balance of demand and supply. Some of the drives of imbalance between electricity demand and supply includes insufficient generation capacity (Bakare et al., 2023c), constraints of the transmission and distribution network, maintenance and outages (Piao and Managi, 2023). This result in economic losses such as the disruption of industrial production, commercial activities, and service sectors, leading to revenue losses, decreased productivity, and potential business closures (Anon, 2023). Furthermore, it provides social disruptions in terms of comfort, health, and education, as essential services like heating, cooling, and lighting are compromised therefore diminishing the quality of life (Pahwa et al., 2013; Raghu.C.N et al., 2018). Backup generators, often used during load shedding, contribute to increased air pollution and carbon emissions, undermining sustainability efforts(Kazmi et

al., 2019). Some of the mitigation strategies that can be deployed consist of diversifying generation mix sources, including renewable energy (Awan et al., 2022; Tightiz and Yoo, 2022), investment in transmission and distribution infrastructure (De Laurentis and Cowell, 2022), deploying of energy storage systems, such as batteries (Khan et al., 2022), deployment of DSM concepts (Bakare et al., 2023d; Usman et al., 2022), integration of advanced smart grid technologies, providing real-time monitoring, predictive analytics, and self-healing networks (Bello-Pierre et al., 2023; Majeed Butt, Zulqarnain and Majeed Butt, 2021), robust regulatory frameworks that encourage private sector investments, promote competition, and incentivise renewable energy adoption (Lu et al., 2020), international collaboration among countries facing similar challenges (Mir et al., 2020), can lead to improved security of supply and enhance the overall resilience of electricity system.

This research focuses on DLC, a concept of DSM, which enables utilities to remotely manage and temporarily reduce the energy consumption of specific appliances or devices during peak demand periods. Consumers agree to participate in exchange for incentives or reduced electricity rates (Usman et al., 2022). The study assesses the effects of implementing the DLC concept as a means to reduce load shedding, offer cost savings to residential households during peak hours, and redirect a significant portion of the energy supply to the commercial and industrial sectors. This approach acts as a catalyst for fostering rapid economic growth and urbanisation.

This study employs a primary data collection from households that participated in a paper survey (results shown in chapter 4) to address the aim and objectives. The collected data was employed in MATLAB to construct an authentic residential demand profile and develop a DSM model. Additionally, excel was utilised to analyse the quantitative data gathered, enabling an assessment of the effects of DLC on energy savings.

5.3. Simulation Results

This section shows the result of the simulation undertaken to create the energy load profile of residential household in Nigeria. It also illustrates the impact of the implementation of DLC illustrating the role the concept can play in reducing load shedding.

The majority of participants in our study consisted of households with individuals aged over 30. The data collection process has delivered several advantages to the respondents, with some of the notable benefits being an enhanced understanding of the household's appliance count, energy consumption patterns, and energy expenditure. This approach was designed to

encompass a diverse range of households, thus enabling us to form a comprehensive perspective of residential energy profiles. This rich dataset is instrumental in our examination of the potential impact of implementing DLC in the residential sector as an alternative remedy for load shedding.

Gathering this data is an essential prerequisite for the research, as the information available from utility sources alone lacks the comprehensiveness required for our study. The household demand load profile is provided in Appendix E.

5.3.1 Residential Energy Load Profile

Based on survey result, Figure 5.1 indicates insightful data regarding household energy consumption patterns of households. On the graph, the x-axis represents the number of households, while the y-axis denotes individual household energy consumption in kilowatt-hours (kWh). It distinguishes energy utilisation patterns between daytime and night-time.

Our findings reveal higher energy consumption during the day than at nights. Nevertheless, there are instances where specific households exhibit higher energy consumption during night-time than during the day. This variation can be attributed to factors such as air conditioning or heating usage, lighting, and electronic device operation.

Overall, this information contributes to a deeper understanding of residential energy consumption trends and aids in the development of effective strategies for reducing energy usage and enhancing energy efficiency. The result from the data shows an average energy consumption of 72.98 kWh (see Table 5.1). The introduction of DLC demonstrates a significant reduction in household energy consumption, with an average usage of 50.6 kWh, as depicted in Figure 5.2.

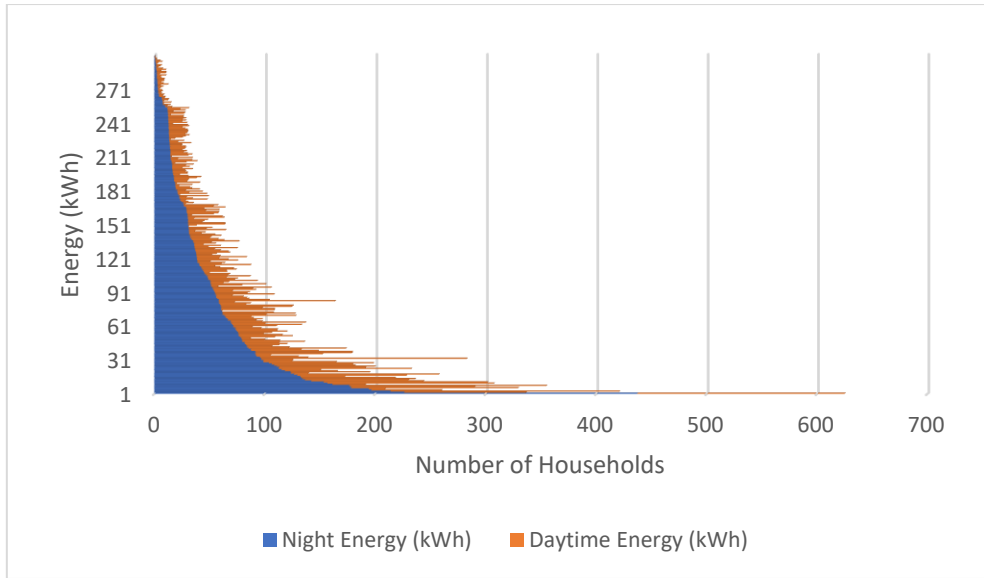


Figure 5. 1: Residential Energy Profile

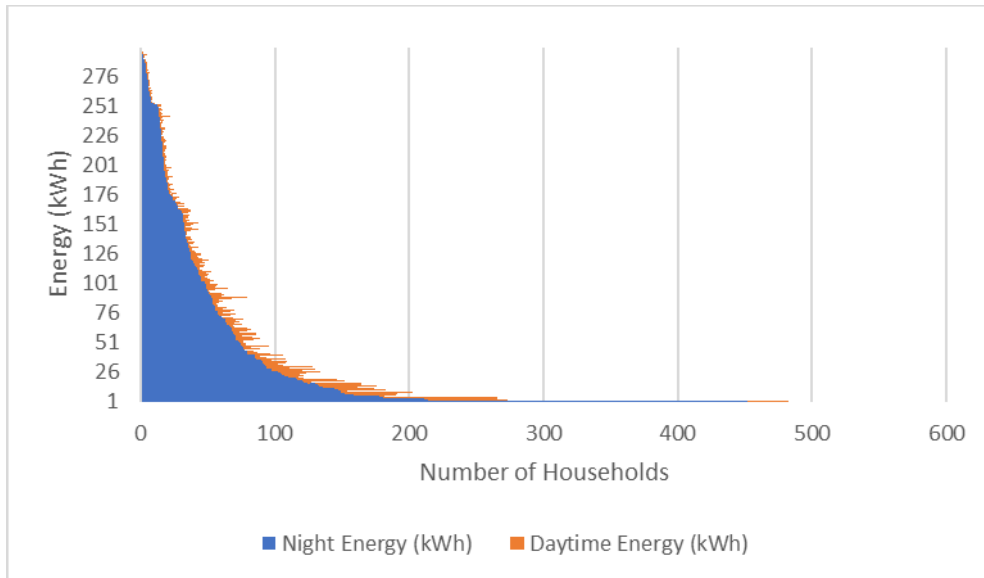


Figure 5. 2: Residential Energy Profile with DLC

Table 5. 1: Comparison of Energy Consumption with and without DLC

Strategy	Average Energy Consumption With & Without DLC		Saving With DLC
	Without DLC (kWh)	With DLC (kWh)	%
Nighttime	44.66	43.82	2
Daytime	28.32	6.78	76

Figure 5.3 shows an average reduction of 21.52 kWh energy consumption. Reductions range from modest savings to extreme cases exceeding 170 kWh, indicating varying levels of

dependency on daytime energy use and the potential for DLC to curtail high-consuming appliances or activities.

Interestingly, the negative minimum value -5.25 kWh suggests some instances where energy consumption with DLC slightly exceed normal consumption. This could be due to anomalies, behavioural changes, or the timing of DLC implementation. Despite this, most cases show a significant positive reduction, with 50% of reduction the differences fall between 7.5 and 25.78 kWh, signifying consistent energy savings. The large standard deviation of 25.27 kWh indicates substantial variation in savings across different households, influenced by factors such as appliances type, household occupancy during the day, or the consistency of DLC application. The high upper bound of 172.67 kWh demonstrates that households with higher energy consumption could benefit immensely from DLC, potentially leading to substantial shifts in energy usage patterns.

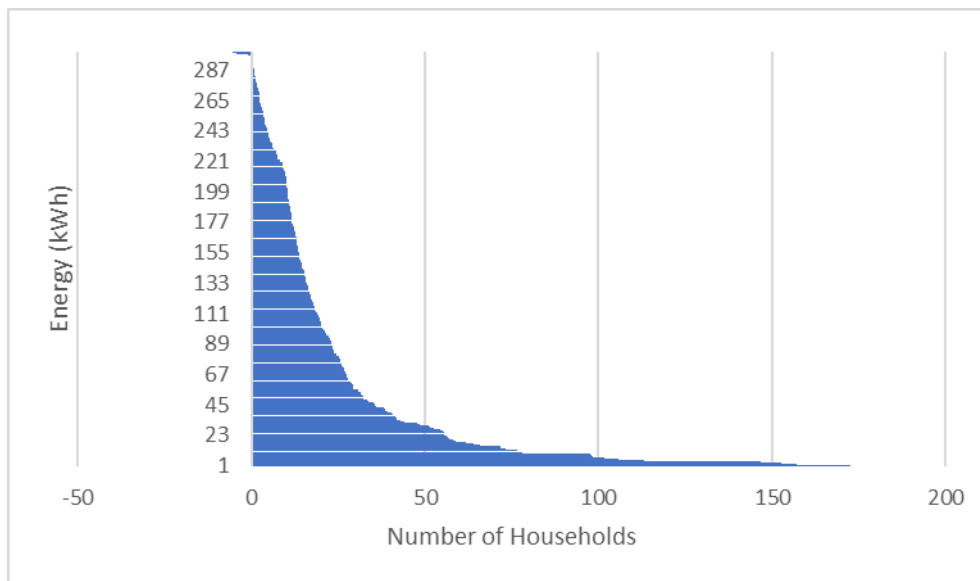


Figure 5. 3: Difference of Daytime Energy Profile with and without DLC

Nigeria consistently faces load shedding, and the extent of load shedding fluctuates from one region to another with estimated load shedding up to 70%. The country has witnessed a sustained reduction in energy generation with a recent decline of 16.4% week on week, with power generation dropping from 3501.20 megawatts (MW) to 4,187.6 megawatts (MW) for its 200 million population (Olukoya, 2023). Load shedding is a measure employed by utility companies to manage and temporarily curtail electricity supply, aimed at rectifying imbalances between demand and supply. This global adopted practice arises from insufficient power generation and inadequacies in transmission and distribution infrastructure, which can lead to

significant economic losses and disrupt the social well-being of households, affecting their comfort, health, education, and overall quality of life (Pahwa et al., 2013; Raghu. C. N et al., 2018). When a 70% load shedding scenario is introduced as experienced in Nigeria, the average energy profile for the day becomes 21.89 kWh, with 8.49 kWh during the daytime and 13.4 kWh during the night-time. When comparing the innovative DLC to load shedding, there is a notable 20% reduction in electricity expenses for households.

Table 5. 2: Cost of Energy for Different Scenario

Scenario	Utility Time (Hr)	Generator Time (Hr)	Energy Cost/day (NGN)
LS	3.6	0	424.67
LS + GEN (2)	3.6	2	1684.69
LS + GEN (4)	3.6	4	2520
LS + GEN (6)	3.6	6	3782
LS + GEN (8)	3.6	8	5044
Proposed DLC	7	0	339.18
Comparison between DLC with LS			20%
Comparison between DLC with LS+GEN (4)			87%
Comparison between DLC with LS+GEN (8)			93%

LS: Load Shedding; GEN (2) means home Generator Operating for Two Hours per day; GEN (4) means home Generator Operating for Four Hours per day; GEN (6) means home Generator Operating for Six Hours per day; GEN (8) means home Generator Operating for Eight Hours per day

Table 5.2 above presents the cost of energy for households across various load shedding and generator usage scenarios. In the context of a 70% load shedding situation, the cost of grid-supplied energy stands at 424.67 NGN, based on Nigeria's utility rate of 50.01 NGN/kWh. For households equipped with a 5 kVA fuel generator consuming around 1 liter per hour, the analysis indicates that running the generator for 8 hours in addition to the grid providing 30% of energy during the day would amount to a total cost of 5044 Naira. However, if the generator is operated for 4 hours and utility provides energy for 3.6 hours, the cost is reduced to 2520 Naira.

Comparing the proposed DLC to a household running home generators for 4 hours per day during power cut period, provides significant cost savings amounting to a remarkable 87% but with a 5% decrease in comfort level. Furthermore, comparing the proposed DLC with a household running a home generator for 8 hours per day during power cut period shows impressive 93% cost savings but with a 39% decrease in comfort level.

This shows the financial advantages of embracing DLC. These findings illuminate the potential for substantial financial benefits and enhanced energy management with the implementation of DLC in the residential sector. Table 5.3 below shows comfort level for households at different scenarios.

Table 5. 3: Comfort Level of Residence

Scenario	Utility Time (Hr)	Generator Time (Hr)	Hours of supply of load/day (Hr)
LS	3.6	0	3.6
LS + GEN (2)	3.6	2	5.6
LS + GEN (4)	3.6	4	7.6
LS + GEN (6)	3.6	6	9.6
LS + GEN (8)	3.6	8	11.6
Proposed DLC	7	0	7
Comparison between DLC with LS			28%
Comparison between DLC with LS+GEN (4)			-5%
Comparison between DLC with LS+GEN (8)			-39%

LS: Load Shedding; GEN (2) means home Generator Operating for Two Hours per day; GEN (4) means home Generator Operating for Four Hours per day; GEN (6) means home Generator Operating for Six Hours per day; GEN (8) means home Generator Operating for Eight Hours per day. “-” means the comfort level for using the DLC method is lower than the load shedding method.

5.3.2. Billing System

The Nigeria electricity supply industry classifies the billing system into pre-paid system (being metered by utility), and the post-paid billing systems (estimated billing) as highlighted previously in chapter 4. Figure 5.4 illustrates the energy consumption pattern among households with a post-paid billing system, revealing higher energy usage during the daytime compared to night-time. Similarly, Figure 5.5, which represents energy patterns for households with a pre-paid billing system, exhibits a similar trend, with most households consuming more energy during the daytime than at night. The study discloses that households on the post-paid billing system consume an average of 33.09 kWh during the daytime, while those on the pre-paid billing system average 23.69 kWh (Table 5.4). This variance can be attributed to the fact that consumers using the pre-paid system have greater control over their energy expenditures through real-time energy monitoring, leading to enhanced energy efficiency and cost savings (Gumyusenge et al., 2018; Jack and Smith, 2017), while the post-paid offer convenience such that consumers do not need to make upfront payment, however, this results shows reduced awareness of energy consumption and potential higher bill due to lack of real-time monitoring (Kambule, Yessoufou and Nwulu, 2018).

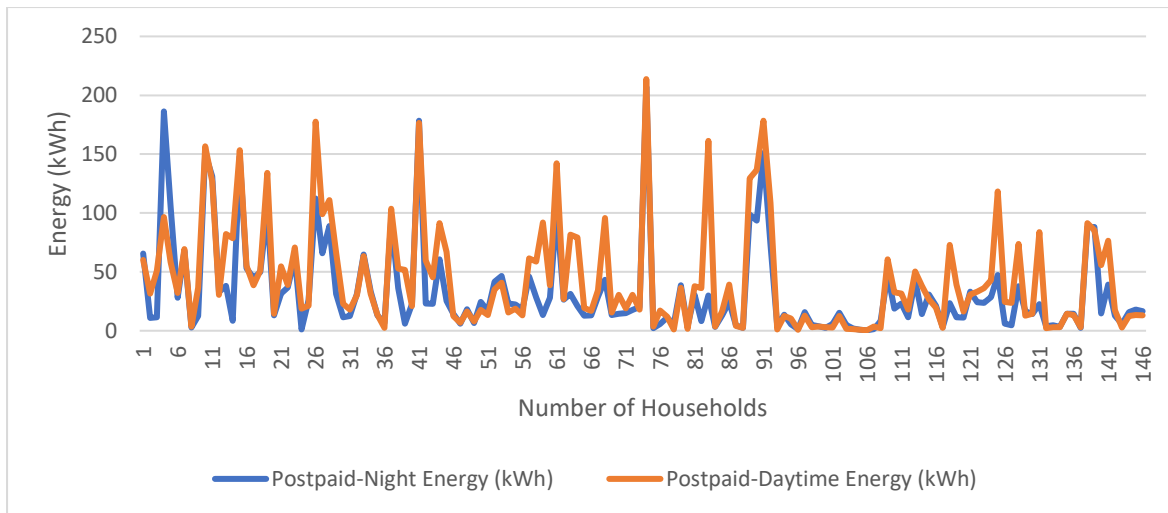


Figure 5. 4: Post-Paid Residential Energy Profile

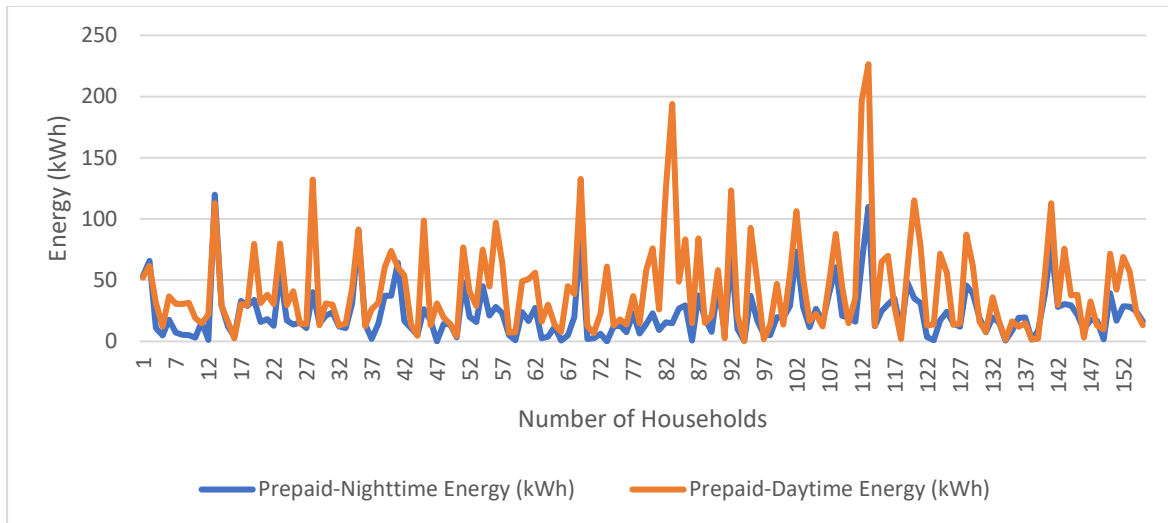


Figure 5. 5: Pre-Paid Residential Energy Profile

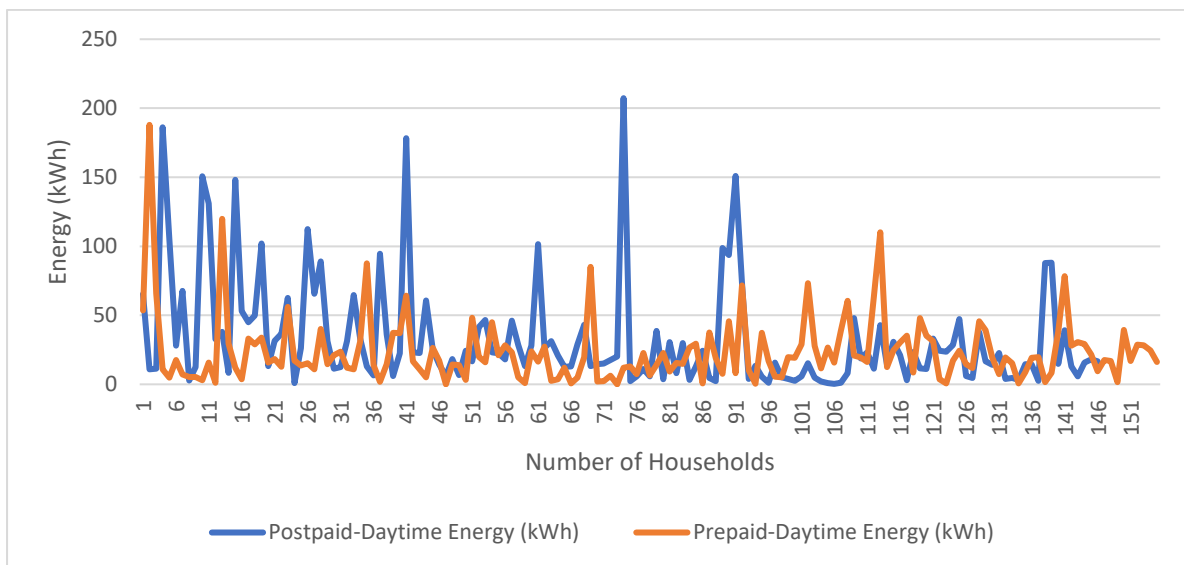


Figure 5. 6: Comparison of Daytime for Pre-paid and Post-paid Billing System

Upon analysing the comparison between the two billing systems, In Nigeria, the post-paid billing system does not accurately represent energy consumption, as households are invoiced based on estimations, regardless of the quantity and usage hours of their appliances. The introduction of DLC results in an average energy consumption of 5.9 kWh for customers using the pre-paid billing system, yielding an estimated cost 295.07 energy savings of 75% during the daytime. Meanwhile, for customers on the post-paid billing system, the average energy consumption is 7.68 kWh, with an estimated energy savings of 77% (see Table 5.4).

Table 5. 4: Comparison of Daytime for Pre-paid and Post-paid Billing System

Average Energy Consumption With & Without DLC				
Billing System	Pre-Paid		Post Paid	
Strategy	Without DLC	With DLC	Without DLC	With DLC
Nighttime (kWh)	45.04	44.72	44.17	42.82
Daytime (kWh)	23.69	5.9	33.09	7.68

Table 5.5 outlines the energy costs for different billing systems. The data shows that deployment of DLC results in significant energy savings when comparing to load shedding. The average saving of using DLC is 17% for households using pre-paid billing systems, and 23% for households using post-paid billing systems. In a specific scenario where households on the pre-paid billing system run a generator for 4 hours during power cut period, the energy expenditure amounts to 2875.43 NGN, while households under the post-paid billing system on the same scenario incurs an expenditure of 3016.42 NGN.

When comparing the proposed DLC to running home generators for 4 hours per day during power cut period, the result shows that for the households on the pre-paid billing system receives a 90% decrease in household expenditure but a 5% decrease in comfort level. For the households on the post-paid billing that run generator for 4 hours during the power cut period, he proposed DLC method shows an 87% decrease in household expenditure and a 5% decrease in comfort level. Furthermore, the data shows that under a scenario that a household runs a home generator for 8 hours during power cut, the results indicated that for the pre-paid billing system the proposed DLC method provides 95% decrease in household expenditure and a 5% decrease in comfort level while on the pre-paid billing an 83% decrease in household expenditure and a 5% decrease in comfort level.

This highlights the trade-off between increased comfort and higher costs for households, as detailed in Table 5.6.

Table 5. 5: Cost of Energy under Various Billing System Scenarios

Scenario	Utility Time (Hr)	Generator Time (Hr)	Energy Cost/day (NGN)	
			Pre-paid	Post-paid
LS	3.6	0	355.43	496.41
LS + GEN (2)	3.6	2	1615.43	1756.41
LS + GEN (4)	3.6	4	2875.43	3016.42
LS + GEN (6)	3.6	6	4135.43	4276.41
LS + GEN (8)	3.6	8	5395.43	5536.41
Proposed DLC	7	0	295.07	384.29
Comparison between DLC with LS			17%	23%
Comparison between DLC with LS+GEN (4)			90%	87%
Comparison between DLC with LS+GEN (8)			95%	83%

LS: Load Shedding; GEN (2) means home Generator Operating for Two Hours per day; GEN (4) means home Generator Operating for Four Hours per day; GEN (6) means home Generator Operating for Six Hours per day; GEN (8) means home Generator Operating for Eight Hours per day

Table 5. 6: Comfort Level of Residence under various Billing System Scenarios

Scenario	Utility Time (Hr)	Generator Time (Hr)	Hours of supply of load/day (Hr)	
			Pre-paid	Post-paid
LS	3.6	0	3.6	3.6
LS + GEN (2)	3.6	2	5.6	5.6
LS + GEN (4)	3.6	4	7.6	7.6
LS + GEN (6)	3.6	6	9.6	9.6
LS + GEN (8)	3.6	8	11.6	11.6
Proposed DLC	7	0	7	7
Comparison between DLC with LS			28%	28%
Comparison between DLC with LS+GEN (4)			-5%	-5%
Comparison between DLC with LS+GEN (8)			-39%	-39%

LS: Load Shedding; GEN (2) means home Generator Operating for Two Hours per day; GEN (4) means home Generator Operating for Four Hours per day; GEN (6) means home Generator Operating for Six Hours per day; GEN (8) means home Generator Operating for Eight Hours per day. “-” means the comfort level for using the DLC method is lower than the load shedding method.

5.3.3. Different Representative Groups

5.3.3.1 Household with Different Number of Occupants

Socio-economic factor can have significant impact on energy consumption. Factors such as income level, family structure, age, level of education, awareness of emission reduction and energy consumption habits influences the behaviour of energy consumption (Demiral and Demiral, 2023). Figure 5.7 accentuates energy consumption patterns based on household size. It illustrates that larger households, with increased heating, cooling, lighting, and appliance demands, typically have higher energy consumption. Conversely, smaller households tend to exhibit lower energy demand due to reduced resource needs.

Table 5.7 highlights a noticeable trend of increased energy consumption in larger households. The findings reveal that households with 2 to 3 occupants typically have an average energy usage of 23.59 kWh, whereas households with 7 or more residents consume an average energy

of 43.02 kWh. Moreover, after the implementation of DLC, there is an observed average energy consumption reduction to 4.51 kWh during the daytime, with a slight increase to 32.92 kWh during night-time for households with 7 or more occupants.

For households with 4 to 5 members, the average energy consumption is reduced to 26.25 kWh during the day and 42.46 kWh during the night. Finally, households with 2 to 3 occupants see a remarkable reduction in energy consumption, with averages of 6.66 kWh during the day and 41.89 kWh during the night, attributed to the implementation of DLC. Specifically, households with 7 or more members achieve a substantial 71% reduction in energy consumption, while those with 4 to 7 members achieve a 75% reduction, and households with 2 to 3 occupants realise an impressive 81% energy savings (see Table 5.8).

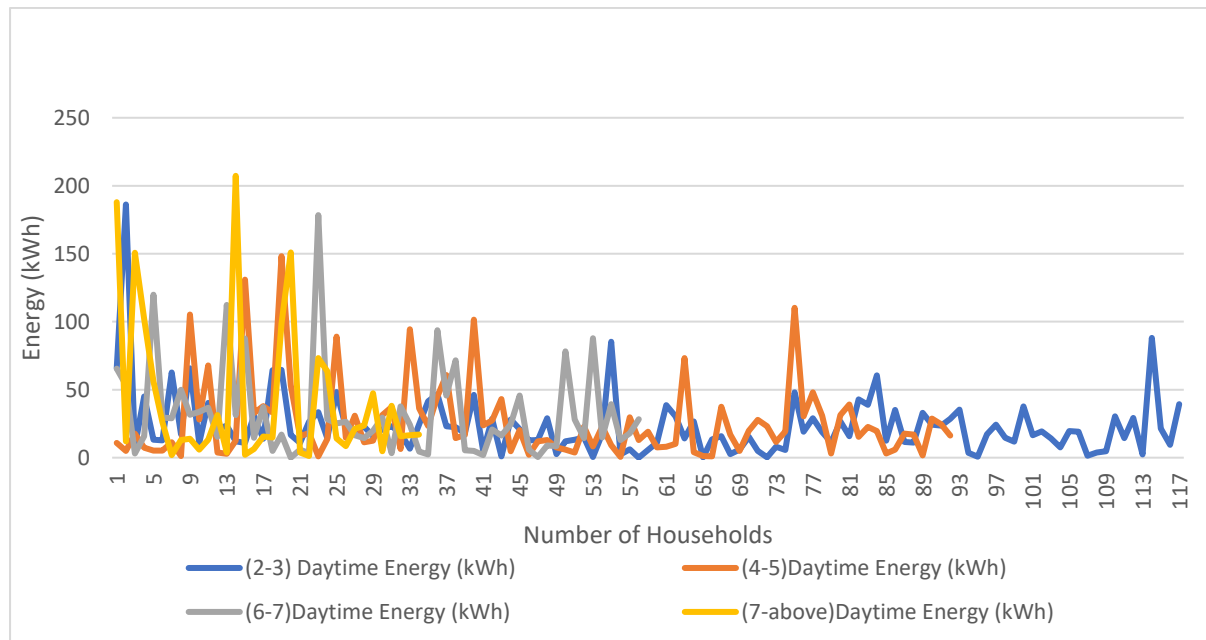


Figure 5. 7: Number of Households

Table 5. 7: Analysis of Energy Consumption based on Number of Occupant with and without DLC

Average Energy Consumption With & Without DLC								
Occupants Number	(2-3)		(4-5)		(6-7)		(7 Above)	
Strategy	Without DLC	With DLC	Without DLC	With DLC	Without DLC	With DLC	Without DLC	With DLC
Nighttime (kWh)	34.13	32.92	42.46	41.89	49.47	48.62	78.66	78.17
Daytime (kWh)	23.59	4.51	26.25	6.66	32.51	8.12	43.02	12.57

Table 5. 8: Average Energy Consumption Savings based on Number of Occupants with DLC

Average Energy Consumption Saving with DLC				
Occupant Number	(2-3)	(4-5)	(6-7)	(7 Above)
Nighttime (%)	4	1	2	1
Daytime (%)	81	75	75	71

When we examine the impact of deploying DLC versus utility load shedding across various household sizes, the data reveals intriguing insights. For households with 2 to 3 occupants, the average energy consumption with load shedding stands at 7.1 kWh. In contrast, with the implementation of DLC, this figure drops significantly to 4.51 kWh. The data presented in Table 5.9 offers insights into energy costs across households of varying sizes of household members. When we analyse the disparities between deploying DLC and implementing load shedding, significant differences in energy savings become evident. Specifically, for households comprising 2 to 3 members, we observe substantial energy savings of 36%, while households with 4 to 5 members experience a 15% reduction in energy costs. In the case of households with 6 to 7 members, energy savings reach 17%, with a more modest 3% reduction for households exceeding 7 members.

In a specific scenario where households run a generator for 4 hours per day during power cut period, the resulting expenditures vary households with 2 to 3 members incur a total cost of 2873.493 NGN, while those with 4 to 5 members spend 2913.76 NGN. Similarly, households with 6 to 7 members will see a total cost of 3007.73 NGN, and households exceeding 7 members face a total expense of 3165.43 NGN.

When we compare these costs to the expenses associated with deploying DLC in the same scenario, the data reveals remarkable energy savings. Specifically, households with 2 to 3 members achieve a substantial 92% reduction in energy bill, while households with 4 to 5 members experience an impressive 89% decrease. For households with 6 to 7 members, energy savings reach 86%, and even larger households exceeding 7 members still benefit from a notable 80% reduction in energy expenses but under this scenario the comfort level of households drops by 5%.

In an alternative scenario where a household intends to enhance the comfort level from the initial DLC level, which involves operating a generator for 8 hours per day during power cut, the associated costs vary depending on the household size. Specifically, households comprising 2 to 3 members will incur an expense of 5393.93 NGN, while those with 4 to 5 members will

spend 5433.76 NGN. For households consisting of 6 to 7 members, the cost will amount to 5527.73 NGN, and those with 7 members or more will face an expenditure of 5685.43 NGN. This represents a notable 96% decrease in costs for 2 to 3-member households. Interestingly, as the household size increases, there is a gradual reduction in expenditure, eventually reaching a substantial 89% cost reduction. Comparing the comfort level under this scenario provides 39% decrease in comfort level. This trend is clearly depicted in Table 5.09 and Table 5.10, which provides a comprehensive overview of the varying cost of energy and varying levels of comfort for different households.

Table 5. 9: Cost of Energy for Different Occupant Numbers of a Household

Scenario	Utility Time (Hr)	Generator Time (Hr)	Energy Cost/day (NGN)			
			Occupant Numbers			
			(2-3)	(4-5)	(6-7)	(Above 7)
LS	3.6	0	353.93	393.76	487.73	645.42
LS + GEN (2)	3.6	2	1613.93	1653.76	1747.73	1905.43
LS + GEN (4)	3.6	4	2873.93	2913.76	3007.73	3165.43
LS + GEN (6)	3.6	6	4133.93	4173.76	4267.73	4425.43
LS + GEN (8)	3.6	8	5393.93	5433.76	5527.73	5685.43
Proposed DLC	7	0	225.43	333.99	406.20	628.77
Comparison between DLC with LS			36%	15%	17%	3%
Comparison between DLC with LS+GEN (4)			92%	89%	86%	80%
Comparison between DLC with LS+GEN (8)			96%	94%	93%	89%

LS: Load Shedding; GEN (2) means home Generator Operating for Two Hours per day; GEN (4) means home Generator Operating for Four Hours per day; GEN (6) means home Generator Operating for Six Hours per day; GEN (8) means home Generator Operating for Eight Hours per day

Table 5. 10: Comfort Level of Residence for Different Occupant Numbers of a Household

Scenario	Utility Time (Hr)	Generator Time (Hr)	Hours of supply of load/day (Hr)			
			Occupant Numbers			
			(2-3)	(4-5)	(6-7)	(Above 7)
LS	3.6	0	3.6	3.6	3.6	3.6
LS + GEN (2)	3.6	2	5.6	5.6	5.6	5.6
LS + GEN (4)	3.6	4	7.6	7.6	7.6	7.6
LS + GEN (6)	3.6	6	9.6	9.6	9.6	9.6
LS + GEN (8)	3.6	8	11.6	11.6	11.6	11.6
Proposed DLC	7	0	7	7	7	7
Comparison between DLC with LS			28%	28%	28%	28%
Comparison between DLC with LS+GEN (4)			-5%	-5%	-5%	-5%
Comparison between DLC with LS+GEN (8)			-39%	-39%	-39%	-39%

LS: Load Shedding; GEN (2) means home Generator Operating for Two Hours per day; GEN (4) means home Generator Operating for Four Hours per day; GEN (6) means home Generator Operating for Six Hours per day; GEN (8) means home Generator Operating for Eight Hours per day. “-” means the comfort level for using the DLC method is lower than the load shedding method.

5.3.3.2 Household working in Different Sectors

Studies have shown that higher income group monotonically have higher levels of socio-economic productive capacities and energy intensities (Pelenur, 2018), there is a positive correlation between income levels and energy consumption (Khan et al., 2023). This research reveals that, among residential sectors, student households exhibit the lowest energy consumption at 18.85 kWh, while households working in the public sector and private sector workers consume 30.77 kWh and 32.04 kWh, respectively, households that are retirees have average energy consumption of 24.42 kWh (see table 5.11). Interestingly, the deployment of DLC leads to substantial energy savings across different categories, revealing significant benefits. Prior to implementing DLC, households working in the public sector consumes an average of 33.77 kWh, with DLC in place, these households achieve an impressive 75% reduction in energy consumption. Households who run businesses consume less energy as

compared to those working in the public and private sector with an average energy consumption of 25.9 kWh, however, the introduction of DLC, their energy consumption significantly drops by 5.42 kWh, indicating an outstanding 79% energy savings. DLC implementation for retired households results in 74% energy savings, bringing their average daytime consumption down to 6.26 kWh. It worth noting that there is a slight increment in average consumption during the night-time (see Table 5.12).

Table 5. 11: Comparison on the Energy Consumption with and without for Households working in Different Sectors

Average Energy Consumption With & Without DLC										
Household working in Different Sector	Public Sector		Business		Private Sector		Student		Retired	
Strategy	Without DLC	With DLC	Without DLC	With DLC	Without DLC	With DLC	Without DLC	With DLC	Without DLC	With DLC
Nighttime (kWh)	45.62	44.95	40.87	40.03	54.84	52.3	34.79	34.52	50.67	51.55
Daytime (kWh)	30.77	7.71	25.9	5.42	32.04	8.55	18.85	3.75	24.42	6.26

Table 5. 12: Average Energy Consumption Savings with DLC for Households working in Different Sectors.

Average Energy Consumption Saving with DLC					
Household working in different Sector	Public Sector	Business	Private Sector	Student	Retired
Nighttime (%)	1	2	5	1	-2
Daytime (%)	75	79	73	80	74

In the context of managing household energy, the comparison between traditional utility-activated load shedding and the introduction of DLC reveals some intriguing findings, especially when considering the different occupations of these households. Business-oriented households typically consume an average of 7.77 kWh of energy when subjected to the conventional utility-activated load shedding. However, when they incorporate DLC into their energy management approach, their energy consumption significantly drops to 5.42 kWh. This remarkable reduction in energy usage leads to a substantial 30% decrease in their electricity consumption compared to the traditional load shedding method. Households working in the public sector experience an average energy consumption of 9.23 kWh with the implementation of load shedding. Conversely, the adoption of DLC results in a notable reduction, lowering their energy consumption to 7.71 kWh, translating to a 16% decrease in energy consumption compared to utility load shedding. Households working in the private sector see a comparatively lower yet significant 11% decrease in energy consumption when using DLC in

their energy management strategy instead of load shedding. This highlights the adaptability and advantages of DLC, even in households with private sector employment. Households that are student benefit significantly from DLC, with a remarkable 34% reduction in energy consumption compared to traditional load shedding. This underscores the suitability of DLC for households with varying occupancy and energy usage patterns, such as those of students. Finally, retired households can also reap the advantages of DLC. The introduction of DLC results in a significant 15% reduction in energy consumption levels. This emphasises the versatility of DLC in enhancing the well-being of households, particularly those in the retired demographic.

The data in Table 5.13 presents a detailed breakdown of energy costs in various scenarios, while Table 5.14 offers insights into the hours of comfort for different household categories. In a specific scenario where a home generator operates for 4 hours per day during power cut period, the study reveals that household that work in the public sector will face an expenditure of 2981.62 NGN. Business-oriented households will incur costs of 2908.58 NGN, household that work in the private sector will spend 3000.73 NGN, Household who are student will spend 2802.87 NGN, and retiree households will spend 2886.30 NGN.

Comparing these costs to the implementation of DLC to running a home generator during power cut period, we observe an increase in expenses of 87%, 91%, 86%, 93%, and 89% for households in the public sector, business sector, private sector, student households, and retiree households, respectively and 5% decrease in comfort level across the various working household's groups.

For those seeking a higher level of comfort, which involves running an 8-hour generator per day during power cut periods, the expenditure rises to 5501.62 NGN for households working in the public sector, 5428.58 NGN for household that run businesses, 5520.73 NGN for household that work in the private sector, 5322.87 NGN for students, and 5436.30 NGN for household who are retirees. This information highlights the significant cost differences between these scenarios and the potential benefits of DLC.

Table 5. 13: Cost of Energy for Households working in Different Sectors.

Scenario	Utility Time (Hr)	Gen Time (Hr)	Energy Cost/day (NGN)				
			Public Sector	Business	Private Sector	Student	Retired
LS	3.6	0	461.62	388.58	480.73	282.87	366.30
LS + GEN (2)	3.6	2	1721.62	1648.58	1740.73	1542.87	1626.30
LS + GEN (4)	3.6	4	2981.62	2908.58	3000.73	2802.87	2886.30
LS + GEN (6)	3.6	6	4241.62	4168.58	4260.73	4062.87	4146.30
LS + GEN (8)	3.6	8	5501.62	5428.58	5520.73	5322.87	5406.30
Proposed DLC	7	0	385.80	271.29	427.63	187.40	313.15
Comparison between DLC with LS			16%	30%	11%	34%	15%
Comparison between DLC with LS+GEN (4)			87%	91%	86%	93%	89%
Comparison between DLC with LS+GEN (8)			93%	95%	92%	96%	94%

LS: Load Shedding; GEN (2) means home Generator Operating for Two Hours per day; GEN (4) means home Generator Operating for Four Hours per day; GEN (6) means home Generator Operating for Six Hours per day; GEN (8) means home Generator Operating for Eight Hours per day

Table 5. 14: Residence Comfort Level Based on Different Occupation.

Scenario	Utility Time (Hr)	Gen Time (Hr)	Hours of supply of load/day (Hr)					
			Public Sector	Business	Private Sector	Student	Retired	Public Sector
LS	3.6	0	3.6	3.6	3.6	3.6	3.6	3.6
LS + GEN (2)	3.6	2	5.6	5.6	5.6	5.6	5.6	5.6
LS + GEN (4)	3.6	4	7.6	7.6	7.6	7.6	7.6	7.6
LS + GEN (6)	3.6	6	9.6	9.6	9.6	9.6	9.6	9.6
LS + GEN (8)	3.6	8	11.6	11.6	11.6	11.6	11.6	11.6
Proposed DLC	7	0	7	7	7	7	7	7
Comparison between DLC with LS			28%	28%	28%	28%	28%	28%
Comparison between DLC with LS+GEN (4)			-5%	-5%	-5%	-5%	-5%	-5%
Comparison between DLC with LS+GEN (8)			-39%	-39%	-39%	-39%	-39%	-39%

LS: Load Shedding; GEN (2) means home Generator Operating for Two Hours per day; GEN (4) means home Generator Operating for Four Hours per day; GEN (6) means home Generator Operating for Six Hours per day; GEN (8) means home Generator Operating for Eight Hours per day. “-” means the comfort level for using the DLC method is lower than the load shedding method.

5.3.3.3 Household with Different Level of Education

Table 5.15 illustrates that households with a degree-level education consume an average of 32.34 kWh, those at high school level consume 25.26 kWh, elementary level with an average energy consumption of 32.51 kWh, households with no formal education has the less average energy consumption of 11.69 kWh. Existing research has indicated that education level and awareness of energy conservation practices influence energy consumption behaviours. Consequently, households with higher education levels are more inclined to adopt energy-efficient practices (Delmas and Lessem, 2012). While education can have a positive impact on energy consumption behaviour, it is important to note that it is not the sole determining factor.

Socio-economic factors, including government policies and technological advancements, can also significantly shape energy consumption patterns.

Table 5.15: Comparison on Energy Consumption with and without DLC Based on Level of Education.

Average Energy Consumption With & Without DLC								
Education Level	Degree		High School		Elementary		No Formal	
Strategy	Without DLC	With DLC	Without DLC	With DLC	Without DLC	With DLC	Without DLC	With DLC
Nighttime (kWh)	53.33	52.2	37.5	36.91	45.85	44.52	9.77	10.34
Daytime (kWh)	32.24	7.9	25.26	5.78	32.51	8.06	1169	1.68

Table 5.16 comprehensively presents these findings, shedding light on the impact of DLC on energy savings and consumption patterns across households with varying educational backgrounds. The data underscores the exciting impact of DLC on energy consumption patterns and savings, with consequences for diverse educational backgrounds.

Among households with members holding degrees, the introduction of DLC leads to a noteworthy average energy consumption of 7.9 kWh. This translates to a substantial 75% reduction in daytime energy consumption. Additionally, while there is a relatively minor 2% average energy savings during night-time, the overall energy consumption profile for these households improves significantly, enhancing cost-effectiveness. Households where members have completed high school education also benefit significantly from DLC, with average energy savings of 77%. The impact of DLC is especially prominent during the daytime, resulting in substantial reductions in energy consumption. Even households with members who have completed only elementary education have witnessed substantial energy savings of 74%. The deployment of DLC optimises energy utilisation aligning with the overarching goal of energy efficiency. Interestingly, households where members have received no formal education, despite having comparatively lower average energy consumption, experience the most significant energy savings. With a remarkable 84% reduction in daytime energy consumption, DLC demonstrates its capacity to optimise energy use. However, there is a slight 6% increment in night-time energy consumption, which does not offset the substantial daytime savings.

Table 5. 16: Average Energy Consumption Savings with DLC for Different Level of Education.

Energy Consumption Saving With DLC				
Education Level	Degree	High School	Elementary	No Formal
Nighttime (%)	2	2	3	-6
Daytime (%)	75	77	74	84

Comparing the disparities between conventional utility-activated load shedding and the implementation of DLC based on the level of education reveals noteworthy insights.

Degree-Level households consume an average energy consumption of 32.24 kWh during the daytime. A comparative analysis of the effects of load shedding versus DLC demonstrates that households implementing DLC experience a remarkable 18% decrease in energy consumption. Households with high school-level educated members experience a substantial 24% decrease in energy consumption with the application of DLC compared to traditional load shedding. This shift towards higher comfort is underscored by a pronounced decrease in energy consumption during the daytime hours, which not only enhances the residents' quality of life but also results in significant cost savings. Elementary-level households observe a 13% decrease in energy consumption due to the deployment of DLC in lieu of load shedding. Surprisingly, households with no formal education, despite their lower average energy consumption of 11.69 kWh, experience substantial benefits from DLC. The shift from load shedding to DLC leads to an impressive 52% decrease in energy consumption for these households. Essentially, the utilisation of DLC demonstrates a significant merit across households with varying educational background. These outcomes underscore the versatility of DLC as an effective solution for managing energy in a range of educational settings.

Table 5.17 shows energy cost across varied households' scenarios based on educational backgrounds. The data reveals that achieving a 7-hour comfort level through DLC entails varying costs for households based on their educational backgrounds. Degree-educated households would incur an expense of 395.07 NGN, high school-educated households 289.00 NGN, elementary-level households 403.17 NGN, and those with no formal education 84.06 NGN. In a scenario where household run a home generator for 4 hours per day during power cut period, this results in differential costs for households according to their educational qualifications. Degree-educated households would witness an 87% decrease in their energy expenses, amounting to 3000.64 NGN. High school-educated households would experience a 90% cost decrement, totalling 2898.99 NGN. Households with an elementary education

background would encounter an 86% decrease, with energy costs totalling 2985.82 NGN. Conversely, households with no formal education would bear a 97% decrease, leading to an expenditure of 2695.32 NGN. Under this scenario, the proposed DLC provides 5% decrease in comfort level.

For households seeking to run a home energy generator for 8 hours per day during power cut period, degree-educated households would spend 5523.64 NGN, high school-educated households 5418.99 NGN, elementary-educated households 5505.82 NGN, and households with no formal education 5215.32 NGN. Comparing the proposed DLC to the different households based on the education shows the degree educated 87% decrease in household expenditure, High school educated 90%, elementary level education 86% and household with no formal education 97% but a 39% decrease comfort level across the various representative groups. Table 5.18 shows the residential comfort level categorised according to the education level.

Table 5. 17: Cost of Energy for Different Household Scenarios by Educational Backgrounds.

Scenario	Utility Time (Hr)	Gen Time (Hr)	Energy Cost/day (NGN)			
			Degree	High School	Elementary	No Formal
LS	3.6	0	483.64	378.99	465.82	175.32
LS + GEN (2)	3.6	2	1743.64	1638.99	1725.82	1435.32
LS + GEN (4)	3.6	4	3003.64	2898.99	2985.82	2695.32
LS + GEN (6)	3.6	6	4263.63	4158.99	4245.82	3955.32
LS + GEN (8)	3.6	8	5523.64	5418.99	5505.82	5215.32
Proposed DLC	7	0	395.07	289.00	403.17	84.06
Comparison between DLC			18%	24%	13%	52%
Comparison between DLC with LS+GEN (4)			87%	90%	86%	97%
Comparison between DLC with LS+GEN (8)			93%	95%	93%	98%

LS: Load Shedding; GEN (2) means home Generator Operating for Two Hours per day; GEN (4) means home Generator Operating for Four Hours per day; GEN (6) means home Generator Operating for Six Hours per day; GEN (8) means home Generator Operating for Eight Hours per day

Table 5. 18: Residential Comfort Level for Different Scenario by Educational Backgrounds.

Scenario	Utility Time (Hr)	Generator Time (Hr)	Hours of supply of load/day (Hr)			
			Degree	High School	Elementary	No Formal
LS	3.6	0	3.6	3.6	3.6	3.6
LS + GEN (2)	3.6	2	5.6	5.6	5.6	5.6
LS + GEN (4)	3.6	4	7.6	7.6	7.6	7.6
LS + GEN (6)	3.6	6	9.6	9.6	9.6	9.6
LS + GEN (8)	3.6	8	11.6	11.6	11.6	11.6
Proposed DLC	7	0	7	7	7	7
Comparison between DLC			28%	28%	28%	28%
Comparison between DLC with LS+GEN (4)			-5%	-5%	-5%	-5%
Comparison between DLC with LS+GEN (8)			-39%	-39%	-39%	-39%

LS: Load Shedding; GEN (2) means home Generator Operating for Two Hours per day; GEN (4) means home Generator Operating for Four Hours per day; GEN (6) means home Generator Operating for Six Hours per day; GEN (8) means home Generator Operating for Eight Hours per day. “-” means the comfort level for using the DLC method is lower than the load shedding method.

Table 5. 19: Summary of Cost of Energy across Different Representative Groups

Scenario	Utility Time (Hr)	Energy Cost/day (NGN)														
		Billing System		Occupant Number				Household working in Different Sector					Education Level			
		Pre-paid	Post-paid	(2-3)	(4-5)	(6-7)	(Above 7)	Public Sector	Business	Private Sector	Student	Retired	Degree	High School	Elementary	No Formal
LS	3.6	355.43	496.41	353.93	393.76	487.73	645.42	461.62	388.58	480.73	282.87	366.30	483.64	378.99	465.82	175.32
LS + GEN (4)	3.6	2875.43	3016.42	2873.93	2913.76	3007.73	3165.43	2981.62	2908.58	3000.73	2802.87	2886.30	3003.64	2898.99	2985.82	2695.32
LS + GEN (8)	3.6	5395.43	5536.41	5393.93	5433.76	5527.73	5685.43	5501.62	5428.58	5520.73	5322.87	5406.30	5523.64	5418.99	5505.82	5215.32
Proposed DLC	7	295.07	384.29	225.43	333.99	406.20	628.77	385.80	271.29	427.63	187.40	313.15	395.07	289.00	403.17	84.06
Comparison between DLC with LS		17%	23%	36%	15%	17%	3%	16%	30%	11%	34%	15%	18%	24%	13%	52%
Comparison between DLC with LS+GEN (4)		90%	87%	92%	89%	86%	80%	87%	91%	86%	93%	89%	87%	90%	86%	97%
Comparison between DLC with LS+GEN (8)		95%	83%	96%	94%	93%	89%	93%	95%	92%	96%	94%	93%	95%	93%	98%

LS: Load Shedding; GEN (4) means home Generator Operating for Four Hours per day; GEN (8) means home Generator Operating for Eight Hours per day

Table 5. 20: Summary of Comfort Level across Different Representative Groups

Scenario	Utility Time (Hr)	Energy Cost/day (NGN)														
		Billing System		Occupant Number				Household working in Different Sector					Education Level			
		Pre-paid	Post-paid	(2-3)	(4-5)	(6-7)	(Above 7)	Public Sector	Business	Private Sector	Student	Retired	Degree	High School	Elementary	No Formal
LS	3.6	355.43	496.41	353.93	393.76	487.73	645.42	461.62	388.58	480.73	282.87	366.30	483.64	378.99	465.82	175.32
LS + GEN (4)	3.6	2875.43	3016.42	2873.93	2913.76	3007.73	3165.43	2981.62	2908.58	3000.73	2802.87	2886.30	3003.64	2898.99	2985.82	2695.32
LS + GEN (8)	3.6	5395.43	5536.41	5393.93	5433.76	5527.73	5685.43	5501.62	5428.58	5520.73	5322.87	5406.30	5523.64	5418.99	5505.82	5215.32
Proposed DLC	7	295.07	384.29	225.43	333.99	406.20	628.77	385.80	271.29	427.63	187.40	313.15	395.07	289.00	403.17	84.06
Comparison between DLC with LS		28%	28%	28%	28%	28%	28%	28%	28%	28%	28%	28%	28%	28%	28%	28%
Comparison between DLC with LS+GEN (4)		-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%
Comparison between DLC with LS+GEN (8)		-39%	-39%	-39%	-39%	-39%	-39%	-39%	-39%	-39%	-39%	-39%	-39%	-39%	-39%	-39%

LS: Load Shedding; GEN (4) means home Generator Operating for Four Hours per day; GEN (8) means home Generator Operating for Eight Hours per day. “-” means the comfort level for using the DLC method is lower than the load shedding method.

5.4. Conclusion

The chapter provides simulation result of the innovative DLC method as an alternative solution to load shedding in developing countries. The result was analysed across three different scenarios.

The proposed DLC method was compared with load shedding considering three load shedding scenarios: 1) nobody uses generators during power cut period, 2) running home generators for 4 hours per day during power cut period, and 3) running home generators for 8 hours per day during power cut period.

In Scenario 1), where nobody uses home generators during power cuts, comparing DLC to load shedding reveals that households on post-paid billing experience greater savings. In terms of occupant number, smaller households demonstrate higher cost savings. For people working in various sectors, students benefit the most from the proposed DLC, as they are more responsive to appliance changes. Additionally, households with no formal education receive higher cost savings. The simulation results for this scenario indicate a substantial 28% improvement in comfort level for each representative group.

In the context of Scenario 2), where the proposed DLC is compared to households operating home generators for 4 hours per day during power cuts, the results unveil valuable insights. Regarding billing systems, pre-paid billing demonstrates higher energy cost savings, while smaller households consistently exhibit greater savings in terms of occupancy. Notably, among people working in various sectors, households comprised of students experience the most significant benefit, with a striking 93% reduction in household expenditure. Furthermore, the simulation outcomes indicate that households with no formal education achieve the highest energy cost savings, boasting an impressive 97% decrease in household expenditure. In this scenario, when contrasting the proposed DLC with the operation of a generator for 4 hours daily during power cuts across diverse representative groups, a discernible trend emerges. While there is a decline in energy cost savings, a notable 5% reduction in comfort level is observed across the various representative groups. This suggests that, despite potential economic benefits, the shift to DLC might be associated with a marginal decrease in overall comfort for households in different representative categories.

In Scenario 3), a comprehensive comparison between the proposed DLC and households operating home generators for 8 hours per day during power cuts. The pre-paid billing system exhibits remarkable prowess, registering the highest decrease in energy savings at an

impressive 95%. Notably, households with 2-3 occupants take the lead in achieving the highest energy savings, underscoring the impact of occupancy on cost dynamics. Student households emerge as the most responsive to DLC, securing the most substantial cost savings. Meanwhile, households with no formal education showcase a commendable 98% decrease in energy cost savings. Despite these economic gains, the simulation outcomes reveal a significant 39% decrease in comfort levels across diverse representative groups. This emphasises the intricate balance between economic savings and the comfort implications associated with the transition to DLC in diverse household settings.

Furthermore, the results have revealed that socio-economic factors such as household income, family structure, and education levels significantly influence energy consumption patterns. Understanding these socio-economic factors that impact household energy consumption is pivotal for formulating effective energy policies and strategies.

In summary, the study indicates that DLC is a highly effective solution for reducing energy consumption, increasing comfort, and lowering electricity expenses. It offers benefits across different billing systems, household sizes, occupational contexts, and educational backgrounds. These findings underscore the versatility and value of DLC in managing energy consumption in diverse settings and highlight its potential to contribute to energy efficiency and cost savings for households. This holistic approach is essential to achieve a balanced and inclusive energy transition. The subsequent chapter will assess the framework of implementing DLC and the formulation of DSM Strategy in Nigeria.

CHAPTER 6

DISCUSSIONS AND RECOMMENDATIONS

Summary:

This chapter examines the limitation of the research, discussion areas of constraints when conducting the research. Additionally, the chapter offers recommendations for the formulation of DSM in Nigeria

6.1 Discussion on Limitation of the Research

6.1.1 Survey-Based Demand Profiling

In an ideal research scenario, this research would benefit from having access to comprehensive demand data from households including a detailed composition of the demand profile, clearly specifying how different appliances contribute to the overall loads. However, these datasets were not available, and it is difficult to obtain real-life data in particular with requirement of detailed composition. In reality, this study utilised created load profiles based on the data obtained from real-life surveys, representing the best available approach for our research. This approach would affect the simulation results, in terms of the amount of energy cost savings and comfort level of residents. However, a comparison of the energy cost savings and comfort level improvement between the load shedding approach and the DLC method was conducted under the same load profiles. The comparison results proved the effectiveness of the DLC method and demonstrate DLC as a viable DSM strategy replacing the conventional load shedding.

6.1.2 Regional Sensitivity

In this research, the demand profiles are primarily based on surveys conducted in specific locations. While this approach provides valuable insights, it is important to acknowledge its limitations when generalising the findings to other areas. To address these potential limitations, conducting surveys in diverse areas and averaging the results could bolster the overall robustness of the findings.

Furthermore, opting for a paper-based survey approach makes the study location-sensitive, meaning changes in the research location could potentially influence the research findings and outcomes due to its close association with the specific environment.

With additional time, the research could have significantly increased the sample size of our survey. This larger sample would not only enhance the accuracy of the collected data but also reduce the chance of sampling errors. This would lead to improved precision in our analysis and provide the opportunity for in-depth subgroup analyses. Consequently, such an approach would lead to a much more comprehensive understanding of residential energy consumption and load profiles, significantly enriching the depth of our research.

6.1.3 Sensitivity Analysis for Generator Operations

This research conducted a sensitivity analysis, examine the implication of various home generator operations focusing on its 2-, 4-, 6-, and 8-hours operation. It is essential to emphasise that while the initial survey data formed a valuable basis, the accuracy and effectiveness of these results could be greatly enhanced through the integration of real-life case study data sources offering precise information.

Furthermore, this research considered the use of a petrol generator, with an assumed average consumption rate of 1 liter per hour. It is crucial to acknowledge that our research findings may exhibit variations due to several influential factors. These factors include the generator's capacity, the impact of different load levels on fuel consumption patterns, the specific type of generator utilised (whether petrol or diesel), and disparities in the prices of petrol and diesel. These variables have the potential to introduce diversity in our research outcomes, and it is imperative to be aware of these potential limitations. Obtaining precise data on each household's generator and load profile could significantly enhance the accuracy of the results.

6.2 Discussion on the Impact of DLC on Different Representative Groups

6.2.1 Impact of DLC on Household working in the Public Sector.

- 56% of civil servants use the prepaid system, yet those on the post-paid system consume, on average, 23% more energy than their prepaid counterparts.
- Although a greater portion (37%) of civil servants live in 2-3 housing apartments, they, on average, use less energy than the 9% of civil servants residing in households with 7 or more occupants, who consume 12% more energy than those in 2-3 households.
- While civil servants make up the largest population within all occupational categories, it is interesting to note that the private sector consumes 26% of the energy, slightly surpassing the energy consumption of civil servants by 1%, and it stands as the highest energy consumer among all different occupational categories.
- Within the civil servant category, the degree-holders constitute the largest segment, making up 71% of the total civil servant population. They also stand out as the group with the highest energy consumption, representing 36% of the total energy usage in this category.

This shows that, among civil servants, the choice of the billing system significantly influences energy consumption. Specifically, civil servants using the post-paid system consume a considerable 23% more energy, on average, compared to those on the prepaid system. This

implies that the billing system plays a notable role in shaping energy consumption behaviours. It is imperative to underline that, although both billing systems offer substantial energy savings, we strongly advocate for the promotion of a transition from the post-paid to the pre-paid system to maximise the financial benefits and energy efficiency for households.

The study findings indicate that a significant proportion of households are associated with the public sector, predominantly 71% of the total population, characterised by a prevalence of degree-level education and concentration in 2 to 3 member households. Intriguingly, while 56% of these households employ the pre-paid billing system, it is noteworthy that 44% of this group contributes to 61% of the total energy consumption. To enhance household energy efficiency, there exists a clear opportunity for targeted initiatives focused on transitioning this specific group from post-paid to pre-paid billing systems, which can result in substantial improvements in both energy consumption and cost savings.

6.2.2 Impact of DLC on Household working in the Private Sector.

- In the private sector, 66% of households use the prepaid system, with an average energy consumption of 22.72 kWh. Meanwhile, 34% of private sector households use the post-paid system, and they consume an average of 49.91 kWh, which is 37% higher than the average energy consumption of those using prepaid systems.
- In the private sector, it is evident that even though 2-3 households are the most prevalent, 7-above households consume 32% more energy than the second largest consumers, which is the 6-7 household.
- In the private sector, there is a clear correlation between the number of household apartments and energy consumption, with higher numbers of households corresponding to increased energy usage.
- In the private sector, the prevalence of degree holders is notably high at 63%, exceeding all other educational groups within the private sectors. On the other hand, individuals within the elementary group are the highest energy consumers, accounting for a significant 64% of the total energy consumption.

The private sector households, constituting the majority at 31%, mostly reside in 2 to 3 member households and exhibit an admirable trait by consuming 10% average energy consumption. An interesting revelation surfaces among the 13% living in more spacious 7 and above member households, as they are the highest energy consumers, devouring a remarkable 55% energy.

This group is predominantly well-educated, with 63% holding degrees, yet intriguingly, 64% of those in the elementary education group consume a higher amount of energy. Moreover, in terms of billing systems, it is intriguing to note that while 66% of households are on the pre-paid system, 34% on post-paid arrangements consume 37% more energy than their pre-paid counterparts.

6.2.3 Impact of DLC on Household who run Businesses.

- Within the business sector, 55 households use the post-paid billing system, accounting for 65% of the total, with an average energy consumption of 25.40 kWh, while the remaining 35% utilises the prepaid system and consume an average of 26.84 kWh. The result shows that, within the business group, there is a marginal difference in energy consumption between the two billing systems. Specifically, those using the prepaid system consume, on average, 3% more energy than those on the post-paid system. This suggests that the billing system may not be the primary factor influencing energy usage within this group, and other factors or behaviors could be contributing to this small difference in consumption.
- While a greater percentage of business owners, specifically 43%, reside in 2-3 member households, it is noteworthy that 24% of business owners living in 4-5 member households consume 33.17kWh. This consumption level is 12% higher than those in 2-3 member households and represents the highest energy consumption within the entire business group.
- Within the business sector households, there is a greater number of degree holders, accounting for 38% of the business population. Notably, this group also comprises the highest energy consumers, representing 33% of the total energy consumption. On the other hand, the lowest energy consumers in the business group are those with no formal education.

While 43% of households in the business sector are situated in 2 to 3 member households, a surprising 24% of those residing in 4 to 5 member households exhibit higher energy consumption, consuming 29%. Intriguingly, even though 65% of these households are on post-paid billing systems, it is the 35% on pre-paid billing that consumes 51% of the energy. Furthermore, among the business household population, 38% are degree holders, with this group being the highest energy consumers, utilising 33% of the total energy.

6.2.4 Impact of DLC on Households who are Students.

- Among the student group, 56% use the prepaid system with an average energy consumption of 19.99kWh, while the remaining 44% utilise the postpaid system, consuming an average of 16.46 kWh, which is 10% less than the prepaid users.
- This shows that, within the student group, the choice of billing system significantly influences energy consumption. Students using the postpaid system consume, on average, 10% less energy than their counterparts on the prepaid system. In the student group, it is noticeable that despite 2-3 member households being the most common (54% of total households), energy consumption is equal for both 2-3 member households and 6-7 member households, despite a substantial 42% difference in their occupancy rates.
- Among students, those holding a degree constitute the largest group, comprising 63% of the total student population. Notably, this group also ranks as the highest energy consumers, accounting for 54% of the total energy usage.

Student households are primarily situated in 2 to 3 member households, making up the majority at 54% of the total population. In terms of energy consumption, both 6 to 7 member and 2 to 3 member households exhibit the highest consumption levels, each contributing 41% of the total energy usage. Notably, a significant percentage of students, constituting 63%, hold degrees and consume the highest amount of energy, reaching 54%. An interesting observation is that 56% of students use the prepaid billing system consuming 10% more energy than their counterparts on postpaid plans. This conclusion suggests that billing systems plays a notable role in shaping energy consumption patterns among students.

6.2.5 Accessing the Effect of DLC on Household that are Retired.

- Among retirees, 75% use the prepaid system with an average energy consumption of 14.99 kWh. In contrast, the remaining 25% of retirees using the post-paid system have a notably higher average electricity consumption of 52.69 kWh, which is approximately 56% greater than those on the prepaid system.
- Similar to the private sector, those on post-paid billing systems consume more energy than those on pre-paid systems, confirming the impact of billing arrangements on energy usage.

- In the retired household group, 2-3 member households have the highest occupancy, accounting for 33% of all households. Interestingly, households with 7 or more members outpace all other household types in energy consumption within this group.
- In retired households, the majority of individuals hold a degree level education, representing a significant 90% of the total population. Strikingly, this group also tops the charts as the highest energy consumers, accounting for 94% of the total energy usage. Notably, the study does not have respondents in both elementary and high school educated households.

Among retired households, the majority are located in 2 to 3 member households, accounting for 33%, while those in households with 7 or more occupants consume significantly more energy at 58%. A noteworthy 90% of retiree households have attained a degree-level education, and this group exhibits the highest energy consumption. Interestingly, there is a 50% higher prevalence of retirees using the prepaid billing system compared to those on postpaid plans. However, it is important to highlight that those on postpaid plans consume 56% more energy than their counterparts on the prepaid billing system.

Table 6. 21: Summary of Impact of DLC on Different Representative Groups

Sector	Billing System	Percentage of Households	Average Energy Consumption	Comparison to Other Billing System	Key Observations
Public Sector	Prepaid	56%	24.39 kWh (Lower energy consumption)	Post-paid consumers use 23% more energy	Post-paid system users consume significantly more energy; 71% of civil servants hold degrees and use 36% of the sector's energy.
	Post-paid	44%	39.76 (kWh Higher energy consumption)		37% live in 2-3 member households but use less energy compared to larger households.
Private Sector	Prepaid	66%	22.72 kWh	Post-paid consumers use 37% more energy	7 or more member households consume 32% more energy than 6-7 member households.
	Post-paid	34%	49.91 kWh		Degree holders are prevalent, but elementary education group consumes more energy.
Business Sector	Prepaid	35%	26.84 kWh	Post-paid consumers use 3% less energy	Energy consumption is marginally higher in prepaid system; 24% in 4-5 member households have the highest energy use.
	Post-paid	65%	25.40 kWh		Degree holders make up 38% but consume 33% of the energy.
Student Sector	Prepaid	56%	19.99 kWh	Post-paid users consume 10% less energy	Degree holders (63%) are the highest energy consumers, contributing to 54% of the total energy usage.
	Post-paid	44%	16.46 kWh		Equal energy consumption observed between 2-3 and 6-7 member households despite different occupancy rates.
Retired Sector	Prepaid	75%	14.99 kWh	Post-paid users consume 56% more energy	90% of retirees hold a degree and account for 95% of the total energy usage.
	Post-paid	25%	52.69 kWh		7 or more member households consume significantly more energy; higher prevalence of prepaid system use.

6.3 Recommendation

In this thesis, we recognise the paramount role of DSM in helping Nigeria bridge its energy security gap. Nigeria's electricity supply industry currently resides in a transitional stage, heavily reliant on load shedding for energy management. However, it faces several critical challenges such as government interference, non-reflective pricing, and implementation hurdles. To address the energy security gap in Nigeria, a strategic approach is needed. The thesis provides findings and recommendations, forming a formulated strategy that can be employed by both utility and government entities:

1. DLC Implementation:

- The utility can introduce the innovative concept proposed in this thesis, which acts as an appealing alternative to traditional load shedding. This approach effectively addresses the issue of limited energy resources while simultaneously enhancing household comfort.
- Provide incentives to encourage households to participate in DLC programs, promoting significant energy savings and enhanced comfort, as demonstrated by successful implementations in developed countries like the US, UK, and Australia.
- Promote DLC to residential customers for use during daytime hours, as research indicates that energy consumption is significantly lower on average when DLC is implemented.
- Establishing an aggregator system, such as a load serving entity or DR aggregator (DRA), similar to those found in developed countries. This system would provide an effective platform for promoting, overseeing and implementing DLC programmes.

2. Policy Reforms and Market Formalisation:

- Initiate policy reforms to reduce government interference in the electricity supply industry.
- Reform the market and ensure policymakers are committed to DSM policies and programmes.
- Address the non-reflective pricing system to encourage investments in the energy industry, which, in turn, creates a favourable platform for the deployment of DSM strategies.
- Post-paid systems are associated with higher energy consumption, with 44% of post-paid households accounting for 61% of the total energy usage. To address this issue,

policy reforms should prioritize incentivizing the adoption of pre-paid systems as a strategy to reduce excessive energy consumption.

- Establish a framework for assessing, revising, and overseeing the DSM initiatives.
- Developing incentives to encourage utility investments in DSM infrastructure and promote customer engagement.
- Accelerating the shift from transitional stage of the Nigerian electricity supply industry to medium-term framework, establishing a competitive wholesale market to encourage and attract private investment.

3. Focus on Renewable Energy and Grid Enhancement:

- Implement the Power Sector Recovery Programme (PSRP) to tackle tariff issues, improve governance, and stimulate investments in renewable energy.
- Siemens partnership and Power Sector Recovery Programme (PSRP) can modernise the grid and support renewable energy adoption.
- Ensure renewable energy integration within the DLC system to promote environmental sustainability.
- Streamline the procedures for households to access and embrace renewable energy sources. By making it easier for households to access to renewable energy which can decrease the reliance on post-paid electricity billing system and foster more sustainable energy consumption habits.
- Centralise balancing mechanisms within the market to ensure grid stability and reliability.

4. Target Approach for Households:

- Prioritise households with specific characteristics, such as those comprising of 6 or more members, as they tend to demonstrate higher levels of energy consumption.
- Focus on households with at least an elementary level of formal education, as the thesis's findings indicate that educated households tend to utilise more appliances, which is twice the consumption of households with no formal education.
- Place emphasis on households comprising 2-3 members, often consisting of civil servants, as they constitute a significant portion of the population and spend 6 -10% of their income to electricity expenses, as revealed by the research results.

- Develop a framework to promote a higher rate of customer transition from post-paid to pre-paid billing systems, as the results indicates that post-paid customers are less inclined to participate in energy management.

5. Efficient Energy Management:

- Educating households on energy efficient practices and financial benefit of pre-paid systems can drive a substantial reduction of their overall energy consumption.
- Educate households about the potentials for cost savings attainable through energy-efficient practices.

6. Billing Systems:

- Revise the billing system to strategically position it for investments, enhancements, and long-term sustainability.
- Motivate households with incentives to switch from post-paid to pre-paid billing systems, promoting benefit and enhanced energy efficiency. The data shows that households on post-paid billing systems leads to 37% higher energy consumption compared to pre-paid systems in the private sector.
- Provide incentives for transitioning to pre-paid system could help target high consumption groups such as students, civil servants and retirees
- Implement pricing programme, such as time of use rates, as an effective tool for energy management.

7. Public Awareness and Education:

- Households with post-paid billing systems, including those for students and retirees, generally consume more energy than those with pre-paid systems. Therefore, increasing public awareness and education will help promote the benefits of DLC and renewable energy
- Address barriers related to cost, awareness, and access.
- Implement educational campaigns for households that highlight the financial and energy-saving benefits of pre-paid billing and participating in DLC programs.
- Offer incentives to motivate households to adopt renewable energy solutions.
- Enhance awareness of energy-saving practise and DSM among households.

- Highlight the advantages of DSM, including decreased energy usage and financial savings. This is particularly important as the research demonstrates that implementing DSM programmes like DLC results in substantial cost reductions and enhanced comfort levels compared to traditional load shedding.

8. DSM infrastructure

- Given the current situation with 62.7% of households lacking meters, providing meters to bridge this gap is crucial for advancing DSM and establishing a sophisticated metering infrastructure that enables bidirectional two-way communication.
- Establish the necessary infrastructure to support a range of demand response initiatives and control mechanisms for diverse DSM programmes.
- Create robust data management systems for accurate data collection and analysis, along with advanced analytics and forecasting tools to support data-driven decision-making.
- Development of a robust cyber threat infrastructure especially as DSM programmes deals with smart meter and data network.
- Create a user-friendly tools like mobile app, customer portals to engage with utility, educate customer on energy management, and facilitate their active participation in DSM programmes.
- Modernise the electrical grid to enable seamless integration with DSM infrastructure, ensuring efficient coordination between energy demand and supply.

CHAPTER 7

CONCLUSIONS AND FUTURE WORK

Summary:

This chapter provides a brief description of the conclusions of the research carried out for this thesis. It also identifies the principal knowledge contributions and industrial contributions made in the thesis and gives some suggestions for further work.

7.1 Conclusions

The chapter summarizes the achievements of this research, outlines its contributions to the realms of knowledge and industry and offers insights into potential areas for future research endeavours.

The rationale of this study stems by the pressing need to tackle the predicaments afflicting the Nigerian electricity industry. These predicaments encompass a substantial energy deficit, leading to frequent nationwide power disruptions, the practice of load-shedding, and the emergence of critical energy crises. The root causes of these issues are primarily traced back to deficiencies in the transmission infrastructure, inadequacies in distribution facilities, the lack of comprehensive metering systems, shortages in fuel supply, a lack of competition within the market, and inefficiencies in managing the available energy resources.

To overcome these obstacles and improve the power supply in Nigeria, DSM strategies are crucial in improving electricity consumption patterns at the customer level, ultimately enhancing the overall energy situation in the country.

This thesis aimed to achieve the following:

- Provides an overview of DSM initiatives and review the challenges encountered by the Nigerian electricity supply industry.
- Provides the energy consumption pattern in Nigeria's residential sector and the impact of innovative DLC.
- Examine the extent of consumer understanding, awareness, and acceptance of DSM.
- Formulate strategies for the deployment of DSM.

The primary aims of this thesis was to optimise residential electricity demands by developing an innovative DSM strategy, which addresses Nigeria's electricity challenges and improve electricity supply to the residential sector. The purpose of this chapter is to outline how this thesis has answered the research questions and addressed the aim and objectives outlined in CHAPTER 1

7.2 Achievement of Research Objectives

The research questions have been dissected into four objectives, revealing how the thesis has answered the research questions and addressed the aim and objectives of this thesis.

Objective 1: To develop a DSM strategy for the distribution system by critically evaluating the literature on the state of the network grid (technical and non-technical challenges) and state of the art methods for DSM.

This objective has been addressed in CHAPTER 2 and answers research question 1 (outlined in CHAPTER 1). The literature review shows that most research focused on consumers in industrialised or developed economies, leaving a significant gap regarding alternative solutions for consumers in developing economies.

Objective 2: To evaluate and analyse residential customers' understanding, awareness, attitude, perspective, and willingness to adopt DSM programme via paper-based survey.

This objective was approached in CHAPTER 4. Research question 3 was also answered by conducting paper-based surveys. The research results illuminate a significant trend in household behaviour, where a considerable number of homes have embraced energy-saving practices, including conscientious measures such as turning off lights and investing in energy-efficient light bulbs. Additionally, a substantial portion of these households has eagerly signalled their willingness to engage in DSM initiatives, underlining their receptivity to more efficient energy practices. The study has identified cost and awareness as bottleneck for increased penetration of renewable energy.

Objective 3: To develop a technical model to evaluate the effect of implementing DLC of DSM and identify areas of improving DSM strategies considering the customers awareness and reactions.

This objective is addressed in CHAPTER 3 of the introduction of the DLC method and CHAPTER 5 of presenting the simulation results of implementing DLC. Under the innovative DLC approach, households experience increased cost savings and enhanced comfort. This solution offers an alternative to the conventional load shedding practices. The proposed DLC method controls residential loads by classifying loads into three different categories according to the criticalness of the loads and controls the corresponding load categories at different network conditions. This work answered the research question 2.

Objective 4: To explore and analyse energy consumption patterns and responsiveness on DSM strategies among various representative groups of residential customers and formulate a DSM Strategy for Nigeria

This objective is achieved with the analysis results presented in CHAPTER 5 (Section 5.3.3) and CHAPTER 6 (Section 6.2). It is evident that socio-economic factors, including households' education, employment status, and income, plays a crucial role in shaping individual household load profiles. The study indicated the need to encourage the transition of households from the post-paid billing system to the pre-paid billing system for enhanced energy management. Furthermore, the study highlights that the formulation of a DSM strategy necessitates a multifaceted approach, including policy reform, heightened awareness, infrastructure development for DSM, facilitating energy efficiency, cost reduction, and the promotion of sustainable energy practices.

7.3 Original Contribution to Knowledge

This section outlines the contribution that this thesis has made to the on-going debate on energy management.

7.3.1 Knowledge Contribution

The following empirical contributions have been made.

1. This work developed an innovative DLC method for residential grids, as an alternative approach to load shedding in the residential sector to improve the power supply in developing countries.
2. This work developed a methodology of using paper-based survey data to generate electricity demand profiles, which established a numerical dataset that can be used for future DSM studies.
3. This work developed an innovative DLC approach which classifies the load profiles into three categories according to the criticalness of the demands, and directly control the appliances by the appliances' category. The DLC approach outperforms the conventional load shedding in terms of energy cost savings and customer comfort level.
4. This work identified the representative group in the residential sector who are more responsive to the DLC approach, and also emphasised the role of responsive and active end users in the success of applying the DLC approach. The household with lower occupant number, the household occupied by students, and the household with no formal education will have more cost of savings if you apply DLC than load shedding.
5. This work provided detailed understandings of the public perception of Nigerian households to engage in DSM initiatives.

7.3.2 Contribution to Industrial and Commercial Practices

This study contributes to industrial practices by:

1. The methodology was initially devised for residential applications but holds broader applicability, including its potential application to the commercial and industrial sector (non-domestic buildings). For example, it can be employed to analyse business energy load profiles, enabling a comparative assessment of critical load supply in relation to cost-saving opportunities.
2. This work provides an alternative DSM strategy for network operator to implement in the residential sector to reduce energy costs of residents and improve the comfort level at the same time.
3. This work identifies the representative residential groups who are more responsive to DSM strategies. This provides to industry a few target groups to implement DSM which are more effective than other groups.

7.4 Opportunities for Future Research

Some potential research scopes could build on the analysis in this PhD thesis and could benefit from further research, as follows:

One of the outcomes of this research was the establishment of electricity demand profile. Given the absence of accessible data at the time of the study, the research relied on paper-based survey as the primary method for collecting the necessary data. Incorporating real-time data such as smart meter data can capture the intricate composition of demand, including the specifics of each household's appliances, which can represent a promising avenue for future research in this field. Such an approach would not only advance the accuracy and precision of our findings but also provide a more comprehensive and enriched understanding of residential energy consumption and load profiles.

In this research, the paper-based survey was conducted in the North-Eastern State of Adamawa State, Nigeria. However, broadening our study's geographic scope to encompass the entire nation will yield a more extensive and diverse range of demographic data and valuable insights into energy consumption behaviours. This broader focus area will, in turn, greatly enrich the

research outcomes, resulting in a more comprehensive, robust, and insightful set of research findings.

Collecting real-time data at the individual households, which includes specific details about the generator types, capacities, and precise energy consumption figures, represents an invaluable opportunity for us to enrich our findings and strengthen the depth of our research. This specific data holds the key to enhancing the accuracy and reliability of our research outcomes. Additionally, it can provide a more detailed understanding of the energy consumption patterns and habits of households, thereby allowing for more targeted and effective DSM strategies.

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APPENDIX A: PAPER-BASED SURVEY QUESTIONS



As part of my PhD research at Cranfield University, I am researching energy consumption and management in Nigeria.

This research is aimed to find out information about the public understanding, knowledge, awareness, and acceptance of the use of demand-side management strategies. Demand-side management is a concept that is designed to encourage consumers to reduce or increase demand and shift patterns of electricity consumption in order to improve power system reliability, provide adequate monitoring and deferred investment.

This questionnaire will help us to understand the energy needs and identify opportunities to help you reduce your energy bills. I would be pleased if you could help me by completing this questionnaire form.

All the information that I collect will be kept confidential and will not be passed on to any third party in a form that you will be able to be identified. It is perfectly acceptable for you not to participate or to stop at any point during completing this questionnaire form. Your participation or non-participation in this study will not affect you personally.

Note only collective data-based research will be published and no individual responses will be disclosed at any point.

At your request, I will also make my findings available to you when I have completed my study. If you are interested, contact me at rilwan.usman@cranfield.ac.uk. or contact my PhD Supervisor at p.mirzania@cranfield.ac.uk. You can also contact either of us if you have questions about the research after you have completed your part of the study.

This research is approved by Cranfield University Research Ethics and Integrity Committee
I volunteer to participate in this study, entitled "Survey of a Residential Load Profile for Demand-side Management in Nigeria"

Researcher' print name: RILWAN USMAN

Email Address: rilwan.usman@cranfield.ac.uk

If you have read and understood these instructions, and you do not have any questions about them, please enter your name below.

GENERAL INFORMATION

1. Household Name:
2. Telephone Number:
3. Email:
4. Occupation: Student Business Civil Servant Retired Others
5. Education: Degree High School Elementary No Formal Education
6. Age: Under 18 18-30 31-60 60 Above

HOUSEHOLD INFORMATION

7. Number of Households: (2-3) (4-5) (6-7) (7 Above)
8. Number of children: (1-2) (3-7) (Above 7) (None)
9. Age of Children: (Age under 5) (5 - 17) (18 – 30) (30 Above)
10. Type of Housing: Owned Rent
11. Number of rooms in the house: (1) (2) (3) (Above 3)

EXPENDITURE

12. Total monthly amount spends on electricity: (1-5%) (6-10%) (11-30%) (Above 30%)

13. Which type is your energy bills?

a. Prepaid b. Post-paid

If Prepaid,

How much is your monthly electricity vending? (Under 10,000) (Above 10,000)

What is the monthly cost of your electricity vending?

If Post-paid,

How do you pay your energy bills? (Tick) (Under 10,000) (Above 10,000)

a. Monthly

b. Quarterly

c. Random

14. Please identify appliances used in your house.

Time of Use

	Number:	Morning	Afternoon	Evening	All Day
Lighting: LED light Bulb					
Compact fluorescent lamp (CFL)					
Water heater					
Microwave					
Television					
Refrigerator					
Freezer					
Air Conditioner					
Pumps					
Water Dispenser					

15. How often do you use/utilize the following appliance?

	(Daily)	(Twice a week)	(Often)	(Never)
Washing Machine				
Iron				
Oven				

15. b What time do you usually use the following appliance?

	(Morning)	(Afternoon)	(Evening)
Washing Machine	☐	☐	☐
Iron	☐	☐	☐
Oven	☐	☐	☐

16. Are you aware of ways of saving energy? Tick as many as are relevant to you.

- I'm aware of a lot of ways of saving energy ☐
- I'm aware of 3-4 ways of saving energy ☐
- I'm aware of some basic ways of saving energy ☐
- I have no idea of any ways of saving energy ☐
- When purchasing an appliance, I consider the power rating of the equipment ☐

17. Have you made any thought to save energy in your home?

- A lot ☐
- A fair amount ☐
- Not very much ☐
- None at all ☐

18. Have you ever had an opportunity to reduce energy use/usage at home?

YES ☐ NO ☐

If yes, so tick as many as are relevant to you.

- (a) I use energy-saving bulbs ☐
- (b) I turn off lights and other appliances before I leave home ☐
- (c) I use energy-saving appliances ☐
- (d) I try to change my daily habits to save energy ☐

19. Do you practise saving energy outside your home, for example at school, at work, at relatives' homes, at your friends' homes?

- (a) Always ☐
- (b) Usually ☐
- (c) Sometimes ☐
- (d) Rarely ☐
- (e) Never ☐

20. If you had to monitor the use of energy at home, do you think it would help you to become more aware of the importance of energy management?

YES ☐ NO ☐

21. When the power from the grid goes out, is generator an alternative source for you?

YES ☐ NO ☐

22. Are you willing to participate in an energy management program to reduce load shedding?

YES ☐ NO ☐

23. Would you participate in a scheme that limits equipment available for use during working hours (8-5 pm) for reduced electricity bills?

YES ☐ NO ☐

24. If you need to buy any new electrical appliances, and energy-efficient appliances cost more than conventional ones, will you purchase energy-efficient appliances?

YES ☐ NO ☐

25. Are you aware of any energy-saving scheme that the government is running?

YES ☐ NO ☐

26. What would motivate you to change your behaviour to reduce energy use? Tick as many as are relevant to you.

- (a) Cost ☐
- (b) Environmental reasons ☐
- (c) Awareness ☐
- (d) None at all ☐

27. Are you aware that renewable energy can be used to run electrical appliances in a home?

YES ☐ NO ☐

28. Do you use any renewable energy resources at home? Tick any

- (a) Wind ☐
- (b) Solar Energy ☐
- (c) Hydropower ☐
- (d) Battery Storage ☐
- (e) None at all ☐

29. What is the barrier for you to switch from grid energy to renewable energy?

- (a) Cost of purchase ☐
- (b) lack of information on renewable energy ☐
- (c) Return on investment is very slow ☐
- (d) Appearance of the devices ☐
- (e) lack of access ☐

APPENDIX B: ETHICS APPROVAL LETTER



13 October 2021

Dear Mr Usman ,

Reference: CURES/14707/2021

Title: Alternative Demand Side Management Strategies for Optimal Operation of Electric Power Systems in Nigeria

Thank you for your application to the Cranfield University Research Ethics System (CURES).

We are pleased to inform you your CURES application, reference CURES/14707/2021 has been reviewed. You may now proceed with the research activities you have sought approval for.

If you have any queries, please contact CURES Support.

We wish you every success with your project.

Regards,

CURES Team

APPENDIX C: MATLAB CODE

```
% RESIDENTIAL LOAD CONTROL
clc
%%Define Parameters
Define Parameter Timeslots and Cost per kWhr
t = [0.5:0.5:24];
daytime_timeslot = [zeros(1,12) ones(1,24) zeros(1,12)];
night_timeslot = [ones(1,12) zeros(1,24) ones(1,12)];
Daytime_cost = 55.91;
night_time_cost = 55.91;
DLC_Cost = 39.14;

Parameter for Electrical Appliances
n_li = 50;
d_li_night= [ones(1,12) zeros(1,24) ones(1,12)];
d_li_day = [zeros(1,12) ones(1,24) zeros(1,12)];
DLC_d_li_night= [ones(1,12) zeros(1,24) ones(1,12)];
DLC_d_li_day = [zeros(1,48) ones(1,0) zeros(1,0)];

n_fa = 0;
d_fa_night= [ones(1,0) zeros(1,36) ones(1,4) zeros(1,8)];
d_fa_day = [zeros(1,24) ones(1,4) zeros(1,20)];
DLC_d_fa_night= [ones(1,12) zeros(1,24) ones(1,12)];
DLC_d_fa_day = [zeros(1,48) ones(1,0) zeros(1,0)];

n_ac = 3;
d_ac_night= [ones(1,12) zeros(1,24) ones(1,12)];
d_ac_day = [zeros(1,12) ones(1,24) zeros(1,12)];
DLC_d_ac_night= [ones(1,12) zeros(1,24) ones(1,12)];
DLC_d_ac_day = [zeros(1,12) randi([0,1],10,1)' zeros(1,26)];

n_tv = 1;
d_tv_night= [zeros(1,36) randi([0,1],12,1)'];
d_tv_day = [zeros(1,12) randi([0,1],24,1)' zeros(1,12)];
DLC_d_tv_night= [zeros(1,36) randi([0,1],12,1)'];
DLC_d_tv_day = [zeros(1,12) randi([0,1],12,1)' zeros(1,24)];

n_rf = 2;
d_rf_night= [ones(1,12) zeros(1,24) ones(1,12)];
d_rf_day = [zeros(1,12) ones(1,24) zeros(1,12)];
DLC_d_rf_night= [ones(1,12) zeros(1,24) ones(1,12)];
DLC_d_rf_day = [zeros(1,12) randi([0,1],6,1)' zeros(1,30)];

n_fr = 1;
d_fr_night= [ones(1,12) zeros(1,24) ones(1,12)];
d_fr_day = [zeros(1,48) ones(1,0) zeros(1,0)];
DLC_d_fr_night= [ones(1,12) zeros(1,24) ones(1,12)];
DLC_d_fr_day = [zeros(1,12) randi([0,1],6,1)' zeros(1,30)];

n_wd = 1;
d_wd_night= [ones(1,12) zeros(1,24) ones(1,12)];
d_wd_day = [zeros(1,12) ones(1,24) zeros(1,12)];
DLC_d_wd_night= [ones(1,12) zeros(1,24) ones(1,12)];
```

```

DLC_d_wd_day = [zeros(1,12) randi([0,1],6,1)' zeros(1,30)];

n_mw = 1;
d_mw_night= [ones(1,0) zeros(1,48) ones(1,0)];
d_mw_day = [zeros(1,27) randi([0,1],1,1)' zeros(1,20)];
DLC_d_mw_night= [zeros(1,39) randi([0,1],1,1)' zeros(1,8)];
DLC_d_mw_day = [zeros(1,28) randi([0,1],1,1)' zeros(1,19)];

n_dw = 1;
d_dw_night= [ones(1,12) zeros(1,24) ones(1,12)];
d_dw_day = [zeros(1,12) ones(1,24) zeros(1,12)];
DLC_d_dw_night= [zeros(1,11) randi([0,1],1,1)' zeros(1,35) randi([0,1],1,1)'];
DLC_d_dw_day = [zeros(1,48) randi([0,1],0,1)' zeros(1,0)];

n_wp = 1;
d_wp_night= [ones(1,0) zeros(1,36) ones(1,2) zeros(1,10)];
d_wp_day = [zeros(1,12) ones(1,2) zeros(1,34)];
DLC_d_wp_night= [ones(1,0) zeros(1,36) ones(1,4) zeros(1,8)];
DLC_d_wp_day = [zeros(1,48) ones(1,0) zeros(1,0)];

n_ir = 1;
d_ir_night= [zeros(1,37) randi([0,1],4,1)' zeros(1,7)];
d_ir_day = [zeros(1,18) ones(1,2) zeros(1,28)];
DLC_d_ir_night= [zeros(1,37) randi([0,1],4,1)' zeros(1,7)];
DLC_d_ir_day = [zeros(1,48) ones(1,0) zeros(1,0)];

n_wm = 1;
d_wm_night= [zeros(1,37) randi([0,1],4,1)' zeros(1,7)];
d_wm_day = [zeros(1,28) ones(1,4) zeros(1,16)];
DLC_d_wm_night= [zeros(1,37) randi([0,1],4,1)' zeros(1,7)];
DLC_d_wm_day = [zeros(1,48) ones(1,0) zeros(1,0)];

n_ov = 0;
d_ov_night= [ones(1,0) zeros(1,48) ones(1,0)];
d_ov_day = [zeros(1,28) ones(1,4) zeros(1,16)];
DLC_d_ov_night= [ones(1,12) zeros(1,24) ones(1,12)];
DLC_d_ov_day = [zeros(1,48) ones(1,0) zeros(1,0)];

```

%% Normal Usage Lightening

p_li = 0.01*0.5;

% Power

%d_li = 1;

% Duration time (hours)

%d_li_day=2;

t_li_day = d_li_day*n_li;

% Time (hours)

t_li_night= d_li_night.*n_li;

w_li1 = daytime_timeslot.*t_li_day;

% Machine working time daytime

w_li2 = night_timeslot.*t_li_night;

% Machine working time night

E_li1_daytime = w_li1*p_li ;

% Energy (Day time)

E_li2_Night = w_li2*p_li ;

% Energy (Night time)

E_li_total = E_li1_daytime + E_li2_Night ;

% Energy (Total)

cost_li1_daytime = E_li1_daytime*Daytime_cost;

% Cost (Day time)

cost_li2_Night = E_li2_Night*night_time_cost;

% Cost (Night time)

cost_li_total = cost_li1_daytime + cost_li2_Night;

% Cost (Total)

%% DLC Lightening

p_li = 0.01*0.5;	% Power
%d_li = 1;	% Duration time (hours)
%d_li_day=2;	
DLC_t_li_day = DLC_d_li_day*n_li;	% Time (hours)
DLC_t_li_night= DLC_d_li_night.*n_li;	
DLC_w_li1 = daytime_timeslot.*DLC_t_li_day;	% Machine working time daytime
DLC_w_li2 = night_timeslot.*DLC_t_li_night;	% Machine working time night
DLC_E_li1_daytime = DLC_w_li1*p_li ;	% Energy (Day time)
DLC_E_li2_Night = DLC_w_li2*p_li ;	% Energy (Night time)
DLC_E_li_total = DLC_E_li1_daytime + DLC_E_li2_Night ;	% Energy (Total)
DLC_cost_li1_daytime = DLC_E_li1_daytime*Daytime_cost;	% Cost (Day time)
DLC_cost_li2_Night = DLC_E_li2_Night*DLC_Cost;	% Cost (Night time)
DLC_cost_li_total = DLC_cost_li1_daytime + DLC_cost_li2_Night;	% Cost (Total)
%% Normal Usage Fan	
p_fa = 0.075*0.5;	% Power
%d_fa = 1;	% Duration time (hours)
%d_fa_day=2;	
t_fa_day = d_fa_day*n_fa;	% Time (hours)
t_fa_night= d_fa_night.*n_fa;	
w_fa1 = daytime_timeslot.*t_fa_day;	% Machine working time daytime
w_fa2 = night_timeslot.*t_fa_night;	% Machine working time night
E_fa1_daytime = w_fa1*p_fa;	
E_fa2_Night = w_fa2*p_fa;	
E_fa_total = E_fa1_daytime + E_fa2_Night;	
cost_fa1_daytime = E_fa1_daytime*Daytime_cost;	
cost_fa2_Night = E_fa2_Night*night_time_cost;	
cost_fa_total = cost_fa1_daytime + cost_fa2_Night;	
%% DLC Fan	
p_fa = 0.075*0.5;	% Power
%d_fa = 1;	% Duration time (hours)
%d_fa_day=2;	
DLC_t_fa_day = DLC_d_fa_day*n_fa;	% Time (hours)
DLC_t_fa_night= DLC_d_fa_night.*n_fa;	
DLC_w_fa1 = daytime_timeslot.*DLC_t_fa_day;	% Machine working time daytime
DLC_w_fa2 = night_timeslot.*DLC_t_fa_night;	% Machine working time night
DLC_E_fa1_daytime = DLC_w_fa1*p_fa;	% Energy (Day time)
DLC_E_fa2_Night = DLC_w_fa2*p_fa;	% Energy (Night time)
DLC_E_fa_total = DLC_E_fa1_daytime + DLC_E_fa2_Night ;	% Energy (Total)
DLC_cost_fa1_daytime = DLC_E_fa1_daytime*Daytime_cost;	% Cost (Day time)
DLC_cost_fa2_Night = DLC_E_fa2_Night*DLC_Cost;	% Cost (Night time)
DLC_cost_fa_total = DLC_cost_fa1_daytime + DLC_cost_fa2_Night;	% Cost (Total)

%% Normal Usage Air Condition

p_ac = 2*0.5;

% Power

%d_ac = 1;

% Duration time (hours)

%d_ac_day=2;

t_ac_day = d_ac_day*n_ac;

% Time (hours)

t_ac_night= d_ac_night.*n_ac;

w_ac1 = daytime_timeslot.*t_ac_day;

% Machine working time daytime

w_ac2 = night_timeslot.*t_ac_night;

% Machine working time night

E_ac1_daytime = w_ac1*p_ac;

% Energy (Day time)

E_ac2_Night = w_ac2*p_ac;

% Energy (Night time)

E_ac_total = E_ac1_daytime + E_ac2_Night;

% Energy (Total)

cost_ac1_daytime = E_ac1_daytime*Daytime_cost;

% Cost (Day time)

cost_ac2_Night = E_ac2_Night*night_time_cost;

% Cost (Night time)

cost_ac_total = cost_ac1_daytime + cost_ac2_Night;

% Energy (Total)

%% DLC Air Condition

p_ac = 2*0.5;

% Power

%d_ac = 1;

% Duration time (hours)

%d_ac_day=2;

DLC_t_ac_day = DLC_d_ac_day*n_ac;

% Time (hours)

DLC_t_ac_night= DLC_d_ac_night.*n_ac;

DLC_w_ac1 = daytime_timeslot.*DLC_t_ac_day;

% Machine working time daytime

DLC_w_ac2 = night_timeslot.*DLC_t_ac_night;

% Machine working time night

DLC_E_ac1_daytime = DLC_w_ac1*p_ac;

% Energy (Day time)

DLC_E_ac2_Night = DLC_w_ac2*p_ac;

% Energy (Night time)

DLC_E_ac_total = DLC_E_ac1_daytime + DLC_E_ac2_Night ;

% Energy (Total)

DLC_cost_ac1_daytime = DLC_E_ac1_daytime*Daytime_cost;

% Cost (Day time)

DLC_cost_ac2_Night = DLC_E_ac2_Night*DLC_Cost;

% Cost (Night time)

DLC_cost_ac_total = DLC_cost_ac1_daytime + DLC_cost_ac2_Night;

% Cost (Total)

%% Normal Usage Television

p_tv = 0.2*0.5;

% Power

%d_tv = 1;

% Duration time (hours)

%d_tv_day=2;

t_tv_day = d_tv_day*n_tv;

% Time (hours)

t_tv_night= d_tv_night.*n_tv;

w_tv1 = daytime_timeslot.*t_tv_day;

% Machine working time daytime

w_tv2 = night_timeslot.*t_tv_night;

% Machine working time night

E_tv1_daytime = w_tv1*p_tv;

% Energy (Day time)

E_tv2_Night = w_tv2*p_tv;

% Energy (Night time)

E_tv_total = E_tv1_daytime + E_tv2_Night;

% Energy (Total)

cost_tv1_daytime = E_tv1_daytime*Daytime_cost;

% Cost (Day time)

cost_tv2_Night = E_tv2_Night*night_time_cost;	% Cost (Night time)
cost_tv_total = cost_tv1_daytime + cost_tv2_Night;	% Cost (Total)
%% DLC Television	
p_tv = 0.2*0.5;	% Power
%d_tv = 1;	% Duration time (hours)
%d_tv_day=2;	
DLC_t_tv_day = DLC_d_tv_day*n_tv;	% Time (hours)
DLC_t_tv_night= DLC_d_tv_night.*n_tv;	
DLC_w_tv1 = daytime_timeslot.*DLC_t_tv_day;	% Machine working time daytime
DLC_w_tv2 = night_timeslot.*DLC_t_tv_night;	% Machine working time night
DLC_E_tv1_daytime = DLC_w_tv1*p_tv;	% Energy (Day time)
DLC_E_tv2_Night = DLC_w_tv2*p_tv;	% Energy (Night time)
DLC_E_tv_total = DLC_E_tv1_daytime + DLC_E_tv2_Night ;	% Energy (Total)
DLC_cost_tv1_daytime = DLC_E_tv1_daytime*Daytime_cost;	% Cost (Day time)
DLC_cost_tv2_Night = DLC_E_tv2_Night*DLC_Cost;	% Cost (Night time)
DLC_cost_tv_total = DLC_cost_tv1_daytime + DLC_cost_tv2_Night;	% Cost (Total)
%% Normal Usage Refrigerator	
p_rf = 0.9*0.5;	% Power
%d_rf = 1;	% Duration
%d_rf_day=2;	
t_rf_day = d_rf_day*n_rf;	% Time (hours)
t_rf_night= d_rf_night.*n_rf;	
w_rf1 = daytime_timeslot.*t_rf_day;	% Machine working time daytime
w_rf2 = night_timeslot.*t_rf_night;	% Machine working time night
E_rf1_daytime = w_rf1*p_rf;	% Energy (Day time)
E_rf2_Night = w_rf2*p_rf;	% Energy (Night time)
E_rf_total = E_rf1_daytime + E_rf2_Night;	% Energy (Total)
cost_rf1_daytime = E_rf1_daytime*Daytime_cost;	% Cost (Day time)
cost_rf2_Night = E_rf2_Night*night_time_cost;	% Cost (Night time)
cost_rf_total = cost_rf1_daytime + cost_rf2_Night;	% Cost (Total)
%% DLC Refrigerator	
p_rf = 0.9*0.5;	% Power
%d_rf = 1;	% Duration
%d_rf_day=2;	
DLC_t_rf_day = DLC_d_rf_day*n_rf;	% Time (hours)
DLC_t_rf_night= DLC_d_rf_night.*n_rf;	
DLC_w_rf1 = daytime_timeslot.*DLC_t_rf_day;	% Machine working time daytime
DLC_w_rf2 = night_timeslot.*DLC_t_rf_night;	% Machine working time night
DLC_E_rf1_daytime = DLC_w_rf1*p_rf;	% Energy (Day time)
DLC_E_rf2_Night = DLC_w_rf2*p_rf;	% Energy (Night time)
DLC_E_rf_total = DLC_E_rf1_daytime + DLC_E_rf2_Night ;	% Energy (Total)

DLC_cost_rf1_daytime = DLC_E_rf1_daytime*Daytime_cost;	% Cost (Day time)
DLC_cost_rf2_Night = DLC_E_rf2_Night*DLC_Cost;	% Cost (Night time)
DLC_cost_rf_total = DLC_cost_rf1_daytime + DLC_cost_rf2_Night;	% Cost (Total)
%% Normal Usage Freezer	
p_fr = 0.05*0.5;	% Power
%d_fr = 24;	% Duration time (hours)
%d_fr_day=2;	
t_fr_day = d_fr_day*n_fr;	% Time (hours)
t_fr_night= d_fr_night.*n_fr;	
w_fr1 = daytime_timeslot.*t_fr_day;	% Machine working time daytime
w_fr2 = night_timeslot.*t_fr_night;	% Machine working time night
E_fr1_daytime = w_fr1*p_fr;	% Energy (Day time)
E_fr2_Night = w_fr2*p_fr;	% Energy (Night time)
E_fr_total = E_fr1_daytime + E_fr2_Night;	% Energy (Total)
cost_fr1_daytime = E_fr1_daytime*Daytime_cost;	% Cost (Day time)
cost_fr2_Night = E_fr2_Night*night_time_cost;	% Cost (Night time)
cost_fr_total = cost_fr1_daytime + cost_fr2_Night;	% Cost (Total)
%% DLC Freezer	
p_fr = 0.05*0.5;	% Power
%d_fr = 24;	% Duration time (hours)
%d_fr_day=2;	
DLC_t_fr_day = DLC_d_fr_day*n_fr;	% Time (hours)
DLC_t_fr_night= DLC_d_fr_night.*n_fr;	
DLC_w_fr1 = daytime_timeslot.*DLC_t_fr_day;	% Machine working time daytime
DLC_w_fr2 = night_timeslot.*DLC_t_fr_night;	% Machine working time night
DLC_E_fr1_daytime = DLC_w_fr1*p_fr;	% Energy (Day time)
DLC_E_fr2_Night = DLC_w_fr2*p_fr;	% Energy (Night time)
DLC_E_fr_total = DLC_E_fr1_daytime + DLC_E_fr2_Night ;	% Energy (Total)
DLC_cost_fr1_daytime = DLC_E_fr1_daytime*Daytime_cost;	% Cost (Day time)
DLC_cost_fr2_Night = DLC_E_fr2_Night*DLC_Cost;	% Cost (Night time)
DLC_cost_fr_total = DLC_cost_fr1_daytime + DLC_cost_fr2_Night;	% Cost (Total)
%% Normal Usage Water Dispenser	
p_wd = 1.3*0.5;	% Power
%d_wd = 1;	% Duration time (hours)
%d_wd_day=2;	
t_wd_day = d_wd_day*n_wd;	% Time (hours)
t_wd_night= d_wd_night.*n_wd;	
w_wd1 = daytime_timeslot.*t_wd_day;	% Machine working time daytime
w_wd2 = night_timeslot.*t_wd_night;	% Machine working time night

E_wd1_daytime = w_wd1*p_wd;	% Energy (Day time)
E_wd2_Night = w_wd2*p_wd;	% Energy (Night time)
E_wd_total = E_wd1_daytime + E_wd2_Night;	% Energy (Total)
cost_wd1_daytime = E_wd1_daytime*Daytime_cost;	% Cost (Day time)
cost_wd2_Night = E_wd2_Night*night_time_cost;	% Cost (Night time)
cost_wd_total = cost_wd1_daytime + cost_wd2_Night;	% Cost (Total)
%% DLC Water Dispenser	
p_wd = 1.3*0.5;	% Power
%d_wd = 1;	% Duration time (hours)
%d_wd_day=2;	
DLC_t_wd_day = DLC_d_wd_day*n_wd;	% Time (hours)
DLC_t_wd_night= DLC_d_wd_night.*n_wd;	
DLC_w_wd1 = daytime_timeslot.*DLC_t_wd_day;	% Machine working time daytime
DLC_w_wd2 = night_timeslot.*DLC_t_wd_night;	% Machine working time night
DLC_E_wd1_daytime = DLC_w_wd1*p_wd;	% Energy (Day time)
DLC_E_wd2_Night = DLC_w_wd2*p_wd;	% Energy (Night time)
DLC_E_wd_total = DLC_E_wd1_daytime + DLC_E_wd2_Night ;	% Energy (Total)
DLC_cost_wd1_daytime = DLC_E_wd1_daytime*Daytime_cost;	% Cost (Day time)
DLC_cost_wd2_Night = DLC_E_wd2_Night*DLC_Cost;	% Cost (Night time)
DLC_cost_wd_total = DLC_cost_wd1_daytime + DLC_cost_wd2_Night;	% Cost (Total)
%% Normal Usage Microwave	
p_mw = 1.7*0.5;	% Power
%d_mw = 1;	% Duration time (hours)
%d_wm_day=2;	
t_mw_day = d_mw_day*n_mw;	% Time (hours)
t_mw_night= d_mw_night.*n_mw;	
w_mw1 = daytime_timeslot.*t_mw_day;	% Machine working time daytime
w_mw2 = night_timeslot.*t_mw_night;	% Machine working time night
E_mw1_daytime = w_mw1*p_mw;	% Energy (Day time)
E_mw2_Night = w_mw2*p_mw;	% Energy (Night time)
E_mw_total = E_mw1_daytime + E_mw2_Night;	% Energy (Total)
cost_mw1_daytime = E_mw1_daytime*Daytime_cost;	% Cost (Day time)
cost_mw2_Night = E_mw2_Night*night_time_cost;	% Cost (Night time)
cost_mw_total = cost_mw1_daytime + cost_mw2_Night;	% Cost (Total)
%% DLC Microwave	
p_mw = 1.7*0.5;	% Power
%d_mw = 1;	% Duration time (hours)
%d_wm_day=2;	
DLC_t_mw_day = DLC_d_mw_day*n_mw;	% Time (hours)
DLC_t_mw_night= DLC_d_mw_night.*n_mw;	
DLC_w_mw1 = daytime_timeslot.*DLC_t_mw_day;	% Machine working time daytime

DLC_w_mw2 = night_timeslot.*DLC_t_mw_night;	% Machine working time night
DLC_E_mw1_daytime = DLC_w_mw1*p_mw;	% Energy (Day time)
DLC_E_mw2_Night = DLC_w_mw2*p_mw;	% Energy (Night time)
DLC_E_mw_total = DLC_E_mw1_daytime + DLC_E_mw2_Night ;	% Energy (Total)
DLC_cost_mw1_daytime = DLC_E_mw1_daytime*Daytime_cost;	% Cost (Day time)
DLC_cost_mw2_Night = DLC_E_mw2_Night*DLC_Cost;	% Cost (Night time)
DLC_cost_mw_total = DLC_cost_mw1_daytime + DLC_cost_mw2_Night;	% Cost (Total)
%% Normal Usage Heater	
p_dw = 4*0.5;	% Power Dish washer
%d_dw = 1;	% Duration time (hours) washing
%d_dw_day=2;	
t_dw_day = d_dw_day*n_dw;	% Time (Day hours) washing
t_dw_night= d_dw_night.*n_dw;	% Time (Night hours) washing
w_dw1 = daytime_timeslot.*t_dw_day;	% Machine working time daytime
w_dw2 = night_timeslot.*t_dw_night;	% Machine working time night
E_dw1_daytime = w_dw1*p_dw;	% Energy (Day time)
E_dw2_Night = w_dw2*p_dw;	% Energy (Night time)
E_dw_total = E_dw1_daytime + E_dw2_Night;	% Energy (Total)
cost_dw1_daytime = E_dw1_daytime*Daytime_cost;	% Cost (Day time)
cost_dw2_Night = E_dw2_Night*night_time_cost;	% Cost (Night time)
cost_dw_total = cost_dw1_daytime + cost_dw2_Night;	% Cost (Total)
%% DLC Heater	
p_dw = 4*0.5;	% Power Dish washer
%d_dw = 1;	% Duration time (hours) washing
%d_dw_day=2;	
DLC_t_dw_day = DLC_d_dw_day*n_dw;	% Time (hours)
DLC_t_dw_night= DLC_d_mw_night.*n_dw;	
DLC_w_dw1 = daytime_timeslot.*DLC_t_dw_day;	% Machine working time daytime
DLC_w_dw2 = night_timeslot.*DLC_t_dw_night;	% Machine working time night
DLC_E_dw1_daytime = DLC_w_dw1*p_mw;	% Energy (Day time)
DLC_E_dw2_Night = DLC_w_dw2*p_mw;	% Energy (Night time)
DLC_E_dw_total = DLC_E_dw1_daytime + DLC_E_dw2_Night ;	% Energy (Total)
DLC_cost_dw1_daytime = DLC_E_dw1_daytime*Daytime_cost;	% Cost (Day time)
DLC_cost_dw2_Night = DLC_E_dw2_Night*DLC_Cost;	% Cost (Night time)
DLC_cost_dw_total = DLC_cost_dw1_daytime + DLC_cost_dw2_Night;	% Cost (Total)
%% Normal Usage Water pump	
p_wp = 0.6*0.5;	% Power
%d_wp = 1;	% Duration time (hours)
%d_wp_day=2;	
t_wp_day = d_wp_day*n_wp;	% Time (hours)

t_wp_night= d_wp_night.*n_wp;	
w_wp1 = daytime_timeslot.*t_wp_day;	% Machine working time daytime
w_wp2 = night_timeslot.*t_wp_night;	% Machine working time night
E_wp1_daytime = w_wp1*p_wp;	% Energy (Day time)
E_wp2_Night = w_wp2*p_wp;	% Energy (Night time)
E_wp_total = E_wp1_daytime + E_wp2_Night;	% Energy (Total)
cost_wp1_daytime = E_wp1_daytime*Daytime_cost;	% Cost (Day time)
cost_wp2_Night = E_wp2_Night*night_time_cost;	% Cost (Night time)
cost_wp_total = cost_wp1_daytime + cost_wp2_Night;	% Cost (Total)
%% DLC Water pump	
p_wp = 0.6*0.5;	% Power
%d_wp = 1;	% Duration time (hours)
%d_wp_day=2;	
DLC_t_wp_day = DLC_d_wp_day*n_wp;	% Time (hours)
DLC_t_wp_night= DLC_d_wp_night.*n_wp;	
DLC_w_wp1 = daytime_timeslot.*DLC_t_wp_day;	% Machine working time daytime
DLC_w_wp2 = night_timeslot.*DLC_t_wp_night;	% Machine working time night
DLC_E_wp1_daytime = DLC_w_wp1*p_wp;	% Energy (Day time)
DLC_E_wp2_Night = DLC_w_wp2*p_wp;	% Energy (Night time)
DLC_E_wp_total = DLC_E_wp1_daytime + DLC_E_wp2_Night ;	% Energy (Total)
DLC_cost_wp1_daytime = DLC_E_wp1_daytime*Daytime_cost;	% Cost (Day time)
DLC_cost_wp2_Night = DLC_E_wp2_Night*DLC_Cost;	% Cost (Night time)
DLC_cost_wp_total = DLC_cost_wp1_daytime + DLC_cost_wp2_Night;	% Cost (Total)
%% Normal Usage Iron	
p_ir = 2.5*0.5;	% Power
%d_ir = 1;	% Duration time (hours)
%d_ir_day=2;	
t_ir_day = d_ir_day*n_ir;	% Time (hours)
t_ir_night= d_ir_night.*n_ir;	
w_ir1 = daytime_timeslot.*t_ir_day;	% Machine working time daytime
w_ir2 = night_timeslot.*t_ir_night;	% Machine working time night
E_ir1_daytime = w_ir1*p_ir;	% Energy (Day time)
E_ir2_Night = w_ir2*p_ir;	% Energy (Night time)
E_ir_total = E_ir1_daytime + E_ir2_Night;	% Energy (Total)
cost_ir1_daytime = E_ir1_daytime*Daytime_cost;	% Cost (Day time)
cost_ir2_Night = E_ir2_Night*night_time_cost;	% Cost (Night time)
cost_ir_total = cost_ir1_daytime + cost_ir2_Night;	% Cost (Total)
%% DLC Iron	
p_ir = 2.5*0.5;	% Power
%d_ir = 1;	% Duration time (hours)

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%d_ir_day=2;

DLC_t_ir_day = DLC_d_ir_day*n_ir; % Time (hours)
DLC_t_ir_night= DLC_d_ir_night.*n_ir;
DLC_w_ir1 = daytime_timeslot.*DLC_t_ir_day; % Machine working time daytime
DLC_w_ir2 = night_timeslot.*DLC_t_ir_night; % Machine working time night

DLC_E_ir1_daytime = DLC_w_ir1*p_ir; % Energy (Day time)
DLC_E_ir2_Night = DLC_w_ir2*p_ir; % Energy (Night time)
DLC_E_ir_total = DLC_E_ir1_daytime + DLC_E_ir2_Night ; % Energy (Total)

DLC_cost_ir1_daytime = DLC_E_ir1_daytime*Daytime_cost; % Cost (Day time)
DLC_cost_ir2_Night = DLC_E_ir2_Night*DLC_Cost; % Cost (Night time)
DLC_cost_ir_total = DLC_cost_ir1_daytime + DLC_cost_ir2_Night; % Cost (Total)

%% Normal Usage Washing Machine
p_wm = 0.8*0.5; % Power washing machine

%d_wm = 1; % Duration time (hours) washing
%d_wm_day=2;

t_wm_day = d_wm_day*n_wm; % Time (Day hours) washing
t_wm_night= d_wm_night.*n_wm; % Time (Night hours) washing
w_wm1 = daytime_timeslot.*t_wm_day; % Machine working time daytime
w_wm2 = night_timeslot.*t_wm_night; % Machine working time night

E_wm1_daytime = w_wm1*p_wm; % Energy (Day time)
E_wm2_Night = w_wm2*p_wm; % Energy (Night time)
E_wm_total = E_wm1_daytime + E_wm2_Night; % Energy (All Day)

cost_wm1_daytime = E_wm1_daytime*Daytime_cost; % Cost (Day time)
cost_wm2_Night = E_wm2_Night*night_time_cost; % Cost (Night time)
cost_wm_total = cost_wm1_daytime + cost_wm2_Night; % Cost (All day)

%% DLC Washing Machine
p_wm = 0.8*0.5; % Power washing machine

%d_wm = 1; % Duration time (hours) washing
%d_wm_day=2;

DLC_t_wm_day = DLC_d_wm_day*n_wm; % Time (hours)
DLC_t_wm_night= DLC_d_wm_night.*n_wm;
DLC_w_wm1 = daytime_timeslot.*DLC_t_wm_day; % Machine working time daytime
DLC_w_wm2 = night_timeslot.*DLC_t_wm_night; % Machine working time night

DLC_E_wm1_daytime = DLC_w_wm1*p_wm; % Energy (Day time)
DLC_E_wm2_Night = DLC_w_wm2*p_wm; % Energy (Night time)
DLC_E_wm_total = DLC_E_wm1_daytime + DLC_E_wm2_Night ; % Energy (Total)

DLC_cost_wm1_daytime = DLC_E_wm1_daytime*Daytime_cost; % Cost (Day time)
DLC_cost_wm2_Night = DLC_E_wm2_Night*DLC_Cost; % Cost (Night time)
DLC_cost_wm_total = DLC_cost_wm1_daytime + DLC_cost_wm2_Night; % Cost (Total)

%% Normal Usage Oven
p_ov = 2*0.5; % Power

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%d_ov = 1; % Duration time (hours)
%d_ov_day=2;

t_ov_day = d_ov_day*n_ov; % Time (hours)
t_ov_night= d_ov_night.*n_ov;
w_ov1 = daytime_timeslot.*t_ov_day; % Machine working time daytime
w_ov2 = night_timeslot.*t_ov_night; % Machine working time night

E_ov1_daytime = w_ov1*p_ov; % Energy (Day time)
E_ov2_Night = w_ov2*p_ov; % Energy (Night time)
E_ov_total = E_ov1_daytime + E_ov2_Night; % Energy (Total)

cost_ov1_daytime = E_ov1_daytime*Daytime_cost; % Cost (Day time)
cost_ov2_Night = E_ov2_Night*night_time_cost; % Cost (Night time)
cost_ov_total = cost_ov1_daytime + cost_ov2_Night; % Cost (Total)

%% DLC Oven
p_ov = 2*0.5; % Power

%d_ov = 1; % Duration time (hours)
%d_ov_day=2;

DLC_t_ov_day = DLC_d_ov_day*n_ov; % Time (hours)
DLC_t_ov_night= DLC_d_ov_night.*n_ov;
DLC_w_ov1 = daytime_timeslot.*DLC_t_ov_day; % Machine working time daytime
DLC_w_ov2 = night_timeslot.*DLC_t_ov_night; % Machine working time night

DLC_E_ov1_daytime = DLC_w_ov1*p_ov; % Energy (Day time)
DLC_E_ov2_Night = DLC_w_ov2*p_ov; % Energy (Night time)
DLC_E_ov_total = DLC_E_ov1_daytime + DLC_E_ov2_Night ; % Energy (Total)

DLC_cost_ov1_daytime = DLC_E_ov1_daytime*Daytime_cost; % Cost (Day time)
DLC_cost_ov2_Night = DLC_E_ov2_Night*DLC_Cost; % Cost (Night time)
DLC_cost_ov_total = DLC_cost_ov1_daytime + DLC_cost_ov2_Night; % Cost (Total)

data_li = [w_li2; E_li2_Night; cost_li2_Night; w_li1; E_li1_daytime; cost_li1_daytime];
fileID_li = fopen('Power_consump_Lighting points.txt','w');
fprintf(fileID_li, '%15s %12s %8s %12s %12s %12s \n', 'li Night Timeslot (Hours)',...
'Energy (kWh)', 'cost(NGN)', 'Day Timeslot(Hours)', 'Energy(kWh)', 'cost(NGN)');
fprintf(fileID_li, '%15.4f %15.4f %15.4f %15.4f %15.4f %15.4f \n', data_li);

data_fa = [w_fa2; E_fa2_Night; cost_fa2_Night; w_fa1; E_fa1_daytime; cost_fa1_daytime];
fileID_li = fopen('Power_consump_fan.txt','w');
fprintf(fileID_li, '%15s %12s %8s %12s %12s %12s \n', 'fa Night Timeslot (Hours)',...
'Energy (kWh)', 'cost(NGN)', 'Day Timeslot(Hours)', 'Energy(kWh)', 'cost(NGN)');
fprintf(fileID_li, '%15.4f %15.4f %15.4f %15.4f %15.4f %15.4f \n', data_fa);

data_ac = [w_ac2; E_ac2_Night; cost_ac2_Night; w_ac1; E_ac1_daytime; cost_ac1_daytime];
fileID_ac = fopen('Power_consump_Air condition.txt','w');
fprintf(fileID_ac, '%15s %12s %8s %12s %12s %12s \n', 'AC Night Timeslot (Hours)', 'Energy
(kWh)', 'cost(NGN)', 'Day Timeslot(Hours)', 'Energy(kWh)', 'cost(NGN)');
fprintf(fileID_ac, '%15.4f %15.4f %15.4f %15.4f %15.4f %15.4f \n', data_ac);

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data_tv = [w_tv2; E_tv2_Night; cost_tv2_Night; w_tv1; E_tv1_daytime; cost_tv1_daytime];
fileID_tv = fopen('Power_consump_Televison.txt','w');
fprintf(fileID_tv, '%15s %12s %8s %12s %12s %12s \n', 'TV Night Timeslot (Hours)', 'Energy (kWh)', 'cost(NGN)', 'Day Timeslot(Hours)', 'Energy(kWh)', 'cost(NGN)');
fprintf(fileID_tv, '%15.4f %15.4f %15.4f %15.4f %15.4f %15.4f \n', data_tv);

data_rf = [w_rf2; E_rf2_Night; cost_rf2_Night; w_rf1; E_rf1_daytime; cost_rf1_daytime];
fileID_rf = fopen('Power_consump_Refrigerator.txt','w');
fprintf(fileID_rf, '%15s %12s %8s %12s %12s %12s \n', 'RF Night Timeslot (Hours)', 'Energy (kWh)', 'cost(NGN)', 'Day Timeslot(Hours)', 'Energy(kWh)', 'cost(NGN)');
fprintf(fileID_rf, '%15.4f %15.4f %15.4f %15.4f %15.4f %15.4f \n', data_rf);

data_fr = [w_fr2; E_fr2_Night; cost_fr2_Night; w_fr1; E_fr1_daytime; cost_fr1_daytime];
fileID_fr = fopen('Power_consump_Freezer.txt','w');
fprintf(fileID_fr, '%15s %12s %8s %12s %12s %12s \n', 'FR Night Timeslot (Hours)', 'Energy (kWh)', 'cost(NGN)', 'Day Timeslot(Hours)', 'Energy(kWh)', 'cost(NGN)');
fprintf(fileID_fr, '%15.4f %15.4f %15.4f %15.4f %15.4f %15.4f \n', data_fr);

data_wd = [w_wd2; E_wd2_Night; cost_wd2_Night; w_wd1; E_wd1_daytime; cost_wd1_daytime];
fileID_wd = fopen('Power_consump_Water Dispenser.txt','w');
fprintf(fileID_wd, '%15s %12s %8s %12s %12s %12s \n', 'WD Night Timeslot (Hours)', 'Energy (kWh)', 'cost(NGN)', 'Day Timeslot(Hours)', 'Energy(kWh)', 'cost(NGN)');
fprintf(fileID_wd, '%15.4f %15.4f %15.4f %15.4f %15.4f %15.4f \n', data_wd);

data_mw = [w_mw2; E_mw2_Night; cost_mw2_Night; w_mw1; E_mw1_daytime; cost_mw1_daytime];
fileID_mw = fopen('Power_consump_Microwave.txt','w');
fprintf(fileID_mw, '%15s %12s %8s %12s %12s %12s \n', 'MW Night Timeslot (Hours)', 'Energy (kWh)', 'cost(NGN)', 'Day Timeslot(Hours)', 'Energy(kWh)', 'cost(NGN)');
fprintf(fileID_mw, '%15.4f %15.4f %15.4f %15.4f %15.4f %15.4f \n', data_mw);

data_dw = [w_dw2; E_dw2_Night; cost_dw2_Night; w_dw1; E_dw1_daytime; cost_dw1_daytime];
fileID_dw = fopen('Power_consump_Dish Washer.txt','w');
fprintf(fileID_dw, '%15s %12s %8s %12s %12s %12s \n', 'DW Night Timeslot (Hours)', 'Energy (kWh)', 'cost(NGN)', 'Day Timeslot(Hours)', 'Energy(kWh)', 'cost(NGN)');
fprintf(fileID_dw, '%15.4f %15.4f %15.4f %15.4f %15.4f %15.4f \n', data_dw);

data_wp = [w_wp2; E_wp2_Night; cost_wp2_Night; w_wp1; E_wp1_daytime; cost_wp1_daytime];
fileID_wp = fopen('Power_consump_Water Pump.txt','w');
fprintf(fileID_wp, '%15s %12s %8s %12s %12s %12s \n', 'WP Night Timeslot (Hours)', 'Energy (kWh)', 'cost(NGN)', 'Day Timeslot(Hours)', 'Energy(kWh)', 'cost(NGN)');
fprintf(fileID_wp, '%15.4f %15.4f %15.4f %15.4f %15.4f %15.4f \n', data_wp);

data_ir = [w_ir2; E_ir2_Night; cost_ir2_Night; w_ir1; E_ir1_daytime; cost_ir1_daytime];
fileID_ir = fopen('Power_consump_Iron.txt','w');
fprintf(fileID_ir, '%15s %12s %8s %12s %12s %12s \n', 'IR Night Timeslot (Hours)', 'Energy (kWh)', 'cost(NGN)', 'Day Timeslot(Hours)', 'Energy(kWh)', 'cost(NGN)');
fprintf(fileID_ir, '%15.4f %15.4f %15.4f %15.4f %15.4f %15.4f \n', data_ir);

data_wm = [w_wm2; E_wm2_Night; cost_wm2_Night; w_wm1; E_wm1_daytime; cost_wm1_daytime];
fileID_wm = fopen('Power_consump_Washing machine.txt','w');
fprintf(fileID_wm, '%15s %12s %8s %12s %12s %12s \n', 'WM Night Timeslot (Hours)', 'Energy (kWh)', 'cost(NGN)', 'Day Timeslot(Hours)', 'Energy(kWh)', 'cost(NGN)');
fprintf(fileID_wm, '%15.4f %15.4f %15.4f %15.4f %15.4f %15.4f \n', data_wm);

```

```

data_ov = [w_ov2; E_ov2_Night; cost_ov2_Night; w_ov1; E_ov1_daytime; cost_ov1_daytime];
fileID_ov = fopen('Power_consumption_Oven.txt','w');
fprintf(fileID_ov, '%15s %12s %8s %12s %12s %12s \n', 'OV Night Timeslot (Hours)', 'Energy (kWh)', 'cost(NGN)', 'Day Timeslot(Hours)', 'Energy(kWh)', 'cost(NGN)');
fprintf(fileID_ov, '%15.4f %15.4f %15.4f %15.4f %15.4f %15.4f \n', data_ov);

fprintf(fileID1, '%15s %12s %12s \n', 'Night Timeslot (Hours)', 'Energy (kWh)', 'cost(NGN)');
fprintf(fileID, '%6.4f %20.4f %20.4f %20.4f %20.4f %20.4f \n', data);
%plot(t, E_ac2_Night)

%plot(t, E_li1_daytime, '-+r')
hold on
%plot(t, E_fa1_daytime, '-ob')
%plot(t, E_tv1_daytime, '-*c')
%plot(t, E_ac1_daytime, '-xk')
%plot(t, E_rf1_daytime, '-.m')
%plot(t, E_fr1_daytime, '-dw')
%plot(t, E_wd1_daytime, '->y')
%plot(t, E_dw1_daytime, '-<g')
%xlabel('Day Time (h)')
%ylabel('Energy (kWh)')
%legend('Lightening', 'Fan', 'Television', 'Airconditioner', 'Refrigerator', 'Freezer', 'Water Dispenser', 'Dish Washer')
%xlim([-1 25])
%ylim([-1 7])
%hold off

%plot(t, E_mw1_daytime, '-+r')
%hold on
%plot(t, E_wp1_daytime, '-ob')
%plot(t, E_ir1_daytime, '-*c')
%plot(t, E_wm1_daytime, '-xk')
%plot(t, E_ov1_daytime, '-.m')
%xlabel('Day Time (h)')
%ylabel('Energy (kWh)')
%legend('Microwave', 'Water pump', 'Iron', 'Wash Machine', 'Oven')
%xlim([-1 25])
%ylim([-1 7])
%hold off

%plot(t, E_li2_Night, '-+r')
%hold on
%plot(t, E_fa2_Night, '-ob')
%plot(t, E_tv2_Night, '-*c')
%plot(t, E_ac2_Night, '-xk')
%plot(t, E_rf2_Night, '-.m')
%plot(t, E_fr2_Night, '-dw')
%plot(t, E_wd2_Night, '->y')
%plot(t, E_dw2_Night, '-<g')
%xlabel('Night Time (h)')
%ylabel('Energy (kWh)')
%legend('Lightening', 'Fan', 'Television', 'Airconditioner', 'Refrigerator', 'Freezer', 'Water Dispenser', 'Dish Washer')
%xlim([-1 25])

```

```

%ylim([-1 7])
%hold off

plot(t,E_mw2_Night,'-+r')
hold on
plot(t,E_wp2_Night,'-ob')
plot(t,E_ir2_Night,'-*c')
plot(t,E_wm2_Night,'-xk')
plot(t,E_ov2_Night,'-.m')
xlabel('Night Time (h)')
ylabel('Energy (kWh)')
legend('Microwave','Water pump','Iron','Wash Machine','Oven')
%xlim([-1 25])
%ylim([-1 7])
%hold off

formatSpec = '%4.18s %8.18s \n'; % or %8.3f mm
fprintf(formatSpec,'Energy Night Time','Cost Night Time')

formatSpec1 = '%12.5f %18.5f\n'; % or %8.3f mm
%washing_machine_data = [E_wm_Night; cost_wm_Night];
%fprintf(formatSpec1,washing_machine_data)
%P = [Power_Washing_Machine, Power_Dishwasher,power_Airconditioner,Power_TV,...
%    Power_Iron,Power_Oven,Power_Fridge]

%% Normal usage
complete_datatype_energy =
sum(E_li1_daytime+E_fa1_daytime+E_ac1_daytime+E_tv1_daytime+E_rf1_daytime+E_fr1_daytim
e+...

+E_wd1_daytime+E_mw1_daytime+E_dw1_daytime+E_wp1_daytime+E_ir1_daytime+E_wm1_day
time+E_ov1_daytime)

complete_nighttime_energy =
sum(E_li2_Night+E_fa2_Night+E_ac2_Night+E_tv2_Night+E_rf2_Night+E_fr2_Night+...

+E_wd2_Night+E_mw2_Night+E_dw2_Night+E_wp2_Night+E_ir2_Night+E_wm2_Night+E_ov2_
Night)

complete_total_energy = sum(E_li_total+E_fa_total+E_ac_total+E_tv_total+E_rf_total+E_fr_total+...
    E_wd_total+E_mw_total+E_dw_total+E_wp_total+E_ir_total+E_wm_total+E_ov_total )

% DLC
DLC_complete_datatype_energy =
sum(DLC_E_li1_daytime+DLC_E_fa1_daytime+DLC_E_ac1_daytime+DLC_E_tv1_daytime+...

+DLC_E_rf1_daytime+DLC_E_fr1_daytime+DLC_E_wd1_daytime+DLC_E_mw1_daytime+DLC_
E_dw1_daytime+DLC_E_wp1_daytime+...
    +DLC_E_ir1_daytime+DLC_E_wm1_daytime+DLC_E_ov1_daytime)

DLC_complete_nighttime_energy =
sum(DLC_E_li2_Night+DLC_E_fa2_Night+DLC_E_ac2_Night+DLC_E_tv2_Night+....

+DLC_E_rf2_Night+DLC_E_fr2_Night+DLC_E_wd2_Night+DLC_E_mw2_Night+DLC_E_dw2_N
ight+DLC_E_wp2_Night+...

```

```

+DLC_E_ir2_Night+DLC_E_wm2_Night+DLC_E_ov2_Night)

DLC_complete_total_energy =
sum(DLC_E_li_total+DLC_E_fa_total+DLC_E_ac_total+DLC_E_tv_total+DLC_E_rf_total+....

+DLC_E_fr_total+DLC_E_wd_total+DLC_E_mw_total+DLC_E_dw_total+DLC_E_wp_total+DLC
_E_ir_total+....
+DLC_E_wm_total+DLC_E_ov_total )

%%%%%%%%%%%%Normal cost
cost_daytime
=sum(cost_li1_daytime+cost_fa1_daytime+cost_ac1_daytime+cost_tv1_daytime+cost_rf1_daytime+.
...

+cost_fr1_daytime+cost_wd1_daytime+cost_mw1_daytime+cost_dw1_daytime+cost_wp1_daytime+
cost_ir1_daytime+....
+cost_wm1_daytime+cost_ov1_daytime)

cost_Night =
sum(cost_li2_Night+cost_fa2_Night+cost_ac2_Night+cost_tv2_Night+cost_rf2_Night+....

+cost_fr2_Night+cost_wd2_Night+cost_mw2_Night+cost_dw2_Night+cost_wp2_Night+cost_ir2_Ni
ght+...
+cost_wm2_Night+cost_ov2_Night)

total_cost = sum(cost_li_total+cost_fa_total+cost_ac_total+cost_tv_total+cost_rf_total+...
+cost_fr_total+cost_wd_total+cost_mw_total+cost_dw_total+cost_wp_total+cost_ir_total+...
+cost_wm_total+cost_ov_total)
%%%%%%%%%%%%DLC COST

DLC_cost_daytime
=sum(DLC_cost_li1_daytime+DLC_cost_fa1_daytime+DLC_cost_ac1_daytime+DLC_cost_tv1_day
time+....

+DLC_cost_rf1_daytime+DLC_cost_fr1_daytime+DLC_cost_wd1_daytime+DLC_cost_mw1_dayti
me+DLC_cost_dw1_daytime+...

+DLC_cost_wp1_daytime+DLC_cost_ir1_daytime+DLC_cost_wm1_daytime+DLC_cost_ov1_dayti
me)

DLC_cost_Night =
sum(DLC_cost_li2_Night+DLC_cost_fa2_Night+DLC_cost_ac2_Night+DLC_cost_tv2_Night+...

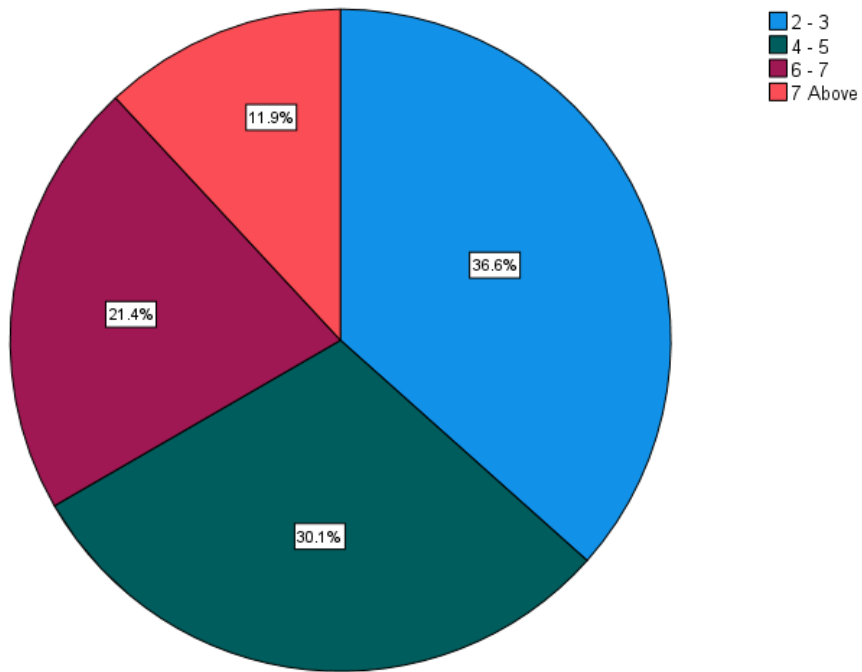
+DLC_cost_rf2_Night+DLC_cost_fr2_Night+DLC_cost_wd2_Night+DLC_cost_mw2_Night+DLC_
cost_dw2_Night+....
+DLC_cost_wp2_Night+DLC_cost_ir2_Night+DLC_cost_wm2_Night+DLC_cost_ov2_Night+)

DLC_total_cost =
sum(DLC_cost_li_total+DLC_cost_fa_total+DLC_cost_ac_total+DLC_cost_tv_total+....

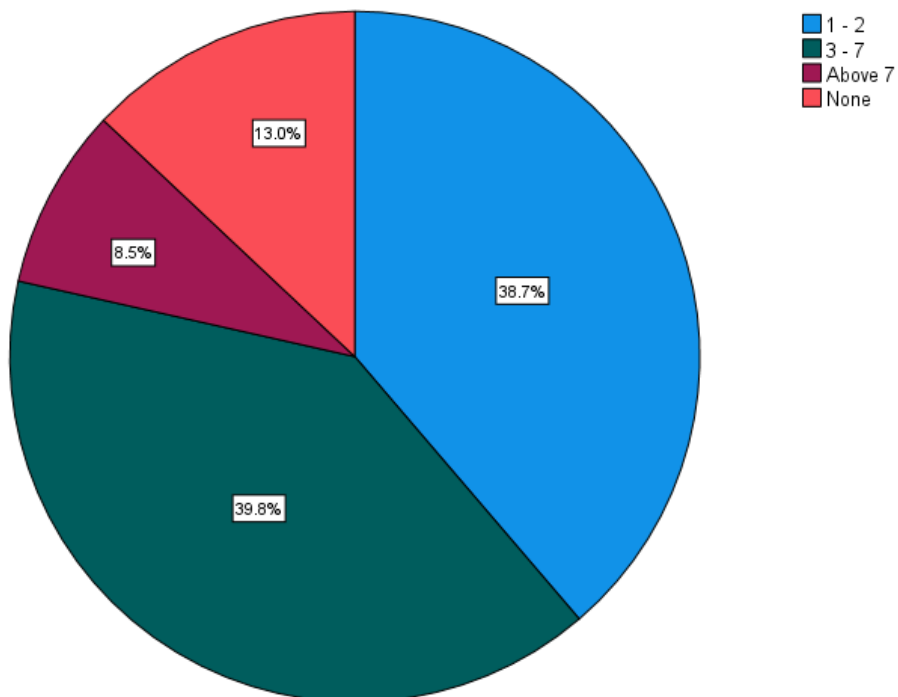
+DLC_cost_rf_total+DLC_cost_fr_total+DLC_cost_wd_total+DLC_cost_mw_total+DLC_cost_dw_
total+....
+DLC_cost_wp_total+DLC_cost_ir_total+DLC_cost_wm_total+DLC_cost_ov_total)

```

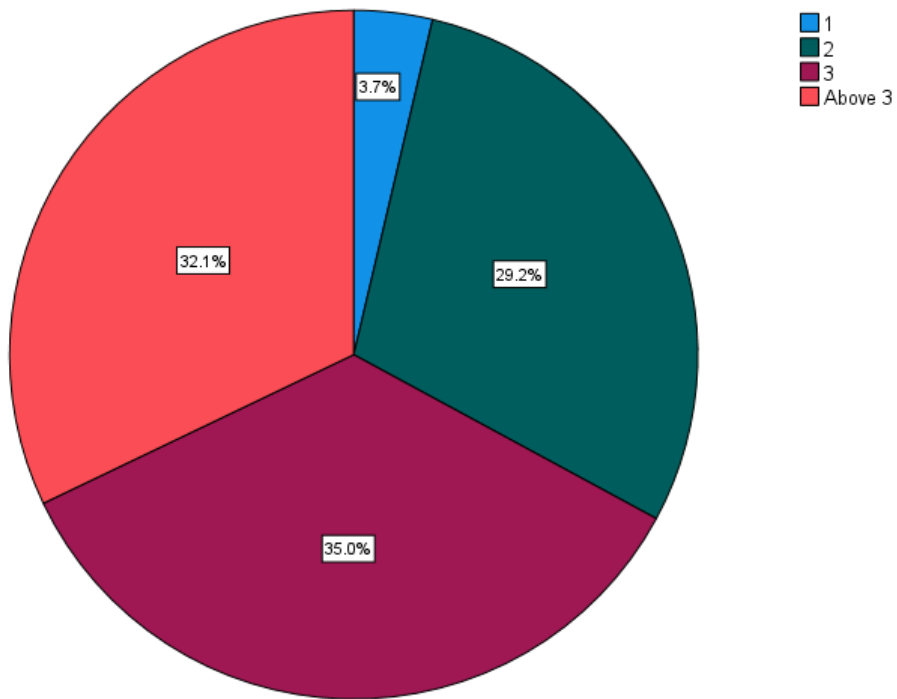
APPENDIX D: SURVEY RESULT



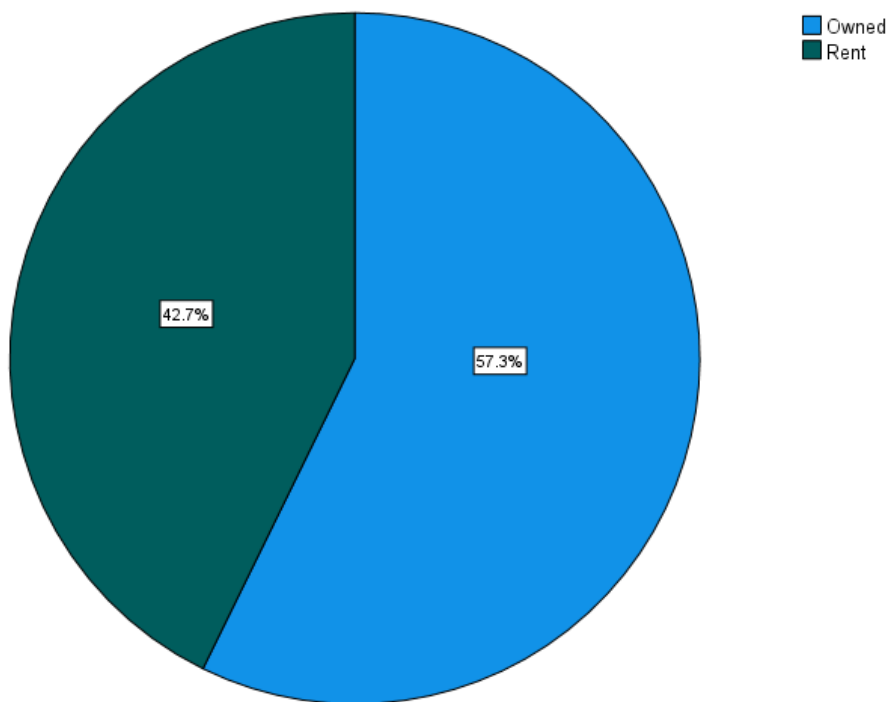
Number of Households



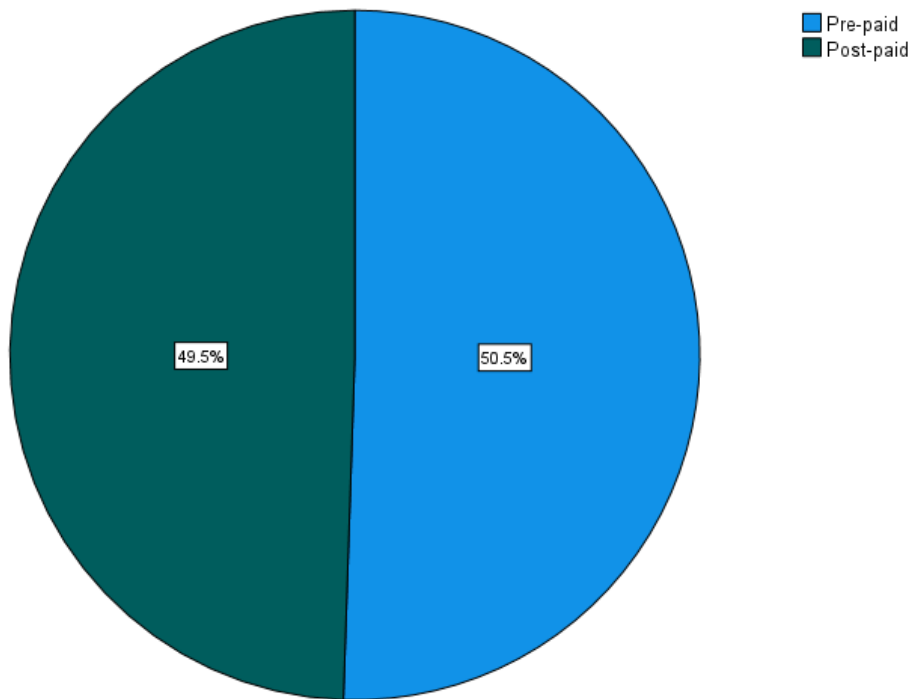
Number of Children



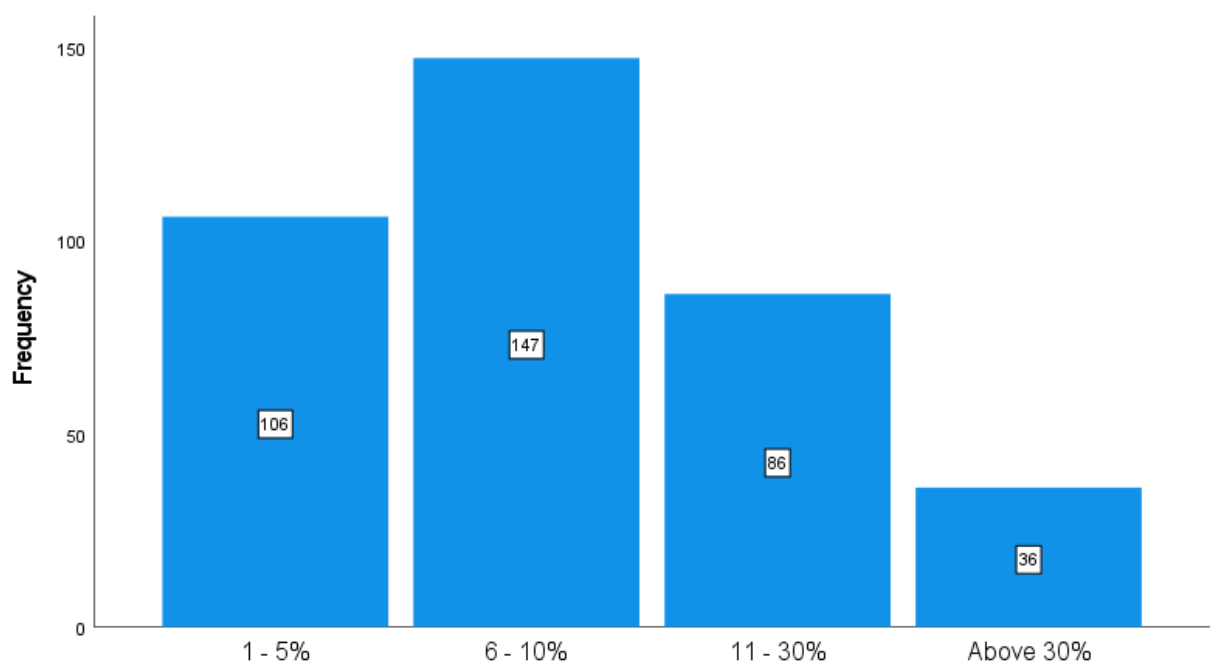
Number of Rooms in the House



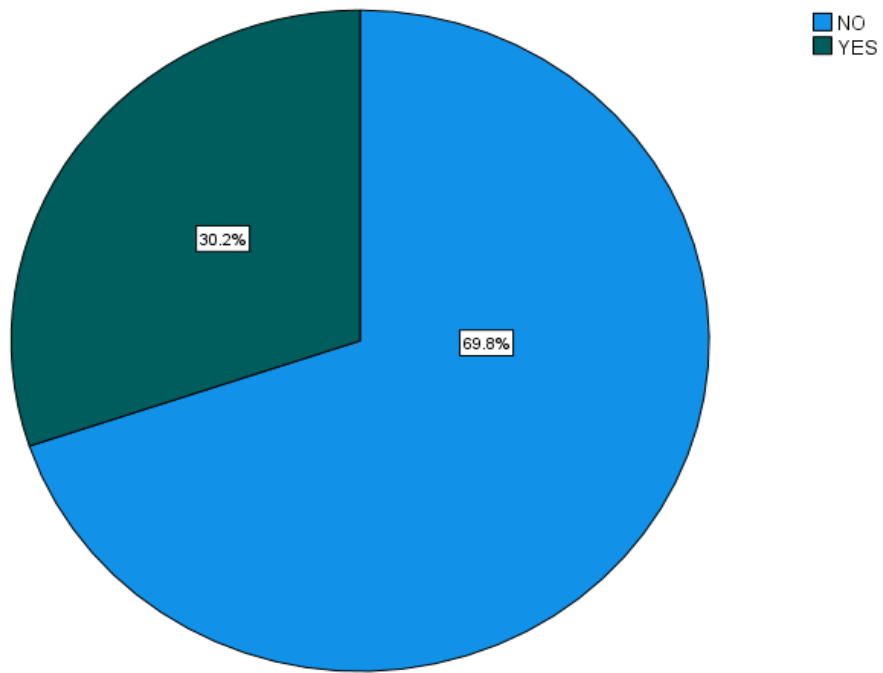
Nature of House Ownership



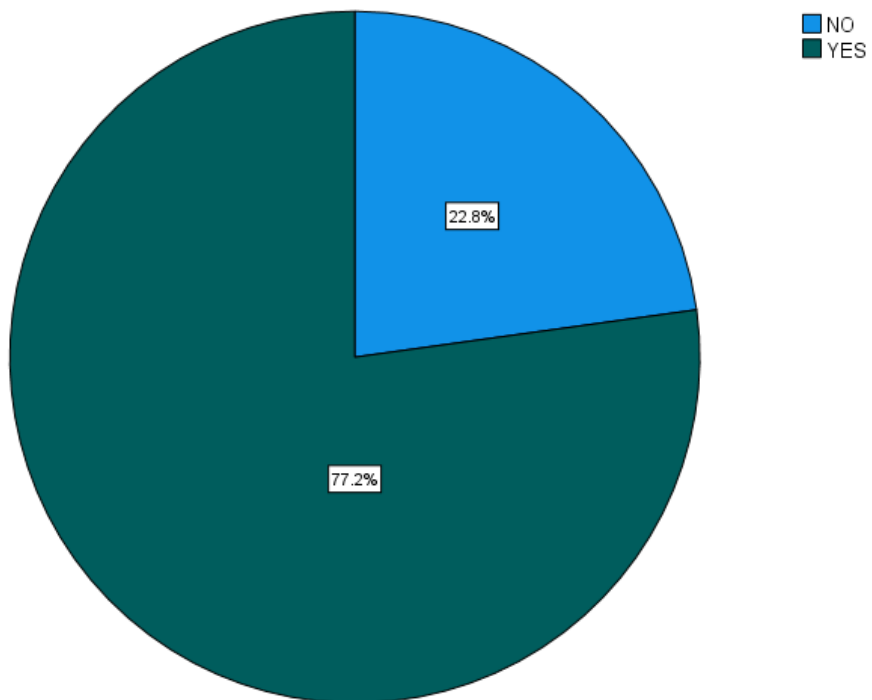
Billing System



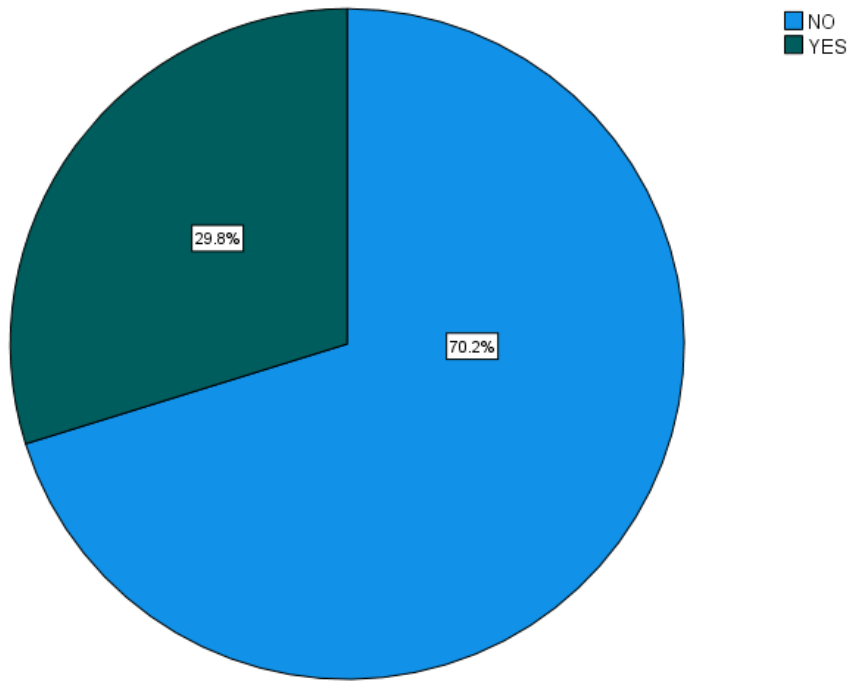
Total Monthly Expenditure on Electricity



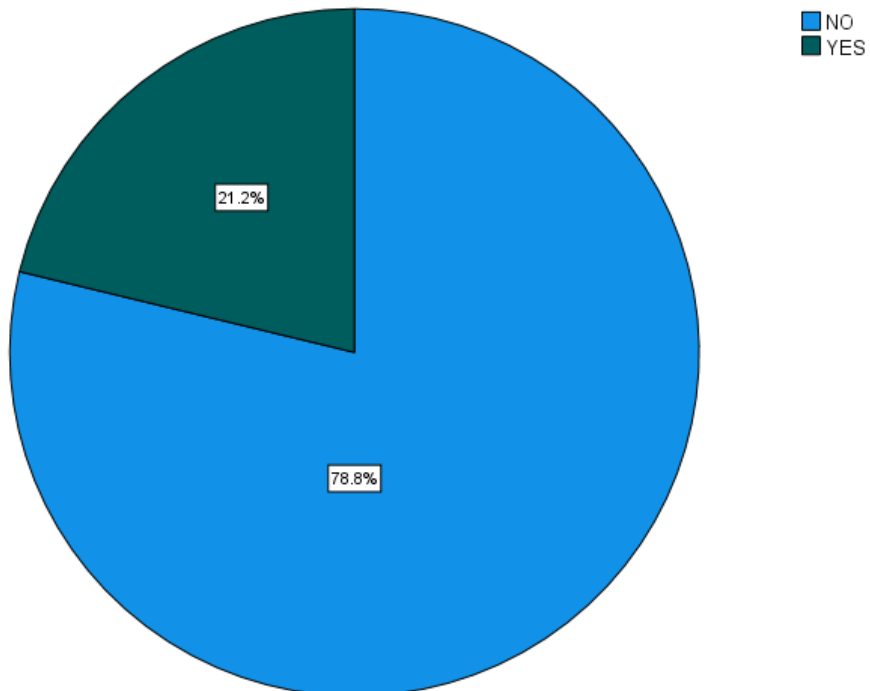
Number of Households Considering Power Rating When Purchasing Appliances



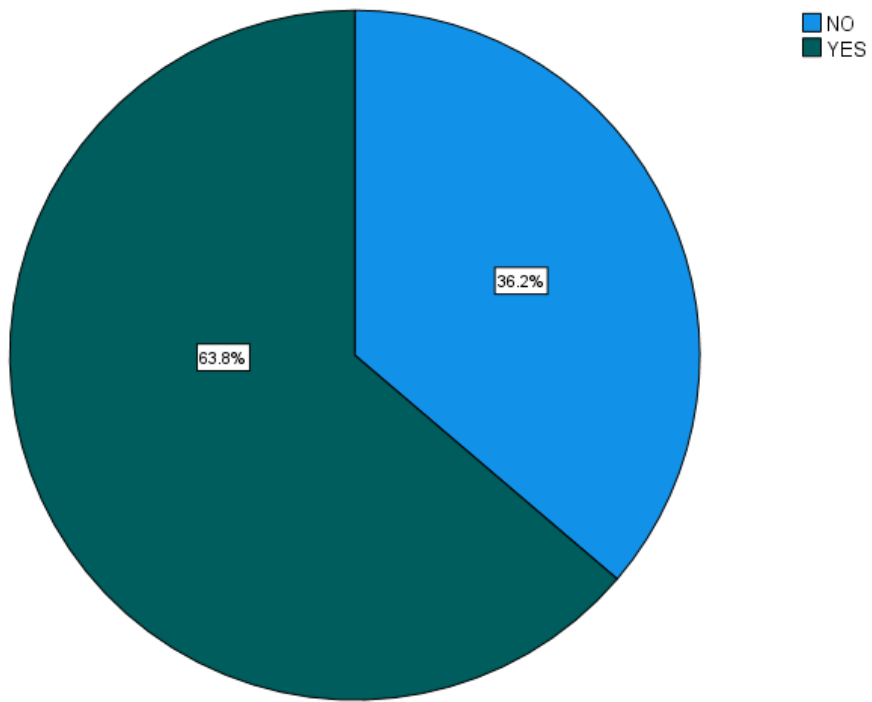
Number of Households Practicing Energy Management



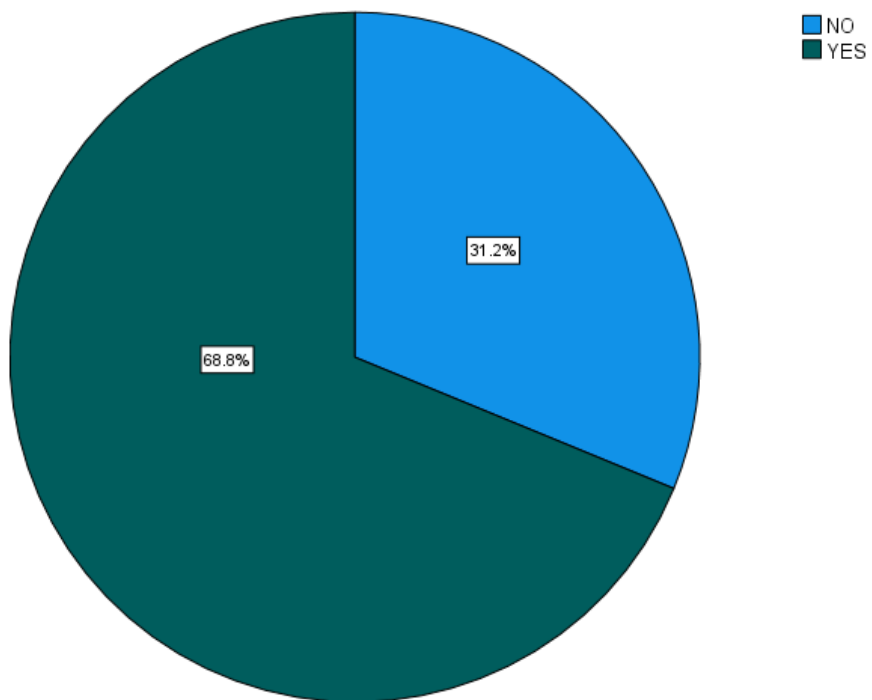
Awareness of 3-4 Energy Saving Methods



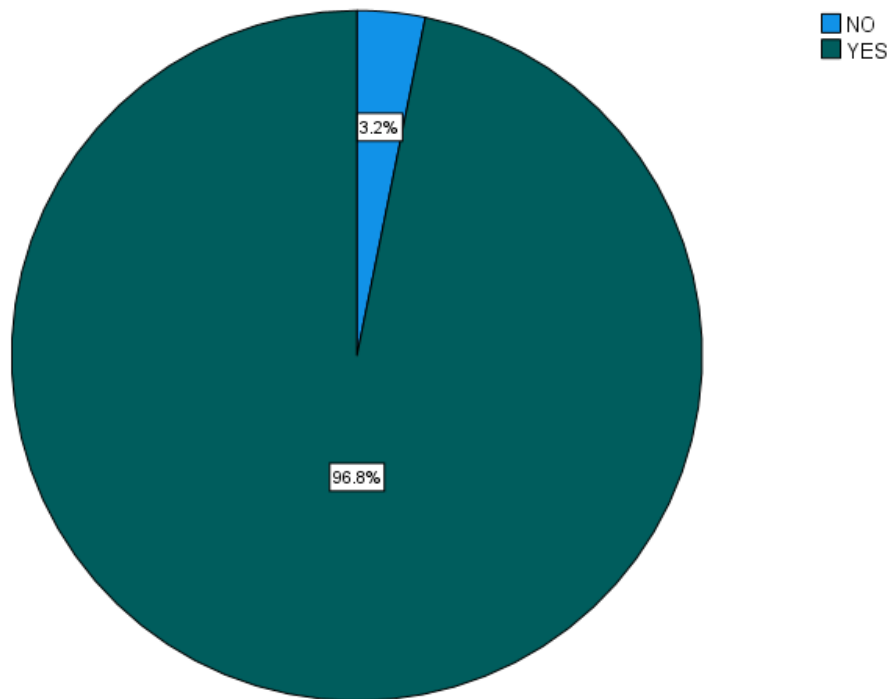
Number of Households Unaware of Energy Saving Practices



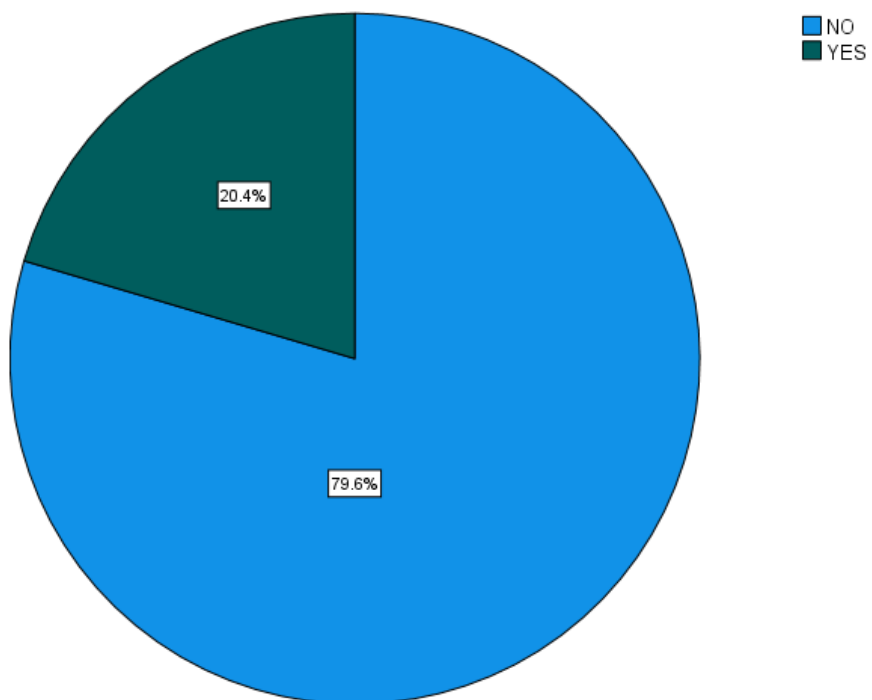
Households Using Energy-Saving Bulbs



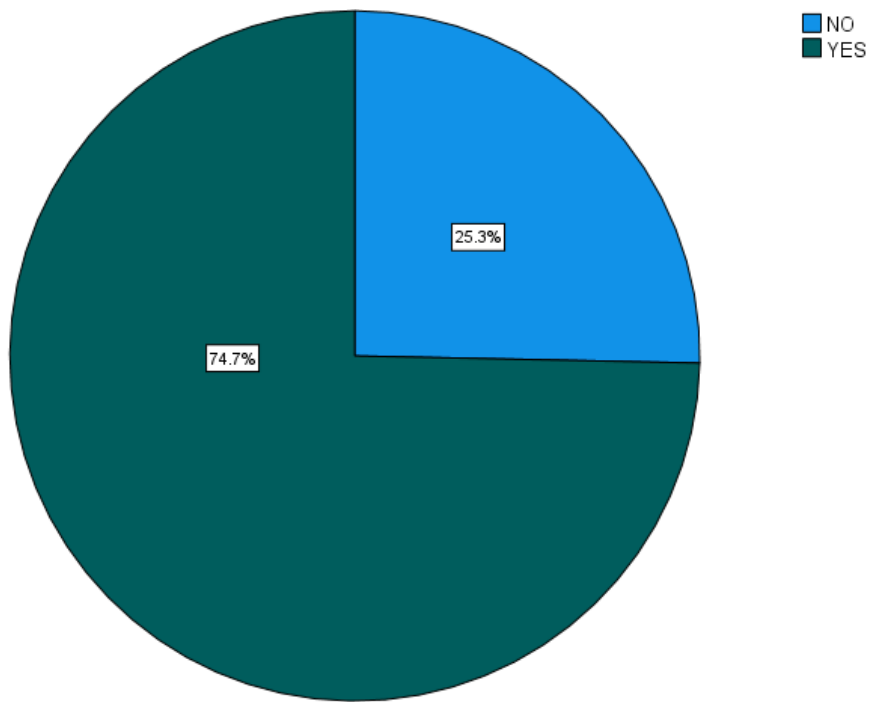
Households That Switch Off Lights and Appliances Before Leaving Home



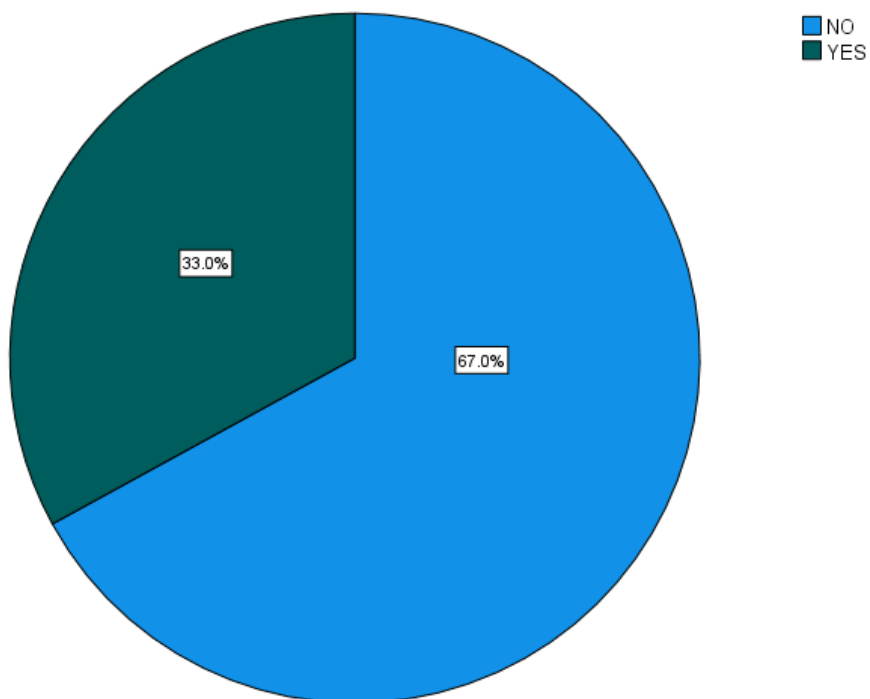
Does Monitoring Energy Use at Home Increase Awareness of Energy Management



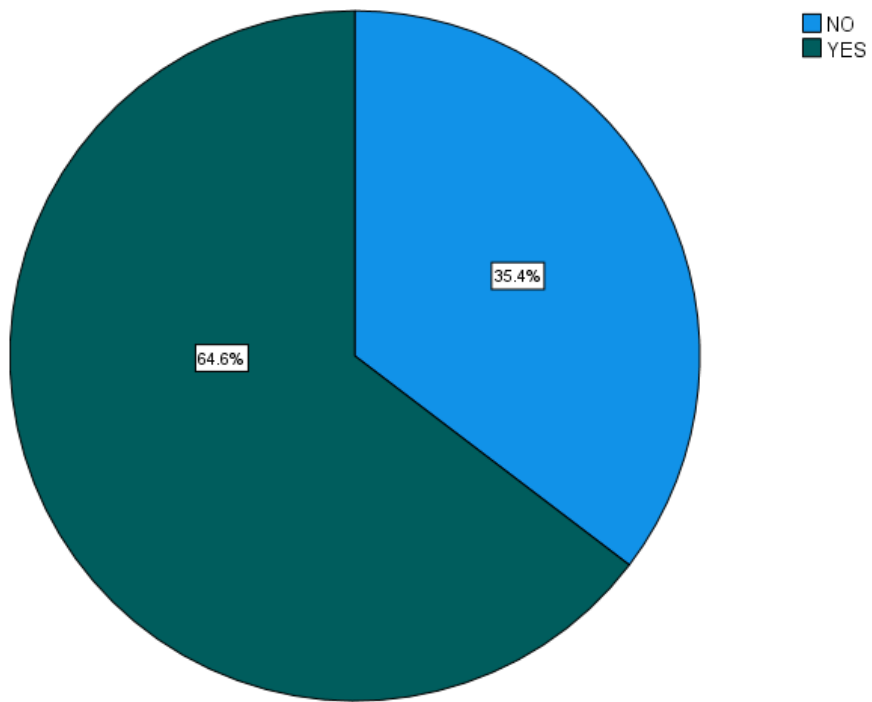
Household Awareness of Government Energy-Saving Programs



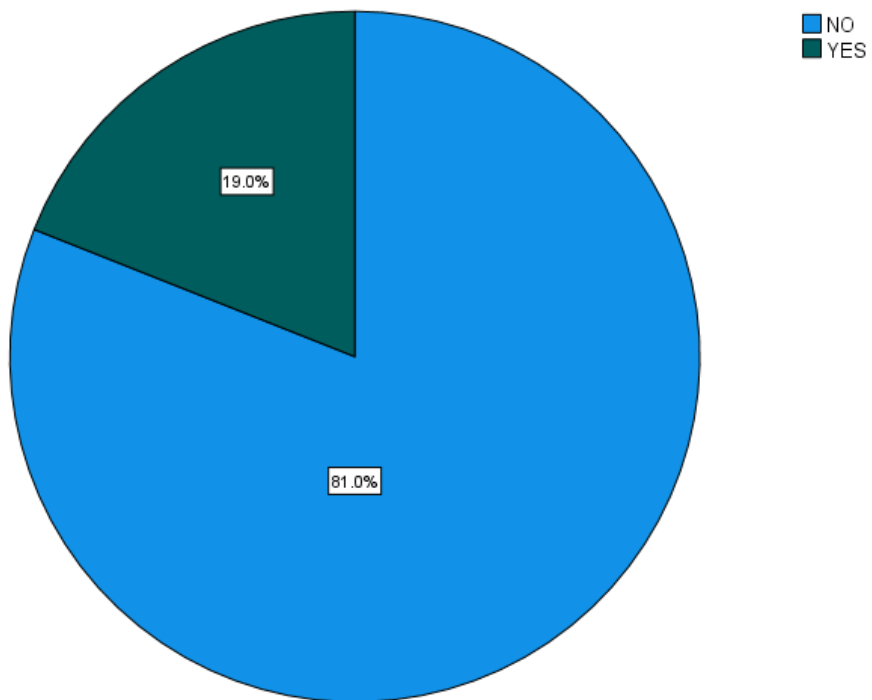
Household Perceptions of Cost as a Motivator for Changes in Energy Use Behaviour



Household Perceptions of Environmental factors as a Motivator for Changes in Energy Use Behaviour



Cost of Purchase as a Barrier for Households Switching from Grid Energy to Renewable Energy



Lack of Information on Renewable Energy as a Barrier to Switching from Grid to Renewable Energy

APPENDIX E: HOUSEHOLD DEMAND LOAD PROFILE

Normal Energy Consumption				Direct Load Control		
ID	Night Energy (kWh)	Daytime Energy (kWh)	Total Energy (kWh)	Night Energy (kWh)	Daytime Energy (kWh)	Total Energy (kWh)
1	60.22	65.47	125.69	62.92	11	73.92
2	52.22	53.55	105.77	52.97	26.35	79.32
3	437.4	187.95	625.35	452.05	30.8	482.85
4	61.72	65.82	127.54	58.02	9.2	67.22
5	31.57	10.8	42.37	36.47	1.8	38.27
6	12.14	4.85	16.99	18.24	1.45	19.69
7	36.84	17.65	54.49	35.84	2.05	37.89
8	30.82	7.22	38.04	35.17	0.05	35.22
9	30.52	5.28	35.8	31.22	0	31.22
10	31.4	5.23	36.63	32.55	0.1	32.65
11	19.1	3	22.1	22.75	0.7	23.45
12	14.68	15.75	30.43	17.63	3.15	20.78
13	50.96	11.4	62.36	50.16	1	51.16
14	96.6	186.2	282.8	92.8	13.53	106.33
15	21.8	1.25	23.05	25.35	0	25.35
16	112.8	119.85	232.65	104.75	14.18	118.93
17	58.3	105.25	163.55	53.65	7.28	60.93
18	32.2	28.15	60.35	32	11.43	43.43
19	69.22	67.72	136.94	70.57	12.73	83.3
21	29.1	29.45	58.55	31.55	3.45	35
22	16.2	12.05	28.25	21	1.8	22.8
23	2.5	3.75	6.25	5.95	0	5.95
24	3.65	2.8	6.45	7.4	1.6	9
25	36.43	12.4	48.83	32.98	1.15	34.13
26	156.75	150.65	307.4	149.25	52.95	202.2
27	126.6	130.95	257.55	132.2	32.43	164.63
28	30.34	32.8	63.14	27.29	5.4	32.69
29	82.12	37.95	120.07	76.57	11.83	88.4
31	30.6	33.15	63.75	36.85	4	40.85
34	78.62	8.45	87.07	77.12	0	77.12
37	153.34	148.19	301.53	146.84	35.2	182.04
40	29.36	29	58.36	32.91	4.65	37.56
42	55.28	53.15	108.43	55.68	11.4	67.08
47	38.54	44.89	83.43	42.79	9.6	52.39
52	51.12	49.9	101.02	52.37	7.85	60.22
53	134.12	102.02	236.14	136.02	25.46	161.48
54	14.37	13.12	27.49	13.97	2.93	16.9

55	54.7	31.52	86.22	84.42	11.63	96.05
56	79.55	33.8	113.35	73.2	3.13	76.33
57	38.83	36.68	75.51	37.58	8.05	45.63
58	31.16	15.85	47.01	33.36	1.4	34.76
59	37.95	18.2	56.15	35.75	6.93	42.68
61	30.6	12.65	43.25	33.3	1.45	34.75
62	79.81	56.15	135.96	85.46	8.23	93.69
63	70.81	62.55	133.36	67.76	14.07	81.83
64	18.88	1	19.88	17.48	5.43	22.91
65	21.3	26.1	47.4	16.05	2.7	18.75
66	29.35	17.15	46.5	30.45	6.45	36.9
67	41	13.7	54.7	41.75	2.15	43.9
68	14.64	15.25	29.89	15.69	2.1	17.79
69	177.45	112.4	289.85	151.8	39.13	190.93
70	98.9	65.7	164.6	84.7	21.65	106.35
71	13.95	10.8	24.75	13.75	1.8	15.55
72	110.83	89.05	199.88	102.63	30.95	133.58
73	66.3	31.4	97.7	62.65	13.58	76.23
74	132.26	40.2	172.46	121.16	6.35	127.51
75	13.16	14.55	27.71	19.01	1.35	20.36
76	31.04	21.05	52.09	31.29	5.4	36.69
77	30.01	23.55	53.56	32.4	5.25	37.65
78	13.06	12.05	25.11	16.61	1.8	18.41
79	14.43	10.8	25.23	14.2	0.9	15.1
82	43.26	30.8	74.06	36.66	3.9	40.56
83	22.99	11.4	34.39	17.24	1	18.24
84	17.94	12.4	30.34	16.99	0.9	17.89
85	30.16	31.3	61.46	31.8	4.6	36.4
86	91.44	87.65	179.09	93.49	15.75	109.24
87	12.48	13.9	26.38	15.18	1.03	16.21
88	26.4	1.85	28.25	27.2	0.8	28
89	31.52	14.55	46.07	35.47	1.35	36.82
90	60.48	37.25	97.73	64.78	10.5	75.28
91	73.99	37.2	111.19	70.99	5.5	76.49
92	60.29	64.2	124.49	55.14	8.73	63.87
93	63.45	64.65	128.1	48.4	7.5	55.9
94	54.02	16.72	70.74	44.57	2.85	47.42
95	13.86	10.8	24.66	15.46	0.9	16.36
100	4.64	5.04	9.68	6.94	0.75	7.69
101	98.64	26.4	125.04	79.39	7.05	86.44
102	13.2	17.04	30.24	14.9	1.45	16.35
103	30.94	0	30.94	27.49	0	27.49
104	31.3	33.35	64.65	34.7	5.85	40.55
105	13.65	13	26.65	13.85	2.05	15.9
106	2.52	6.47	8.99	5.12	0.4	5.52

109	19.5	14.3	33.8	15.85	0.98	16.83
110	14.17	13.92	28.09	14.82	3.4	18.22
111	103.69	94.54	198.23	97.19	32.6	129.79
112	52.78	36.25	89.03	47.43	6.95	54.38
113	51.57	6	57.57	49.92	0.05	49.97
114	4.33	3.28	7.61	5.48	0.9	6.38
115	76.65	48.25	124.9	48.55	16.78	65.33
116	20.92	22.57	43.49	18.42	5.45	23.87
118	176.43	178.4	354.83	158.33	31.5	189.83
119	40.51	20.01	60.52	33.56	3.48	37.04
121	59.45	23.25	82.7	47.7	3.6	51.3
122	45.52	22.76	68.28	41.7	2.35	44.05
123	28.96	15.9	44.86	33.51	3.6	37.11
124	74.95	45	119.95	63.85	5.63	69.48
125	44.85	21	65.85	34.95	4.63	39.58
126	91.49	60.74	152.23	78.89	8.05	86.94
127	97.01	28.21	125.22	74.26	4.25	78.51
128	64.32	23.1	87.42	53.57	4.6	58.17
129	66.84	25.2	92.04	54.94	2.23	57.17
134	12.44	14.37	26.81	16.19	2.2	18.39
135	6.82	5.98	12.8	6.12	2.1	8.22
136	16.34	18.24	34.58	13.29	2.85	16.14
139	7.8	6.65	14.45	4.3	0.4	4.7
140	17.6	24.4	42	15.7	2.95	18.65
141	13.26	16.79	30.05	18.66	2.4	21.06
142	35.12	41.53	76.65	36.92	8	44.92
143	40.84	46.53	87.37	37.04	8.05	45.09
144	15.6	23.1	38.7	19.9	2.1	22
145	18.74	22.43	41.17	16.84	2.4	19.24
146	13.04	18.1	31.14	13.64	2.7	16.34
152	61.6	46.08	107.68	62.85	7.58	70.43
154	7.24	5.07	12.31	5.74	0.13	5.87
155	58.64	28.4	87.04	43.59	6.2	49.79
156	92	13.25	105.25	63.9	2.5	66.4
157	7.46	0.9	8.36	7.16	0.9	8.06
159	38.74	28.02	66.76	37.19	4.93	42.12
161	142.16	101.45	243.61	144.31	29.63	173.94
163	27	26.35	53.35	31.35	4.2	35.55
164	81.72	31.4	113.12	85.02	4.1	89.12
166	79.08	20.88	99.96	74.93	2.98	77.91
169	19.25	12.7	31.95	17.45	1.55	19
170	16.91	13.08	29.99	13.16	2.5	15.66
171	48.97	23.85	72.82	44.67	4.8	49.47
173	34.19	28.89	63.08	29.54	5.48	35.02
174	50.76	16.55	67.31	53.71	4.96	58.67

175	56.19	27.3	83.49	52.19	6.25	58.44
177	95.65	43.2	138.85	90.55	18	108.55
178	15.98	2.5	18.48	13.03	0	13.03
180	30.06	3.75	33.81	33.51	0	33.51
182	13.44	12	25.44	13.64	2	15.64
183	15.65	13.25	28.9	14.2	1.5	15.7
184	30.6	14.5	45.1	12.7	2.15	14.85
187	19.04	14.95	33.99	18.79	1.9	20.69
188	7.75	0.6	8.35	6.95	0.05	7
189	30.6	17.65	48.25	34.65	1	35.65
190	45.2	4.8	50	42.7	2.9	45.6
191	17.85	20.2	38.05	32.33	7.3	39.63
192	213.75	207.3	421.05	210.8	54.55	265.35
193	38.64	19.8	58.44	39.49	8.35	47.84
195	132.8	85.2	218	130.2	33.7	163.9
196	12.46	2.05	14.51	19.91	0.5	20.41
197	3.65	2.25	5.9	5.5	0.8	6.3
198	6.75	2.4	9.15	9.25	1.2	10.45
199	22.84	6.15	28.99	24.34	1.65	25.99
200	61.09	0	61.09	60.59	0	60.59
201	12.86	12.1	24.96	12.86	1.5	14.36
202	17.88	12.98	30.86	15.68	1.2	16.88
203	17.1	5.7	22.8	18.25	1.8	20.05
204	13.84	7.45	21.29	14.09	1.9	15.99
205	12.02	11.1	23.12	16.92	2.15	19.07
206	1.2	5.8	7	6.4	0.7	7.1
208	36.5	38.6	75.1	39.1	6.85	45.95
209	1.6	3.7	5.3	2.95	0.5	3.45
210	37.76	30.5	68.26	48.4	9.25	57.65
211	37	22.8	59.8	37.3	5.63	42.93
212	14.8	6.4	21.2	16.25	1.7	17.95
214	58.45	14.15	72.6	54.7	2.93	57.63
215	36.12	8.2	44.32	31.67	2.1	33.77
216	76.01	22.8	98.81	75.71	19.88	95.59
217	26.02	9.25	35.27	29.72	7.45	37.17
218	123.87	15.52	139.39	124.37	2.13	126.5
219	194	14.8	208.8	177.8	3.9	181.7
220	48.66	26.7	75.36	44.91	6.5	51.41
221	83.2	29.55	112.75	103.85	19.15	123
222	14.76	0.6	15.36	14.01	0.08	14.09
223	161.32	29.8	191.12	149.02	5.25	154.27
224	3.44	3.24	6.68	3.34	0.9	4.24
225	84.15	37.65	121.8	72.2	12.15	84.35
226	16.71	12.96	29.67	18.06	2.3	20.36
227	39.28	24.38	63.66	38.58	11.65	50.23

228	4.12	4.57	8.69	6.02	1.2	7.22
229	2.42	2.42	4.84	3.77	0.6	4.37
235	129.54	98.74	228.28	133.24	42.45	175.69
236	136.41	93.66	230.07	116.76	29.6	146.36
237	14.96	19	33.96	18.86	2.6	21.46
238	20.76	7.6	28.36	20.31	1.68	21.99
239	178.36	150.9	329.26	180.36	49.15	229.51
240	58.28	45.7	103.98	57.23	13.53	70.76
241	2.44	8.1	10.54	3.69	0.8	4.49
242	123.28	71.7	194.98	120.78	31	151.78
243	21.12	10.2	31.32	20.32	4.93	25.25
244	108.56	73.2	181.76	93.26	35.1	128.36
247	1.06	3.96	5.02	3.46	0.5	3.96
248	0.36	0.36	0.72	0.36	0	0.36
249	12.54	13.49	26.03	16.89	1.35	18.24
250	10.22	5.52	15.74	6.07	0.63	6.7
251	0.74	1.24	1.98	1.14	0.5	1.64
252	12.74	15.74	28.48	12.94	2.05	14.99
253	2.94	5.04	7.98	4.14	2.4	6.54
254	3.54	3.84	7.38	3.54	1.5	5.04
255	3.12	2.52	5.64	5.52	0.08	5.6
257	2.72	5.82	8.54	6.27	0.48	6.75
258	12.4	15.3	27.7	15	1.8	16.8
259	1.6	4.9	6.5	2.95	0.63	3.58
261	1.4	2	3.4	1.4	0.8	2.2
262	0.96	0.96	1.92	0.96	0	0.96
263	0.36	0.36	0.72	0.36	0	0.36
264	3.44	1.24	4.68	2.09	0.5	2.59
265	92.74	37.4	130.14	89.59	8.03	97.62
266	48.29	17	65.29	47.49	4.38	51.87
267	2.26	8.1	10.36	3.51	0.9	4.41
268	1.82	5.6	7.42	4.32	1.2	5.52
269	13.49	5	18.49	16.59	1.75	18.34
270	46.93	19.7	66.63	45.28	9.08	54.36
271	60.6	48	108.6	67.85	11.88	79.73
272	13.86	19.2	33.06	16.06	2.8	18.86
273	54.94	29	83.94	51.64	10.85	62.49
274	106.34	73.3	179.64	106.69	14.33	121.02
275	32.52	18.8	51.32	30.52	4.9	35.42
276	51.45	27.8	79.25	49.6	6.05	55.65
277	31.6	23.1	54.7	32.1	7.45	39.55
278	18.07	11.4	29.47	22.02	1.45	23.47
279	16.6	11.6	28.2	19.1	1.3	20.4
280	22.32	26.6	48.92	23.57	2.7	26.27
281	12.12	15.8	27.92	17.12	1.35	18.47

282	50.42	42.8	93.22	48.52	7.08	55.6
283	47.9	38.9	86.8	50.45	9.65	60.1
284	87.76	60.6	148.36	90.76	17.53	108.29
285	44.24	20.8	65.04	53.94	2.83	56.77
286	14.66	19.4	34.06	17.26	2.15	19.41
287	35.4	16.2	51.6	32.7	5.6	38.3
288	196.46	63.6	260.06	196.66	68.85	265.51
289	226.39	110.1	336.49	214.26	59.1	273.36
290	12.72	12.56	25.28	1.82	2.6	4.42
292	38	14.05	52.05	39.65	4	43.65
293	64.9	24.6	89.5	70.5	4.56	75.06
294	69.86	30.3	100.16	72.31	4	76.31
295	28.78	35.2	63.98	34.18	4.45	38.63
296	1.98	8.5	10.48	5.18	0.4	5.58
297	60.74	48	108.74	61.29	7.55	68.84
299	26.72	30.8	57.52	27.02	5.3	32.32
300	19.64	21.2	40.84	19.84	3.85	23.69
302	2.5	3.1	5.6	2.5	0.65	3.15
303	72.98	23.5	96.48	69.13	4.25	73.38
304	39.07	11.5	50.57	36.82	1.85	38.67
305	16.45	11.2	27.65	17.6	1.95	19.55
307	30.8	33.1	63.9	27.9	7.9	35.8
308	33.31	24.3	57.61	32.86	10.3	43.16
309	36.26	23.6	59.86	13.76	8.05	21.81
310	42.92	28.56	71.48	42.82	5.45	48.27
311	118.34	47.32	165.66	115.14	5.95	121.09
312	115.24	35.25	150.49	109.89	7.4	117.29
313	77.62	31.25	108.87	70.92	17.83	88.75
315	12.96	3.6	16.56	14.41	0.6	15.01
316	13.61	0.8	14.41	13.51	0.8	14.31
317	71.64	17.1	88.74	65.49	3.15	68.64
318	56.15	24.3	80.45	56.9	9.8	66.7
319	13.4	14.7	28.1	15.9	2.75	18.65
320	14.62	11.86	26.48	16.07	2.4	18.47
321	87.22	45.71	132.93	94.42	16.75	111.17
322	24.51	6	30.51	25.96	3.6	29.56
323	23.58	4.64	28.22	21.18	5.5	26.68
324	73.6	37.8	111.4	76.05	5.68	81.73
325	61.91	39.2	101.11	57.06	3.75	60.81
327	12.88	16.6	29.48	16.63	2.15	18.78
328	16.02	19.3	35.32	20.62	1.78	22.4
329	14.36	14.18	28.54	15.81	2.75	18.56
330	7.66	7.5	15.16	7.46	0	7.46
331	35.92	19.5	55.42	33.82	3.33	37.15
333	16.26	15.38	31.64	14.16	2.38	16.54

334	1.56	0.6	2.16	2.16	0	2.16
337	83.68	22.7	106.38	78.88	5.65	84.53
338	16.32	8.9	25.22	19.62	1.4	21.02
339	11.98	19.2	31.18	16.98	0.8	17.78
340	14.8	19.6	34.4	21.95	0.75	22.7
341	1.66	1.5	3.16	2.06	0.6	2.66
342	2.14	8.4	10.54	7.24	0.88	8.12
345	2.12	3.9	6.02	5.52	0.6	6.12
346	53.54	38.2	91.74	53.34	14.7	68.04
347	3.08	4.7	7.78	4.73	0.8	5.53
348	112.8	78.3	191.1	97.3	22.75	120.05
349	29.6	28.1	57.7	31.95	2.4	34.35
350	2.94	3.2	6.14	3.99	0.6	4.59
351	14.52	14.5	29.02	16.42	0.4	16.82
352	75.72	30.5	106.22	66.67	3.25	69.92
354	13.32	14.4	27.72	13.97	0.5	14.47
355	37.58	29.3	66.88	40.88	5.5	46.38
356	3.07	2.43	5.5	4.82	0.6	5.42
357	91.4	87.9	179.3	91.9	10	101.9
358	85.44	88.02	173.46	85.84	22.13	107.97
360	38.12	21.46	59.58	41.67	1.4	43.07
361	55.84	14.74	70.58	56.54	13.08	69.62
363	76.36	39.26	115.62	69.61	16.75	86.36
364	17.47	12.92	30.39	15.82	1.4	17.22
365	2.72	5.82	8.54	3.92	1.8	5.72
366	3.04	9.44	12.48	6.74	1.8	8.54
367	12.6	15.8	28.4	15.1	0.9	16
368	32.6	17.6	50.2	39.8	7.83	47.63
369	13.36	18	31.36	17.71	2.1	19.81
371	13.2	16.6	29.8	14.55	3.15	17.7
372	13	17	30	15.6	1.55	17.15
373	9.78	1.7	11.48	7.68	0.73	8.41
374	71.43	39.3	110.73	67.73	11.35	79.08
375	42.31	16.9	59.21	43.01	8.03	51.04
376	69.03	28.7	97.73	69.18	16.45	85.63
377	57.26	28.3	85.56	55.61	5.65	61.26
378	23.46	24.48	47.94	23.46	4.8	28.26
380	13.28	16.3	29.58	15.03	0.85	15.88