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Modelling the Determinants of Rooftop Solar PV adoption among Urban Households in Ghana

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MODELLING THE DETERMINANTS OF ROOFTOP SOLAR PV ADOPTION AMONG URBAN HOUSEHOLDS IN GHANA

A thesis submitted to the Pan African University Institute of Water and Energy Sciences (Including Climate Change) in partial fulfilment of the requirements for the degree of Master of Science in Energy (Policy option).

By

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PAUWES/2019/MEP11

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November 4, 2021

AUTHOR DECLARATION

I, Nathan Tetteh, hereby declare that this thesis titled "Modelling the Determinants of Rooftop Solar PV adoption among Urban Households in Ghana" represents my original work and has not been submitted to another institution for the award of a degree, diploma, or certificate. I also declare that all words and ideas from other works presented in this thesis have been duly cited and referenced under the academic rules and regulations.

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BIOGRAPHICAL SKETCH

Nathan Tetteh holds an MPhil in Urban Planning from the Kwame Nkrumah University of Science and Technology, Ghana and a Bachelor of Science degree in Planning from the University for Development Studies, Ghana (First Class Honours). He has a strong passion for sustainability research, with a particular emphasis on energy and environmental research. He works well with both quantitative and quantitative tools, including handling geospatial data. His greatest strength, however, is in quantitative analysis and drawing statistical inferences. He has a couple of publications in Q1 and Q2 journals, with others currently in review. Nathan developed a strong passion for Renewable Energy research during his time at the Pan African University, where he served as the research coordinator for the Climate Change and Gender Club of the university during his period of enrolment.

He is due to graduate with an MSc in Energy Science (Policy option) from the Pan African University, specialising in renewable energy. Nathan has adequate experience in the use of relevant software such as R and STATA to analyse data. He handles relevant energy modelling and simulation software aptly and is open to advancing his skills in other software, including programming.

Nathan currently serves as an intern at MicroEnergy International GmbH, where his primary duties include the writing of high-quality project funding proposals and assisting in consultancy services. He is a visiting researcher at the Technical University of Berlin, Germany, under Professor Christian von Hirschhausen, head of the Workgroup for Infrastructure Policy who together are working on developing models for the adoption of solar PV systems in Ghana using empirical data from surveys. He also offers teaching assistant services at the Technical University of Berlin as part of his secondary research internship duties. He previously served as a Research and Graduate Assistant at the Kwame Nkrumah University of Science and Technology and had the opportunity to also carry out a series of evaluative exercises for reputable organizations such as the GIZ and the Ministry of Local Government and Rural Development, Ghana. He blends well with teams of different cultural backgrounds is always open to learning.

ABSTRACT

The increasing calls for sustainable production and consumption of energy have led to a surge in the drive of governments across the world to invest in promoting the uptake of such technologies. Rooftop Solar PV systems have therefore gained prominence in the energy transformation discourse of many countries. Evidence-based models are therefore significant for the design of policy interventions to promote sustainable adoption. This study, therefore, examines through a cross-sectional survey, the determinants of rooftop Solar PV technology adoption in Ghana, from the perspectives of households to provide evidence useful for explaining their behaviour, and consequently inform policy.

A total of 596 urban households were surveyed using a set of pre-tested structured questionnaire in three principal cities: Accra, Kumasi, and Tamale. Binary and Multinomial logistic regression analyses were used in determining the attributes of the households that are statistically significant in explaining their adoption behaviour, as well as investigating the heterogeneity of the adoption behaviour across the diverse socio-economic attributes of the respondents. Both models were taken to be statistically significant at $p<0.05$.

The results showed that five attributes of the households were significant across a total of six levels in predicting the likelihood of adoption among the respondents: awareness of the existence of a rooftop programme (coefficient=4.66); household size (coefficient=0.23); landlord tenancy status (coefficient=1.35); rent-free occupancy tenancy status (coefficient=0.83); tertiary level of education (coefficient=1.22); and electricity expenditure (coefficient=-0.0007). The nature of interactions was thus used to specify a linear predictor model for the adoption behaviour of the households. A statistically significant variation in adoption behaviour was observed across two main variables: awareness and tenancy statuses of respondents.

The study recommends among others that further comprehensive surveys be conducted by the country's Energy Commission to establish causality evidence in the adoption behaviour of households to contribute towards refining existing policy models and increase their likelihood of success in facilitating the sustainable uptake of the technology. Further, policy interventions should target landlords and property developers, while current efforts should be geared towards robust models for financing and awareness creation to stimulate the uptake among households.

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LIST OF ACRONYMS AND ABBREVIATIONS

BLR	Binary Logistic Regression
EC	Energy Commission
ECREE	ECOWAS Centre for Renewable Energy and Energy Efficiency
EE	Energy Efficiency
GCPS	Grid Connected Solar Photovoltaic System
GSS	Ghana Statistical Services
MLR	Multinomial Logistic Regression
NRSP	National Rooftop Solar Programme
PAUWES	Pan African University Institute of Water and Energy Sciences
PV	Photovoltaic
RET	Renewable Energy Technology
SGD	Sustainable Development Goals
TAM	Technology Acceptance Model

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CHAPTER ONE

OVERVIEW OF THE STUDY

1.1 Introduction

In the advent of globalization and increasing concerns for climate change, the most feasible future scenarios of energy have been severally argued. The over-reliance on fossils and their accompanied contribution to increased greenhouse gas emissions has shifted the debate towards energy transformation and energy efficiency. While energy efficiency policy instruments are on the rise in countries that already have higher access to electricity, energy transformation has been argued to have the potential of achieving a dual objective of increasing access to energy and at the same time reducing climate change.

It is important therefore to understand sufficiently, the actual determinants of renewable energy technology adoption, particularly from the perspective of the end-users of the technology. Reinforcing the determinants in a positive dimension through evidence-based policy is essential in initiatives that intend to facilitate the transformation. The holistic adoption of developmental trajectories of other countries without a thorough understanding of the actual determinants within the local context is a significant contributing factor to the slow adoption rates of alternative energy sources. This study, therefore, seeks to examine the contextual determinants of renewable energy technology adoption from a micro-perspective, and apply a dynamic modelling perspective to suggest a framework of sustainable transition in Ghana.

1.2 Background to the Study

Rapid rates of population growth and globalization, as well as increasing urbanities, have translated into increased demand for energy globally. Initial statistics by the International Energy Outlook (2019) suggested that global energy consumption would increase steadily by about 50% within the frame of 2018 and 2050. However, in their Global Energy Report 2020, the IEA indicated that there was a 3.8% reduction in the overall energy demand globally in the first quarter of 2020- a phenomenon that has been attributed to increased confinements to control the prevalence of the COVID-19 pandemic in most countries (IEA, 2020). Notably, the large investment in oil and natural gas infrastructure has been described as the key factor that contributed to the vast economies of most countries, making them be seen as more developed than others. Countries were thus in the 18th and 19th centuries focused on investment in fossils to develop their economies (Mutezo & Mulopo, 2021).

The narrative has however changed since the advent of sustainable energy thinking in the late 20th century (Zou, Zhao, Zhang, & Xiong, 2016). Simulated scenarios by the International Energy Agency (IEA) and other renowned global agencies such as the International Renewable Energy Agency (IRENA) suggest that current consumer behaviour and trends threaten the environment and compromise intergenerational equity and social justice in access to resources significantly (IEA & IRENA, 2017). Owing to this, several economies have demonstrated their transformational drive-in actions such as energy technology investment, policy design and implementation, the imposition of regulations and infrastructure development. Africa as a continent has implemented initiatives such as the Programme for Infrastructure Development in Africa (PIDA), the Africa Renewable Energy Initiative (AREI), the AfDB New Deal on Energy, the Africa Clean Energy Corridor, and the Programme Harmonisation of Regulatory Frameworks in its Energy Sector, and in its member states in a bid to both expand economies and at the same time, meet the energy demands of its citizens within uniquely varied attributes of local contexts.

The Ghanaian energy situation can be described as complex. The country currently relies largely on thermal energy and hydropower to meet its energy needs (Asumadu-Sarkodie & Owusu, 2016). While the former relies on the gas-powered plant for the generation of energy, the latter generates its power from three main dams: the Akosombo dam, Kpong dam and the Bui dam (Eshun & Amoako-Tuffour, 2016). The country's recent growth in the industrial sector, increasing population, increase in urbanisation rate and growth in the middle-class share of its population have been identified as key drivers of increased energy demand (Energy Commission of Ghana, 2019; Mensah et al., 2016). Consequently, the Ghanaian government has aimed to develop an infrastructure to increase investment in renewable energy and enhance energy efficiency. The Strategic National Energy Plan of the country, as well as collaborative arrangements through the adoption and implementation of the ECOWAS Renewable Energy Policy (EREP), are all indicators of the government's commitment to achieving these targets.

The foregoing affirms the need for a thorough understanding of the key drivers of the adoption of renewable energy technologies. Elsewhere, literature affirmed that the key drivers within any energy system do not function in isolation but have a series of interconnected relationships with each other (Karatayev et al., 2016). The integrated analysis of these factors within the framework of a system's dynamics modelling approach has severally been demonstrated in the works of Qudrat-Ulllah (Qudrat-Ullah, 2013, 2015). Other authors modelled these determinants using econometric approaches that estimate the interactions between the various variables and their varying degrees of influence on adoption (Best, Burke, & Nishitateno, 2019; Bondio, Shahnazari, & McHugh, 2018; Muhammad Irfan, Zhao, Rehman, Ozturk, & Li, 2021). Owing to this background, this study intends to adopt a micro-perspective approach to model the determinants of renewable energy technology adoption among households in Ghana, primarily through econometric approaches, to make significant policy input, both for the country and others within the sub-Saharan African context who share similar attributes.

1.3 Research Problem

Scholarly works on renewable energy adoption in Ghana shows that the country has abundant resources which when developed sustainably can result in a transformation of the country's energy sector to one that is dominated by renewable (Agyekum, 2020; Ankrah & Lin, 2020; Gyamfi et al., 2015). However, the adoption of such energy sources is relatively low, with the country currently having less than 10% of its total energy supply being accounted for by other renewable energy sources such as solar PV (Ministry of Energy, 2019). Studies that sought to illuminate the challenges in access to these technologies cited limited technological advancement, insufficient knowledge on the diversity of alternatives available and limited capital investment in the renewable energy sector as main barriers to the adoption (Adjei, 2020; Lin & Ankrah, 2019). Other authors who approached the issue from a more regional perspective have demonstrated that while government commitment is undeniably crucial for the drive to energy transformation, the aptness of policies in driving these interventions is debatable (Kruger & Eberhard, 2018; Pueyo, 2018; Ram, 2006).

In a response by the government of Ghana to address such inadequacies in the adoption of renewable energy, a policy intervention known as the National Rooftop Solar PV programme was conceived and rolled out in 2016 to ensure that households and other low-voltage consumers can install grid-tied solar PV systems to complement their energy supply. The programme assumes the form of a Capital Subsidy intervention, under which beneficiaries are given certain forms of capital subsidies to cover part of the cost of the solar panel component of the PV system. The government's intention as reflected in the project objectives was to install 200,000 solar PV systems on suitable rooftops and tie them to the grid to reduce peak load up to 200MW in the medium term. The project's implementation has been under the auspices of the Energy Commission under a centralised system, where households and other potential beneficiaries were required to meet a defined set of criteria to be able to benefit from the programme.

While the project has been in implementation for about 5 years at the time of this study, evidence on the progress of the project towards attaining its medium-term objectives suggests that adoption rates among urban households for rooftop solar PV are still low. Again, evidence from the literature suggests that subsidy interventions alone are inadequate to drive the adoption of renewable energy technologies. This is because the socio-economic attributes of the targeted users themselves have an important role to play in defining the willingness of people to adopt a given technological innovation. The foregoing therefore suggests that understanding the determinants of the adoption of such rooftop solar PV technology among urban households in Ghana will significantly contribute towards re-defining the most feasible policy options and models that can work best to accelerate the attainment of the project objectives. It is upon this rationale that this study is implemented in three major cities in Ghana to examine the determinants of rooftop solar PV adoption among urban households and suggest evidence-based models that can help to enhance the sustainable adoption of such technologies among these households and improve the implementation of the National Rooftop Solar PV programme. The findings from this study are useful for policy planning within other developing countries that share similar socio-economic attributes with Ghana.

1.4 Research Questions and Hypothesis

1.4.1 Main Research Question

The study seeks to find answer the main question: How can the behaviour of households be guided on best practices to enhance sustainable adoption of rooftop Solar PV?

1.4.2 Sub Research Questions

- What are the factors that drive the adoption of rooftop solar PV among urban households in Ghana?
- What is the nature of interactions between the significant determinants in the adoption of rooftop solar PV in Ghana?
- How do the determinants of adoption of Solar PV vary across the diverse socio-economic characteristics of urban households?
- What are the best practices and policy alternatives that will enhance the sustainable adoption of rooftop solar PV technology in Ghana?

1.5 Research Objectives

Working on the tentative hypothesis that the rate of rooftop solar PV adoption in Ghana can be increased if the interactions between the determinants can be modelled and applied to managing the policy drive, this study intends to comprehensively examine the key determinants of rooftop solar PV technology adoption in Ghana and develop suitable models for their behaviour. Specifically, its aims are:

- To examine the factors that drive the adoption of rooftop solar PV among urban households in Ghana
- To model the nature of interactions between the significant determinants in the adoption of rooftop solar PV in Ghana
- The investigate the variation of the determinants of adoption of Solar PV across the diverse socio-economic characteristics of urban households
- To suggest best practices and policy alternatives that will enhance the sustainable adoption of rooftop solar PV technology in Ghana

1.6 Scope of the study

Geographically, this research is implemented in three cities in Ghana: Accra, Kumasi, and Tamale. Accra, which is the national capital and located in southern Ghana, has a large proportion of high-income households, who all things being equal should have a very high potential affordability for

RET such as rooftop Solar PV systems. Kumasi, which falls in the middle sector of the geographical stretch and couples as Ghana's second-largest city has similar socio-economic attributes as Accra. Tamale, which is in the northern sector of Ghana, has the most significant potential for solar energy due to the generally higher temperatures and is a principal city in the northern sector that is farthest away from the national capital where the Energy Commission is currently spearheading the implementation of the National Rooftop Solar PV Programme is located, hence its inclusion. The intention is to understand and compare the dynamics across these three locations to give a geographical balance of the situation across the country.

The content of the study covers the factors that influence renewable energy technology adoption, the relative importance of those factors, a linear model that describes the behaviour of these households, as well as evidence-based policy recommendations to enhance the adoption of renewable energy technologies in Ghana.

Timewise, it takes a snapshot survey of the situation as it is at the time of the implementation of this study. Only the behaviour of households that are willing to participate in the study are analysed included in this study will extensively be examined.

1.7 Overview of study Methodology

This study assumes the form of a mixed-method approach, largely adopting the attributes of a cross-sectional survey (Grimshaw, 2000; Tanner, 2018), but leaning more towards a quantitative design. The survey is undertaken using a set of pre-tested questionnaires among heads of households in the selected study cities. Quantitative methods are used to generate descriptive summaries on the key variables within the data, and to examine the factors that influence the adoption of rooftop solar PV systems among households. These factors are then discussed with preliminary evidence in the literature on the determinants of renewable energy technology adoption among households. Quantitative methods are then further used to determine the relative importance of these factors using regression tools. The result of this stage is then used to linearly model the behaviour of the determinants of rooftop solar PV technology adoption among urban households in Ghana.

Thematic analysis is applied in the analysis and presentation of qualitative results on the challenges and policy alternatives suggested by the respondents in the study. All quantitative analysis is done using STATA 14.2. Inductive logic with experts in the field of energy is used in deriving the policy alternatives with inferences from the initial quantitative results. Adequate ethical considerations are made to ensure that sensitive data obtained from the participants are reported with a high degree of anonymity and confidentiality.

1.8 Significance of the Study

While human development has been at the centre of the global developmental discourse, evidence has shown severally that economic growth is very important to ensure that enough income is generated to be able to meet the basic needs of the people. With most urban Ghanaian households being connected to the existing grid, and with limited evidence on off-grid connections, the study has a significant potential of increasing uptake of renewable energy and energy efficiency, thereby stimulating overall economic development in a sustainable and environmentally friendly way, raising Human Development Indices among residents of the country. This contributes to progress towards increasing access to affordable and clean energy, which is primed by the United Nations in Sustainable Development Goal 7 (see Golubchikov and Badyina, 2012; Inter-Agency and Expert Group on SDG Indicators (IAEG-SDGs), 2016; Klopp and Petretta, 2017), and contributes towards CO_2 emission reduction targets in Ghana. It will further contribute towards the realisation of the dream of sustainable cities and communities in SDG 11.

Again, a study on the determinants of renewable energy technology adoption in a developing context such as Ghana using econometric principles, particularly from a micro-perspective, contributes significantly towards filling existing academic lacuna within the study context. The evidence gathered, therefore is not only useful in supplementing scholarship, but further provides serves as a useful entry point for future research on the phenomenon using advanced economic tools, and towards model building not only for adoption practice in Ghana but also in the entire sub-region.

Further, the study generates evidence that is useful for policy, as well as interventions by the private sector and other international bodies who seek to invest in diverse energy technologies in the country. The World Bank, the Islamic Development Bank, the Sustainable Energy for All, as well as the ECREEE organisation and others, are all potential beneficiaries of this study.

1.9 Organisation of the Study

Following the various formats available for presenting a master's thesis, this study adopts the traditional monograph thesis structure in presenting its findings. Given this, the study report is logically organized into five progressive chapters. The first chapter contains a general overview of the study. It presents a background to the study, discusses the research problem, study questions and the study objectives. The scope of the study and an overview of the research methodology, as well as a description of the significance of the study, is also contained in the first chapter. The second chapter contains a review of relevant literature on the adoption of rooftop solar PV technology, with a particular orientation towards the developing context. It also discusses the theoretical underpinnings of the study as well as a presentation of the study's conceptual framework. This was then advanced by the third chapter which dwells on the literature review to present a description of the study setting and study methodology. The fourth chapter then presents the study results and the evidence-based models that were developed based on the behaviour of the households. The final chapter concludes the study with a general discussion of the results, which were then summarized into major findings for policy recommendations and a general study conclusion.

CHAPTER TWO

OVERVIEW OF LITERATURE ON ROOFTOP SOLAR PV ADOPTION

2.1 Introduction

This section presents a review of relevant literature on the development of renewable energy technology and its uptake, with an orientation towards rooftop solar PV technology adoption. While attempts have been made to draw from comprehensive literature on the subject, the selected literature was predominantly based on their sensitivity to the developing context. The chapter commences with a review of fundamental theories that underlie the study, after which it discusses empirical literature on the promotion of the uptake of rooftop solar PV technology.

A conceptual framework was then modelled for the study based on the interactions between the various study variables, theories, and methods. This was then followed by a summary of the review of literature which then informed the advancing chapter of this study.

2.2 Contextualising Grid-Connected Photovoltaic Systems (GCPS)

The scientific community has been largely conclusive on the significant threat of burning fossils for energy to the global climate and environmental sustainability. Consequently, transforming energy economies into renewable energy-dependent economies has been professed as having the greatest probability of contributing towards reducing the likely severity of the predicted harm. While a plethora of renewable energy alternatives are available, Distributed Generation systems, dominant of which is the solar Photovoltaic technology, has gained increasing prominence in recent times. For geographical areas that are disconnected from the grid, these systems are often connected in isolated forms, as opposed to being largely tied to the main electric utility grid in areas that are already connected to the main grid (Grid Connected Photovoltaic Systems).

For a more generic understanding, the term "grid" within the energy systems discourse can be defined as connoting a networked system that allows for power production, transmission, and distribution to different people (customers) who have needed to be served (Obi & Bass, 2016). A similar conceptualisation of the term grid as an arrangement of interacting networked units working in a coordinated manner, with a focal dispatch source of energy can be inferred from the works of Peffley and Pearce when they examined the potential for grid defection of small and medium-sized enterprises using solar photovoltaic, battery and generator hybrid systems (Peffley & Pearce, 2020).

While the literature has been consistent on the fundamental components of the GCPS having a higher likelihood of being the same, there is evidence to suggest that the physical properties and design specifications may vary across different set-ups (Table 1). Regardless, each structural configuration the use of semiconductors such as silicon to convert light from the sun to an electrical energy level that is consistent with the voltage running through the main grid, with an extra ability to self-adjust to arrest damages that might occur in the system (Sichilalu et al., 2016). This validates the need for a feasibility assessment of the generation, regulation, or storage of electrical energy. Design specifications for grid-tied connections are therefore significantly influenced by both attributes of the facility being connected to the grid, as well as attributes of the existing main (Ghenai & Bettayeb, 2019; Nwaigwe et al., 2019a; Peffley & Pearce, 2020). An apt technical understanding and selection of components therefore cannot be compromised since deviations will have severe consequences on power stability within the entire grid.

Scholarship on the design of GCPS to enhance effective operationalisation suggests further that tying the system to the main grid must be done where the system is closest to the grid (Mahela & Shaik, 2017; Nwaigwe et al., 2019a). Reducing connecting distances in this regard has therefore been described as one that does not only contribute towards an overall reduction in connection costs but also further provides an opportunity for maximising the number of connections and electric flow that can be fitted unto the grid (Peffley & Pearce, 2020). Again, for most developing countries where income levels are low, keeping connection distances short implies that lower costs will be incurred on the procurement of connecting cables, thereby contributing towards reducing the financial constraint faced by many households in the installation of such GCPS.

Table 1: Essential components of a Grid-Connected Photovoltaic System

GCPS Component	Role in the GCPS
An Electric Grid	This main interconnection between utility producers and consumers provides the platform upon which a GCPS can be fixed in the first place. The grid provides electricity to supplement what is being produced by the PV and absorbs the excess electricity produced by the PV under appropriate net metering arrangements
Solar Panels	Main semi-conductor device assembled to convert
Inverter	Conversion of DC to AC at a voltage consistent with that running through the main electric grid. Attention should be paid to power and efficiency
Bidirectional Meter	Required for the estimation of electricity being exchanged between the adjoining unit and the grid, as well as estimating the amount of electricity being consumed in the facility Often, twin KiloWatt hour meters are recommended. The estimation of the net consumption will be the basis for determining and implementing appropriate net-metering tariffs.
AC Breaker Panel and Fuses	Useful for the separation of the various electricity consumption lines in the facility into different channels on a circuit board.

Safety Switches and Cabling	Useful for the separation of voltage yield from the inverter for upkeep or testing. The safety switches further disconnect the PV from the rest of the system when there is a disturbance Isolated switches with the highest possible DC voltages and currents of the array are often preferred (Peffley & Pearce, 2020)

Source: Author’s construct, 2021 (adapted from various sources)

Despite preferences to reduce the overall requirements in any energy system from a cost perspective, the unreliable nature of supply that characterises most of these resources necessitates the provision of storage systems (Satpathy & Pamuru, 2021). Regardless, the debates surrounding the necessity of such storage systems in GCPS are inconclusive. While some authors posit that batteries are not a requirement in GCPS since unused energy is simply ejected unto the grid and adds up to the total electricity flow within the grid, others contend that the addition of batteries enables storage of power produced during the day for usage at night, thereby minimising the overall requirement of supplementary power from the grid during peak usage hours. Again, opponents of having batteries in a GCPS argue that such systems are environmentally friendly and requirements for maintenance and cost.

What is worth noting is that PV systems connected to the grid without batteries are the least complex set-ups and are also the least expensive solar PV arrangement accessible, and by not charging and keeping up batteries they are likewise progressively productive (Qiu et al., 2018). The common evidence from the literature is that grid associated solar power systems are not an entirely autonomous power source, hence not an independent system. In any event, where the main electrical grid gets disrupted, the entire lightning system may go out of function, even when the sun is emitting enough radiations (Prabaharan et al., 2019). A typical strategy suggested for overcoming this challenge is to have some type of temporal storage device fused within the structure (Sichilalu et al., 2016).

According to several research experiences in the installation of solar PV in a grid-tied system, the rationale of having flexibility in the set-up is that while the cost of installation is relatively low within the entire framework of the structure, its contribution to ameliorating hitches in the flow of electrical charges, particularly in surges due to excess charges, is very significant (Tsianikas et al., 2019). Again, its extra storage function allows for a moderately working condition with low costs of electricity bills. The major fallback is that their presence requires that an adequate number of solar panels should be introduced to produce the necessary measure of electrical flow that will allow for the extra generation for storage (Tsianikas et al., 2019).

From the foregoing, the redundancy of expensive backup batteries within the connection is evident. Since grid-tied systems feed their solar energy legitimately once again into the grid, such costly backup batteries can therefore be discarded from most grid-tied solar PV designs (Obi & Bass, 2016). Another upside of the connection to the consumer is that the permanent attachment of the solar to the grid also implies that solar energy utilization and solar board estimating computations are not required. Several works have associated this to the system considerations, which could be as small as 1.0kWh on a given rooftop but have a high multiplier effect on decreasing electricity bills for the facility utilising the system (Gerber et al., 2020), and peak loads for the operator of the grid (utility company) (Orioli & di Gangi, 2013).

Grid-Connected PV System, whether installed with a capacitor battery component or not, can create a lot of electrical flow on days with very bright sunlight, where the flow of the radiation to the facility is less impeded (Nwaigwe et al., 2019b; Quansah et al., 2017). In such cases, lower energy levels are required within the system for electrical energy production. For stability in such connections, however, utility operators are often conscious of the maximum load to allow to be connected unto the grid. Since the power being produced from the various PV cells might have different voltages, it is imperative to ensure that appropriate conversions are done to ensure that the level of power being ejected into the grid is consistent with that in the main grid for purposes of stability (Guidara et al., 2020). Again, such companies must ensure that the unstable ejection of power unto the grid is managed to prevent fluctuations that can affect the entire stability of the grid (Orioli & di Gangi, 2013). The overabundance of electricity does not destroy the system but is transmitted to the main grid to be utilized by adjoining consumers who unconsciously have access to such clean, renewable energy sources, with the unaware consumers helping subsidize consumption cost for the installer through a "net metering" plan.

Consequently, Grid-Connected Photovoltaic Systems (GCPS) in the context of this study connoted solar Photovoltaic systems that produce electricity in parallel to the main utility grid. Such systems utilise their solar equipment to convert sunlight into electrical energy for the facility to which they are fixed, whiles trading the excess power generated unto the main grid (Nwaigwe et al., 2019a). Thus, such GCPS does not need storage components since any excess power that is produced and not consumed by the primary facility is simply fed into the main grid to add to the total power available in the entire national grid. The solar PV system is attached to the facility (either on top of the roof or anywhere else besides the facility that allows for direct exposure of the surface to sunlight), then together with an inverter, the Direct Current (DC) generated is transformed for consumption where it is produced. A secondary function of the inverter beyond its conversion process of DC to Alternating Current (AC), includes observing the flow of electrical charges in the mains to ensure that the electricity that is produced is consistent with the power running through the main phase of the utility grid.

Regardless of the type of setup, the common characteristics of GCPS are summarised in Table 2.

Table 2: Common parameters of GCPS and their descriptions

Essential Parameter	**Details on characteristics**
Operating range	1 kW up to 300 MW
Fuel used	Sun
Application types	Residential, commercial, and utility-scale
Efficiency of PV cells	12–16% for crystalline silicon, 11–14% for thin film, and 6–7% organic cells
Environmental impact	No direct CO_2, CO, NOx emissions
Benefits	Low operating and maintenance costs, modular type, no direct emissions, and sustainable technology.

Drawbacks	Higher installation costs, fluctuating output power due to the variation in weather patterns, require mechanical & electronic tracking devices and backup storage for maximum efficiency.
Installation costs	600 − 1300 (USD/kW)
Operation & maintenance annual costs	0.004 and 0.07 USD/kWh (ac) for utility scale generation and grid-connected residential systems respectively

Source: Adopted from (Lupangu & Bansal, 2017)

2.3 Theoretical Underpinnings of the Study

2.3.1 Solar PV technology Adoption and Diffusion of Innovations Theory by Rogers

Technology adoption has been over the years viewed as a form of the innovation diffusion process. The 1950s witnessed a significant evolution in the study of the adoption of innovative technologies, particularly among rural settings. This rigorous expansion in scholarship on the concept during the period led to the emergence of several paradigms on how new technologies across agriculture, health, education, and business are best diffused into new environments. Among the many such diffusion, theories are that of Everet Rogers in 1962 on the Diffusion of Innovations. Rogers's theory attempted to describe how he envisages the spread or diffusion of innovations over time among a given group of people.

It is imperative to note that the theory does not conceptualise innovation to mean only technological advancement, but also the evolution of new ideas and practices. Other latter researchers argue that a technological invention can only be considered an innovation when its existence is made known to the consumers through marketing and awareness activities. They advance their conceptualisation on the premise that any discovery which is not extended beyond the laboratory should be limited to being viewed only as an invention. Consequently, innovation in its conceptualisation of a social phenomenon must demonstrate the ability to respond to a social need. Consequently, this study conceptualises innovation as an advancement in technology (specifically Solar PV systems). Regardless of what is considered innovation, previous research on the process of innovation diffusion is largely centred around two main variables: the extent of technology push (Hysa & Calabrese, 2015) and the level of demand-pull (Gold, 1987). Hysa & Calabrese expanded the initial arguments of Drucker (1985), Popper (1959) and Schumpeter (1936, 1943) to argue that entrepreneurs upon

The foregoing suggests that there is a complex relationship between technology advancement and the commercialisation of the technology. Such a relationship lays the foundation for the claim that the emergence of innovation such as solar PV technology alone does not suggest a translation into a straightforward diffusion process. Following this, Rogers affirmed that innovations diffuse through a dynamic process of communication among given members of a social system. Consequently, he emphasised the role of change agents in influencing people's decisions regarding the adoption of new technologies and ideologies. Rogers stressed, however, that as consistent with every human society, the communication process is a two-way channel bounded by feedback, suggesting that the reactions of targeted users of technology can provide significant information to improve the process.

The innovation process was described by Rogers as one that comprises of six interrelated stages: problem definition, basic and applied research, development, commercialisation, adoption and diffusion, and consequences. However, at the adoption stage of the innovation, Roger suggested five factors that he perceived to have a strong influence on the actual adoption likelihood among the end-users: a. the perceived attributes of the innovation, b. the type of innovation-decision being made, c. the communication channels between the innovator and the end-users, d. the nature of the social system within which the innovation is being implemented, e. the extent of change agents' promotion efforts. The complexities of the variables that determine the likelihood of a household to adopt the GCPS in this study are therefore analysed with sensitivity to these factors.

It should be noted that an integral part of the innovation diffusion process is time. The theory maintains that innovation does not diffuse spontaneously, but rather, adopters take some amount of time length to get convinced as to whether they take up the innovation. This suggests that the mental process of the individual is as important as the interplay of the other social variables that define the choice. The overall aim of the individual is to reduce the degree of uncertainty in expectations regarding the use of the innovation before opting for it. Consequently, if marketing systems and communication channels are streamlined towards increasing the confidence of the targeted users of the technology, diffusion time will be most likely shorter. Following this, tentative assumptions can be made that if renewable energy policies are designed to increase the confidence of people in the adoption of such technologies, including GCPS, adoption rates are likely to be higher. This resonance of the tenets of the diffusion of innovation theory with the overall objective of the study justifies its selection as one of the underlying ideological bases for the implementation of the study.

2.3.2 The Technology Acceptance Model

While several behavioural theories seek to shed light on the complexities of the adoption of technologies, the Technology Acceptance Model (TAM) is adopted as a set of complementary ideological propositions for viewing and interpreting the behaviour of households in this study. The TAM was proposed by (Fred D. Davis, 1989) and advanced in (F.D. Davis, Bagozzi, & Warshaw, 1989). The model seeks to explain the main variables that influence the behaviour of people towards new technology. In his original work (sometimes referred to as TAM1[1]), Davis identified perceived usefulness as the first variable that alters behaviour. He explains that this variable is defined by the extent to which people believe the technology will help them do their work better. He further described perceived ease of use as another variable that describes the extent to which the user of a given technology sees the use as one free of major efforts.

The TAM derives its roots from the Theory of Reasoned Action (Fishbein, 1980). While the theory is limited in the extent to which it specifies the influence of external variables such as government policies, availability of financing schemes, level of awareness about the diversity of options available, and the culture of the users on the adoption of the technology, it provides an insight for explaining the behaviour of households concerning their responsiveness to renewable energy technology adoption. It will therefore be applied with an acknowledgement of its limitations.

Evidence from literature maintains that the original model gauged the relative impact of four internal variables upon the actual usage of the technology. The internal variables in the original

[1] See Turner, M., Kitchenham, B., Brereton, P., Charters, S., & Budgen, D. (2010). Does the technology acceptance model predict actual use? A systematic literature review. Information and software technology, 52(5), 463-47

TAM were the perceived usefulness of the model (PU), the perceived ease of model use (PEU), the attitude towards use (A) and the behavioural intention to use (BI) (Bagozzi, 2007; Lee et al., 2003). Notably, whiles these variables can be varied as independent or dependent depending on the parameter being estimated, subsequent literature that expatiated the model maintained that behavioural intention can be used usually as a dependent variable to test the validity of the other variables but can be varied as both dependent and independent.

In the scope of this study, it can be implied that an urban household's adoption and usage of solar PV technology is heavily influenced by its behavioural intention, which significantly will be determined by the household or organisational culture. In cases where the culture is flexible, allowing for innovation adoption, the tenets of the theory can be applied to predict a higher probability of adoption and usage of the grid-tied Solar PV system. Further, the extent to which the household perceive grid-tied solar PV as useful is essential in estimating their chances of adoption. Households will only adopt the technology if they see it as having the potential of reducing their energy costs and increasing reliability in consumption and productive uses.

The theory has been revised by some latter proponents. For example, Venkatesh and Davis along these lines proposed a reconsidered version of the Technology Acceptance Model, which they alluded to as TAM2 (Lee et al., 2003). In their reviewed version, they exempted attitude towards use and rather added extra variables, for example, subjective norm and experience. What is noted is that the revised theory maintained the core idea of the original model. Evidence on the variables proposed inside the TAM can be regularly estimated utilizing a short but comprehensive instrument of data collection. The evidence gathered can then be used to predict the urban household adoption likelihood. If data is estimated on the required variables, actual adoption and use of the new technology, is typically estimated through statistical manipulation of the self-detailed variables.

It has severally been revealed that since its conception, the Technology Acceptance Model and its varied strands have been applied to estimating the behaviour of both households and firms for new technologies (McCord, 2006). Common instances of the application of the theory are seen in studies on the adoption and modification of content tools, intranet operations, and the World Wide Web. What has been the major strength behind its application is that the model has been approved for inner consistency, where its variables score exceptionally well against whatever measure is used. As an outcome, therefore, the aftereffects of the application of the Technology Acceptance Model are in most frequent ways acknowledged as being very precise indicators of use and selection.

Be that as it may, the trend in technology behaviour assessment indicates that the social rationale behind the use of a specific technology is more regularly studied than the actual use of the technology (Mortenson & Vidgen, 2016). Studies such as that of Keung et al. discovered that the Technology Acceptance Model anticipated that even though the technology may probably be received by the organization based on their internal cultural dynamics, it could later be abandoned after just about a year of its adoption. Latter applications of the Technology Acceptance Model to study the behaviour of the same firm, therefore, generated different results from the initially observed behaviour of the same firm using the same model (Taherdoost, 2018). This has raised concerns about whether the Technology Acceptance Model is comprehensive and reliable enough to be used as an exact indicator of actual use instead of social aim to use. Such limitations are acknowledged in this study.

The adoption of this model as a lens for viewing the likelihood of the adoption of the grid-tied solar PV in Ghana is motivated by the assumption that if an urban household examined in this study perceives that technology as useful, demonstrates readiness to adopt it, and goes ahead to demonstrate a learning attitude towards the technology, which will then increase the perceived ease of use among the workers within the industry, the rate of adoption will be high. The tentative hypothesis is that with households being interested primarily in a balance between electricity cost and reliability maximisation, (and assuming they operate under the assumptions of consumer rationality, the probability of increasing preference towards cheap but reliable energy for domestic uses will be higher), a comprehensive feasibility study on the phenomenon will go a long way towards generating evidence on independent parameters that describe the households and which significant underlying variables policy interventions should target.

2.3.3 Framework for the application of theory to the study

With the study being modelled upon the principles of Rogers' Theory of Diffusion of Innovations and the Technology Acceptance Model, this work employs a theoretical lens that conceives the probability of an urban household to adopt a Roof-Tied GCPS system as a dependent variable, defined by a myriad of components.

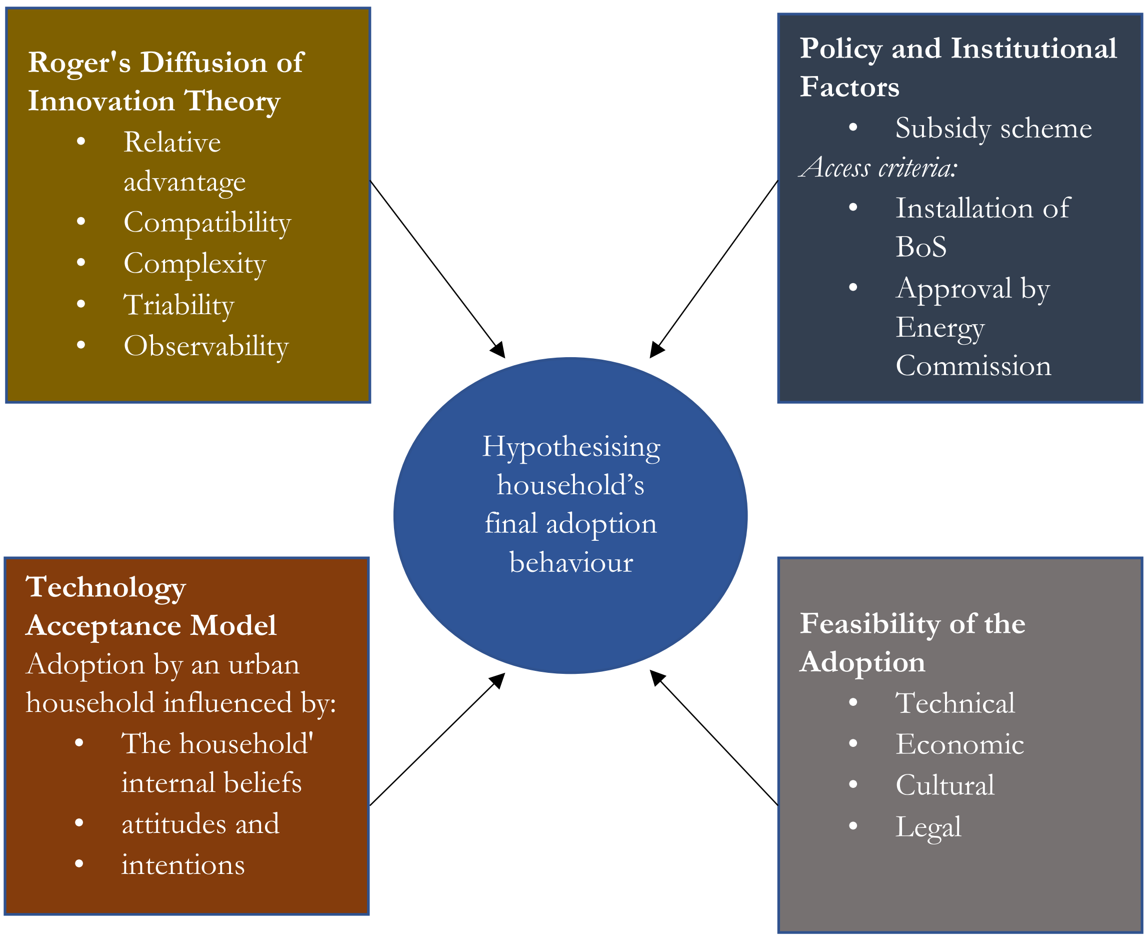

Figure 1: Theoretical basis for hypothesising adoption behaviour of households

Source: Author's Construct, 2021

The proposed model maintains that despite the behavioural intentions and household's responses, policy and institutional factors are essential in determining the likelihood of renewable energy transition among urban households. The policy environment for renewable energy transition must be favourable to the households, by allowing latent benefits for actors who utilise their finances to expand the energy infrastructure. Investors' motivation comes from a favourable policy climate and the existence of adequate infrastructure that will support their operations.

Notably, such adoptions must be greatly streamlined with the government's demonstration of commitment through net metering agreements between the urban households and utility companies, such that excess transmissions to the grid can be estimated and later be used to subside necessary access in cases where the semi-independent solar PV system of the industry due to one reason or the other fails to produce to meet demand capacity of the household. Reduced tariffs and other policy instruments are significant ways through which policy environment can complement a household's intention to either adopt or not adopt the renewable energy technology being advocated.

The fourth component in the framework reflects the need for comprehensive evidence on the feasibility of the transition. Comprehensive feasibility evidence is a great tool for reinforcing a household's transition attitude, and this is the prime focus of this study. As previously explained, feasibility studies usually do precede committal of resources, and with renewable energy technologies being perceived as a capital intensive at the beginning, especially for resource scales that will power industry, adequate empirical evidence must be generated for use of the household and government. This study, therefore, is contextualised within urban Ghana (Accra, Kumasi, and Tamale), to sample and generate evidence on the drivers of Grid-tied Solar PV adoption among households, with implications for enhancing adoption of the GCPS in Ghana.

2.4 Overview of Literature on the Evolution of Renewable Energy Technology Adoption

The trend of adoption of Grid Connected Solar Photovoltaic Systems has been increasing significantly over the years. The advancement in technology, as well as increasingly falling prices of the basic materials (silicon) for the manufacture of such systems, the increasing attention of governments manifested in the provision of incentives and increasing levels of environmental awareness, are seen as essential contributing factors to such trends. In some near recent studies, for example, evidence suggests that the manufacturing costs per watt for a PV module, which stood at about 100 USD in the 1970s, has reduced significantly to about 1.00 USD per watt since 2014, with such costs even lower among large-scale wholesale orders (Reichelstein & Yorston, 2013).

With such reducing costs comes a focus on promoting investments into technologies that leverage the use of solar cells to produce electricity at quantities adequate for both domestic and industrial consumption. One of such is the development of Rooftop Solar PV technologies. Considering its increasing significance, literature on the subject has severally sought to provide scientific evidence to inform policy and contribute towards enhancing adoption rates. Notably, there is a significant variation in the literature between the developed countries, and countries rising out of poverty. Most research works on the developing context focus on the potentials of such systems in enhancing access to energy among rural and isolated areas. While there is significant potential for the adoption of technologies such as rooftop solar PV in urban areas too, scholarly works on such contexts, particularly in Sub Saharan Africa and Ghana specifically is scanty, stimulating the need for more research in filling the gap.

2.4.1 Evolution of Relevant Adoption literature for Renewable energy

The global energy transformation discourse has been given significant attention in research and practice in the last decade. Global level inquisition on the determinants or renewable energy technology adoption was demonstrated largely in the works of (Akarsu & Korucu Gümüşoğlu, 2019) when they modelled the determinants of renewable energy technology adoption using a panel regression approach. While the study extensively draws on macroeconomic variables access to electricity, GDP per capita, energy exports and imports among others, it sheds no light on the micro-perspective, with no clear evidence on the behaviour of the final energy consumers and their attitudes towards renewable energy technology adoption. Again, the behaviour of other macro-level economic determinants of renewable energy technology adoption was demonstrated in the works of (Murshed & Alam, 2021). While their study focused on the context of Bangladesh, it draws on the strengths of econometric models to establish that while technological innovations were significant in altering consumer behaviour towards renewables, variables such as the positive oil process shocks were ineffective in influencing renewable energy demand behaviour.

Elsewhere (Akintande, Olubusoye, Adenikinju, & Olanrewaju, 2020) threw light on the African context when they modelled the determinants of renewable energy technology consumption in Africa. The authors utilised Bayesian Model Averaging (BMA) techniques to conclude that macroeconomic variables such as urban population, population growth rate, energy use, human capital and electric power consumption were the main determinants of renewable energy technology in the selected African countries. Similarly, (Akarsu & Korucu Gümüşoğlu, 2019) utilised data from 17 Sub Saharan African countries over 25 years to investigate the determining factors of renewable energy technology growth in Sub Saharan Africa. They also advanced their study by drawing on several macro-level variables such as prices of fossil fuels, emission levels and CO_2 per capita, the Gross Domestic Product and energy imports among others as essential determinants of renewable energy technology development within the developing context. Essentially, the macro-perspective adopted in these earlier studies obscures evidence on the actual technology adoption behaviour of the consumers to provide a direction in policy.

While (Rahut, Behera, & Ali, 2017) approached the issue by integrating both macro and micro perspectives within three countries in Sub-Saharan Africa (Tanzania, Ethiopia, and Malawi) using econometric models, the focus was on the adoption of renewable energy for lighting purposes among households. Essentially, the identified disparities in the geographical location of consumers as an essential determinant of renewable energy technology adoption among households. Their study further demonstrated evidence on gender, income levels and educational levels as essential parameters that bring a variation in the willingness of households to adopt Renewable Energy technology as a source of lighting.

In other studies, more related to the Ghanaian context, (Bukari et al., 2021a) examined the willingness of households to use renewable energy technology, as well as how much they are willing to pay for the technology. Contextualised within a Ghanaian urban setting, they concluded that the heavy reliance of households on hydropower supplied through the main grid was due to reliability, accessibility, and affordability. They demonstrated that while awareness of alternative renewable energy technologies is low, there is significant evidence of willingness to pay for alternative energy sources. (Kwakwa, 2019) also examined the determinants of renewable energy consumption in Ghana based on the demand theory. He modelled renewable energy consumption as a function of income, industrialisation, price, and financial development. Again, the macro-level variables considered limits the extent of influencing policy from the perspectives of those who need to adopt the technology. (Odonkor & Adams, 2020) also focused on nuclear energy development, generating evidence on the social acceptance of nuclear technology and its relevance on the successful development of the technology to augment the country's electricity resources. However, since the debates regarding the renewability of nuclear energy are inconclusive at the time of this study, efforts have been made to exclude it from the renewable energy sources considered in this study.

From the foregoing, it can be realised that while substantive evidence has been generated on determinants of renewable energy technology adoption in Sub-Saharan Africa, including Ghana, many of these works focused on the analysis of macro-level variables. Consequently, the extent to which the existing findings can be used to predict the behaviour of energy users to inform policy that will bolster energy transformation is limited. It is also worth noting that while small and medium scale enterprises have been described as potential adopters of renewable energy technology with multiplier effects, there is little or no evidence on the behaviour of these urban households in the Ghanaian context. This study, therefore, seeks to examine the determinants of renewable energy technology adoption within an urban Ghanaian context from a micro perspective, generating evidence on the behaviour of households for policy.

2.4.2 Determinants of Renewable Energy Adoption

An examination of the plethora of literature on renewable energy technology diffusion into a new region implies that it is a process and not an event. The earliest hypothesis on endogenous technological change outlines three major phases of the transition and adoption process: invention, innovation, and diffusion (Popp et al. 2011). The proposition maintains that in the invention stage, new information on the new technology to be adopted is created by intentional innovators. After adequate research on the invention, the innovation phase follows, which signifies the commercialization stage of an invention. Consequently, the new technology gradually diffuses into the wider society. It is this diffusion process that prompts the reception or selection of another technology by individuals, firms, or organisations in a given country.

It must be stated that the process outlined by Popp et al (2011) is not a traditional sequence of stages that must be followed. Several research works have demonstrated the numerous factors that account for the extent to which a given country adopts a technology. With renewable energy transition being a form of the technology adoption process, several research works have enumerated factors that ease or hinder the adoption rates of renewable energy such as Grid-Tied solar PV system (Bauwens, 2016; Jefferson, 2008; Sardianou & Genoudi, 2013; Vidadili et al., 2017). At a more disaggregate level, the role of media technology in contributing towards diffusion is noted. Comin & Hobijn (2010) affirms that papers, radios, and Televisions among others, are essential media that conveys information about relatively new technology, and the depth of such information flow affects the rate of technology adoption (Comin & Hobijn, 2010). Essentially, the media is the prime source of information on every new technology, and their contribution to enhancing knowledge on the structure, use, possible benefits, and downsides of the new technology cannot be understated.

Again, Grübler (2003) in his study, proposed four varied classes of minute-level factors that influence the rate of the diffusion of technology: he considers the apparent advantage surrounding the usage of the technology; the compatibility of the new technology to existing systems and structures; the intricacy or ease of use of the technology; and the vulnerability identified with the advantages from a technology (Comin & Hobijn, 2010). The argument is that when the variables move in the positive direction, adoption of such technology is likely to be higher. The reverse is true, which aligns perfectly with the arguments of Keller (2004), who also investigated that experimental proof on universal technology diffusion. Keller identified that if there is an increasingly perceived higher advantage emanating from the use of the new technology, rates of adoption will be higher (Comin & Hobijn, 2010).

Caselli and Coleman (2001) further identified the rate of human capital development as essential in the diffusion of technology. They discovered proof that technology selection is upgraded by more elevated levels of human capital in the given context. The implication is that technology selection is greatly informed by the level to which the people are enlightened about it. This agrees with calls for advanced education and training on the usage of renewable energies are a potential for enhancing their adoption, particularly within the context of most developing countries. In recent times, investment in renewable energy training in higher levels of education has increased this is motivated by convictions that such increased education and skill training is integral to increasing the development, adoption, and usage of such new technologies (Caselli & Coleman, 2001).

Not too far from the level of human capital development, poverty levels have been identified as an integral determinant of renewable energy transition (Benhabib & Spiegel, 2005). In tandem with the tenets of the energy ladder, the argument has been that reduction in poverty levels, is inversely proportional to the rate of adoption of cleaner energy sources, herein conceptualised as renewable energy technology. The ideology underlying the model proposes that households with high-income levels seek to utilise cleaner energy, which matches their new income status (Masera et al., 2000). However, the phenomenon of energy stacking has also been identified in some literature, where households, individuals, and firms, do not transit wholly unto the usage of clean energy.

Elsewhere, the rate of adoption of renewable energy has been argued to be affected significantly by global goals (Lund, 2007; Omer, 2008; United Nations, 2019). Several pieces of evidence have been cited where international agreements on local participation in combating climate change, local roles in international efforts to reduce air pollution, a global call for increased energy security and overall quality of life for citizens, have triggered the diffusion and adoption of renewable energy among countries. The argument further maintains that signing on to those agreements such as the Sustainable Development Goals, oblige countries to introduce renewable energy technologies that will contribute towards the attainments of the targets which are specified within such goals.

The legal and institutional framework of the country has also been perceived as significant determinants of the rate of adoption of new technology such as renewable energy technologies (Doner, 2007; Jacobsson & Lauber, 2006; Karatayev et al., 2016). This has been closely related to international obligations. However, the variation here is the recognition of the autonomy of countries to prioritise investment in renewable energy technology, without any international obligation. Such local initiatives result in the promulgation of laws that enforces not only household's energy behaviour, but also that of institutions and industries. Commonly reflected is that such laws often emanate from energy deficiency issues within countries. When governments are unable to produce enough to meet demand by relying solely on the existing fossils, they tend to advocate for a switch to renewables, as a way of complementing existing sources.

The foregoing suggests that the determinants of renewable energy transition and adoption of such new technologies can be categorised into individual/institutional factors and national factors.

Attributes that relate to the household or firm's behaviour include the level of knowledge and income, whereas national factors relate to legal and policy frameworks, as well as the extent of information dissemination through institutions such as the media. This study, therefore, conceptualises urban households in Ghana as entities, operating within a society whose systems and structures support the renewable energy transition, and assesses what drives these households to adopt the Grid-tied solar PV system to complement energy delivery in the country, to use the results to model sustainable adoption frameworks.

2.5 The Political Economy of Renewable Energy Technology Development in the Developing Context

Electricity supply and renewable energy are thought of as a techno-economic issue supposed to be guided by a mandate to fulfil the basic need of access to energy within a framework of comprehensive feasibility studies and rational allocation of resources. However, the available evidence in the literature suggests that most interventions in developing countries are driven largely by political desires, with limited application of scientific processes (political liberalization of the energy market) (Ng'ethe et al., 2004). Power-laden processes define who gets power, when and how and at what price (Newell & Phillips, 2016). Often, the initial interventions are characterised by long-term planning and construction with accompanying high costs, with significant evidence of political authority imposition in subsequent development and extension (Hughes, 1993) cited in (Ferrall et al., 2021). Thus, technical expertise often finds itself in a position of "speaking truth to power" (Hoppe, 1999).

While governments have been at the centre of most renewable energy interventions, the role of the private sector in ensuring that renewable energy targets are met is severally demonstrated. As common in every social landscape, the relationship between several actors to shape policy direction is characterised by several dynamics which if not properly managed result in power incongruences (Ferrall et al., 2021). Political systems characterised by competition for electoral gains, with a degree of ethnic sensitivity have shrouded techno-economic rationality in the allocation of resources for renewable energy infrastructure development in most economies (Booth & Golooba-Mutebi, 2014). The foregoing implies that a positively reinforcing loop should be forged between the techno-economic and political structures to ensure sustainable transition spaces.

Again, while the development of renewable energy technologies extends beyond the local economy, the flow of transnational ideas, capital and technology influence the political landscape in most developing contexts (Booth & Golooba-Mutebi, 2014). While the renewable energy resources are often within the geographical boundaries of the country (except in cases where there is cooperation with other countries to develop a shared resource), the need for technology and investment capital from external sources creates room for trans-national exchange of ideas and institutions, with trans-local dynamics surrounding the resources themselves (Coenen et al., 2012). Global presence is therefore considered an external force in the development of such renewable energy resources. However, policies and investment directions in these developing countries are plagued by the infiltration of ideas often defined by the conditions of supports being received by such external forces (Newell & Phillips, 2016).

Global ideas are thus embedded in defining the priorities, direction, and specific investment priorities in these countries. This makes the renewable energy economies of most developing countries to be dominated by ideologies of neoliberalism (Newell & Phillips, 2016). While the influence of the state is being minimised, the oversight responsibility of establishing regulations that should guide the management of the externalities associated with neoliberal investment landscapes rests on the shoulders of the domestic governments (Ferrall et al., 2021). The Solar Photovoltaic market is consistent with political ideologies that seek to allow for significant inclusion of private actors, with state oversight and regularisation.

However, the policy objectives of governments in these countries often result in governments intervention through subsidies, thereby deepening the influence of domestic political preferences in defining the allocation of resources (Meus et al., 2021). While significant criteria are often set to define who can access these subsidies and the conditions under which they can access them, evidence has shown that subsidies are not entirely effective in driving the diffusion of these technologies if they are not well defined and controlled (Liu & Ronn, 2020). To provide a comprehensive understanding of how the adoption of these renewable energy technologies can best be improved sustainably, it is imperative therefore to understand the behaviour of the adopters and potential adopters, and how this plays out within a given system of political ideologies. Understanding the determinants of adoption of rooftop solar PV among urban households in Ghana will therefore contribute towards shaping policy and the entire techno-economic landscape, to enhance the sustainable transformation of energy systems.

2.6 Position and Contestations of Subsidy as a tool for Advancing Renewable Energy Technology Uptake

The contestations surrounding what should be the best policy direction and support instrument to facilitate the uptake of renewable energy technology have been largely driven by the macroeconomic and institutional features of the context being argued. In most instances, welfare effects and investment incentives have dominated practice as the commonest forms of support instruments to enhance adoption rates (Lekavičius et al., 2020). Such support schemes could either be in the form of provision of subsidies per MWh to producers (generation-based instruments), or reimbursement of renewable energy generators with a certain share of their initial investment capital (proportional subsidization) (Alolo et al., 2020). While the former most commonly include the use of Feed-in tariffs, sliding feed-in premiums and fixed feed-in premiums, the latter often include investment-based subsidies and capacity-based subsidies (ibid).

Even though such support schemes often result in general economic impact, the literature suggests that income disparities and the need to reduce inequality in the positive impacts of transiting to renewable energy among households often dominate the motivation behind such support schemes. (Chapman et al., 2019) argued that commonly, the energy transition drive is separated from issues concerning social equity and energy justice. However, the intersection between these variables often manifests in literature for several reasons. First, these issues are crucially important for the wellbeing of the entire society, which implies that the transitional drive and sustainable development should not be exclusive of equity and social justice objectives (Pereira et al., 2019). Again, it is argued that if support schemes are not provided to address issues of inequality, emissions rates will most likely continue to be higher among the very poor proportion of the population and extremely high among those that fall in the very wealthy group, which altogether then the initial environmental goals for the transition (Galvin & Sunikka-Blank, 2018). Further, such support schemes facilitate active participation by different groups of the society in the transition process, thereby promoting inclusiveness (Lekavičius et al., 2020)

Despite its numerous benefits, evidence suggests that renewable energy subsidies in most economies go together with taxes for fossil fuels. This is because such subsidies are often implemented within a domain of constraint of balance between government revenue and expenditure. In abstracting the interplay, (Bao et al., 2021) provided a two-stage behavioural model to explain the optimal policy design for renewable energy subsidy policies. They argued that under the constraints of government income and expenditure, renewable energy surcharges increase if the subsidy rates on renewable energy also increase, or if tax rates reduce. Consequently, an increase in the proportion of subsidised renewable energy generation in an economy increases the renewable energy surcharges. This they indicated is more common in economies whose investments are driven largely using Feed-in Tariff policies. The implications of this on the sustainability of such policies, therefore, led to their conclusion that adjusting such policies by reducing subsidy rates or increasing the environmental tax rates is the most optimal approach to using subsidies as a tool for increasing renewable energy adoption rate.

In most developing economies such as that of Ghana, government interventions in the renewable energy market have been largely in the form of subsidies, government-led large-scale investments or partnerships with private entities (Bukari, Kemausuor, Quansah, & Adaramola, 2021). Regardless, the commonest form of intervention that has been directed at enhancing access among households is the subsidy option. These subsidies often take two forms: assumption of a certain proportion of the cost of investment in the renewable energy technology, or provision of certain components of the infrastructure for installation. Regardless, the extent to which such interventions have contributed to sustainable diffusion of the technologies have been poorly documented. With Ghana currently implementing a subsidy-based intervention in enhancing renewable energy acceleration, this study analyses the extent to which the current National Rooftop Solar PV scheme subsidy policy incentive combines with other determinants of the adoption among households to provide an evidence-based policy option as to how best such tools can contribute towards enhancing access to renewable energy technology.

2.7 Challenges to successful diffusion of Grid-Tied rooftop solar PV technologies

The introduction of new technologies within many contexts is often faced with initial resistance and a manifestation of a seeming lack of interest in the adoption of the technology. In the case of renewable energy technologies such as rooftop solar PV technology, the adoption is argued to often go through a series of progressive stages from a small number of initial early adopters, then gradually diffuses into the whole population across late adopters (Figure 2). Such arguments are consistent with the fundamental tenets of technology diffusion arguments (see diffusion theories).

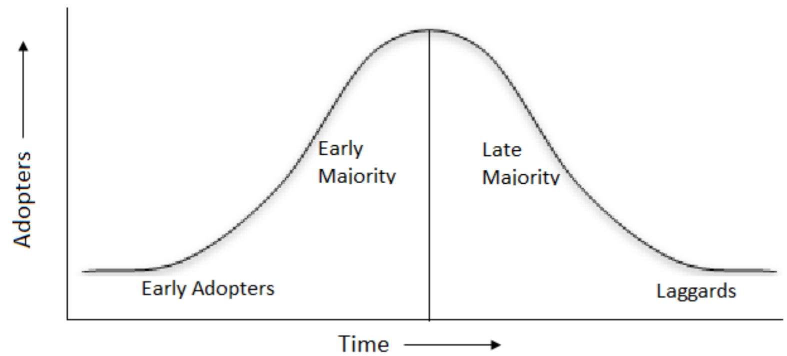

Figure 2: Adoption behaviour for innovation as a function of time

Source: Various sources on Roger's Theory of Innovation Diffusion[2]

In the context of this study, the early adopters are those urban households who can quickly identify the relevance of rooftop Solar PV systems and invest in the technology. This in the scope of this study includes the pilot forms where such technology implementation is studied. Over time, the channels of communication and the message being communicated then influences the latter group to perceive the usefulness of the technology to them, and then eventually, a wider number of households would adopt the technology (Makse & Volden, 2011; Silk et al., 2014). A critical challenge inferred from the analysis of previous studies that sought to investigate the diffusion of these innovations, therefore, is how which specific strategies can be adopted to reduce the time it takes for the technology to diffuse if the perceived socio-economic and environmental benefits are a priority to the country (da Silva, Cerqueira, & Ogbe, 2018; Sarkodie, Crentsil, & Owusu, 2019).

[2] See (See: Dearing & Cox, 2018; Silk, Hurley, Pace, Maloney, & Lapinski, 2014)

This has implications on the policy priorities of governments and makes it ambiguous to define targets that will speed up such response time rates (Makse & Volden, 2011).

Previous research works on the adoption of renewable energy technology deployment have leaned towards limited access to finance as the overarching barrier in the development of such systems. In a comprehensive survey on stakeholder views on the deployment of decentralised renewable energy projects in Ghana, for example, Bukari et al., (2021) found out that the majority of the study participants, who were drawn from among diverse energy experts in Ghana rated financial barrier as the most significant. In general, the electricity sector's investments have a high capital intensity and a long payback time. In most developing contexts, investments in renewable technologies such as solar PV are not in isolation but are reliant on policies that are holistically targeting the country's pursuit of global climate policy objectives (da Silva et al., 2018; Jan, Ullah, & Ashfaq, 2020). Given this, local, international, and global governments will demonstrate financial support to reduce this challenge depending on their perceptions of the cost-effectiveness of investing in such technologies (Bukari et al., 2021; Ofori, Bokpin, Aboagye, & Afful-Dadzie, 2021). A review of the foregoing previous evidence on stimulating technology uptake in developing contexts thus suggests that some policymakers may hold opposing viewpoints in prioritizing financial decisions, posing extra market challenges (Showers, 2011).

Despite the dominance of financial barriers in the literature on challenges in the deployment of renewable energy technologies in the study context, current trend and growth in the sector elsewhere suggest that the advancement of solar power generation using photovoltaic panels (PV) has reached a point where increased investment on a large scale has overacting benefits that outweigh the heavy initial costs of acquisition (Menegaki, 2008; Zhao, Guo, & Fu, 2014). In essence, when investment costs are compared with overarching benefits on the society, the benefits of large scale adoption far outweigh the cost of investment, both at the individual and national levels (Zhao et al., 2014). However, due to the complexity of such systems, ensuring a balance in the configuration for such large-scale adoption rates is a major challenge (Alshahrani, Omer, Su, Mohamed, & Alotaibi, 2019). Most grid networks are therefore confronted with constant enquiries into how to prevent instability in the grid when such technologies are taken up on a large scale (Mirhassani, Ong, Chong, & Leong, 2015; Tavakoli et al., 2020). This often results in limiting the maximum capacities of the systems that are adopted, particularly in developing contexts where technology for stability are low (Alshahrani et al., 2019).

While the challenges in advancing the deployment of grid-tied systems in developing countries are usually technical, evidence on policy inadequacy in responding to these challenges has been highlighted. It is consistently argued that the aptness of policies has a significant influence on the quantum of change that can be expected in the targeted sector (Khan & Zian Reza, 2019). However, most developing countries have been plagued with incongruencies in policies, of which the energy sector is no exception (Khan & Zian Reza, 2019; Martinot, Chaurey, Lew, Moreira, & Wamukonya, 2002). Such policies thus provide directions on governance structures, market regulations, market-based tools that could stimulate investment in these technologies in a sustainable manner, as well as provisions for monitoring and evaluating progress in the sectors (Khan & Zian Reza, 2019; Pfeiffer & Mulder, 2013). An ineffective renewable energy policy will thus imply slow rates of progress towards deploying such systems, including grid-tied systems- a challenge which is highlighted in most developing contexts (Khan & Zian Reza, 2019; Martinot et al., 2002).

While the challenges to the successful adoption of grid-tied solar PV systems in the developing context cannot be exhausted, it can be inferred that these challenges occur at multiple levels, from the end-users of the technology at the lowest level, to the highest level of the renewable energy system-governance and politics. Given this, interventions that seek to augment the uptake of these technologies must be sensitive to addressing the diversity of the challenges. However, since the targeted final change is in the adoption behaviour of the consumers, it is imperative to understand the drivers of the adoption of these technologies among the end-users. While the level of econometric tools and analysis (linear models) used in this study are fully insufficient to establish causality among urban households in Ghana, they provide a basis for further investigations such as Randomized Controlled Trials that can provide more reliable evidence into which specific variables to reinforce to achieve an effective transformation in the adoption behaviour of households for these technologies.

2.8 Framework for modelling the adoption behaviour of households

Examining the adoption behaviour of urban households for renewable energy systems requires a comprehensive understanding of the attributes of the households of interest. As indicated in the framework (Figure 3), studying adoption behaviour, therefore, is modelled essentially on the tenets of the Diffusion of innovations theory and the Technology Acceptance Model. These tenets provide a basis for deductive reasoning and the formulation of an initial hypothesis about the behaviour of the households. In this regard, the study hypothesises that the adoption behaviour of households can be improved if the determinants of the adoption can be modelled among these households, and their varying degrees of predicted probabilities can be used to re-direct policy interventions and the further development of new models. A review of the fundamental principles of these theories essentially commenced the work in the second chapter of this study.

Again, the literature reviewed suggested that the solar PV market embodies an interaction between solar PV demand and housing supply, within a framework of institutions and government priorities. Consistent with the theory of consumer behaviour, individual urban households across every context differ in preference behaviour for goods and services, and therefore has different likelihoods of responding to the same intervention (Sen, 1971; Voicu, 2008). The type of intervention model being implemented to stimulate the adoption of the technology thus creates a certain regime, characterised by a complexity of socio-economic and technical inertia. The regime under study within the scope of this research is thus characterised by the implementation of a capital subsidy intervention by the government of Ghana under the National Rooftop Solar PV Programme. An understanding of the dynamics of the regime is essential for making meaningful inferences from the findings on the behaviour of the households.

Having noted that the attributes of these individual households significantly inform their choices, it is imperative to survey and establish a profile of independent variables for the various iterations towards developing a predictor model for their behaviour. A myriad of estimation options is thus amenable to such analysis. However, consistent with the pragmatic aspects of neoclassical economic theories and estimation approaches, a survey is conducted among the selected urban households, with the application of econometric tools towards the specification of linear models for the behaviour of the urban households, and the processes were well explained in the third chapter of the study.

The individual household was therefore characterised as a consumer, and the nature of interactions in the various variables are explained appropriately in econometric analysis, usually by the tenets of logistic regression models (binary and multinomial logit regressions. Though a latent concept in this solar PV adoption study among households, the choice is often characterised by the perception of utility. From an econometric perspective, utility maximisation of the consumer is prime in the choice decision for products, and this utility has a lot of variables that are unknown to the econometrician and assumed to be independently known by the consumers, hence the introduction of randomness in the utility model.

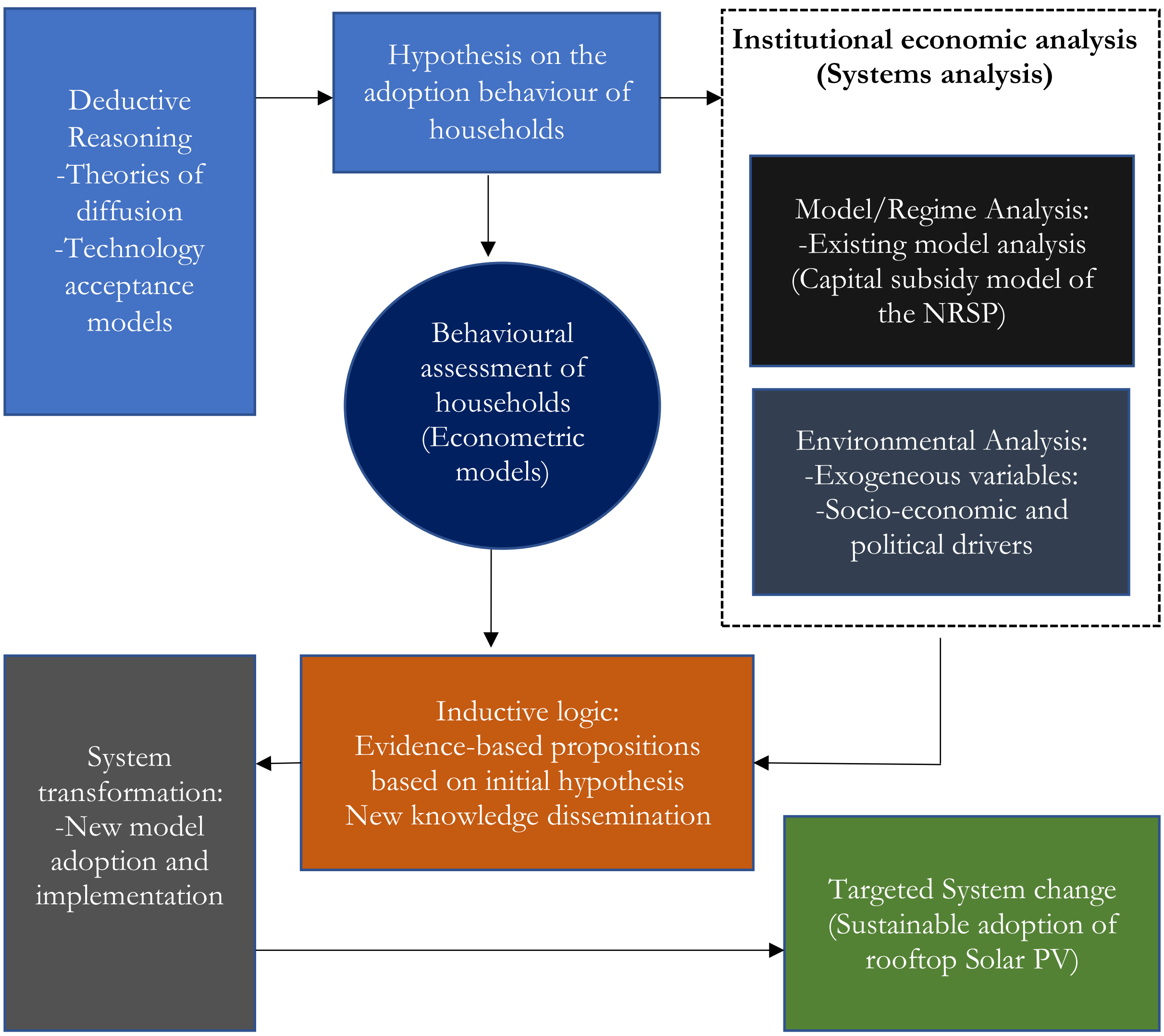

Figure 3: Framework for understanding the adoption behaviour for Rooftop Solar PV

Source: Author’s Construct, 2021

Findings from the study are thus externally valid for making limited inferences about the most probable behaviour of the sampling frame (thus urban households from the selected study cities). These inferences are then discussed with experts in the field of renewable energy policy and planning in Ghana, and then evidence-based policy propositions are suggested for the improvement of the existing model using inductive logic. The logic draws towards a conclusion from the generally observed behaviour of these households, within the frame of the behaviour of the entire landscape for rooftop solar PV adoption in Ghana.

It must be noted that the absence of adequate data for causality analysis limits the application of the findings of this study. However, as an initial step in understanding the rooftop solar PV adoption behaviour in Ghana, it provides the basis for further large-scale econometric analysis that can contribute towards the establishment of causality and further analysis of the institutional economic systems beyond the behaviour of the households that altogether affect the uptake of rooftop solar PV in Ghana. This then becomes a basis for an extensive review of the existing capital subsidy model and the development of new models that can stimulate sustainable rooftop solar PV adoption in Ghana.

2. Summary of Literature Review

The literature commenced by reviewing essential concepts that underlie and investigation into the adoption of Grid-Tied solar PV among households. Two essential behavioural theories were further reviewed and adopted as the theoretical framework for the study: The Technology Acceptance Model and Rogers' Diffusion of Innovation Theory. Upon examining the available empirical evidence on the subject, a theoretical and conceptual framework was prepared as a road map for the study.

The literature review concludes that rooftop Solar PV technology adoption has a significant potential of not only achieving economic and welfare benefits but also leading to a significant reduction in the impact of energy consumption on the environment and climate. However, to promote their adoption, policies must respond adequately to the individual attributes of the households and positively reinforce them. This justifies a study into modelling such variations and using it as a basis for evidence-based policy recommendations.

CHAPTER THREE

DESCRIPTION OF STUDY METHODOLOGY

3.1 Introduction

This third chapter explores the methodological underpinnings of the study. It presents a synopsis of relevant characteristics of the study setting. It describes the various approaches, methods and techniques that were employed in the study. The various sources of data, as well as methods used in analysing and reporting them, are presented.

Ethical considerations that were considered were also presented in this chapter.

3.2 Philosophical Underpinnings of the Study

Worldviews have evolved and contribute towards an appreciation of the rationale behind the explanations and views being presented by the researcher so that others can best understand the researcher's perspective. Due to the nature of the research questions, the study will be modelled upon the tenets of positivism and interpretivism (Ryan, 2018).

Positivism is noted to date back to the 19th century and gained its roots in the physical sciences. The original idea of positivism is best applied in the study of a human thought phenomenon, feelings, or actions that are subject to fixed laws. It is rooted in the belief that when the laws surrounding such action or phenomenon are discovered, human behaviour can be predicted, hence controlled by a scientist (Bryman, 2008). This dominated the sciences for a long time and attached a great deal of importance to the principle of objectivity in research.

Under its ontological quantitative belief, social issues are first conceptualized as "things". Once they are conceptualized in this manner, then they can be studied and their behaviour can be predicted (Grix, 2002). Since the study assumes that the likelihood of a household adopting solar PV technology can be predicted if there is an objective understanding of the nature of variables that determine the willingness to adopt, this makes it amenable to the tenets of positivism. Its methodological use of quantitative techniques such as surveys will generate objective evidence that will become a basis for the subsequent design and validation of the models that will enhance sustainable adoption of rooftop solar PV technology in Ghana.

However, studies in the social sciences do not easily subject themselves to positivist perspectives (Rolfe, 2013). They are based on the adaptations of various methodologies, and incorporation of diverse theoretical backgrounds. It becomes difficult therefore to subject a social science study entirely to the tenets of positivism. Ideally, social science studies envisage the use of methods that are subjectable to alterations and adaptations to the various findings one is likely to encounter on the field, leading to the emergence of relatively new and more flexible research paradigms (Scotland, 2012). The overarching objective of interpretivism research is to gain in-depth insight into the lives of study participants, to develop an empathetic understanding of their actions (Potrac, Jones, & Nelson, 2014). It dwells on the belief that individuals are intricate and complex beings, who have diverse experiences and understanding of the same "objective reality" (Scotland, 2012).

Its ontological dimension of constructivism is further adapted and applied in the study (Grix, 2002). Constructivism emphasises the active role of the individual in the modelling of social reality. The study acknowledges that the individual households have different experiences towards the adoption of rooftop solar PV technology, hence are individually constructed. This follows that to experience the world of the study participants, there is the need to co-construct such attitudes and behaviour that drive the adoption of such emerging technologies through a consensus with the study participants who have varied perceptions of the drivers. Consequently, best practices that will enhance sustainable adoption of the technology would also be derived from a consensus of what would be perceived as the most suitable from the perspectives of the study participants. It aligns with the qualitative methodological adaptations of case studies, phenomenology, and ethnography to shape knowledge, and such tenets will be applied in this study.

3.3 Profile of the Study Setting

This study was contextualised within Ghana, which is a country located in the Western part of Africa. The country, which is spread over an estimated land size of 238,535 km^2 (92,099 square miles) (Ghana Statistical Service, 2014), is one of the fastest-growing economies in West Africa. With a recent estimated population of 30.8 million (2021) (Ghana Statistical Service, 2021), Ghana is subdivided into sixteen (16) administrative regions and administered under a unitary system of government. The study area is located on latitude 7°57'9.97"N and longitude -1°01'50.56"W, bounded by Burkina Faso to its north, Ivory Coast to the West, Togo to its east and the Gulf of

Guinea to its south (Ghana Statistical Service, 2013). Notably, it has an oil exploration basin in the southern belt, along the Gulf of Guinea.

Its capital is Accra, and the country's vast natural resource endowment makes it a favourable setting for this study. The study location is described as one of the preferred investment destinations in Africa, and this, coupled with its rate of population increase and urbanisation, has implications for sustainable energy delivery. The country has a significant solar resource potential, making it economically viable for investment into both utility and commercial-scale solar production.

3.3.1 Brief Overview of Ghana's Energy Sector

Ghana is endowed with several natural resources. Its location has made it possible for the sustenance of a vast diversity of flora and fauna, as well as fossil deposits, hydro resources, and solar resources among others. The potential estimates of the energy sources suggest that with adequate investment and sustainable policies, these can be harnessed to attain a high degree of energy security within the country. Notably, recent statistics published by the Ministry of Energy in 2019 indicate that the country has a total primary energy supply of 11,149 Ktoe in 2019 (Ministry of Energy, 2019). This reflects an increase in the previous year's figure by about 2.7% from 10,852 Ktoe. Out of the total energy supply, further reports indicate that crude oil, biomass and volumes of natural gas account for 38.3%, 37.8% and 18.2% respective volumes of total primary energy stock for the year 2019.

Even though the country's energy sector has been expanding over the period, it was estimated that biomass constituted the largest energy proportion between 2000 and 2011 (Iddrisu & Bhattacharyya, 2015). However, upon discovery and commencement of commercial oil exploration, the oil resource became the highest contributor to the primary energy supply in the country. Such dominance was particularly observed between 2012 and 2019. Overall, investment in the energy sector has resulted in an increase of an average annual growth rate of the total capacity of primary energy produced from the year 2000 to 2019 by about 3.1% (Afrane, 2012).

Concerning the estimated population of about 30.4 million people in 2019, statistics further suggest that the total energy consumption increased from 445.2 kWh/capita recorded for the year 2018 to about 461.7 kWh/capita in 2019. This implies that electricity consumption per capita increased by about 3.7%, and reflects an improvement in the country's energy infrastructure (Ghana Energy Commission, 2018). The commission further reports that the rate of growth in the estimated figures over the period, when compared to 2000 as a base year, implies that total electricity consumption per capita in Ghana has for the period been increasing by an annual rate of about 1.3%. The foregoing suggests that even though electricity infrastructure is expensive to install, the country has been doing well in ensuring that more and more of its citizens are connected to the national grid every year.

Of the main electricity generation sources, large hydro and thermal sources have the most dominant proportions. A total of 63.6% of electricity generation in the country is accounted for by thermal sources, while large hydro accounted for 36.2% in 2020 (Energy Commission, 2021). Other renewables such as solar energy and accounted for 0.3% of the total energy supply in 2020. While adoption rates for other renewable energy shares are low, evidence suggests that in recent times, public and private actions in advancing the deployment of such systems are on the increase. The government of the country has thus invested in the development of commercial scales solar projects such as a 2.5MW plant in Navrongo and a 17MW plant under development in Kaleo/Lawra, both of which are in the northern part of the country and are being managed by the Volta River Authority. Other Independent Power Producers have invested in solar plants such as the 20MW plant by BXC Solar in Winneba, the 10MW Bui Solar project and the 20MW Meienrgy solar project among others (Energy Commission, 2021). Evidence on the household level adoption capacities of other renewables is thus limited in the various reports on the country's energy statistics, providing a stimulus for micro-level studies into the trend of adoption at these levels to contribute towards policies that will promote the adoption of such sustainable technologies in Ghana.

3.3.2 Overview of Electricity Access and Grid Connection in Ghana

Ghana has been experiencing a significant increase in its electrification rate over the years. The country has an estimated overall electricity access rate of 83.5% as of the end of 2019. The available statistics suggest that access rates are higher among urban areas than rural areas, with an average of 93.8% and 70% being reported for these areas respectively as of the end of 2019 (Energy Commission, 2020). Notably, access rates in the southern section of the country are higher and decline gradually with movement towards the northern stretch of the country (Figure 4).

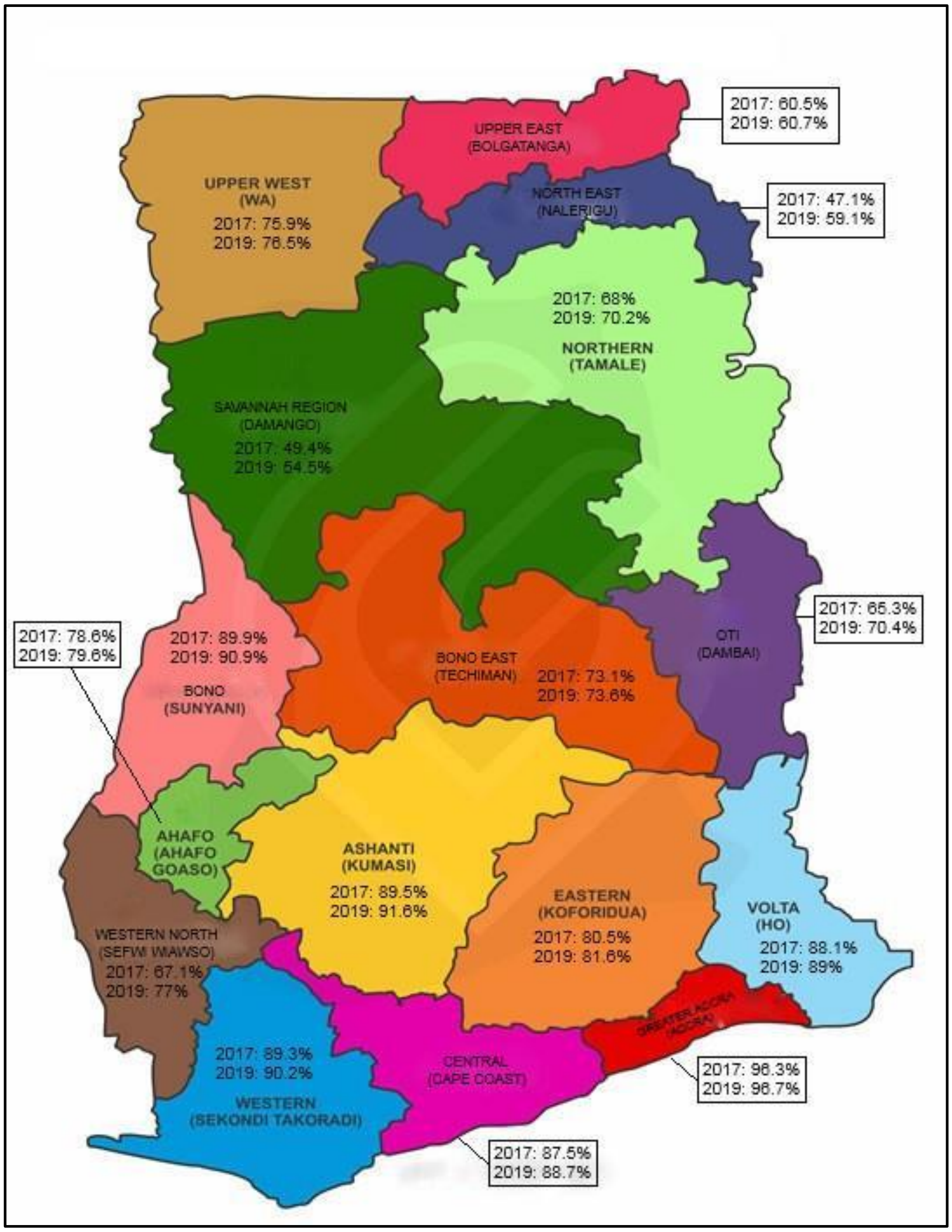

Figure 4: Electricity access rates in Ghana for 2017 and 2019

Source: Energy Commission of Ghana, 2020

Despite the varied distributions on access rates, evidence suggests that almost all of the country's major cities are connected to the main electricity distribution grid (Figure 5-B). This provides a significant potential for the adoption of low-voltage technologies that can be connected to the main electricity distribution grid, of which solar PV technologies are reported to be among the renewable energy options with the highest potentials (Figure 5-A). Policy direction in this regard stimulated the introduction of the National Rooftop Solar PV programme, which sought to increase the uptake of Grid-Connected Solar PV systems among households and Small and Medium Scale Enterprises. The study is therefore contextualised within the regime of the implementation of this capital-subsidy programme, to provide evidence into the underlying determinants of the adoption, to provide a basis for further evidence-based analysis and development of models to facilitate sustainable adoption.

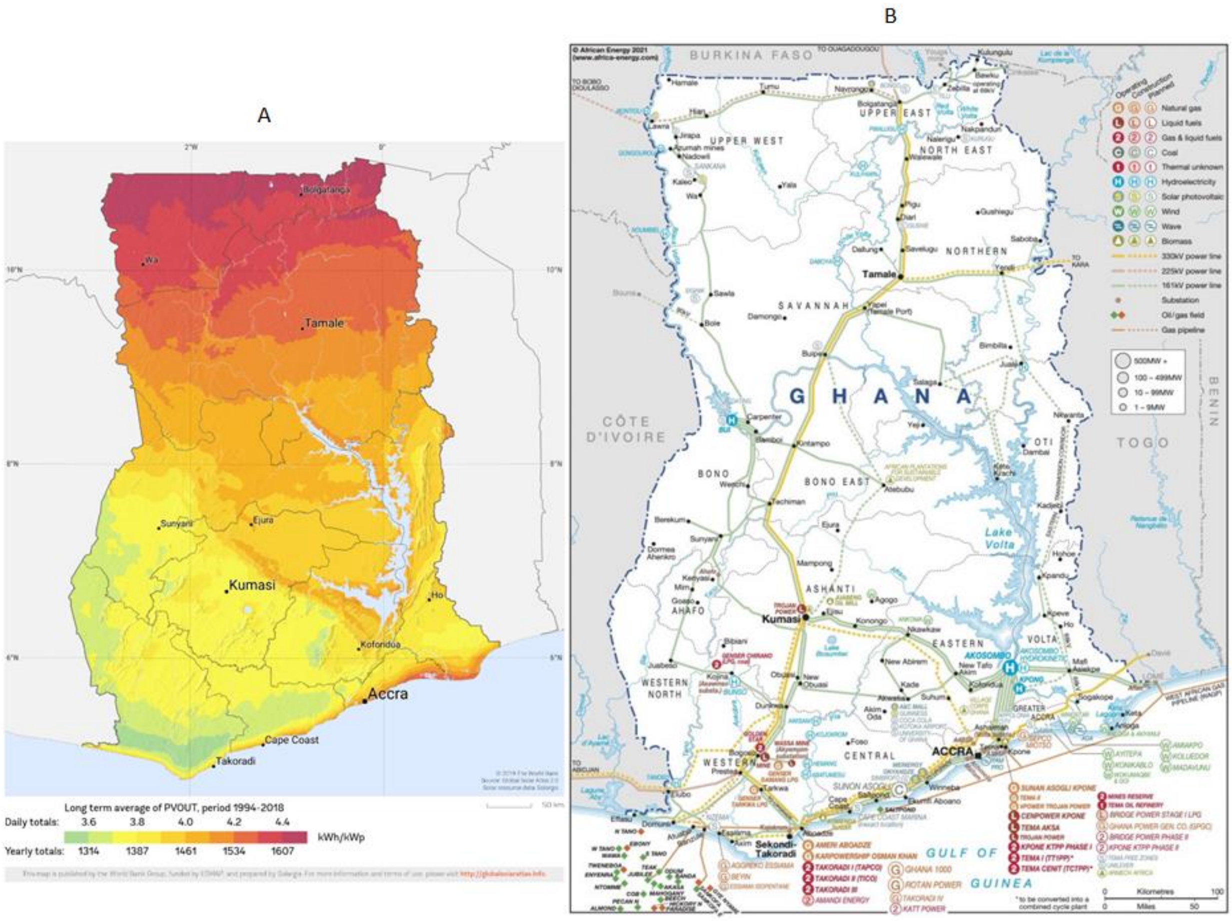

Figure 5: Map of Solar energy Potential of Ghana

Source: A: World Bank Group, Solar Resource Map Potential of Ghana (ESMAP) B. African Energy Consultancy[3]

[3] See https://www.africa-energy.com/map/power-infrastructure-ghana-revised-january-2021 accessed and retrieved on May 16th, 2021 at 17:32 CEST

3.3 Research Design and Approach

3.3.1 Type of Design

The research design establishes a framework for the translating of research objectives into workable projects (Creswell, 2007). It establishes a logic between the research questions and the data, as well as defines the overall methods that are utilized in the collection and analysis of the data (Roux & Vosloo, 2011). Regardless of the strand of research (whether qualitative, quantitative or both) adopted, a research design is essential to defining the overall spine of the research by turning the research problem into a workable project. The qualitative and quantitative strands are the two major forms of approaches for collecting and analysing data in contemporary research, with their varied subcategories (Perumal, 2014). The qualitative designs have been largely described as descriptive and exploratory, dwelling much on the usage of texts for extensive description and explanation of the behaviour of the variables being studied, whereas the quantitative designs are more subjectable to numerical analysis and largely involve surveys and experiments.

The study is implemented in the form of three case studies on household behaviour towards the adoption of the technology in three principal cities of Ghana, each selected from the southern, middle, and northern parts of the country (Accra, Kumasi, and Tamale). The case study methodology (specifically the mixed-method case study design), which involves a thorough study of an entity from its context and perspective using various techniques, is adopted to understand the dimensions of rooftop solar PV technology adoption in Ghana (Yin, 2011). While case studies can assume varied forms, the mixed-methods case study design integrates quantitative and qualitative data collection and analysis techniques to provide in-depth pragmatic evidence for a case, or multiple cases facilitate comparative analysis (Creswell and Clarke, 2018). Due to the nature of the study objectives, the study leans towards a more quantitative design than qualitative, with the latter addressing expert views on policy alternatives that could enhance the adoption of rooftop Solar PV technology among households in Ghana.

Within the context of this study, the quantitative results provide a basis for further studies into the identification of causal factors that drive the adoption and further serve as an entry point for advanced research towards the development of alternative models that could enhance the adoption of the technology. Its results are thus useful for limited generalisation about the adoption behaviour of the households in an inductive manner (O'Reilly, 2009; Soiferman, 2010). Further, the prevalence of relevant qualitative aspects in this study reinforces the use of inductive reasoning in suggesting pragmatic alternatives towards a holistic improvement of the solar PV technology adoption landscape.

As consistent with research that targets understanding behaviour in technological adoption, the behaviour of households towards solar technology adoption in this study is thus understood using a bottom-up approach, first from the perspectives of the local people. The bottom-up approach is consistent with the tenets and research practices of the internship organisation (MicroEnergy International GmbH). Accordingly, multiple perspectives are generated and analysed for patterns and themes, and through a process of co-creation, such individual and collective responses are used to suggest policy alternatives towards enhancing the sustainable adoption of rooftop solar PV technology in Ghana. During the internship towards the preparation of this study, therefore, adequate training on micro-level studies was provided to facilitate the implementation of the study.

3.3.2 Justification for mixed methods case-study design

The mixed-method case study design has been chosen for this research because although the study questions are largely qualitative, there are significant components of some subsidiary issues that, when analysed quantitatively, can significantly enhance the reliability of conclusions that will be drawn from the collected data. The study is implemented towards the award of an MSc degree in Energy Policy, hence the need for the inclusion of some qualitative evidence on strategies that can enhance sustainable adoption of the technology in addition to the quantitative investigation of the adoption behaviour of the households. Again, previous research works by the internship organisation towards the support of policy interventions in Africa are shaped to elicit some qualitative evidence on expert views within the sector being examined in support of quantitative results. This enhances the validity of the findings for policy, hence the adoption of a like approach in this study.

Generally, case studies allow for an in-depth examination of a phenomenon from multiple perspectives within a context-sensitive to the complexity and uniqueness of that particular entity, phenomenon, or real-life situation being researched. For every research, the nature of the questions and objectives, the variables that would be measured, and the competency of the researcher and participants defines the optimal method that would be adopted. Again, policy planning is essentially a qualitative activity and is much improved using relevant quantitative evidence. Adopting a mixed-method perspective in describing the fundamental variables that influence the attitude of households, therefore, enhances a thorough understanding of the parameters that should guide subsequent improvement upon existing policy models towards enhancing the sustainable adoption of rooftop solar PV technology in Ghana.

3.4 Sample Estimation and Selection

Notably, only heads of urban households are targeted in this study. The sample for the survey in each of the study locations is estimated using the sample size determination rule for large population sets as applied by reputable international organisations such as the World Bank in social surveys and other forms of Randomised Controlled Trials (even though this study varies significantly in the application of RCT principles due to its limitations of time, resources and absence of a baseline data), particularly when the sampling frame is unknown[4]. Given that the Ghana Statistical Service in its last official census report (2010) estimated the average household size in Ghana to be 4.4 persons (Ghana Statistical Service, 2013), the total number of households in each city was estimated using the formula below:

$$Total\ Number\ of\ households = \frac{Total\ Population}{Average\ household\ size}$$

Given the last official reported populations of Accra, Kumasi and Tamale to be 2,557,000, 3,544,615 and 683,538[5]. Estimated household sizes were thus as follows:

For Accra:

$$Total\ Number\ of\ households = \frac{2{,}557{,}000}{4.4} = \ 581{,}136$$

For Kumasi:

$$Total\ Number\ of\ households = \frac{3{,}544{,}615}{4.4} = \ 805{,}594$$

For Tamale:

[4] Data on the total number of households in the three study locations was not accessible at the time of the study. The last official data was the 2010 Population and Housing Census, which dates around 12 years at the time of this study

[5] Since the national census reports were limited in defining urban population in the study cities, figures used for the estimation were taken from https://populationstat.com/ghana/ (accessed on July 05, 2021 at 21:06 CEST)

$$Total\ Number\ of\ households = \frac{683{,}538}{4.4} = 155{,}349$$

Given that the study intends to sample both beneficiaries of the National Rooftop Solar programme and non-beneficiary households, it assumed a prevalence rate of 50% for beneficiary households across the total number of households, hence a confidence interval of 7 was assumed for the estimation. An error margin of 0.05 was specified in the sample size calculator. Consequently, an estimated sample size of 196 households was obtained for each of the three cities indicated in Figure 6 (Accra, Kumasi, and Tamale). The figure was however adjusted to 200 respondents from each of the three major cities: Accra, Kumasi and Tamale upon expert consultations and discussions with the study supervisors. Eventually, 596 responses were obtained out of the targeted 600 heads of households[6]. While this figure falls short of the targeted sample size, an error margin of 5% was assumed for non-response rates (30), which was far greater than the total non-responses (4), hence the final obtained responses were taken as valid within the scope of analysis carried out in this work.

The actual selection of the respondents was done using randomized techniques to allow each head of household an equal chance of being included in the study. Consequently, each study municipality was stratified using neighbourhood income classification by the Ghana Statistical Service as the stratification variable (low, middle, and high-income neighbourhoods). A list of housing units within each stratum of the city system was then be obtained and then each housing unit visible on the map was assigned a number for the application of a systematic sampling approach. However, this was substituted for convenience sampling due to the limitations posed by the absence of clear information on the size of the sampling frame for the determination of the n^{th} house during the survey. However, efforts were made by the field assistants to introduce randomness in the selection of each house surveyed on the map. The head of the first household to be met in each housing unit was then surveyed for the study. In cases where the selected head of the household was not available for the survey, the next accessible head of household in the housing unit was surveyed. Only one household head was surveyed from each housing unit in the strata until the required sample size was obtained.

[6] The sample size calculator designed by the creative commons was used in the estimation of the sample size in this study. See details on the tool at https://www.surveysystem.com/sscalc.htm

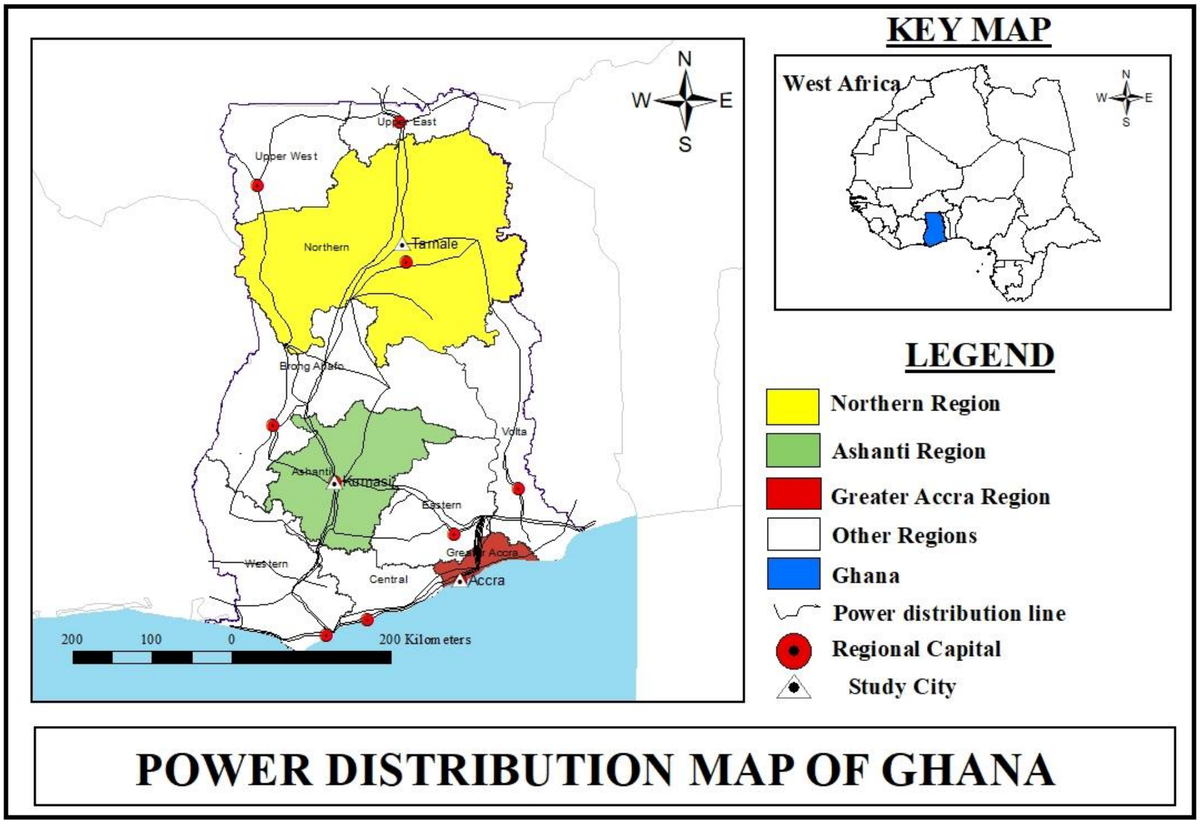

Figure 6: Map of Ghana showing study locations

Source: Author's Construct, 2021

3.5 Data collection techniques

Primarily, the survey data collection technique would be used to measure the socio-economic attributes and adoption behaviour variables among the research participants in line with the research questions. Surveys will facilitate the generation of trends that will help uncover the influence of the participants' diverse socio-economic attributes on rooftop solar PV adoption. A set of pre-tested survey questionnaires is administered using direct face-to-face techniques. Responses to each survey question are pre-coded, and the measured results from the use of surveys are stored and analysed in the STATA software.

Upon thorough understanding of the drivers of rooftop solar PV adoption among urban households, as well as the varying degrees of importance attached to each of these drivers and the variation across the observed study sample, the significant findings will be used to construct an evidence-based framework specifying a model that is more likely to positively reinforce adoption among the urban residents of Ghana. The proposed policy and business model would be validated through holistic empirical research techniques such as focus group workshops and expert panel discussions.

3.6 Methods of Data Analysis

Based on the nature of the study objectives, and the survey methods used in collecting needed data on the respondents to answer the research questions, the document analysis, binary and multinomial logistic regression modelling, and inductive logic were the main methods used in analysing data in this study.

The document analysis technique, which is a systematic qualitative data collection procedure for reviewing the content of documents from both printed and electronic sources to gather useful information (Bowen, 2009), is used to obtain initial evidence on the rooftop solar PV adoption behaviour the households in Ghana. This technique is most useful in scenarios where there is significant existing documentation of the phenomenon being investigated. Some studies have highlighted the usefulness of the document analysis technique in saving time and cost on research data, especially when the phenomenon has been given some amount of attention by previous researchers and institutions (Altheide, Coyle, DeVriese, & Schneider, 2008). Before any analysis of existing documents was carried out, the various documents and reports on the project, as well as relevant scientific papers on rooftop Solar PV adoption in Ghana, were assessed for their relevance to the understanding of the adoption behaviour of urban households within the context of Ghana. For scientific papers included, initial screening was done based on the significance of the topic, its, and the credibility of the document's source. Project reports from the Energy Commission on the status of the National Rooftop Solar PV project were the major component of this analysis.

The quantitative data that were obtained from the field surveys were coded in excel and exported into STATA 14.2. The variables were labelled in STATA 14.2 using dummy coding for categorical variables. Continuous variables however were maintained in their state for all analysis. Depending on the nature of the dependent variable in each linear model analysis, binary and multinomial logistic regression tools were used (explained specifically for each model in the results section of this work). The binary regression model was used to determine the significant variables that influence a household's adoption of the Rooftop Solar PV system. The model was then again used to investigate the nature of interactions between these variables and the specification of a linear predictor model for the adoption of solar PV among the observed sample (Hoffman & Duncan, 2009). When research intends to examine how the attributes of a given entity (herein referred to as an urban household), influences its choice, preference or adoption of a given intervention (herein referred to as the rooftop solar PV systems), then logistic regression models are applicable, hence its selection and use in this study. For all models in the study where the dependent variable has two response options "Yes" or "No", binary logistic regression was used to estimate the relation between the dependent and independent variables (willingness to adopt the technology, and actual application decision made). Consequently, the linear adoption behaviour of an urban household "*H*" in any given survey situation (i) for the Grid connected rooftop solar PV system (j) in each competing alternative situation between adoption or not adoption (s) is then illustrated as:

$$f(H,i) = \beta_h \cdot + X_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where: β_k is the set of regression coefficients estimated for the adoption outcome and X_i connotes all the set of independent variables associated with the observed household. In effect, the full linear predictor for adoption the urban household observed was specified as:

$$f(H,i) = \beta_{0,h} + \beta_{1,h}X_{1,i} + \beta_{2,h}X_{2,i} + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \beta_{n,h}X_{n,i} \ldots\ldots \text{(2)}$$

Where $f(H,i)$ is the function of adopting the Solar PV system; $\beta_{n,k}$ is the regression coefficient attached to the urban household indicating its willingness to adopt the technology; and $\beta_{n,h}X_{n,i}$ is the parameters of the various significant socio-economic attributes of the household. For any linear predictor model, a stochastic error term, Ɛ, is added to account for the fact that other counter-factual variables could influence the behaviour of the household, hence the error term creates room for such unobservable variables within the scope of this study.

Based on this, the willingness to adopt a rooftop solar adoption among urban households based on the attributes of the household is linearly modelled as:

$$\text{Adoption (willigness } \vee \text{ actual decision)} = K + \beta 1(\text{attribute } 1, \text{levels}_{1-n}) + \beta 2(\text{attribute } 2, \text{levels}_{1-n}) + \ldots \beta n(\text{attribute } 3, \text{levels}_{1-n}) + \mathcal{E} \quad \ldots\ldots\ldots\ldots \text{(3)}$$

For all statistical computations made on the determinants of the rooftop solar PV adoption, variables were taken to be statistically significant at $p<0.05$. Based on this, coefficients that are less than 0.05 will be taken as significant, and those greater than 0.05 taken as not statistically significant. A summary of the various methods used in analysing data in response to the research questions is presented in Table 3 below:

Table 3: Research questions and analytical methods

Research Question	**Method of Analysis**
What are the factors that drive the adoption of rooftop solar PV among urban households in Ghana?	Document Analysis Binary Logistic Regression
What is the nature of interactions between the significant determinants in the adoption of rooftop solar PV in Ghana?	Binary and Multinomial Logistic Regression
How do the determinants of adoption of Solar PV vary across the diverse socio-economic characteristics of urban households?	Multinomial Logistic Regression
What are the best practices and policy alternatives that will enhance the sustainable adoption of rooftop solar PV technology in Ghana?	Inductive Logic

Source: Author's construct, 2021

3.7 Validity and Reliability Concerns

The final questionnaire for eliciting the behaviour (see appendix one) was first discussed and reviewed by my supervisor, who is an expert in research across the field of econometrics and survey research to improve the validity of the data. It was then pre-tested in the three study locations, Accra, Kumasi, and Tamale, by randomly among 186 respondents to improve the reliability of the questionnaire. This was done to identify areas of ambiguity in language and flaws in the questions, to make appropriate modifications before they were employed in the main study.

Again, the pilot study provided evidence on the initial behaviour of the predictor models, which was then used to improve the final survey questionnaire. The results from the pilot study were presented in two phases at swarm workshop sessions at the Technical University of Berlin for comments which were later used to improve the survey.

3.9 Ethical Considerations

In line with every research, there is the need for every research to uphold ethical issues. Ethical issues in research have moral and legal implications and can undermine the validity of the study. More importantly, ethics are essential to ensuring that the dignity and security of those who partook in the research are duly protected. In the global age, where information given by a respondent can be easily accessed and utilised for several other unintended purposes by a third user, anonymity, confidentiality, and informed consent are essential ethical principles that must not be compromised by any study.

Advancing from this background, this research ensured that appropriate permission to commence the study was first obtained from the Pan African University. The questionnaire used in the survey was designed in such a way that the respondents were identified by numbers and not their real names. The introductory part of the questionnaire provided a synopsis of my intention for undertaking the research, and respondents were included based on wilfulness. In the event where a chosen respondent was not willing to take part in the study, he/she was simply replaced. The findings were reported using the numeric identification numbers of the respondents, and that enabled me to uphold anonymity and confidentiality in my study.

CHAPTER FOUR

PRESENTATION OF RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the outcomes of the comprehensive survey of 596 households from urban Ghana, precisely Accra, Kumasi, and Tamale. The households were sampled and surveyed to derive essential parameters that can be used to define a predictor model for the behaviour of urban households in terms of their attitude towards adopting Grid-Connected Rooftop Solar PV systems.

The chapter commences with a description of the biographic information of the respondents using summary statistics. The essential socio-economic attributes of these households thus served as the independent variables used in conceptualising their adoption behaviour. Overall, the results are presented with the study objectives.

4.2 Essential Socio-Economic attributes of the study households

A study that sought to understand the rationale behind the adoption behaviour of households for the GCSP systems, is well advanced upon establishing a profile on the participating households. With most households' decisions, particularly investment decisions being driven largely by the heads of the households, the study characterises each participating household using attributes of its head.

The respondents were first distinguished upon their tenancy status. This established a variation between households who owned the housing units in which they reside, and those who occupy rental tenancy statuses. Of the rental population, the majority of the respondents were male, who were largely occupying rental housing tenancy statuses (Figure 7). The next dominant attribute was homeowners, who had a higher representation of females than the rental category. The male dominance observed is consistent with the dominance of many households by male heads in Ghana.

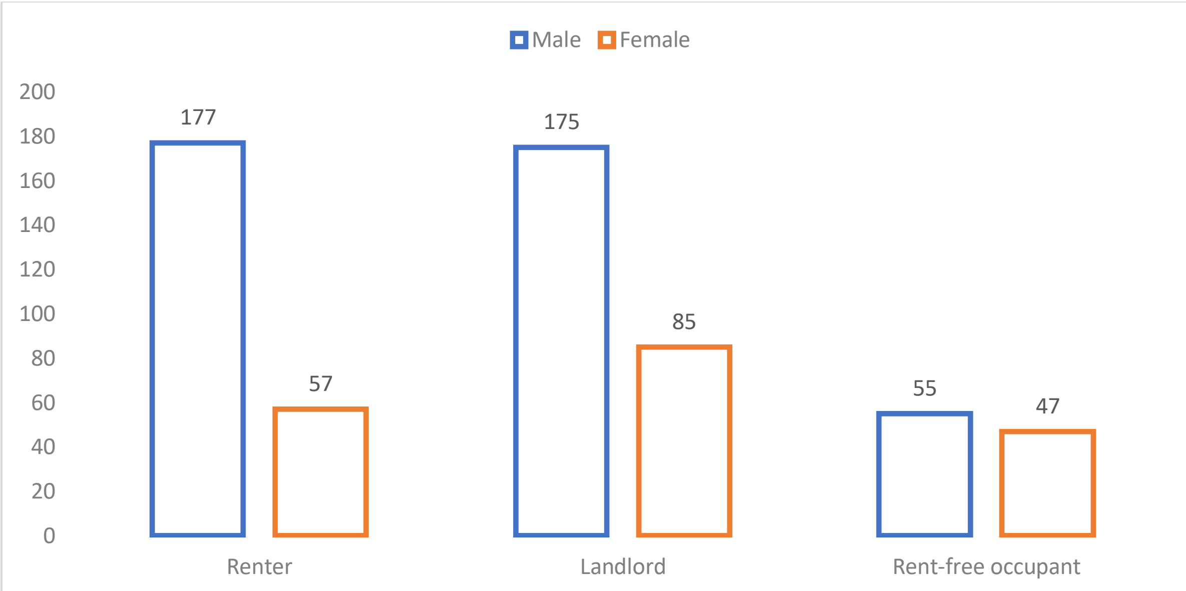

Figure 7: Distribution of respondents by tenancy statuses

The survey further sought to enquire about the awareness rate of its participants on the existing National Rooftop Solar Programme. It was revealed that in all the three study locations, over 50% of the respondents were aware of the existence of the programme (Figure 8). However, there is still a significant number who are not aware of such a programme. Within the framework of the theoretical underpinnings of this study, awareness is conceptualised as one of the most important variables that can have a high influence on the decision of households. The various media through which the participants have been reached ranges from announcements on TV and radio, as well as officials of the Energy Commission of Ghana and friends. These platforms, therefore, provide a useful basis that can be leveraged to further promote awareness creation.

Literature has been consistent on how awareness is a critical driver of renewable energy technology adoption. In tandem with the tenets of the technology acceptance model and the diffusions of innovations theories, the likelihood of people adopting technology based on their perceptions of the benefits and ease of use is often higher. In the works of Irfan, Zhao, Rehman, Ozturk, & Li, (2021), they identified intention-based influenced factors that drive renewable-based energy technology adoption in Pakistan and made similar observations on the significance of awareness.

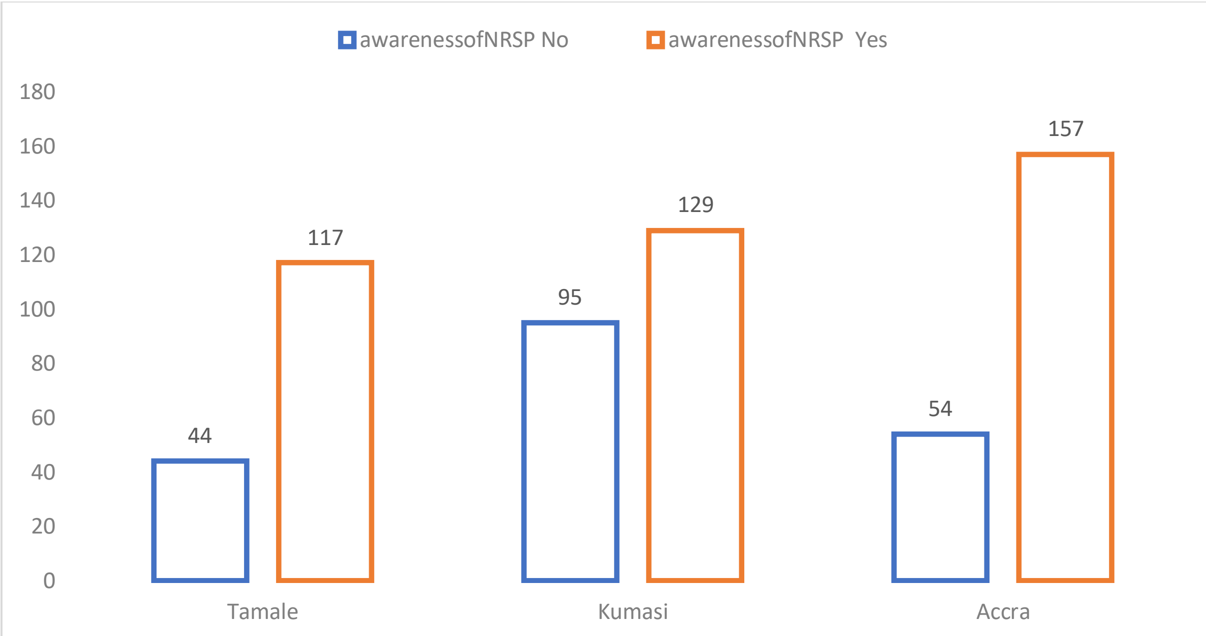

Figure 8: Awareness of NRSP

To further understand the current attributes of the housing unit, the study sought to estimate the current rate of application success (Figure 9). It was revealed that out of the total 257 respondents that have applied for the capital subsidy programme, only a total of 73 households in this study had their applications successful. The study, therefore, identifies a huge gap in the implementation of the intervention. This necessitates why the study sought to understand the role played by the attributes of the housing units themselves in reinforcing the attainment of the study objectives.

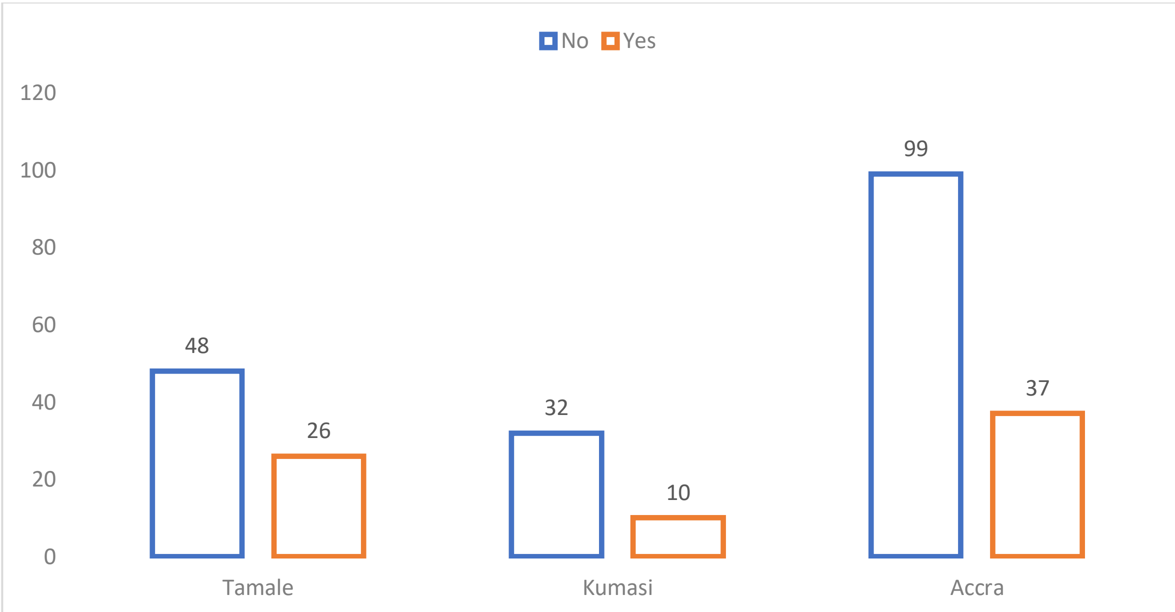

Figure 9: Application success rate

Income levels that accrue from three categories of attribute levels have been analysed: employed, unemployed and passive income. The maximum observed value for monthly income was 9600 Ghana cedis per month, while the minimum observed value is 750 Ghana cedis per month. The mean monthly income level of households in the study was estimated to be GHC 3115.768, with a standard deviation of GHC 2106.396 (NB: 7.07GHC= 1 Euro at the time of this study). It must be noted that the median monthly income recorded for the 396 respondents was GHC 1300.00. Ghana's minimum wage being GH¢10.65, the average Ghanaian household included in the survey is expected to earn above the minimum age, increasing the prospects of affordability for a small size GCPS.

The influence of income on the adoption of renewable energy technologies has been strongly argued consistently across previous works (Muhammad Irfan et al., 2021; Rahut et al., 2017). The argument is that households that tend to have higher incomes and can afford to pay the upfront cost of taking the technology have higher chances of adoption than their base counterparts. This is further consistent with earlier findings of (Muhammad Irfan et al., 2021). The foregoing suggests that the probability of adoption of rooftop solar PV technology are most likely to be higher among middle- and high-income households due to their ability either afford to pay the investment costs out of their pockets or can access credit facilities for such purposes due to their ability to provide collateral. In some contexts, however, income has been insignificant in limiting access. Evidence on community funding through resource pooling has been established by other researchers in contexts such as Bangladesh (Groh, Philipp, Lasch, & Kirchhoff, 2015). This suggests that even among households in Ghana that fall below the mean estimates for income, bottom-up finance models can help improve their affordability for renewable energy systems such as the Grid-Connected Rooftop Solar PV systems.

The average electricity expenditure levels of these households were further investigated. The average monthly expenditure was estimated to be 280.7936, with a standard deviation of 205.7914. Interestingly, some households were revealed to pay monthly bills as low as 30.00 Ghana cedi with the largest values being recorded as Ghana cedis 1110.00. The foregoing suggests that there is considerably a high amount being paid by households on electricity but still falls within the monthly expenditure range for electricity affordability.

4.3 Determinants of Rooftop Solar PV adoption among households

4.3.1 Determinants of actual application decision (Revealed Preference using BLR1)

The study sought to investigate the various socio-economic variables that are significant in influencing the decision of the households to adopt GCSP systems. Actual application effort (ever_applied), was taken as the dependent variable. A total of 596 questionnaires was successfully administered among households from Accra, Kumasi, and Tamale. By design, each head of the household was asked to indicate whether they have ever applied for the NRSP. By default, the dependent variable is dichotomous, with only two alternatives, “yes” or “no”, indicating that a binary logistic regression was suitable for the analysis of the responses. In STATA 14, categorical independent variables were distinguished from continuous variables to reduce the effects of

The rationale was to assess which variables are the most significant in explaining the observable differences between households who have taken an application decision and those who have not. Overall, the model was taken to be statistically significant at $p<0.05$. The model produced a Prob > chi^2 of 0.0000 and a Likelihood Ratio (LR chi^2(14)) of 341.95. The P-value of 0.000, therefore, suggest that the current model exhibits a significant improvement and fit over the baseline or a no model. A total of 44 responses were missing, hence the model generated its results over 552 observations out of the 596 that were surveyed in total. While the odd logs model the relationship between the predictor and the target event, they are essentially a comparison of two probabilities, hence odd logs greater than 1 suggest a higher likelihood of the predictor variable falling into the target event, and less than 1 suggest a higher probability of not falling into the target event. An odd log of 1 suggests equal probabilities of falling into both the target event and the non-target event.

At $p<0.05$, six (6) predictors were found to be statistically significant in the behaviour of households who have ever applied for the NRSP. These predictors are awareness of the NRSP, household size, tenancy status (landlord and rent-free occupants), educational level (tertiary), and electricity expenditure. A coefficient of 4.7 for awareness suggests that for a unit increase in awareness of households on the NRSP, there is an increase in the odd logs of the household making an application decision. This variable again produced the highest statistically significant observed coefficient and being greater than 1 suggest that the probability of the household falling into the category of the ever-applied event is greater than the probability of not falling within that event. This finding is therefore significantly with earlier arguments on how awareness is a key driver to renewable energy technology adoption in many contexts (Muhammad Irfan et al., 2021; Wall, Khalid, Urbański, & Kot, 2021).

For household size, a statistically significant coefficient of 0.23 was observed, suggesting that for a unit increase in the number of persons living in a household, the odd logs of the household falling into the category of those who apply for NRSP increases by 0.23. This predicted change in odd logs affirms the significant relationship between the increase in household size and the increase in demand for electricity. However, the coefficient is less than 1 suggest that the probability of the household falling in the non-target event is greater than the probability of the household falling in the ever-applied group. A previous econometric analysis by Mohd Irfan, Yadav, & Shaw (2021), suggested that the odd likelihood for solar PV adoption among Indian households also tend to increase with households size. Similarly, Bondio, Shahnazari, & McHugh (2018), in an econometric analysis of the Solar PV adoption market in Australia found out that when households are confronted with rising bills for electricity, their motivation to adopt solar PV is higher. In the Ghanaian context, increasing household size, particularly in urban areas, increases the electricity demand, hence can explain the statistical significance of household size in this model.

For tenancy status, both levels of the attribute were statistically significant, with the household obtaining a coefficient greater than 1 (1.4) for landlords, and less than 1 (0.83) for rent-free occupants. This suggests that for every unit increase in the status of the household towards ownership of the housing unit, there is an increase in the odd logs by 1.4 that the household will apply for the NRSP, with the probability of falling into the ever-applied event being greater than falling into the not-applied event. However, for an ever unit increase in the household's status towards rent-free occupancy, there is an increase in the odd logs of the household applying for the NRSP, but the predicted probability of not falling into the ever-applied event is higher. Bondio et al. (2018), affirmed that the middle class is quicker in taking up solar PV technology. Often, this class mostly have higher indices of home ownership than the lower class which usually fall in the rental category.

For educational level, all other dimensions of the predictor variable were statistically insignificant at $p<0.05$ except tertiary educational level. The coefficient of 1.2 suggests that for a unit increase in a household acquiring tertiary educational status, there is an increase in the odd log of the household by 1.2 in applying for the NRSP. The behaviour of the educational level variable in this model is consistent with that of the same variable in the model of Dharshing (2017) when he conducted an econometric analysis of residential Solar PV in Germany. Again, the odd logs being greater than 1 suggest that the predicted probability of the household falling into the ever-applied event under this model is higher than the probability of not falling into the target event. This finding is consistent with that of Jan, Ullah, & Ashfaq (2020) in their analysis of the determinants of solar PV systems in Pakistan.

Electricity expenditure was further statistically significant at $p<0.05$. However, it obtained a negative coefficient of -0.0007, suggesting that for every unit increase in the household's electricity expenditure, there is a reduction in the odd logs of the household ever applying for the NRSP by 0.0007. Again, the odd logs less than 1 suggest that the predicted probability of the household falling into the non-target group is higher than the predicted probability of the household falling within the target event of applying for the NRSP. Bondio et al. (2018) stressed the role of the rising cost of electricity in stimulating interest in rooftop Solar PV, while this study observed a negative coefficient for the variable.

Table 4: Determinants of application for Rooftop Solar PV

Ever applied	Coef.	Std. Err.	z	P>z	[95% Conf.	Interval]
Awareness of NRSP						
Yes	4.657491	0.637506	7.31	0.0000	3.408003	5.906979
Household size	0.232396	0.045501	5.11	0.0000	0.143216	0.321575
Tenancy status						
Landlord	1.354272	0.339375	3.99	0.0000	0.68911	2.019434
Rent-free occupant	0.830456	0.376275	2.21	0.0270	0.09297	1.567942
Education						
Basic Education	0.402945	0.550401	0.73	0.4640	-0.67582	1.481711
Secondary Education	0.774111	0.463053	1.67	0.0950	-0.13346	1.681677
Tertiary Education	1.217393	0.449275	2.71	0.0070	0.33683	2.097956
Age	0.000132	0.003356	0.04	0.9690	-0.00645	0.00671
Sex						
Female	0.416923	0.274568	1.52	0.1290	-0.12122	0.955066
Employment						
Unemployed	-0.16118	0.484091	-0.33	0.7390	-1.10998	0.787622
Income	6.42E-06	1.07E-05	0.6	0.5480	-1.5E-05	2.74E-05
Electricity expenditure	-0.0007	0.000311	-2.26	0.0240	-0.00131	-9.5E-05
Grid adequacy						
Yes	-0.18581	0.273273	-0.68	0.4970	-0.72141	0.349797
Right to use rooftop						
Yes	0.54559	0.321086	1.7	0.0890	-0.08373	1.174908

Ever applied	Coef.	Std. Err.	z	P>z	[95% Conf.	Interval]
_cons	-7.57695	0.904112	-8.38	0.0000	-9.34898	-5.80493
Number of observations		552				
LR $chi^2(14)$		341.95				
Prob > chi^2		0.0000				
Log likelihood = -206.11242	Pseudo R^2	0.4534				

Source: Author's survey, 2021

Consequently, and based on the specified predictor model of $f(H,i) = \beta_{0,h} + \beta_{1,h}X_{1,i}+\beta_{2,h}X_{2,i}+\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\beta_{n,h}X_{n,i}$, the predictor model for households ever applying for the NRSP can be specified as:

$$
\begin{aligned}
\text{Prediction of Ever applying} \\
&= -0.76 + (4.66 \times awareness\ of\ NRSP) + (0.23 \times household\ size) \\
&+ (1.35 \times household\ being\ the\ landlord) \\
&\vee\ (0.83 \times household\ being\ rent\ free\ occupant) \\
&+ (1.22 \times tertiary\ educational\ level) + (-0.0007 \times electricity\ expenditure) \\
&+ 0.9
\end{aligned}
$$

4.3.2 Determinants of Willingness to Rooftop Solar PV among households (Stated Preference using LR2)

To further examine the determinants of willingness to adopt rooftop Solar PV technology, the survey enquired from households whether they are willing to adopt Rooftop Solar PV systems. Responses were dummy coded using "0" for the base "No" and "1" for the target event "Yes". Again, a binary logistic regression model, taken to be statistically significant at $p<0.05$ was conducted for the responses. The model produced a statistically fit result, with an LR $chi^2(14)$ value of 162.81, and a Prob > chi^2 of 0.0000, which is significant over the baseline.

Of all the independent variables regressed, only awareness was statistically significant at $p<0.05$, with a coefficient of 2.57. This implies that there is a strong positive predictor relationship between awareness of Rooftop Solar PV schemes and the willingness of urban households to adopt them.

In effect, for every unit increase in a household being aware, there is an increase in the odd logs of its willingness to adopt by 2.57. The coefficient, which is greater than 1, further suggests that the probability of the household under study, falling into the target event group (being willing to adopt the technology), is higher than the predicted probability of it falling into the non-target event (not willing to adopt).

Even though the adequacy of grid-connected electricity was statistically insignificant under a two tail-test condition, a one-tail test would have made it statistically significant. This point towards evidence that there is a strong predictor relationship between the extent to which a household perceives electricity coming from the Grid, and its willingness to adopt a supplementary technology (herein the Grid-connected Solar PV system), to support its energy needs.

Table 5: Determinants of Willingness to adopt

Preference for GCSP	**Coef.**	**Std. Err.**	**z**	**P>z**	**[95% Conf.Interval]**	
Awareness						
Yes	2.567436	0.263448	9.75	0.0000	2.051088	3.083784
Household	0.021472	0.039651	0.54	0.5880	-0.05624	0.099188
Tenancy						
Landlord	0.028946	0.341408	0.08	0.9320	-0.6402	0.698093
Rent-free occupant	0.57153	0.360381	1.59	0.1130	-0.1348	1.277864
Education						
Basic Education	0.460871	0.46403	0.99	0.3210	-0.44861	1.370353
Secondary Education	0.539377	0.391679	1.38	0.1680	-0.2283	1.307054
Tertiary Education	0.639279	0.385616	1.66	0.0970	-0.11651	1.395072
Age	0.000502	0.000645	0.78	0.4370	-0.00076	0.001766
Sex	-0.01781	0.278351	-0.06	0.9490	-0.56337	0.527752

Preference for GCSP	Coef.	Std. Err.	z	P>z	[95% Conf.Interval]	
Employment						
Unemployed	-0.40201	0.436362	-0.92	0.3570	-1.25727	0.453244
Income	1.67E-05	1.69E-05	0.99	0.3230	-1.7E-05	4.99E-05
Electricity_expenditure	0.000437	0.000362	1.21	0.2280	-0.00027	0.001147
Grid_adequacy						
Yes	-0.49061	0.270053	-1.82	0.0690	-1.01991	0.038683
Right_to_fuse						
Yes	0.470891	0.29822	1.58	0.1140	-0.11361	1.055392
_cons	-1.2043	0.476914	-2.53	0.0120	-2.13903	-0.26956
Number of observations		552				
LR chi2(14)	162.81					
Prob > chi2	0.0000					
Log likelihood = -213.88685	Pseudo R2	0.2757				

Source: Author's survey, 2021

4.3.3 Determinants of Successful Application (Latent observation of predictor probabilities in beneficiary selection using LR3)

To examine the extent of variation between the various successful applicants, and which attributes of the households tend to make them more successful in their application. It must be noted that under the NRSP, out of the numerous households that make the application, it is the final decision of the Energy Commission of Ghana to determine which households benefit from the scheme and which ones do not. An attempt to define a predictor for the sample will therefore be best made under causality conditions. However, the absence of baseline data for this study limits the validity of causality analysis under the conditions of the results available.

Consequently, predicted probabilities were used to examine which variables are the most significant among the beneficiaries, to make limited inferences on the odd logs of predicting a household's chances of being selected when it applies to the scheme. In this regard, the results of the application among those who have applied were used as the dependent variable. With the dependent variable being dichotomous, and under dummy coding conditions, “Application successful” was dummy coded, with “0” being the base and “1” being the targeted event. A set of predictor variables from the socio-economic attributes of the housing units, as well as relevant attributes of the housing unit, were taken for the model. Awareness of the NRSP was omitted from the model because awareness is the basis for the submission of an application, hence will not have a significant variation across the sub-sample.

The model was taken to be statistically significant at $p<0.05$. A chi^2 probability value of 0.0000, and a Likelihood Ratio (LR chi^2) of 112.73 suggest that at $p<0.05$, the current model exhibits a significant improvement and fit over the base. The model was fitted among 234 observed households who have had successful applications. It was observed that at $p<0.05$, four (4) predictors were found to be statistically significant in predicting the probabilities of successful application. These predictors are the education level of the household (tertiary education), income, grid adequacy and right to use the rooftop.

Tertiary education produced a coefficient of 1.67, indicating that for each unit of increase in a household’s attainment of tertiary education, the odd log for successful application increases by 1.67. The coefficient being greater than 1 further suggests that the household has a higher predicted probability of falling into the target event group (successful application).

Income also produced a coefficient of 0.000038, with a p-value of 0.020. This shows a positive relationship between a household’s income and its chances of successful application, where for every unit increase in the income of a household, the odd log of successful application increases by 0.000038. The coefficient less than 1 suggests that the likelihood of the predicted probability of the households leaning towards the non-target event group (application not successful) is slightly higher. Even though the coefficient is negligible, it tends to suggest that the income level of beneficiary households have a significant predictor contribution in determining application success.

Again, grid adequacy obtained a statistically significant and positive coefficient of 1.88. this suggests that for every unit increase in the adequacy of grid-connected electricity among the households, the odd logs of successful application increased by 1.88. Being greater than 1, the results suggest that the predicted probability of the household falling within the group of successful applicants is higher.

Right to use the rooftop was statistically significant in the model, with a predictor coefficient of 2.31. This suggests that for every unit increase in a household having the right to use its rooftop to fix a grid-connected solar PV system, its odd log of successful application increases by 2.31. being greater than 1, this suggests further that the predicted probability of the household falling into the category of successful applicants is more than twice the probability of the households falling into the non-successful event group.

Table 6: Determinants of Successful Application

Application Successful	**Coef.**	**Std. Err.**	**z**	**P>z**	**[95% Conf.**	**Interval]**
Household	0.044486	0.049347	0.9	0.367	-0.05223	0.141205
Tenancy						
Landlord	0.77297	0.703714	1.1	0.272	-0.60628	2.152224
Rent-free occupant	-1.27512	1.254671	-1.02	0.309	-3.73423	1.183995
Education						
Basic Education	-0.62474	1.357438	-0.46	0.645	-3.28527	2.03579
Secondary Education	-0.17003	0.893396	-0.19	0.849	-1.92105	1.580994
Tertiary Education	1.660753	0.816056	2.04	0.042	0.061314	3.260193
age	0.019019	0.022957	0.83	0.407	-0.02598	0.064013
Sex						
Female	-0.24375	0.418368	-0.58	0.560	-1.06374	0.576236
Employment						
Unemployed	-1.06384	1.153844	-0.92	0.357	-3.32533	1.197658

Application Successful	**Coef.**	**Std. Err.**	**z**	**P>z**	**[95% Conf.**	**Interval]**
Income	3.81E-05	1.64E-05	2.32	0.020	5.98E-06	7.03E-05
Electricity_expenditure	0.000476	0.00059	0.81	0.419	-0.00068	0.001632
Grid_adequacy						
Yes	1.880732	0.468567	4.01	0.000	0.962357	2.799107
righ_to_fuse						
Yes	2.307102	1.020496	2.26	0.024	0.306967	4.307237
_cons	-6.93162	1.716974	-4.04	0	-10.2968	-3.56641
Logistic regression	Number of obs	=	234			
	LR chi2(13)	=	112.73			
	Prob > chi2	=	0.0000			
Log likelihood = -88.868821	Pseudo R2	=	0.3881			

4.4 Heterogeneity in adoption of GCSP among socioeconomic characteristics of urban households

With the previous predictor models establishing enough statistical evidence to infer that there is a significant level of variation, first between the individual predictor variables, and then within their power of predictions, the study sought to further ascertain how the statistically significant determinants, vary across the socio-economically attributes of the urban households. Again, the dichotomous variable, “ever applied”, which has responses “yes” and “no”, was considered the dependent variable, with retention of its original dummy coding values of “1” and “0” for the target event and base respectively.

Predictor variables that were statistically significant from BLR1 were taken and interacted with each other, and the interacting terms were then regressed against ever applying for the Grid Connected Rooftop Solar PV system under the NRSP. Essentially, six variables from the following 5 statistically significant predictors were used in creating the interacting terms:

a. awareness of NRSP

b. household size

c. tenancy status

d. educational level

e. electricity expenditure

The overall model was taken to be statistically significant at $p<0.05$. A McFadden pseudo R^2 os 0.5000 is not statistically significant at $p<0.05$, indicating that the effect of noise on the data was not significant. A probability value of 0.0000, and a chi-square value of 17.59 suggest that at $p<0.05$, the model exhibits a significant improvement and fit over the baseline. The model was fitted among 596 observations. It was observed that at $p<0.05$, awareness was statistically significant across one major variable and two dimensions: tenancy status (landlord status and rent-free occupant status). "Renter" was taken as the base in the model.

Table 7: Significant interacting terms from the heterogeneity model

Ever applied	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Awareness of NRSP x Household						
Yes	0.0354717	0.0115104	3.08	0.002	0.0128632	0.0580803
Yes x Landlord	0.3803554	0.0841168	4.52	0.000	0.2151344	0.5455764
Yes x Rent-free occupant	0.195944	0.0911211	2.15	0.032	0.0169653	0.3749228
_cons	-0.0666366	0.122464	-0.54	0.587	-0.3071787	0.1739056
Number of observations						596

Source	SS	df	MS		
				F (32, 563)	17.59
Model	72.718316	32	2.272447	Prob > F	0.000
Residual	72.731348	563	0.129185	R-squared	0.500
				Adj R-squared	0.4715
Total	145.44966	595	0.244453	Root MSE	0.35942

Results from the model suggest that awareness remain the only statistically significant variable at $p<0.05$. the interactions between awareness and tenancy statuses also produced statistically significant coefficients of 0.38 and 0.20 for landlords and rent-free occupants who were aware respectively. This implies that for every unit increase in awareness of the NRSP, the odd logs of landlords taking an actual decision to apply for a rooftop Solar PV system is 0.38 times higher compared to tenants. Similarly, for every unit increase in awareness, the odd logs of rent-free occupants taking an adoption decision are 0.20 times higher compared to tenants. Regardless, both models produced coefficients less than 1 suggesting a higher predicted probability of both households falling within the non-target event group.

4.5 Policy Alternatives for Improving the adoption of Roof Tied Solar PV Systems among urban households in Ghana

Following an analysis of the behaviour of households, the study sought to further investigate the context-sensitive and evidence-based alternatives that will contribute towards enhancing the adoption of rooftop Solar PV among households. Given this, the survey further investigated respondents' views on the economic, technical, and socio-political challenges of the programme. Respondents were presented with several challenges which were identified through review of secondary data and refined with expert discussions. The responses were weighted according to their frequencies in percentages for each category and ranked, to provide evidence on the most sensitive issues that need to be addressed by policy interventions.

4.5.1 Respondents' views on the Challenges of the NRSP

A total of five economic challenges were presented to the respondents for their views on the ones they perceive to characterise the National Rooftop Solar PV programme. All the problems produced significant standard errors. Importantly, the high cost of supporting infrastructure received the highest proportion rating coefficient of 0.87. The supporting infrastructure refers to all Balance of System Components required for a beneficiary household to be selected for the capital subsidy. Households who wish to benefit from the programme are required to purchase and install inverters, batteries, charge controllers, wires and fixtures, and this balance of system components are perceived to be high among most households. The finding agrees with that of Bondio et al. (2018), who indicated that even though middle-class households would be willing to adopt solar PV technologies, the ability to first afford the necessary capital requirements is critical to successful adoption. Dharshing, (2017) further corroborates this finding in his established evidence on the variation in adoption due to socio-economic differences, of which income and ability to pay for the technology is significant. Ardayfio (2021) in assessing the impact of the NRSP in Accra stressed that the main problem of the beneficiaries is the high cost of batteries, which are a mandatory balance of system components under the programme- a finding consistent with the perceived challenges of the respondents in this study.

Contrary to this, respondents did not perceive unattractive feed-in tariffs as a significant barrier to the adoption. In presenting his view on the subject, a survey participant in Accra affirmed: "*it is not as if they will pay you money if you sell into the grid, so to me, I don't think the tariff is even important to anyone. ECG will make sure you always have some bills to pay, so you just must forget about it. I think that most of these tariffs apply to the big power producing companies, so I don't think it should be among the problems. What is important is for a household to be able to understand that they need to switch to the renewables on their own because of the unreliable nature of the power for some time now…"* (Interview respondent's submission, Accra, 2021). The non-perception of feed-in tariffs as a major barrier among households in Ghana is explainable by the low awareness among households on such economic incentive schemes. Independent Power Producers (IPPs) are the most aware of these schemes since they are the basis for the trading of energy between them and the utility companies (Ackah & Asomani, 2015; Ofori et al., 2021).

Table 8: Economic challenges of NRSP

Proportion estimation of Economic Challenges	**Number of observations = 596**			
	Proportion	Std. Err.	[95% Conf. Interval]	
High cost of supporting infrastructure				

No	0.13255	0.013901	0.107548	0.162309
Yes	**0.86745**	0.013901	0.837692	0.892452
Limited credit options				
Yes	0.486577	0.020491	0.446508	0.52682
No	**0.513423**	0.020491	0.47318	0.553492
High cost of application				
No	0.206376	0.016591	0.175685	0.240861
Yes	**0.793624**	0.016591	0.759139	0.824315
Lack of viable business models				
No	0.364094	0.019726	0.3263	0.403643
Yes	**0.635906**	0.019726	0.596357	0.6737
Unattractive feed-in tariffs				
No	**0.630873**	0.019783	0.591245	0.66881
Yes	0.369128	0.019783	0.33119	0.408755

Source: Author's survey, 2021

In analysing the various technical challenges, again, all the challenges produced statistically significant standard errors at $p<0.01$. The proportion estimates analysis suggest that the most critical challenge perceived among the people was weak monitoring of the programme. Respondents affirmed that they sometimes hardly see the commission actively engaged in making sure the project is on the right track. Evidence from the website of the commission reveals failed attempts by most households to even access the application forms. In a recent study, the relevance of an effective monitoring scheme in driving the implementation of such programmes in Ghana is established (Kumi, 2017).

Even though lack of proper monitoring and maintenance received the lowest proportion estimates for its "yes" with the other challenges in this category, it still obtained an estimate greater than 0.5 out of the maximum 1. This implies that even the least perceived technical challenge received over 50% approval from the respondents, suggesting their overall significance.

Table 9: Technical challenges of NRSP

Proportion estimation of Technical Challenges	**Number of observations = 596**

	Proportion	Std. Err.	[95% Conf. Interval]	
Limited access to experts				
No	0.350671	0.019563	0.313282	0.389989
Yes	**0.649329**	0.019563	0.610012	0.686718
Lack of proper operations and maintenance				
No	0.493289	0.020496	0.453165	0.533499
Yes	**0.506711**	0.020496	0.466501	0.546835
Weak monitoring				
No	0.288591	0.018576	0.253519	0.326393
Yes	**0.711409**	0.018576	0.673607	0.746481

Source: Author's survey, 2021

In analysing the views of the respondents on the various socio-political challenges of the programme, the low level of beneficiary engagement received the highest proportion rating. Respondents there perceive the process of management of the scheme to be overly centralised. Closely, poor stakeholder coordination received a proportional rating of 0.61 out of 1.00, showing consistency in the perception of participants about the significant limitations in engaging the end-users and other relevant actors in the implementation of the programme. The limited coordination of stakeholders on the project is corroborated by the findings of Ardayfio (2021). He attributed the low patronage of the programme to the limited involvement of stakeholders.

Though statistically significant, poor provisions for equity, biases in selection and lack of financial transparency received higher odds for their "no" responses over the "yes". They each received proportional rates lower than 0.5, and since their standard error terms were statistically significant, it suggests that there is enough statistical evidence to suggest that these were not perceived as dominant challenges within the context of the National Rooftop Solar PV programme. This again agrees with the results of Ardayfio (2021), which did not find any significant challenge with equity in benefiting from the intervention.

Table 10: Socio-Political challenges of NRSP

Proportion estimation of Socio-political Challenges	**Number of observations = 596**			
	Proportion	Std. Err.	[95% Conf. Interval]	
Poor stakeholder coordination				
No	0.39094	0.020004	0.352432	0.430855
Yes	**0.60906**	0.020004	0.569145	0.647568
Lack of decentralization				
No	0.45302	0.020407	0.413329	0.493318
Yes	**0.54698**	0.020407	0.506682	0.586671
Poor provisions for equity				
No	**0.662752**	0.019382	0.623699	0.699703
Yes	0.337248	0.019382	0.300297	0.376301
Low level of beneficiary engagement				
No	0.308725	0.018939	0.272818	0.347102
Yes	**0.691275**	0.018939	0.652898	0.727182
Biases in selection				
No	**0.588926**	0.020171	0.548817	0.627888
Yes	0.411074	0.020171	0.372112	0.451183
Political interference				
No	0.335571	0.019358	0.298676	0.374588
Yes	**0.66443**	0.019358	0.625412	0.701324
Lack of financial transparency				
No	**0.578859**	0.020242	0.538678	0.618022
Yes	0.421141	0.020242	0.381978	0.461322

Source: Author's survey, 2021

4.5.2 Strategies for enhancing sustainable Rooftop Solar PV adoption

The study further sought to elicit the views of its respondents and experts on the various strategies that can be used to improve the performance of the project. The views of the participants were elicited with a final open-ended question within the survey questionnaire. However, the views of three experts, one each from the Energy Commission of Ghana, IMANI Centre for Policy and Education, and the Hammond Brew Energy Centre of the Kwame Nkrumah University of Science and Technology, were obtained through internet-based discussions and telephone calls.

The views of the respondents were analysed and consolidated under three themes (Figure 10). These themes were specified based on their response to the challenges that were earlier identified by the participants. Essentially, the views on the responses that could foster an improvement in the process were summarised under socio-political strategies and institutional strategies, technical changes, and economic response.

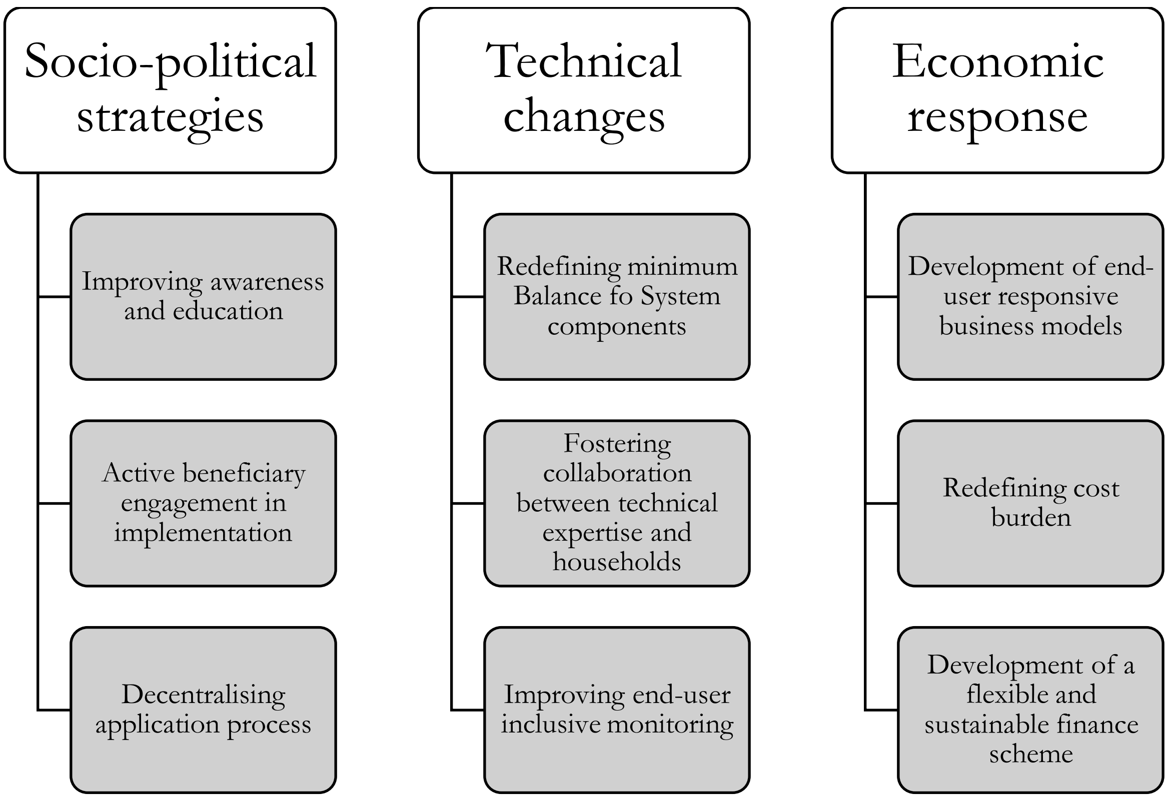

Figure 10: Strategies to improve performance of NRSP

4.6 Summary of results and findings

The study implemented an analysis of the determinants of adoption of rooftop Solar PV, the challenges in the implementation of the current model of the National Rooftop Solar Programme, and a collation of end-user and expert views on strategies to improve upon the programme. The results suggest a significant variation was revealed in the factors that influence the adoption behaviour of urban households for rooftop-Solar PV systems. Again, the interacting effects and observed preliminary behaviour of the variables in the various models suggest that the behaviour of households can be effectively modelled using predictor equations, and that can provide an insight into which specific variables should be targeted to enhance sustainable adoption.

A significant variation in taking adoption decisions was observed when the terms were interacted between the various socio-economic attributes of the respondents, with awareness creating a statistically significant change in the predicted probabilities across the tenancy status variable. Other variables did not produce statistically significant variations across the socio-economic attributes of the respondents.

Based on the experience of the respondents and their familiarity with the socio-economic, political, and institutional context of the study country, several economic, technical, and socio-political challenges were identified, which then provided the basis for collation of views on the best strategies towards facilitating a sustainable adoption. The main findings, therefore, provided the basis for the conclusions and recommendations that were made in the advancing chapter of this study.

CHAPTER FIVE

SUMMARY OF MAJOR FINDINGS, RECOMMENDATIONS AND CONCLUSION

5.1 Introduction

This chapter presents a conclusion to the study. It highlights the major findings in response to the initial research questions and draws conclusions based on those findings. The conclusions and findings are then used to make evidence-based recommendations that will enhance the uptake of Grid-Connected Rooftop Solar PV technology, particularly among urban households in Ghana.

The chapter further discusses the adequacy of the theoretical and conceptual frameworks adopted in the study with their contribution towards comprehensive attainment of the study objectives. Areas for further research were recommended based on the study findings.

5.2 Summary of Major Findings

Research Question One: What are the factors that drive the adoption of rooftop Solar PV among urban households in Ghana?

From the survey and based on the respondent's actual decision to adopt rooftop solar PV under the National Rooftop Solar PV programme, five major factors, which are defined by six major levels, as key drivers to the adoption of rooftop solar PV in Ghana. These factors were obtained from the results of BLR-1, and were statistically significant at $p<0.05$:

1. Awareness (measured by the household's awareness of the existence of NRSP)
2. Household size (defined by the number of people living in each of the study households)
3. Tenancy status (defined by whether the person is a renter, a landlord, or a rent-free occupant, but produced only landlord and rent-free occupants as significant determinants)
4. Educational level (defined by the highest educational qualification obtained by the head of household, of which tertiary qualification is the most significant)
5. Electricity expenditure (defined by the average monthly electricity bill paid by the household).

Research Question Two: What is the nature of interactions between the significant determinants of adoption of rooftop solar PV in Ghana?

Based on the outcome of the logistic regression model among the variables, the coefficients of the various statistically significant variables in objective 1, were used to specify a predictor model for the marginal effects which each of them has on the adoption behaviour of urban households. The model was thus specified as:

$$\begin{aligned}\text{Predictor model for ever applying}\\ &= -0.76 + (4.66 \times awareness\ of\ NRSP) + (0.23 \times household\ size)\\ &+ (1.35 \times household\ being\ the\ landlord)\\ &\vee\ (0.83 \times household\ being\ rent\ free\ occupant)\\ &+ (1.22 \times tertiary\ educational\ level) + (-0.0007 \times electricity\ expenditure)\\ &+ 0.9\end{aligned}$$

The strongest prediction power was obtained by awareness, with tenancy status being second. This was followed by educational level and household size. Electricity expenditure is the least predictor variable.

Research Question Three: How do the determinants of adoption of solar PV vary across the diverse socio-economic characteristics of urban households?

The six statistically significant predictor variables from research question 1 were used in creating the interacting terms. The new model was taken to be statistically significant at $p<0.05$. The model was fitted among 596 observations. It was observed awareness was statistically significant across one major variable and two dimensions: tenancy status (landlord status and rent-free occupant status).

It was revealed that for every unit increase in awareness of the NRSP, the odd logs of landlords taking an actual decision to apply for a rooftop Solar PV system is 0.38 times higher compared to tenants. Similarly, for every unit increase in awareness, the odd logs of rent-free occupants taking an adoption decision is 0.20 times higher compared to tenants. All other interacting terms did not produce a statistically significant variation at $p<0.01$.

Research Question Four: What are the best practices and policy alternatives that will enhance the sustainable adoption of rooftop solar PV technology in Ghana?

The study revealed the following as best policy strategies that will enhance the sustainable adoption of rooftop solar PV among urban households in Ghana

A. **Socio-political strategies**

- Improving awareness and education
- Active beneficiary engagement in implementation
- Decentralizing application process

B. **Technical changes**

- Redefining minimum Balance of System components
- Fostering collaboration between technical expertise and households
- Improving end-user inclusive monitoring

C. **Economic response**

- Development of end-user responsive business models
- Redefining cost burden
- Development of a flexible and sustainable finance scheme

5.3 Study Recommendations

Short Term Policy Recommendations

The following recommendations are made for the short term (3 to 5 years)

1. Institutionalising a learning monitoring and evaluation system for the implementation of the National Rooftop Solar PV programme: Having identified the absence of an effective monitoring and evaluation system as a major challenge in the implementation, the study recommends the setting up of a framework, with adequate legal backing, that will ensure a people-centred approach and learning towards regularly tracking the progress of the project in line with initial objectives. This way, impacts can effectively be estimated using advanced econometric models that will further investigate the behaviour of the significant determinants of the adoption revealed in preliminary studies such as this, and necessary mediation measures can be taken to develop useful evidence-based intervention models that target causal variables to enhance sustainable adoption.

2. Collaborative management of the project with active development partners and private organisations in the energy field: An important observation from the study is the highly centralised nature of the programme, with limited involvement of non-governmental players. With the implementation success not depending on capital subsidy availability alone, enhancing stakeholder engagement and collaboration with institutions that have adequate experience in the implementation of renewable energy projects can contribute towards enhancing project success. The short-term collaboration with organisations such as the GIZ, will enable shared learning from similar experiences, and then the country can consolidate such knowledge and after the end of the collaboration period, adequate lessons would have been learnt to facilitate sustainability.
3. Rolling out awareness campaigns using mainstream media: The study observes the dominant influence of awareness on adoption decisions. However, with a significant proportion of the participants indicating that they are not aware of the existence of the programme, rolling out short campaign messages and fusing them with mainstream media activities such as breaks during news segments on TV and radio will contribute towards enhancing such awareness levels.

Medium-Term Policy Recommendations (5-10 years)

1. Development of Robust finance scheme for the model: The study recommends the development of a finance mechanism that is self-sustaining to replace the current capital subsidy model. This is because of the recorded low levels of adoption observation of low adoption rates among the study sample, which raises questions about the effectiveness of the existing model. Other finance models that provide an avenue for recouping the cost of the capital subsidy components (the panel) can be explored. Notable among such examples is the IDCOL model for financing Solar Home Systems in Bangladesh. Adapting such models to the context of Ghana can promote project sustainability and prevent stagnation of projects due to the lack of annual budgetary allocations from the government for subsidies.
2. Institutionalising agreements with homeowners to incorporate Rooftop Solar PV as part of the building infrastructure with appropriate cost recovery incentives: Having observed a higher adoption likelihood among landlords, it is important to target them in interventions

that seek to affix permanent structures to their facilities. With urban Ghana being dominated by the rental housing sector, whose locational decisions are largely defined by their work, the study recommends that government should liaise with homeowners and property developers to install these rooftop Solar PV systems and use mechanisms such as cost-sharing together with tenants to promote the uptake of the technology.

Long Term Policy Recommendations

1. Localising the production of Solar Panels to reduce cost: With renewable energy technologies, particularly solar technologies becoming increasingly cheaper with mass production, the government should invest in establishing local production centres for the components to reduce import, and subsequently reduce the overall cost for this equipment. The study is mindful of the fact that government does not necessarily have to assume production responsibilities but can enter appropriate Private Sector Participation arrangements with firms that have the capacity and provide an oversight role in managing the externalities as typical of such market systems.

5.4 Implications of Study Findings on Conceptual and Theoretical Framework

The conceptual framework adopted for this study modelled the solar PV adoption behaviour of urban households as a function of their attributes. The results obtained demonstrated clearly that there is a significant predictor relationship between attributes of households and their probability of adopting a rooftop solar PV system. However, the evidence suggests that the attributes of the households alone are inadequate in predicting their overall adoption behaviour. Other environmental factors outside the scope of this study, both endogenous and exogeneous to the regime of the current intervention shape the adoption behaviour, hence the influence of the results on policy is limited to recommendations. Further examining causality based on panel data regression will provide a more reliable framework for comprehensive modelling of the behaviour of households.

Again, the Diffusion of Innovations Theory and the Technology Acceptance Model that were applied to this study provided adequate tenets for hypothesising towards the understanding how the perceptions and attitudes of households influence their uptake of new technology. This explains the lower rates of adoption at these earlier stages of the programme while pointing out the need for time to allow for such adoption to diffuse within the larger population set. However, further institutional economics analyses would contribute towards enhanced clarification of the phenomenon and development of more robust models that can drive the implementation of the programme.

5.5 Areas for Further Research

Based on the initial evidence observed, the following areas are recommended for further research:

a. Panel regression of the determinants of rooftop solar PV adoption, to establish causality among a larger sample.
b. Institutional economics analysis of the adoption of rooftop solar PV in Ghana and other countries with similar socio-economic attributes (such as studies contributing to the understanding of the technical system of the Grid-tied Solar PV system within the context of Ghana, examining the roles and nature of interaction between actors, and analysis of the institutions and organisations that drive the adoption of the technology in Ghana)
c. Developing and comparing evidence-based models (finance, capacity development and awareness, regulation) for the adoption of solar PV in Ghana

5.6 Conclusion

The study adopted a cross-sectional survey with econometric analysis to model the behaviour of urban households in Ghana towards the adoption of Rooftop Solar PV technology. It draws its respondents from both beneficiaries of the National Rooftop Solar PV programme being implemented by the government of Ghana, and non-beneficiaries.

The study generates enough evidence to suggest that the adoption behaviour of households can be modelled using predictor equations. While it is limited in investigating causality due to the absence of baseline data on the beneficiaries themselves, it establishes reliable scientific evidence that can stimulate policy thoughts in terms of which variables among households to target for reinforcement to improve the success rate and sustainability of the program, as well as stimulate the overall increase in the renewable share of electricity in Ghana's overall energy mix.

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Appendix one: Survey Questionnaire

<u>PAN AFRICAN UNIVERSITY</u>

<u>INSTITUTE OF WATER AND ENERGY SCIENCES (INCLUDING CLIMATE CHANGE)</u>

<u>(In collaboration with MicroEnergy International GmbH and WIP, TU Berlin)</u>

I am an MSc Energy Policy student at the Pan African University Institute of Water and Energy Sciences (Including Climate Change) in Algeria. This questionnaire is to help obtain data towards understanding the drivers of Rooftop Solar PV technology adoption among urban households in Ghana, to develop evidence-based models that can enhance sustainable adoption of renewable energy technologies.

You have been selected as a respondent because you are the head of an urban household in Ghana who is a potential beneficiary of the National Rooftop Solar PV programme. Please be assured that every response given in this survey is going to be used solely for academic purposes and reported with high degree of anonymity and confidentiality.

Part II: Adoption of Rooftop Solar PV technology under the National Rooftop Solar Project

This second part of the questionnaire seeks to understand the extent to which you are willing to adopt a grid-tied solar PV technology as well as which factors you significantly influence your decision. Kindly tick your most preferred response in the appropriate box.

1. Will you like to adopt a rooftop Solar PV system connected to the grid?
   1 Yes [ ]
   2 No [ ]
2. If your answer to question 13 above is yes, why will you want to have a grid-tied rooftop solar PV?
   1 I just feel like having it because everyone is talking about it [ ]
   2 To help protect the environment and mitigate climate change [ ]
   3 To cut down household cost on energy [ ]
   4 To enhance reliability in power supply [ ]
   5 Any other reason (please specify) [ ]
   ……
   ……
   ……
3. If your answer to question 13 above is No, why are you not interested in having a grid-tied rooftop solar PV?

1 I have enough electricity for my need from the current source [ ]
2 My current energy source is cheaper for me [ ]
3 I am not aware of any special benefits of grid-tied rooftop solar PV [ ]
4 Any other reason (please specify) [ ]
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………

4. How do you think rooftop solar PV systems tied to the grid should be financed?
   1 One time payment [ ]
   2 Leasing [ ]
   3 Other options [ ]
   Please specify
   ……………………………………………………………………………………………………
   …………………………………………………………………………………………………….
5. Who do you think should bear the cost of rooftop solar PV?
   0 The landlord (even if property is being rented)
   1 The tenants in case of rented house
   1 Shared cost between landlords and tenants

6. Are you aware of the existence of a National Rooftop Solar programme in Ghana?
   1 Yes [ ]
   2 No [ ]
7. If yes, how did you hear about the programme?
   1 Through media announcement (radio, television, newspaper) [ ]
   2 Through a friend/colleague/referral [ ]
   3 From the Website of the Energy Commission [ ]
   4 On social media (Facebook, Twitter, etc…) [ ]
   5 Officials of the Energy Ministry/Commission/ECG [ ]
   6 Other [ ]
8. Are you familiar with the application process to become a beneficiary of the programme?
   1 Yes [ ]
   2 No [ ]
9. Have you ever applied to be considered as a beneficiary of the programme?
   1 Yes [ ]
   2 No [ ]
10. If you have **ever** applied, was your application successful?
    1 Yes [ ]
    2 No [ ]
11. If you have n**ever** applied, what is your reason?
    1 I did not apply because I am not aware [ ]
    2 I have heard that the process is not transparent so I do not want to waste my time [ ]
    3 I know people who have applied and did not get so I did not wish to [ ]
    4 I wish to apply but I do not have access to internet [ ]
    5 I do not have money for the installation of the BOS [ ]

6 I am not able to access a loan from any bank to purchase the BOS [ ]
7 Any other reason (please specify) [ ]
……………………………………………………………………………………………………..

12. For respondents who have indicated yes to question 22 above, how will you describe the application process?
1 Complex [ ]
2 Simple [ ]
13. How much is to total cost you incurred in the installation under the project if your answer to question 23 is Yes?

Parameter	**Description**	**Cost**
BOS components specified by EC	a. Inverter	
	b. Charge controllers	
	c. Batteries	
	d. Cables and others	
EES component	e. LED Lamps	
Installation and other costs	f. Labor/Technician charges	
	g. Other costs	
Solar Panel*	h. Cost of panel	
Total Cost		

**Cost of solar panel is only applicable in cases where the household purchased the panel themselves and had the Energy Commission reimburse them for the cost.*

14. Are you willing to take a loan under flexible conditions based on your household income to pay for a grid-tied rooftop solar PV facility?
1 Yes [ ]
2 No [ ]

Part II: Adoption of Rooftop Solar PV technology under the National Rooftop Solar Project

This section seeks to understand the complexities surrounding the nature and implementation of the National Rooftop Solar project so as to suggest objective models that can ensure sustainable success.

15. Which of the following **economic factors** do you perceive as barriers to successful implementation of the National Rooftop Solar PV programme?

1 High cost of supporting infrastructure/BOS (inverter, cables, battery, etc…) [ ]
2 Limited options for accessing credit to purchase supporting infrastructure [ ]
3 High cost of application (internet, telephone calls, etc…) [ ]
4 Lack of viable business models for beneficiaries [ ]
5 Unattractive feed-in tariffs for economic benefits [ ]
6 Other (please specify) [ ]

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

16. How will you rank the various **economic barriers** to accessing the programme on the given scale? (Please note that each rank can be chosen just once)

	1 insignificant	2 minor	3 moderate	4 major	5 extreme
a. High cost of supporting infrastructure/BOS					
b. Limited options for accessing credit to purchase supporting infrastructure					
c. High cost of application (internet, telephone calls, etc…)					
d. Lack of viable business models for beneficiaries					
e. Unattractive tariffs for grid-integration					

17. Which of the following **technical factors** do you perceive as barriers to the success of the National Rooftop Solar PV programme?

1 Limited access to solar PV technology experts [ ]
2 Weak monitoring arrangements for the programme [ ]
3 Lack of operation and maintenance capacity for solar PV systems [ ]
6 Other (please specify) [ ]

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
………………………

18. How will you rank the various **technical barriers** to affecting the programme on the given scale? (Please note that each rank can be chosen just once)

	1 insignificant	2 minor	3 moderate	4 major	5 extreme
a. Limited access to solar PV technology experts					
b. Weak monitoring arrangements for the programme					
c. Lack of operation and maintenance capacity for solar PV systems					

19. Which of the following **socio-political factors** do you perceive as barriers to benefiting from the National Rooftop Solar PV programme?

1 Poor coordination between stakeholders [ ]
2 Lack of decentralization of the process [ ]
3 Poor provisions for equity in qualifications for the project [ ]
4 Low level of beneficiary engagement [ ]
5 Perceived biases in selection process [ ]
6 Political interference in the project [ ]
7 Lack of financial transparency in the management [ ]
8 Other (please specify) [ ]

………………………………………………………………………………………………………
………………………………………………………………………………………………………
………………………………………………………………………………………………………

20. How will you rank the various **socio-political barriers** to the success of the programme on the given scale? (Please note that each rank can be chosen just once)

	1 insignificant	2 minor	3 moderate	4 major	5 extreme
Poor coordination between stakeholders					
Lack of decentralization of the process					
Poor provisions for equity in qualifications for the project					
Low level of beneficiary engagement					
Perceived biases in selection process					
Political interference in the project					
Lack of financial transparency in the management					

Part III: Respondent's background information

***Instruction**: Please tick where appropriate. Where spaces are provided, kindly write responses briefly.*

21. How many people are in your household? ……………………
22. What is your tenancy status?

    1 Renter [ ]

    2 Landlord [ ]

    3 Rent-free occupant [ ]

23. Do you have legal right to develop a facility on the rooftop of your housing unit?

    1 Yes [ ]

    2 No [ ]

24. What is your level of educational attainment/ current educational level?

    1 No formal education [ ]

    2 Primary School [ ]

    3 Junior High School [ ]

    4 Senior High School [ ]

    5 Tertiary [ ]

25. What is your employment status?

    1 Employed [ ]

    2 Unemployed [ ]

26. If employed, please indicate by ticking, the sector of your employment.

    1 Formal sector [ ]

    2 Informal sector [ ]

27. If you put together the income received by all the members of your households in a month, how much will it be on average? (please use the closest accurate estimate as possible) GH¢ …………
28. How much on average do you spend in a month on electricity bills? GH¢ …………
29. Do you have an account with a bank?

    1 Yes [ ]

    2 No [ ]

30. Are you able to access a loan facility at your bank?

    1 Yes [ ]

    2 No [ ]

31. Kindly indicate your level of satisfaction with the grid connected electricity by ECG/NEDCO.

Dimension	1 very unsatisfied	2 unsatisfied	3 neutral	4 satisfied	5 very satisfied
a. Tangibles: Physical facilities e.g., meters, cable connections, etc…					
b. Reliability: Dependable supply of electricity at all times needed					
c. Responsiveness: Promptness of ECG/NEDCO in solving problems					
d. Assurance: Trust and confidence in technical competency of ECG/NEDCO employees					
e. Empathy: How ECG/NEDCO employees relate to you (care)					
f. Cost: Monthly expenditure on grid supplied electricity					

32. Do you have any other alternative source of electricity in the house?

    1 Yes [ ]

    2 No [ ]

33. If your answer to question 11 above is yes, kindly indicate which of the following apply.

    1 Standby Diesel Generator [ ]

    2 Rooftop solar PV [ ]

    3 Others (please specify) [ ]

    ……………………………………………………………………………………………………

    ……………………………………………………………………………………………………

34. Are you available for further discussions that will help improve the rooftop solar PV programme?

    1 Yes [ ]

    2 No [ ]

35. Any comments or views you wish to share on how the National Rooftop Solar PV project can be upscaled sustainably?

    ……………………………………………………………………………………………………

    ……………………………………………………………………………………………………

Closure and Appreciation

I wish to thank you very much for your time. Be assured once again that all information given will be used solely for academic purposes, and your responses will greatly contribute towards attaining the objectives of the research.

Appendix two: Results of Interacting Terms for Heterogeneity Estimations

Ever_Applied	**Coef.**	**Std. Err.**	**t**	**P>t**	**[95% Conf. Interval]**	
Awareness_of_NRSP						
Yes	0.1177637	0.1221186	0.96	0.335	-0.1221	0.3576274
Household	0.0115664	0.0139274	0.83	0.407	-0.0157896	0.0389225
awareness_of_NRSP#c.Household						
Yes	0.0354717	0.0115104	3.08	0.002	0.0128632	0.0580803
Tenancy						
Landlord	0.0156396	0.1257379	0.12	0.901	-0.231333	0.2626122
Rent-free occupant	0.1971768	0.1931309	1.02	0.308	-0.1821682	0.5765219
awareness_of_NRSP#Tenancy						
Yes#Landlord	0.3803554	0.0841168	4.52	0	0.2151344	0.5455764
Yes#Rent-free occupant	0.195944	0.0911211	2.15	0.032	0.0169653	0.3749228
Education						
Basic Education	0.1022487	0.1619558	0.63	0.528	-0.2158626	0.4203601
Secondary Education	-0.0106774	0.1248777	-0.09	0.932	-0.2559605	0.2346057
Tertiary Education	0.0593433	0.1198962	0.49	0.621	-0.1761553	0.2948419
awareness_of_NRSP#Education						
Yes#Basic Education	0.0654693	0.130197	0.5	0.615	-0.190262	0.3212005
Yes#Secondary Education	0.0480976	0.1078413	0.45	0.656	-0.1637228	0.259918
Yes#Tertiary Education	0.1436867	0.1087654	1.32	0.187	-0.0699487	0.3573222

Ever_Applied	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Electricity_expenditure	0.0000649	0.000317 2	0.2	0.838	- 0.0005582	0.000687 9
awareness_of_NRSP#						
c.Electricity_expenditure						
Yes	- 0.0002804	0.000220 8	-1.27	0.205	-0.000714	0.000153 3
Household	0	(omitted)				
Tenancy#c.Household						
Landlord	- 0.0167187	0.010719 1	-1.56	0.119	-0.037773	0.004335 7
Rent-free occupant	- 0.0032357	0.015410 3	-0.21	0.834	- 0.0335045	0.027033 1
Household	0	(omitted)				
Education#c.Household						
Basic Education	-0.017047	0.022619 5	-0.75	0.451	- 0.0614759	0.027381 9
Secondary Education	- 0.0077802	0.013091 5	-0.59	0.553	- 0.0334942	0.017933 9
Tertiary Education	- 0.0154417	0.013046 6	-1.18	0.237	- 0.0410677	0.010184 3
Household	0	(omitted)				
Electricity_expenditure	0	(omitted)				
c.Household#						
c.Electricity_expenditure	8.82E-06	0.000015 3	0.58	0.564	- 0.0000212	0.000038 8
Tenancy#Education						
Landlord#Basic Education	0.2131999	0.156304 5	1.36	0.173	- 0.0938114	0.520211 2
Landlord#Secondary Education	0.0879784	0.121868 5	0.72	0.471	- 0.1513941	0.327351

Ever_Applied	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Landlord#Tertiary Education	0.1316642	0.1214614	1.08	0.279	-0.1069087	0.370237
Rent-free occupant #						
Basic Education	0.0174703	0.1792228	0.1	0.922	-0.3345568	0.3694974
Rent-free occupant #						
Secondary Education	0.0346323	0.1572667	0.22	0.826	-0.2742688	0.3435334
Rent-free occupant #						
Tertiary Education	-0.00877	0.1606254	-0.05	0.956	-0.3242682	0.3067283
Electricity_expenditure	0	(omitted)				
Tenancy#						
c.Electricity_expenditure						
Landlord	-0.0000624	0.0002066	-0.3	0.763	-0.0004681	0.0003434
Rent-free occupant	-0.0006709	0.0003626	-1.85	0.065	-0.0013831	0.0000414
Electricity_expenditure	0	(omitted)				
Education#						
c.Electricity_expenditure						
Basic Education	-0.0003356	0.0003549	-0.95	0.345	-0.0010326	0.0003614
Secondary Education	0.0001753	0.0003106	0.56	0.573	-0.0004348	0.0007853
Tertiary Education	0.0000633	0.0002746	0.23	0.818	-0.000476	0.0006025
_cons	-0.0666366	0.122464	-0.54	0.587	-0.3071787	0.1739056
Source	SS	df	MS	Number of obs	=	596
				F(32, 563)	=	17.59
Model	72.718316	32	2.272447	Prob > F	=	0

Ever_Applied	**Coef.**	**Std. Err.**	**t**	**P>t**	**[95% Conf. Interval]**	
Residual	72.731348	563	0.129185	R-squared	=	0.5
				Adj R-squared	=	0.4715
Total	145.44966	595	0.244453	Root MSE	=	0.35942
ever_applied	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
awareness_of_NRSP#c.Household						
Yes	0.0354717	0.0115104	3.08	0.002	0.0128632	0.0580803
Yes#Landlord	0.3803554	0.0841168	4.52	0	0.2151344	0.5455764
Yes#Rent-free occupant	0.195944	0.0911211	2.15	0.032	0.0169653	0.3749228
_cons	-0.0666366	0.122464	-0.54	0.587	-0.3071787	0.1739056
Source	SS	df	MS	Number of obs	=	596
				F(32, 563)	=	17.59
Model	72.718316	32	2.272447	Prob > F	=	0
Residual	72.731348	563	0.129185	R-squared	=	0.5
				Adj R-squared	=	0.4715
Total	145.44966	595	0.244453	Root MSE	=	0.35942