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Solar Photovoltaic (PV) – Diesel Hybrid Mini-Grid Systems

And Improving Electricity Access in Rural Ghana

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ABSTRACT

Energy is an essential component of human lives and improving access to clean, affordable, reliable, and modern energy services, as is the objective of the Sustainable Development Goal (SDG) 7, is vital to the wellbeing of people and for socio-economic development. Despite the undoubted importance of energy, globally about 770 million people have no electricity access and 2.5 billion others are without access to clean fuels, thereby relying on traditional solid fuels as their primary source of fuels to meet their energy needs. The use of these traditional fuels has significant impacts on the health, social and economic development of the affected people and the environment. In the bid to achieve the objective of SDG 7 and improve the well-being of the affected global population, several interventions have been set up to address the energy access problem. However, these interventions have not been able to achieve their intended targets due to reasons such as the fact that energy access research and interventions have focused on the science, engineering, and economic dimensions of the problem with limited attention on the social and human dimensions, especially in the Sub-Saharan Africa context. For a comprehensive approach, further research to understand the impacts of socio-cultural practices of end-users such as traditions and behaviours, energy needs/priorities of the users, and energy behaviour is vital.

Echoing the global energy access problem in Ghana, the research aimed to assess the social and cultural determinants of energy access in rural island communities in the Ada East district to better understand the feasibility of solar PV-diesel hybrid mini-grid systems for improving electricity access. The research adopted a mixed-method approach (surveys and interviews) to collect data on the energy needs of the research participants, the socio-cultural determinants of energy access and the factors

promoting and impeding the adoption of renewable energy technologies. The research adopted and applied Quinn et al.'s (2018) logic model for clean fuel scale-up to the adoption of Solar PV-diesel hybrid mini-grids for electricity access.

The results showed that energy needs vary widely within households and communities, and these are impacted by demographics and socio-cultural practices such as energy priorities, gender roles, and intrahousehold decision-making, among others. The research further revealed that to ensure the sustainability of projects and interventions to improve access to modern energy services, there is a need to adopt a "bottom-up" approach to ensure that the needs and concerns of end-users are given adequate consideration. The research is the first to apply Quinn et al.'s (2018) model on clean fuel scale-up to the adoption of renewable energy technologies and establish that it is applicable albeit with some adaptations. The research contributed to the gaps in the literature on energy access by showing the linkages between different age groups and household energy access as well as showing that differences in intrahousehold energy needs and priorities significantly influenced energy choices and decisions. The research also explored the impact that end-user perception has on the willingness to adopt renewable technology and the successful implementation of renewable energy projects in general.

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CHAPTER ONE

INTRODUCTION

1.0 Background

Energy is crucial to human existence and development. The benefits derived from everyday use of energy cuts across the various aspects of human daily lives such as security, production, health care, education, pollution reduction, agriculture, water and sanitation, women empowerment, and other areas. The availability of clean, affordable, and reliable modern energy for everyone is of critical importance; especially to promote improvements in the lives of people globally and sustainable development (Sovacool et al., 2016; Singh et al., 2015; Kemausuor et al., 2011). The significance of energy to human development and advancement is corroborated by Ban Ki-Moon, former Secretary-General of the United Nations (UN), who highlighted that "Energy is the golden thread that connects economic growth, increased social equity, and an environment that allows the world to thrive. Development is not possible without energy, and sustainable development is not possible without sustainable energy" (United Nations Development Programme, 2016).

The launch of the Sustainable Development Goals (SDGs) by the United Nations in 2016 was part of the 2030 Agenda for Sustainable Development. This was a global call to action to improve water access and sanitation, promote health and wellbeing, ensure clean, affordable energy, end poverty and hunger, ensure environmental protection, minimize inequalities, take climate action, and promote sustainable communities (United Nations, 2015). Although energy was not recognised as an individual goal in the Millennium Development Goals (MDGs) that expired in 2015

before the adoption of the SDGs, the SDGs have goal 7 dedicated to ensuring access to affordable, reliable, sustainable, and modern energy for all by 2030. This is in recognition of the importance of clean and sustainable energy to a sustainable future, especially in the face of climate change, and the achievement of several other SDGs.

Despite the importance of clean, affordable and modern energy access for cooking, heating and lighting, a large proportion of the world's population continues to live without access to clean, affordable and reliable energy resources to meet their daily energy needs. According to the World Bank (2018), numerous efforts are being made to improve access to electricity and other modern energy services, however, to be able to achieve SDG 7, a lot more interventions are needed than at present. The International Energy Agency (IEA) (2020) estimates that as of 2019, 770 million people globally had no access to electricity and some 2.6 billion others as of 2018 did not have access to clean cooking fuels and facilities. The only option available for people without access to modern energy services is to rely on traditional energy sources such as biomass, coal and kerosene to meet their energy needs for cooking, lighting and heating. The use of biomass and other traditional fuels produces high levels of household air pollution and continuous exposure to these pollutants produced results in damaging impacts on health. Globally, an estimated 3.8 million people die annually from illnesses linked to household air pollution resulting from the use of fuels such as biomass and coal. Others exposed to this household air pollution produced suffer from damaging respiratory health conditions (World Health Organization, 2021). The reliance on these traditional fuels undermines social and economic development while also posing an environmental risk for the most vulnerable populations in low-income countries, many of whom are children and women (Owusu and Asumadu-Sarkodie, 2016). The absence of electricity, clean cooking fuels and

other modern energy services undermines development and has a significant impact on a wide array of development indicators such as health, poverty reduction, education, livelihoods, water supply and sanitation, gender equality, and food security among several others (World Bank, 2018). The majority of the global population without access to modern energy sources for lighting, cooking, heating and other services are located in Sub-Saharan Africa (SSA), South America and developing Asia. Approximately 75% of the global population without access to electricity live in SSA and only 15% of the population in SSA have access to clean cooking technology and facilities (International Energy Agency, 2020a).

Sovacool (2012) defines this lack of access to clean energy services such as electricity for lighting and modern energy fuels for cooking as energy poverty. This definition of the problem agrees with other definitions that are presented in Chapter 2 of this thesis. With high energy poverty being of major global concern, numerous interventions are being made by governments, civil society organisations, development agencies, Non-Governmental Organizations (NGOs) and private companies to remedy the situation. The number of people gaining electricity access in SSA has seen significant increments of 20 million people annually between 2014 and 2019 as opposed to 9 million people being connected between 2000 and 2013. A majority of these improvements have been recorded across a few countries such as Senegal, Kenya, Senegal, Ghana, Rwanda, Ethiopia, Gabon, and Seychelles (International Energy Agency, 2020a).

Despite the increasing improvement in the electricity access rates in SSA, a lot more work is required to deal with other challenges with electricity availability and access in the region. In most of the countries in SSA recording increasing electricity access, electricity access is predominantly widespread in urban, peri-urban and easily accessible locations, whereas electricity access in rural and remote locations continues

to be low. Electricity connections are usually readily available in urban and easily accessible locations in these countries while rural and remote locations are usually without electricity access and connection (Blimpo et al., 2020; Sarkodie and Adams, 2020; Dagnachew et al., 2017). There are also challenges for the populations in the connected locations, who usually have to contend with unreliable and erratic electricity supply on a daily basis (World Bank, 2018; International Energy Agency, 2017; Angelou and Bhatia, 2014). Some of the contributing factors to the unreliable and erratic electricity supply include growth in demand outpacing the supply due to ageing technology and infrastructure, inadequate network distribution in addition to problems with the existing infrastructure, transmission, and distribution losses. Other factors include power theft, revenue losses and energy losses due to the distance from the generation stations to the end-users, high urbanization rates and inadequate investment (Avila et al., 2017; Kemausuor and Ackom, 2017a; Eshun and Amoako-Tuffour, 2016).

A lot of developing countries, especially in SSA, have a low number of electricity generation plants. For some countries, their electricity generation is over-reliant on hydropower, where applicable, and imported fuel for gas turbines and other thermal generators. This makes the energy mix of these countries less energy secure (Rawn and Louie, 2017). As of 2018, the net generation capacity[1] for countries in SSA excluding South Africa was 80 GW, whereas the generation capacity for South Africa and North African countries was 165 GW. Comparing the net generation capacity for the whole of Africa to that of Europe (net generation capacity in 2017 was 1060 GW),

[1] Referring to the actual amount of electricity generated

it is obvious a lot more work needs to be done to increase the availability of electricity in Sub-Saharan countries (ENTSO-E, 2018; IEA, 2019).

1.1 Decentralised Off-Grid Systems

In addressing the challenge of energy poverty, particularly the lack of electricity access, decentralised off-grid electricity systems, as Ulsrud (2020) points out, are proving to be viable alternatives to centralised grid connection in extending electricity access, especially to rural and remote locations where most of the affected people live. The development of off-grid systems also eliminates a lot of the challenges for extending electricity access to rural and remote locations associated with centralised grid connectivity in SSA currently. Off-grid electrification technologies are suited for areas where grid connectivity is technically and economically less feasible like island communities. Decentralised systems have also been shown to require a relatively less initial investment in comparison to centralised grid infrastructure, and are economically feasible for locations with low consumption levels and populations as is the case in rural and remote locations (Azimoh et al., 2017; Dagnachew et al., 2017; Rawn and Louie, 2017).

According to Dagnachew *et al.*, (2017) the choice of electrification options for a location is dependent on factors like distance from an existing power line; electricity consumption; resource availability; and population density. Thus, in the case of most rural locations across SSA that are several kilometres away from existing power lines, with low populations and low levels of electricity consumption, off-grid electricity generation technologies are the most suitable approach for increasing access. These decentralised off-grid electrification systems may be either developed as standalone

systems like solar home systems or interconnected systems like micro or mini-grids, with their respective advantages and disadvantages.

Decentralised off-grid electrification systems are not connected to centralised electric grids for electricity supply. Off-grid systems are useful in providing electricity access to rural and remote locations where extension of the centralised grid is difficult and sometimes uneconomical. Standalone off-grid electrification systems are small-sized systems used to provide electricity to individual homes and small businesses and are usually powered by renewable energy resources. Micro or mini-grids are off-grid electrification systems that consist of small-scale electricity generation systems used to provide electricity to a limited number of consumers through a local grid. Microgrids have an electricity generation capacity of up to 10 kW whereas mini-grids have a generation capacity ranging from 10 kW to 10 MW (Alam and Bhattacharyya, 2017; Rawn and Louie, 2017; Alliance for Rural Electrification, 2014, 2016).

Globally there are increased concerns about climate change, increased carbon emission levels and other environmental impacts from overreliance on fossil fuels, especially electricity generation. In this regard, a lot of attention is being paid to the potential of diversifying the energy mix of most countries with the integration of renewable energy resources (Adams and Nsiah, 2019). This makes renewable energy technologies use an attractive option in rural electrification in SSA where resource availability permits.

Solar Photovoltaics (PV) is prominent among the renewable energy technologies that are usually utilised for electrification in SSA given their availability and the potential of the resource within the region (Baurzhan and Jenkins, 2016). As pointed out earlier, decentralised off-grid systems are best suited for rural and remote locations and are economical as opposed to centralised grids for electrification in remote locations. Solar

PV systems are a good option for decentralised electrification systems due to the availability of resources in most locations across SSA. Solar PV systems can either be developed as standalone systems or mini-grids, however, there are limitations to using them as a single-generation source. Some of the issues with the use of Solar PV as a sole electricity generation source include variability of the resource such that less energy is generated on rainy and cloudy days, the cost of the panels and batteries and other equipment, cleaning and maintenance, and the limited capacity of the electricity generated, among others. These issues associated with the use of one renewable energy resource as the sole generation source are best resolved when backup systems like generators are added to the setup. The combination of two or more renewable energy sources like solar PV or wind energy and a diesel generator creates a hybrid electricity system. The generator can make up for any losses when the renewable energy resource is not generating enough electricity (Dagnachew et al., 2017; Azimoh et al., 2016). As Azimoh *et al.* (2017) point out hybrid systems have the advantages of the different technologies utilised, with each technology complementing the other to provide a reliable electricity supply and cost-effectively increase electricity capacity. The use of interconnected decentralised systems such as microgrids or mini-grids makes it possible to provide electricity access to several households without the added cost of installing standalone systems for each household.

Existing research and literature addressing the energy access situation globally and making arguments for the use of renewable energy sources in low-income countries, especially within the Sub-Saharan African (SSA) context, have mainly focused on the technical and financial aspects resulting in less emphasis on the social and consumer behaviour context (Bhattacharyya and Palit, 2016; Sovacool, 2014a). Sovacool, Bazilian and Toman (2016) in their work argue that a drawback in the existing body

of knowledge on energy studies is that the existing research and literature have been influenced by expert input and judgements with very limited involvement from other stakeholders and end-users. This has resulted in the development of a vast repository of knowledge on the economic and technical aspects as well as expert input. However, limited research is available on other equally important considerations like social, cultural, gender and political aspects which are significant in the implementation of renewable energy technologies and the energy access discourse in general. In the case of renewable energy mini-grid development in SSA, there is a resulting gap in the body of knowledge on the implementation of sustainable renewable energy mini-grid projects and the impact on the lives of the beneficiaries ultimately. Research on issues about energy choices, energy use decision-makers, determinants of energy needs and choices are also limited thus impeding the understanding of how they influence the successful implementation of renewable energy projects (Sovacool, 2014a). Nuru, Rhoades and Gruber (2021) in their work highlight that, previous debates on the barriers to energy technology development have excluded societal influence and have mainly focused on the economic and technical aspects of their development. They point out that the socio-cultural aspects of technological development are equally as important as the technical and economic aspects. Cloke, Mohr and Brown (2017) explain that many rural energy projects in the Global South especially focus on the technology, economics and financing, and delivery mechanism, whereas the social dimensions such as special energy needs, and aspirations of the beneficiaries are not given enough attention even though those factors impact the sustainability of the projects.

Sovacool (2014a) also makes the argument that energy access research has primarily focused on the science, engineering, and economics aspects with limited research on

the social dimensions such as choice-making, user priorities and other human dimensions of energy access. Sovacool thus advocates the need for further work on these social aspects such as perceptions of end-users, traditions and behaviours, energy needs/priorities of the users, energy behaviour and demand instead of just the focus on supply among others (Sovacool, 2014a). Robinson, Clifford and Jewitt (2022) also point out the problem that researchers, policymakers at various levels and development practitioners mostly emphasise the technical performance of energy technology development and focus less on other factors such as the environmental, socio-cultural, and financial context that end up impeding the successful implementation and continuous use of technologies such as hybrid mini-grids for remote locations. Against this backdrop, it is of great significance that this research examined the significance of socio-cultural factors that influence the adoption of renewable energy technologies and energy choices. This research adds to and extends the revised logic model for clean fuel scale-up by Stanistreet et al., (2019), which in itself is based on the framework developed originally by Quinn et al., (2018). As such it has contributed to the growing literature on the social and cultural aspects of energy geographies and energy research in general in the context of developing countries, especially in the Sub-Saharan Africa region given its high level of energy poverty.

1.2 The Ghanaian Context

Ghana's electrification progress over the last three decades has seen progress with the adoption and implementation of numerous government policies and programs such as the National Energy Policy (NEP) and the Strategic National Energy Plan (SNEP), to name a few. These programs and policies have resulted in the implementation of

projects by the government to improve electricity access as well as promote conducive environments for private companies to get involved in extending electricity access across the country. The proportion of the Ghanaian population with access to electricity (electrification rate) has increased from 23.88% in 1990 to 86.3% as of 2021 (World Bank, 2022). Though there have been gains, a lot more work is required to achieve universal electrification, especially addressing the lack of electricity access in mostly rural and remote locations like island communities such as the island communities in the Volta river and many others. The country's energy mix as of 2020 consisted of 36.2% hydropower, 63.6% thermal generation (gas- and diesel-powered plants) and 0.3% of other renewables (solar and wind) (Ghana Energy Commission, 2021). To secure the reliability of the country's electricity supply it is necessary to diversify the country's energy mix.

In efforts to increase electricity access, several energy projects including solar PV and other renewable energy projects have been undertaken in different parts of the country. These projects are of varying types and sizes such as standalone solar home systems for powering centres for charging mobile phones and batteries in some remote locations, street and traffic lights, solar torchlights, solar-powered water pumps, and standalone solar PV systems for health facilities, schools, security posts and emergency service centres to name a few. Interconnected microgrids and mini-grids have also been implemented in island communities to provide them with electricity access as part of a pilot project by the government of Ghana (Ghana Ministry of Energy, 2016). Congruent with the arguments made in Section 1.1, the literature, research and discussions regarding energy access, renewable energy and decentralised mini-grids in Ghana and Sub-Saharan Africa have mainly focused on technical development, financing and delivery mechanisms. Less attention has been paid to the

social, cultural and consumer behaviour context like the energy needs, priorities, and aspirations of the end-users (Cloke et al., 2017). There is limited literature on the adoption and implementation of mini-grids and hybrid systems as a large proportion of the existing literature has been on standalone projects; hence the existence a gap in the knowledge regarding the geographical applicability of mini-grids for energy access. The recent research focused on the social and cultural aspects of the energy access problem in Sub-Saharan Africa draws attention to the successful implementation of energy access projects in remote locations. An example is the case of hybrid mini grid pilot projects in island communities in Ghana. These communities provide a valuable case study of the value of decentralised off-grid systems for improved access to electricity in remote locations.

In contributing to filling the knowledge gap as well as adding to existing geographical research on energy access and renewable energy development, this research examined in detail the socio-cultural dimensions of energy access, energy needs, energy choices and intrahousehold energy priorities of island communities in the East Ada District in the Greater Accra Region of Ghana within Sub-Saharan Africa. The research also examined the factors that influence hybrid mini-grid adoption and uptake as well as factors influencing equal access to clean, affordable energy from a socio-cultural perspective. The research adopted a logic model for clean fuel scale-up revised by Stanistreet et al., (2019) based on the work of Quinn et al. and extended it to the adoption of hybrid mini grid systems for rural and remote locations. The research examined and drew out the significance of socio-cultural dimensions like the end-user perception, differences in intra-household energy priorities and needs as well as energy choices as an addition to the work by Stanistreet et al., (2019). These and other

adaptations based on the findings are then included in the revised version of the logic model developed by this research.

1.3 Research Aim and Objectives

The main aim of the research was to assess the social and cultural context and dynamics of energy use and electricity access in rural island communities in the Ada East District of southern Ghana and examine the applicability of hybrid mini grids to improve electricity access. It did this by identifying socio-cultural determinants influencing energy needs, priorities, choices and responsibilities as part of assessing the applicability and feasibility of solar PV-diesel hybrid mini-grid power systems as a realistic alternative to provide electricity access to rural island communities.

The research focused on four (4) island communities within the Ada East District of the Greater Accra region of Ghana. The aim of the research was achieved through the following specific objectives:

I. To assess the current energy sources and needs of the participants and the options renewable energy mini-grids offer.

II. To determine the various socio-cultural factors that influence energy use and choices within households and the study communities, and the adoption of renewable energy mini-grid systems.

III. To determine factors impacting equal access to clean, affordable, and sustainable energy in the communities.

IV. To review and assess factors promoting or impeding the development of renewable energy projects, precisely mini-grids as a viable option for improving energy access.

1.4 Research Questions

In a bid to achieve the objectives of the research and the overall aim, research questions were developed, answers to which helped to address each research objective and the overall aim of the research ultimately (Table 1.1).

Table 1.1: Research Questions and their Respective Research Objectives

Research Objectives	Research Questions
Assess the current energy sources and needs of the participants and the options renewable energy mini-grids offer.	What are the current energy sources and requirements of the households especially women, children, and other vulnerable groups in the study locations? Do renewable energy mini-grid systems have the capacity and potential to meet the energy needs of households?
Determine the various socio-cultural factors that impact energy use and choices within households and the study communities, and the adoption of renewable energy mini-grid systems.	What socio-economic and socio-cultural factors influence energy use, choices, and the adoption of renewable energy systems? What are the household level dynamics regarding energy priorities, responsibilities, and decisions?

Determine factors impacting equal access to clean, affordable, and sustainable energy in the communities.	What are the challenges of access to clean and affordable energy in rural and remote communities? What factors impact equal access to clean, affordable, and sustainable energy from a socio-cultural perspective?
Review and assess factors promoting or impeding the development of renewable energy projects, precisely mini-grids as a viable option for improving energy access.	What are the institutional policies, structures, regulatory and legal frameworks in existence to promote renewable energy development? What challenges/ factors impact energy access using renewable energy?

1.5 Significance of the Research

The research has contributed to filling the gaps in the body of knowledge available knowledge on energy geographies research on energy access and poverty, improving energy access and the socio-cultural aspects of energy access interventions in the context of the Global South. The research focused on the uptake of renewable energy technologies and mini grids for providing electricity access to remote rural communities with a focus on rural remote locations in Ghana using hybrid renewable energy mini grids. In the broader context, the study sought to facilitate the understanding of the various economic and socio-cultural elements that influence the adoption and use of renewable energy technologies and innovative energy technology in general.

The research highlighted the challenges and opportunities associated with the use of hybrid renewable energy mini-grids for electrifying remote locations like island communities. The research adopted the logic model for clean fuel scale-up, originally developed by Quinn et al., (2018) and revised by Stanistreet et al., (2019) as its working framework and further extended it through a revised version of the model for hybrid renewable energy mini grid adoption. The revised model developed from the research findings included adaptations for areas that were deemed to be priority areas to facilitate renewable energy uptake such as socio-cultural and economic factors. The study has added to the literature on the socio-cultural dimensions of energy access by examining the differences in intra-household energy needs and priorities and their impact on energy choices and access as a whole. The influence that end-user perception has on their willingness to adopt renewable energy technologies to meet their energy needs has been explored in this research. Other socio-cultural and economic factors influencing energy needs and choices in rural contexts have been examined to understand the applicability of off-grid solutions like hybrid mini grid systems in meeting energy needs. The research has also examined the opportunities and challenges posed to renewable energy sector professionals to understand and develop effective operating mechanisms to make energy access projects and interventions successful. The findings of this research are of significance to government, policy-makers, energy think tanks, developers, and development agencies to better understand the need to factor in the social and cultural dimensions of energy access such as energy needs, priorities, and aspirations of beneficiary communities alongside the technical and economic dimensions.

1.6 Structure of the Thesis

The remainder of this thesis is organised into seven chapters. Chapter Two provides a review of the existing body of literature relevant to the research themes that informed this thesis. The chapter discusses the literature on energy access, its definitions, and the benefits of modern energy access. The approaches by which energy access is measured and accessed are also presented along with discussions on energy access and the Sustainable Development Goals (SDGs). Other themes presented in the chapter include rural electrification in developing countries, the challenges of off-grid renewable energy technologies, and implementation and diffusing models. The contribution of geographers to energy research and a conceptual framework underpinning the research are also presented in this chapter.

Chapter Three provides a background on Ghana. The energy sector of Ghana is discussed detailing the available national energy resources, energy supply, generation, and consumption. The chapter also provides a generalised overview of the energy situation, i.e., electrification and access to clean cooking fuels in rural Ghana. As part of this chapter, the legal and policy framework for the energy sector and specifically renewable energy are also presented. The chapter concludes by discussing the potential of renewable energy technologies (RETs) for improving energy access in Ghana.

Chapter Four discusses the research approach and methodology employed to undertake the research. The chapter discusses research philosophies and the chosen research philosophy that influenced the study as well as the approaches adopted to gather the required data to answer the research questions. Discussions on the selection of study locations and recruitment of participants are also presented. The chapter then goes ahead to discuss the various sources of data and how they are gathered and

analysed to answer the research questions. Positionality, ethical considerations, and methodological limitations associated with the research are also discussed in the chapter.

Chapter Five presented the results of the research on assessing the energy need and use patterns of the participants in line with the objective I and discussions on a how hybrid mini-grid system benefits the communities. The various energy sources the participating households rely on to meet their energy needs are assessed and presented. The chapter presents the demographic and socio-economic characteristics of the participants and their households. Discussions on the influence of the participants' socio-economic and demographic characteristics on their energy needs and choices are also presented. Other discussions on energy needs and uses are also presented.

Chapter Six explored the various factors influencing energy choices, needs, priorities, and aspirations as well as the uptake of hybrid mini-grid systems. The discussions presented are on the socio-cultural dimensions of energy access in the research locations such as gender roles, intra-household energy priorities as well as household size and income levels. Other discussions presented focused on the economic, technical and political dimensions of energy access. Responses from participants of the research are presented in support of the arguments discussed.

Chapter Seven starts off discussing the impact of economic and socio-cultural factors on the use of hybrid mini-grid systems for improving rural electrification on an electrified island community. The impact of the development of a hybrid mini-grid system on the life of inhabitants in the electrified community is discussed. The chapter goes on to examine the influence that variations in renewable energy resources have on the energy generated and the implications for end-users. The perceptions of the

participants on renewable energy use and mini-grid systems and their significance are also presented. The findings of the research and how extends and improves the framework are presented. Other discussions on the implications of the responses from the lived experience of the participants in the electrified island community and the findings of the research are presented in the concluding section of this chapter.

To conclude the thesis, Chapter Eight discusses the key findings from the research as well as the implication of these findings. The summary of the findings of the research is mapped onto the various research objective to show how they had been achieved. Recommendations are suggested on the best ways to address the energy access issues identified by the research to help prepare for tomorrow today, while also highlighting aspects of the energy access challenges in the Global South which require further research.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter presents and examines relevant literature related to the main themes of the research to provide a better understanding of the various aspects of energy access, in a bid to develop a research framework and identify the gaps in the literature. The chapter is sectioned as follows; Section 2.1 sets the tone for the chapter with a discussion of the definitions of modern energy access. The contribution of geographers to energy research is presented in section 2.2. Discussions on the benefits of modern energy access and energy poverty are presented in sections 2.3 and 2.4 respectively. Section 2.5 presents discussions on the methodology for measuring and assessing energy access while section 2.6 provides details about energy access and its links with the Sustainable Development Goals (SDGs), most especially SDG 7. The conceptual and analytical framework that is adopted for the research is discussed in section 2.7 and discussions about the links between gender, socio-cultural practices and energy access are also presented in section 2.8. Discussions on rural electrification in developing countries, current technologies utilised in rural electrification and renewable energy technologies used for rural electrification are presented in sections 2.9, 2.10 and 2.11 respectively. Further discussions on mini-grids and hybrid mini-grids, implementation, and diffusion models together with operational and business models for rural renewable electrification projects are presented in sections 2.12, 2.13 and 2.14 respectively. Section 2.15 discusses the challenges of off-grid renewable energy implementation and diffusion, and the chapter ends with a conclusion in section 2.16.

2.1 Defining Modern Energy Access

Modern energy access has become a popular topic for discussions in academic and development circles and as such, there is a growing body of scholarship on different aspects of the concept of energy access (Ulucak et al., 2021). The concept of energy access has over time been explained with various definitions from different perspectives and dimensions by various scholars, international development agencies and organisations. Gaining a comprehensive understanding of the concept of modern energy access and its roles is a key theme in this research, so it is important to consider some of the earlier and current definitions used for modern energy access from different perspectives and be able to apply them appropriately.

Earlier definitions used in scholarship are presented in the next few paragraphs to help shape these aspects of the discussion. Some definitions of modern energy access that have been used include providing electricity connections to households, electric lighting in a house or erecting an electric pole in a community amongst others and access to clean cooking fuels like LPG (Pachauri, 2011). These earlier definitions and explanations of energy access left out other pertinent aspects of energy access like the reliability of the electricity access provided, the affordability and even the legitimacy of the connection. Defining energy access in this light ignored the fact that modern energy access was not only the availability of electricity connection to households but also the availability of modern energy for cooking, heating and other meaningful and productive uses in the lives of the beneficiaries (Bhatia and Angelou, 2015).

Practical Action (2014) proposed a broader concept and definition which they believe better captions access. Their proposal is the concept of total energy access, which they refer to as “when the full range of energy supplies and services required to support

human social and economic development are available to households, enterprises and community service providers" (Practical Action, 2014, p. 2). The World Bank in a bid to broaden the scope of the definition for the concept of energy access in its report *Beyond Connections-Energy Access Redefined* redefines it as "The ability of the end-user to utilize energy supply that is usable for the desired energy services" (Bhatia and Angelou, 2015, p. ix). This definition captures a broader dimension of the energy access problem, mainly the access, reliability of the supply and its use for productive ventures. The definition of energy access used by the IEA in their report on *Defining energy access: 2020 methodology* is "a household having reliable and affordable access to both clean cooking facilities and to electricity, which is enough to supply a basic bundle of energy services initially, and then an increasing level of electricity over time to reach the regional average" (International Energy Agency, 2020b).

Energy access is also defined by the United Nations (UN) Secretary General's Advisory Group on Energy and Climate Change as "access to clean, reliable and affordable energy services for cooking and heating, lighting, communications and productive uses" (UN AGECC, 2010, p. 2). The UN also in a report on *Sustainable Energy For All In India* defines energy accessibility as "the existence of modern energy in the form of electricity and clean cooking fuel to address energy poverty in a location…it is measured in terms of electrification rate and percentage use of clean cooking fuels" (United Nations Development Program, n.d., p. 3). Even though this definition covers an important aspect of the availability of modern energy supply to replace traditional energy supply to households, it leaves out elements such as reliability and quality of the energy supply, its affordability and if it can be used for productive work as desired by the beneficiaries. Other scholars have also used different definitions of modern energy access in their research; some of which are presented

here, though it is not an exhaustive list. Brew-Hammond (2010) explains energy access as being able to access and having the ability to use different forms of energy such as electricity, LPG, charcoal and fuelwood to meet daily energy needs. Modern energy access has also been pointed out to refer to the ability of households to get access to these modern energy services when they so desire (Nalule, 2019). These point out that access is not only dependent on the availability of modern energy services but should also include the ability of the households to afford the cost of the energy service (Ranjit and O'Sullivan, 2002 as cited Brew-Hammond, 2010).

Pachauri (2011) evaluates existing approaches to define modern energy access and draws attention to the various key dimensions that are used in defining energy access i.e., availability, affordability, quality, and the reliability of the supply as well as acceptability. He also points out interest in the impact that modern energy access has on the lives of the end-users. Bilgiç (2017) also defines energy access as having access to a minimum threshold of modern energy services such as electricity and non-solid cooking fuels with minimal effects on the health of households, which results in productive usage for the beneficiaries. From the definitions presented, despite the diverse perspectives that modern energy access is viewed from, there is some common ground among all these definitions. The key points that run through all these different definitions include the shift from traditional solid energy and fuel sources to clean and sustainable modern energy services, assessments of the quality and reliability of the energy supply and how affordable the cost of access and use is to the end-users. According to International Energy Agency (2020), there is no singular definition for modern energy access. However, there are common elements across the various definitions used, such as access to electricity and clean non-solid fuels as well as energy for productive uses and public services which aligns with the Sustainable

Development Goal (SDG) 7. The lack of a singular definition without doubt has some impact on the efforts aimed at helping to address the problem. With the various energy access definitions considering different dimensions of the problem, it, therefore, means solutions to deal with the problem are most likely to be tailored to the various dimensions considered as part of the chosen definition and as such is problematic and not holistic in its approach. As Nalule (2019) points out a problematic definition or misconception of the general definition of energy access is likely to result in misconceived and less effective solutions to tackling the problem of energy access. According to Pielke & Bazilian (2013), energy access is defined and measured using different dimensions, all of which unfortunately tend to be modest and assume that people without access to modern energy services will only require and use the least amounts or the minimum threshold of access to modern energy services. That assumption results in misleading demand projections and calculations which may end up being substantially below that which will be required. Considering all the definitions of modern energy access presented, it is evident minimal attention is paid to the local context of the end-users, especially the social and cultural backgrounds or traits which are vital to the effectiveness and sustainability of any solution because these traits influence the energy needs and priorities of the end-users.

2.2 Contribution of Geographers to Energy Research

Energy research is continuously evolving, and it is being carried out across various academic disciplines including geography (Sovacool, 2014a). Geographical perspectives on global energy systems date back as far as the 1970s with earlier works focused on areas such as assessments of environmental and economic risk associated

with energy facility siting, examining energy technology diffusion among nations, assessing and mapping of energy production, transport, distribution and use in a regional context and the environmental impacts associated with energy production and use (Calvert, 2016). Cook's work was one of the first to provide geographical dimensions on energy issues with an emphasis on the cultural, ethical and geopolitical dimensions of energy use (Cook, 1976 cited in Solomon & Calvert, 2017).

As a result of the ability of energy issues to cut across different concepts, theories and debates in the various subfields of geography, energy research has been tagged as a "borderland topic" (Calvert, 2016; Baka and Vaishnava, 2020). Contributions of geographers to the subject of energy geographies (geography about energy issues and research) have over the years centred on three broad aspects of global energy systems. These aspects are mainly production, transport and distribution, and consumption. Key geographical research on energy production has focused on the environmental impact of oil production, the impacts of siting of large-scale nuclear plants, and issues with renewable energy development among others (Pueyo, 2018; Solomon and Calvert, 2017)

With regards to energy use and consumption, areas that energy geographers have focused on include low carbon energy transitions (Brown et al., 2018; Silver and Marvin, 2017), urbanisation and energy nexus (Kwakwa and Alhassan, 2018; Gauk and Roose, 2016), energy justice (Jenkins, 2018; Heffron and McCauley, 2017; Sovacool et al., 2017; Jenkins et al., 2016), gender and social aspects of energy access and consumption (Robinson et al., 2022; Pueyo and Maestre, 2019; Winther et al., 2018; Gonda, 2016; Pachauri and Rao, 2013; Sovacool et al., 2013), community and household use of clean energy (Jewitt et al., 2020; Cloke et al., 2017; Campbell et al.,

2016), energy access and poverty (Gregory and Sovacool, 2019; Bouzarovski et al., 2017; Cloke et al., 2017; Frederiks et al., 2015; Heltberg, 2005).

Most of the scholarship in energy geographies on energy use and consumption is focused on the Global North with emphasis on topics such as energy transitions, urbanisation and energy, energy justice and climate change adaptation (Baka and Vaishnava, 2020). However, according to Solomon and Calvert (2017), energy geographies scholarship on the Global South has focused on topics such as energy access and its challenges, improving modern energy access using off-grid technologies, finance, and the energy sector. According to Cloke, Mohr and Brown (2017) decentralised grids, especially mini-grids are increasingly proving to be technically and economically viable modern energy solutions for the millions living in remote off-grid areas who lack access to electricity. Baka and Vaishnava (2020) also point out that a lot more attention and scholarship should be focused on improvements in grid electricity supply and expansion, as well as productive use of energy and the socio-cultural dynamics of the beneficiaries of the energy systems. This research seeks to build on and makes contributions to the body of knowledge on energy geographies research on energy access and poverty, energy access and gender inequality, improving energy access and the socio-cultural aspects of energy access interventions in the context of the Global South.

2.3 Benefits of Modern Energy Access

The importance of clean modern energy services is, without a doubt, vital to every aspect of human lives and cannot be underestimated (Barnes and Samad 2018). The numerous studies that have been conducted on universal access to energy have as

among other things focused on its impact on the beneficiaries. These impacts have been shown to cut across various aspects of human society such as agriculture, security, domestic uses, water and sanitation, education, economy, health, economic activities and poverty and hunger eradication.

Health

One of the direct impacts of the use of traditional solid fuels for domestic uses such as cooking and space heating in households is exposure to indoor air pollution. Indoor pollution results from the release of particulate matter ($PM_{2.5}$) and other pollutants from the combustion of biomass and other solid fuels for cooking and kerosene for lighting. Exposure to indoor air pollution is known to contribute to the death of about 3.8 million people annually and also results in an increased risk of illnesses such as tuberculosis, respiratory diseases, eye problems and impaired lung function (World Health Organization, 2021; Stanistreet et al., 2019; Barnes and Samad, 2018). Household air pollution is noted to be a risk factor associated with low birth weight and it also increased the risk of cataracts and eventual vision loss (Quinn et al., 2018). Smith et al. (2013) argue that within Sub-Saharan Africa and South Asia, traditional solid fuel use within households was a significant risk factor for ill health, surpassing the risk posed by poor sanitation and unsafe drinking water.

Barnes & Samad (2018) in their work note that increased access to modern energy services such as electricity and modern cookstoves and non-solid fuels tends to promote significant improvements in the health of people. For instance, the use of electric bulbs instead of kerosene lanterns for lighting reduces the exposure of households to the smoke from kerosene use and its health implications. They also

argue that the use of improved cookstoves was noted to reduce exposure to indoor air pollution as they burn fuel more efficiently and emit less smoke thereby reducing the emission of particulate matter and other pollutants which adversely impact the health of users.

Barron and Torero (2017) found on average 66% reductions in particulate matter ($PM_{2.5}$) levels in households that have used electricity for two years in comparison to the $PM_{2.5}$ concentrations in those same households before the electricity rollout. Their study also found out with access to electricity, there had been lower prevalence rates of respiratory infections in children as compared to households that had no electricity access. Usually, in households that use traditional solid fuels, women and children are the ones that are affected the most as they do most of the cooking. They also end up spending a lot more time near open fires and are at greater risk of suffering from burns. Women and children are usually the ones in households that are responsible for collecting fuel wood and other solid fuels for cooking (Stanistreet et al., 2019). The availability of clean and affordable modern cooking fuels like Liquified Petroleum Gas (LPG) and improved modern cookstoves helps to reduce if not eliminate the negative health implications of the use of traditional solid fuels.

The health impact of access to modern energy services like electricity is not limited to households as community services, such as health care delivery, are largely influenced by the availability and reliability of modern energy services like electricity. As Barron & Torero (2014) point out, electricity access has implications on health care delivery and the operation of health centres, and the use of advanced medical equipment is facilitated by the provision of electricity access. Castán Broto & Kirshner (2020) discuss the impact that energy access has on healthcare service delivery during the COVID-19 pandemic emphasising the close linkage between the availability of

electricity access and the provision of the appropriate level of healthcare service required for treating COVID patients needing advanced medical care. Their work also points out that electricity is required to power advanced medical equipment used in health facilities as well as refrigerate and store vaccines and other medications to provide the needed care to patients. Clean modern energy is also required in health care facilities for other vital services such as space and water heating, sterilisation, and incineration. With the absence of adequate access to modern energy services in low-income countries, healthcare service delivery is significantly impacted and limited. The absence of basic modern energy services like electricity also negatively impacts the levels of emergency service response that can be offered. The availability of electricity access allows for healthcare facilities to operate extended night-time hours and the provision of services that will not be possible in the absence of electricity such as surgical procedures and child delivery services (Hirmer and Guthrie, 2017).

Economic Activities and Agriculture

The availability of electricity access can increase household income. With electricity access households that operate income-generating ventures can extend the operating hours into night-time. For economic activities that require motive power, electricity use can result in increased efficiency and quicker turnaround times (Barnes and Samad, 2018; Khandker et al., 2014). Several studies have found that electricity has an impact on income-generating activities and productivity. Khandker et al. (2014) in their study of rural household access in India note that households with electricity access reported increases in income as compared to households that did not have electricity. The use of appliances like TVs and radio sets helped to facilitate access to

information and knowledge on business, agriculture and other economic activities which resulted in better practices and a subsequent increase in income.

Westphal et al. (2017) explore how critical energy is in economic productivity for enterprises of various sizes showing the positive correlation between per capita electricity consumption and the per capita gross domestic product (GDP) in various cities. They point out that even though electricity access does not necessarily cause economic growth it is an essential service that promotes GDP and economic growth. Barnes et al. (2014) in their study on the effect of rural electrification on rural production in Columbia, India, and Indonesia found out the use of electric pump sets for irrigation resulted in significant increases in farm production. In Indonesia, productivity increases were recorded but they mostly did not come from agricultural activities but rather from new business and income-generating ventures.

The traditional form of agriculture without access to modern energy systems will predominantly rely on human and animal labour to supply the mechanical energy required for agricultural activities. According to Sokona et al. (2012) over-reliance on human and animal mechanical power usually results in reduced yields and consequently limited income for farmers. With the focus moving from orthodox ways of agriculture to modern mechanised forms of agriculture, the impact of energy access on agriculture cannot be underestimated. Access to and the utilisation of modern energy services and new agricultural equipment and machinery in the various processes in agriculture is vital to income generation and poverty eradication. Modern energy like electricity and other efficient non-solid fuels are required to operate irrigation systems and other advanced agricultural machinery, as well as being utilised in other processes such as the processing, preservation, storage, and transport of the produce. As Barnes et al. (2014) point out electricity access allows farmers to easily

irrigate their fields with the use of electric pumps which are efficient and require minimal maintenance compared to diesel irrigation pumps. The use of irrigation systems also enables farmers to produce several crops on their fields in a year, thus resulting in increased crop yields and income for them. Electricity access also facilitates the use of post-harvest machinery for processing, preservation, and the storage of agricultural products which consequent has a positive impact on the income generated.

Education

Availability and access to energy do have significant impacts on education. The provision of electricity access in households and schools facilitates teaching and learning. In schools, electricity access enables the use of various technology (i.e., computers and other devices) and applications to facilitate teaching and learning (Barnes and Samad, 2018; Ulsrud et al., 2015). The study of science and technology courses especially those with practical or laboratory work components is also made possible with access to electricity. Online studies and communication are also made possible through computers and mobile phones that require electric power to operate. In households, the provision of electricity access enables both adults and children to study at any time of the day with electric lighting at night. The use of computers, tablets and other devices that facilitate learning is also possible with electricity access. Access to electric lighting results in increased literacy and has been known to have a direct influence on streams of future income over a person's lifetime (Barnes et al., 2014). The use of gadgets and devices like TVs, radios and computers also enhances the awareness of the beneficiaries on current events and other educational programmes.

Sovacool et al. (2013) in their work on the Malian government-managed energy program Multifunctional Platform (MFP) for the extension of access to modern energy services within rural communities found that for the communities that benefited from the MFP project, positive impacts on education were observed. These included an increased number of females enrolling in school, an increased level of female attendance and improvements in academic performance. The beneficiary communities were also found to have recorded higher test scores, and reduced drop-out rates. According to Barnes & Samad (2018), when households have access to electricity and electric lighting, both adults and children have the opportunity to study longer in the evenings. This enables students to be better prepared for school which results in increased interest in attending school and reducing drop-out rates. They also point out that the availability of electricity in schools facilitates teaching and learning as technology to enhance teaching and learning can readily be used to offer better access to knowledge and information.

Communication and Entertainment

The use of modern devices such as TVs, radios, computers, and mobiles is not limited to educational purposes and creating awareness of current events, they are also a means of entertainment and communication for users. Electricity access allows for the use of radios and TVs for entertainment. The use of mobile phones and other gadgets usually increases with households' access to electricity. Charging mobile phones at home results in time-saving and cost reduction as compared to the cost of charging them in shops (Barnes and Samad, 2018). Increasingly mobile phones are used for financial transactions, especially in developing countries and without electricity access, these vital services would not be possible. The use of mobile phones allows users to

communicate and keep in touch with friends and family. Computer use is vital for access to information, communication, gaining knowledge and entertainment. As a learning tool, the computer is more interactive than either radios or televisions (Mulugetta et al., 2019). The use of computers and internet access makes a plethora of information on various topics and entertainment readily available and communication easy with the stroke of a few keys. These services require electricity access without which it is impossible to benefit them.

Space Cooling, Heating, and Food Preservation

The availability of electricity access allows for the use of electric fans and air conditioning in warmer climates resulting in increased comfort. Besides cooling spaces, electric fans can also be used to drive away and reduce bites from insects. Electricity access also allows for the use of refrigerators to preserve food better to avoid food spoilage and results in improved quality of life for the beneficiaries by avoiding ailments associated with eating spoiled food (Barnes and Samad, 2018; Bilgiç, 2017; Hirmer and Guthrie, 2017). In colder climates, space heating is essential in households to keep warm, which requires the use of heating appliances, stoves, and fireplaces. The availability of electricity, natural gas and improved stoves and fireplaces (with flues) ensures that houses are warmed up with no or minimal indoor pollution (Barnes and Samad, 2018).

Gender Equity

Women are usually impacted negatively by the use of traditional cooking methods with biomass and other solid fuels. Mostly women and children are tasked with the

responsibility of searching and collecting biomass and fuelwood for use with traditional cookstoves. In doing this they are subjected to carrying heavy loads of solid fuels and trekking long distances. The availability and access to modern energy services like electricity, improved cookstoves and LPG have the potential to address these gender inequities (Winther et al., 2018). Long exposure of women and children to smoke and indoor air pollutants from the use of biomass and other traditional solid fuels impacts negatively on their health. The use of modern and clean cooking methods reduces the negative health effects and results in less time being spent on cooking activities. The time saved on the part of the women can be used for other beneficial and productive activities. Standal & Winther (2016) in their study explore how and the extent to which electricity access resulted in women's empowerment in rural India and Afghanistan. They found that electricity access improved the conditions within which the women performed their traditional roles of caregiving. Electricity access was also noted to enhance income generation for the women and with it came some comfort, convenience and enhanced social status. In rural Afghanistan, the men expressed a change in their perspectives on the value of women's abilities after seeing some of them work as engineers.

Public Lighting and Potable Water

Electrification rollout improves community services like street lighting. Streetlights and other public lighting improve security in beneficiary communities. Aside from reducing crime rates, street and public lighting enhance safety on streets and roads for pedestrians and drivers alike (Bilgiç, 2017). Electricity remains an important component of the supply of safe drinking water to many communities. Many

communities rely on the use of electric pumps and electricity-powered treatment and supply systems to provide their people with potable water. Without access to electricity, the supply of potable water to these communities will be compromised and that could result in inconveniences and health implications (Barnes and Samad, 2018).

2.4 Energy Poverty

According to Sovacool (2014a), the absence of a generalised definition of poverty has made the conceptualisation of energy poverty difficult. As such, there are agreed definitions of energy poverty which therefore results in varying definitions being applied to the concept by different researchers (A.T. Kearney Energy Transition Institute, 2018; Sadath and Acharya, 2017; González-Eguino, 2015). Sokołowski et al. (2020) point out the dichotomy in the definition of energy poverty in the context of developing and developed countries. The definition in the context of developing countries focuses on access to modern energy services whereas in developed countries it pertains to income and energy expenditure. The differences in the cost of modern energy services and the quality of the supply across countries make it almost impossible to apply a single indicator to different contexts. Some of the definitions are considered in this section.

Early definitions of energy poverty can be traced to Boardman (1991) who first came up with the concept of "energy poverty" which suggested that a household could be deemed to be "energy poor" when the expenditure on energy use exceeded a threshold of 10% of the household's annual income (Boardman, 1991 cited in Apergis et al., 2022). The United Nations Development Program (UNDP) also defines energy poverty as "the inability to cook with modern cooking fuels and the lack of a bare

minimum of electric lighting to read or for other household and productive activities at sunset" (Gaye 2007 p. 4). Energy poverty as Sovacool (2012) explains is the lack of access to modern energy services such as electricity for lighting and modern energy non-solid fuels for cooking. Another definition also in use is that of Reddy (2000) who defines energy poverty as "the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe and environmentally benign energy services to support economic and human development" (Reddy, 2000 cited in González-Eguino, 2015, p. 379). Sokołowski et al.'s (2020) definition of energy poverty is given as "a situation when a household is unable to afford the energy needed to provide its members with adequate warmth, cooling, lighting, and appliance use" (p. 92). Despite the varying definitions of the energy poverty concept, they all aim to echo the unavailability of access to affordable modern energy services such as clean non-solid fuels and electricity that are required for basic energy needs such as cooking, lighting, and heating.

There are available several approaches and methods by which energy poverty can be measured. One of the approaches focuses on tracking the minimum energy threshold needed to meet the basic energy needs of lighting, heating, and cooking. Another approach assesses the poorest households in a country and their energy and amounts used while another examines the proportion of household income that energy expenditure takes up (Sovacool, 2014b). Some of the approaches for measuring energy poverty and access are discussed in section 2.5. The most common concept utilised to illustrate energy poverty is the "energy ladder" concept mainly for cooking and heating. The energy ladder (Table 2.1) by definition is "the percentage of population among the spectrum running from simple biomass fuels (dung, crop residues, wood, charcoal) and coal (or soft coke) to liquid and gaseous fossil fuels (kerosene, liquefied

petroleum gas, and natural gas) to electricity (Holdren and Smith, 2000 cited in Sovacool, 2014a, p. 24).

According to Sovacool (2014a, p. 24), the energy ladder concept explains that "the primary types of energy used in rural areas or developing counties can be arranged on a ladder with the simplest or most traditional fuels and sources such as animal power, candles and wood, at the bottom and the more advanced or modern duels such as electricity and refined gasoline placed at the top". Based on the energy ladder concept, households move up from the lower levels of the ladder, where they depend on the simplest and traditional fuels, to the top levels, where advanced and efficient energy sources are used, with increased household income as well as improvement in economic status (Poddar et al., 2021).

Table 2.1: The Energy Ladder for Household Energy Use

Energy service	**Developing countries**			**Developed countries**
	Low-income households	**Middle-income households**	**High-income households**	
Cooking	Wood (including wood chips, straw, shrubs, grasses, and bark), charcoal, agricultural residues, dung	Wood, agricultural residues, coal, kerosene, biogas	Wood, kerosene, biogas, liquefied petroleum gas, natural gas, electricity	Electricity, natural gas
Lighting	Candles, kerosene (sometimes none)	Kerosene, electricity	Electricity	electricity
Space heating	Wood, agricultural residues, dung (often none)	Wood, agricultural residues	Wood, coal, electricity	Oil, natural gas, electricity
Other appliances	None	Electricity, batteries	Electricity	Electricity

Source: (Sovacool, 2014b)

Studies to ascertain the existence and applicability of the energy ladder concept point out the fact that it does exist across several developing countries (Song et al., 2018; Farsi et al., 2007; Gupta and Köhlin, 2006; Masera et al., 2000). An interesting aspect of the existence of the energy ladder was the fact most households with improvements in economic status did not move from traditional energy sources to modern energy sources in a linear order but they were usually engaged in fuel stacking. Fuel stacking behaviour meant that households at any of their given income levels at any given time used more than one energy or fuel source, with the proportion of cleaner and efficient energy sources increasing with higher income levels. Households engaged in fuel stacking behaviour usually did not do away with the traditional sources of energy but used them together with the cleaner sources and in some instances backslid to relying solely on the traditional energy source (Jewitt et al., 2020; Dickinson et al., 2019; Piedrahita et al., 2016; Masera et al., 2000). Fuel stacking behaviours in many households across developing countries have been attributed to reasons such as fuel affordability and convenience (i.e., type of food cooked and quantities). These help to deal with issues with supply and accessibility to non-solid fuels like LPG refills (Stanistreet et al., 2019).

2.5 Measurements and Assessments of Energy Access

Tait (2017) points out that most of the common criteria or metrics for measuring energy access have traditionally been dependent on the supply-side using binary indicators mainly based on access to modern stoves, or non-solid traditional fuel and electricity connection to households. The use of these binary metrics provided valuable information that was simple and easy to compare but do not capture the multiple dimensions of energy access (Angelou and Bhatia, 2014). Binary metrics do not

provide information on other dimensions such as affordability of the supply for the end-user, the consumption patterns, the quality of the supply and for instance the continued use of biomass in tandem with electricity access or modern stoves in some instances thus reducing the intended beneficial health impacts of clean fuel access (Tait, 2017; Bhanot and Jha, 2012). Holistic measurement of energy access should involve the supply side as well as other aspects like reliability and quality of the supply, consumption patterns and affordability. As Tait (2017) posits, the measurement of these other dimensions such as consumption levels and reliability are challenging to achieve as opposed to the measurement of the supply. Several approaches to measuring energy access have attempted to go beyond the binary indicators and incorporate dimensions such as consumption using average regional electricity consumption as a benchmark metric of adequate consumption. These approaches include the Multidimensional Energy Poverty Index (MEPI) and the Energy Development Index (EDI). The MEPI presented by Nussbaumer et al. (2012) focuses on modern energy services deprivation and considers the incidence and intensity of energy poverty. The (MEPI), considers energy poverty in relation to energy deprivation and uses numerical values to give an idea of household energy poverty on a national scale. However, it does not factor in the productive uses of energy as well as energy uses beyond the household (Mendoza et al., 2019). The EDI was developed by the International Energy Agency (IEA) and presents the energy access levels of countries and distinguishes between energy levels at community and household levels. The EDI provides a score for each country which is consist of an aggregation of individual indicators like clean cooking, electricity, productive use and public services indicators (Serwaa Mensah et al., 2014). The limitations of these approaches are that they assume that the benchmark consumption used is representative of an adequate level of consumption and ignores

the fact that the regional averages used can vary across countries and regions given that climate, culture, and socioeconomic factors have been noted to influence consumption (Bhanot & Jha, 2012; Kennedy et al., 2020).

To fully capture the multidimensions of energy access, the Energy Sector Management Assistance Program (ESMAP) provides a comprehensive definition of energy access as "the ability to obtain energy that is adequate, available when needed, reliable, of good quality, affordable, legal, convenient, healthy, and safe for all required energy applications across households, productive enterprises, and community institutions" (Angelou and Bhatia, 2014, p. 2). This new definition by ESMAP led to the development of a new measurement method for energy access based on a multidimensional methodology and different from the binary metric. The new method, the Mult-Tier Framework (MTF) comprised different measurements of electricity and cooking services. The MTF considers several dimensions that influence energy access as compared to the supply-sided binary metric, and thus complements it.

2.5.1 Multi-Tier Framework for Energy Access

The Multi-Tier Framework measures attributes or dimensions of energy access such as availability, capacity, exposure, quality, reliability, efficiency, affordability, health and safety, convenience and legality for cooking, heating, and electricity services at different levels.

2.5.1.1 Multi-Tier Framework for Electricity Access

In using the MTF for measuring electricity access (Table 2.2), a tier classification is assigned for all of the considered attributes/ dimensions independently. Under the

MTF for electricity access, the attributes considered are reliability, quality, capacity, affordability, health and safety, legality, and availability. The lowest tier possible is Tier 0, where there is no energy access, and the highest tier is Tier 5 where there is access to full modern energy service. For each household, each attribute or dimension is independently evaluated and the overall energy access level for that household is the lowest tier obtained across all the attributes. Thus, the household energy access level is determined by its lowest ranking or tier. These ratings can be averaged to calculate the energy access ratings for several households (World Bank and the World Health Organization, 2021; Bhatia and Angelou, 2015).

Under the Multi-Tier Framework (MTF) for measuring energy access, the attributes or dimensions considered are:

Capacity

The capacity of the energy supply is a consideration of the ability of the system to generate enough electricity for the end-users to operate various appliances and other productive uses. The capacity of the electricity supply system may range from a few watts of electricity to power LED lights, radio sets to hundreds or thousands of watts for the operation of other appliances such as refrigeration, microwaves, and heaters.

Reliability

The electricity supply reliability refers to the frequency and duration of disruptions in the supply and is mainly applicable to grid-connected households (i.e., both centralised and decentralised grids). Unscheduled disruptions in supply have negative impacts on the uses that can be derived from electricity access. The determination of reliability is dependent on: (i) the amount of time the electricity supply is disrupted and (ii) the frequency with which it happens.

ATTRIBUTES		TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Capacity (power capacity ratings)		< 3W	3W – 49W	50W – 199W	200W-799W	800W-1999W	≥2kW
Availability	Day	< 4 hrs	Min 4 hrs		Min 8 hrs	Min 16 hrs	≥ 23 hrs
	Evening	< 1 hr	Min 1 hr	Min 2 hrs	Min 3 hrs	Min 4 hrs	
Reliability	(Frequency of disruptions per week)	> 14				4-14	≤ 3
	(Duration of disruptions per week)					> 2 hrs (if frequency ≤ 3)	≤ 2 hrs
Quality (voltage problems affect the use of desired appliances		Yes				No	
Affordability (cost of a standard consumption package of 365 kWh/year		≥ 5% of household expenditure (income)			<5% of household expenditure		
Formality (bill is paid to the utility, pre-paid card seller, or authorized representative		No				Yes	
Health and Safety (having past accidents and perception of high risk in the future)		Yes				No	

Table 2.2: Multi-Tier Framework for measuring access to electricity

Source: Bhatia & Angelou, 2015

Availability

The electricity supply availability refers to how long (time) or the duration within which the electricity is available to the end-users. The measurement of availability is done using two indicators based on the time during which the electricity is available:

(i) the hours in total within 24 hours and (ii) the number of hours in the evening. A longer duration of availability means that users can utilise the electricity for their various needs when needed and have the freedom to choose when to make use of the electricity. The final availability tier is determined based on the lowest value of both the daytime duration and the evening duration tiers (World Bank and the World Health Organization, 2021; Bhatia and Angelou, 2015).

Quality

The electricity supply quality attribute refers to the supply to end-users being of the right voltage to operate various appliances properly. Most equipment or household appliances require electricity access to be of a minimum voltage to operate properly and fluctuations in the voltage levels could result in damage to appliances and electrical fires.

Affordability

The affordability attribute of electricity supply indicates the ability of households in paying for their electricity consumption. Its assessment is done by comparing total household expenditure and a benchmarked electricity use cost of the household. It is dependent on (i) the amount of electricity used, (ii) the electricity price, and (iii) the consumer's ability to pay for the electricity used. Typically, affordability will be set at not using more than 5% of household monthly expenditure on electricity of 30 kWh each month (World Bank and the World Health Organization, 2021).

Formality

The formality attribute under the MTF has to do with monitoring electricity connections to identify illegal connections. Illegal connections are a safety risk to the

other users and the community as a whole and result in financial losses to utility companies.

Health and Safety

The health and safety attribute of electricity supply refers to the risk that electricity poses to households connected. When connections are poorly or illegally done, they can result in fires and electrocution. It covers any injuries and damages, or losses related to the electricity supply (World Bank and the World Health Organization, 2021; Bhatia and Angelou, 2015).

2.5.1.2 Multi-Tier Framework for Cooking

To measure access to clean and modern cooking services and fuel using the multi-tier framework multiple factors related to access are considered such as cooking conditions, user behaviour, safety, cookstove stacking, convenience and cost. The MTF for cooking (Figure 2.1 and Table 2.3) is based on the following attributes: exposure; convenience; fuel availability; affordability; efficiency; and safety (World Bank, 2020). For each attribute, there are six tiers varying from tier 0, where there is zero access to clean fuels and modern cookstoves and traditional solid fuels are used, to tier 5 where there is full access to clean fuels and modern cookstoves. Under the MTF for cooking, modern energy cooking services access for a household refers to one that achieves tier 4 or above across all the six attributes for measurement.

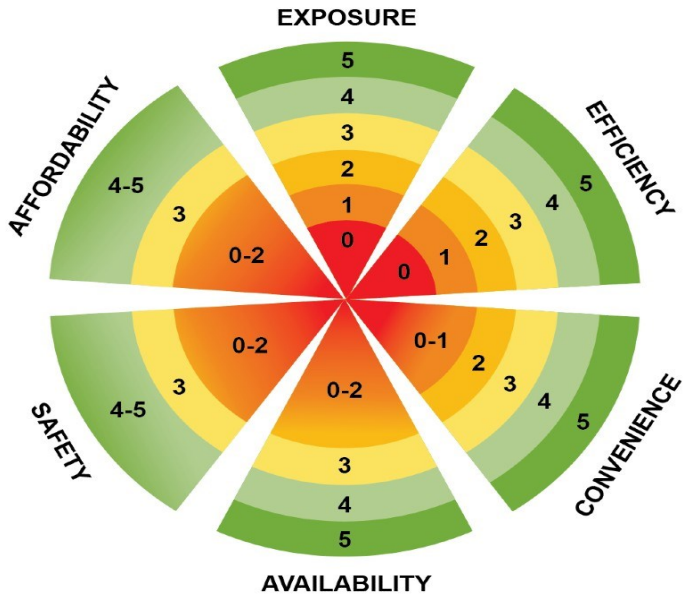


Figure 2.1: Multi-Tier Framework for Cooking
Source: World Bank, 2020

The attributes considered under the MTF for cooking are:

Efficiency: How efficient the processes of combustion and heat transfer are given specified stoves and fuels.

Exposure: This refers to the exposure of consumers to household and indoor air pollutants like $PM_{2.5}$ and carbon monoxide (CO). The factors that influence emissions include fuel quality, the stove design and emissions and ventilation. Exposure is higher in lower tiers and lowers in higher tiers (World Bank, 2020).

Availability: This refers to how readily available the fuels and stove are for cooking purposes when needed by the consumer.

Safety: This considers the severity of accidents and injuries related to cookstoves and fuel.

Table 2.3: Multi-Tier Framework for measuring access to modern energy cooking solutions

ATTRIBUTES		TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER
Cooking Exposure	ISO's voluntary performance targets (Default Ventilation)						
	$PM_{2.5}$ (mg/MJd)	>1030	≤1030	≤481	≤218	≤62	≤5
	CO (g/MJd) gn	>18.3	≤18.3	≤11.5	≤7.2	≤4.4	≤3.0
	High Ventilation						
	$PM_{2.5}$ (mg/MJd)	>1489	≤1489	≤733	≤321	≤92	≤7
	CO (g/MJd)	>26.9	≤26.9	≤16.0	≤10.3	≤6.2	≤4.4
	Low Ventilation						
	$PM_{2.5}$ (mg/MJd)	>550	≤550	≤252	≤115	≤32	≤2
	CO (g/MJd)	>9.9	≤9.9	≤5.5	≤3.7	≤2.2	≤1.4
Cookstove Efficiency	ISO's voluntary performance Targets	≤10%	>10%	>20%	>30%	>40%	>50%
Convenience	Fuel acquisition and preparation time (hours per week)	≥7		<7	<3	<1.5	<0.5
	Stove preparation time (minutes per meal)	≥15		<15	<10	<5	<2
Safety		Serious Accidents over the past 12 months				No serious accident over the past year	
Affordability		Fuel cost ≥5% of household expenditure (income)				Fuel cost <5% of household expenditu (income)	
Fuel availability		Primary fuel available less than 80% of the year				Available 80% of the year	Readily availab through the yea

Source: Bhatia & Angelou, 2015; Energy Sector Management Assistance Program, n.d.

Convenience: The convenience attribute considers issues such as the reliability of the stove for cooking, the quality of heat for cooking and time spent acquiring fuel. Reliability of the stove focuses on how the stove-fuel system works and the ease with which the stove can be lit, and the fire maintained throughout cooking. The quality of the heat considers whether the heat generated can cook the food within the expected time, to the expected quality as well as the quantity of food to be cooked (Stanistreet et al., 2019). The time spent in either purchasing or collecting the fuel and the time spent to get the stove ready. It is measured as hours per week spent collecting or purchasing fuel and minutes per meal spent preparing the stove (World Bank, 2020).

Affordability: The affordability attribute indicates the proportion of household expenditure spent on cookstoves and fuel. Large proportions of household budgets are spent in the lower tiers whereas a lower share of expenditure is spent at the higher tiers (World Bank, 2020; World Bank and SEforAll, 2016).

The MTF places emphasis on the perspectives of the users about the key attributes of their cooking methods. The framework facilitates the capturing of information on various attributes such as access to cooking fuel and cooking conditions, user behaviour, use of multiple cooking facilities, safety, and convenience. It also allows for comprehensive tracking of progress based on a broad range of data at the household level. The multidimensional element allows for a better understanding of the issue with access using an aggregation of households across social, gender, economic and geographic dimensions (World Bank, 2020).

2.6 Energy Access and Sustainable Development Goals

Access to modern energy services is vital for economic and social development. Access to modern energy which is reliable and affordable is necessary for the proper functioning of various sectors. The provision of modern energy access has impacts on education, healthcare delivery, household cooking and heating, household and community lighting, agriculture, transportation, livelihoods and other aspects of everyday life (Klaiber, 2015). Access to clean and sustainable energy is also critical for environmental protection and the actions being taken to deal with climate.

In 2015, the United Nations member states adopted the 2030 Agenda for Sustainable Development, and at this agenda's core were the 17 Sustainable Development Goals (SDGs) launched in 2016. These goals were a call to action by both developing and developed countries to tackle global issues such as inequality, poverty, environmental degradation, climate change, injustice, and peace to achieve a sustainable future for humanity. Due to the significance of energy in human existence, it is included as part of the 17 SDGs as Goal number 7 or SDG 7.

The aim of Goal 7 of the SDGs is to "ensure access to affordable, reliable, sustainable and modern energy" (United Nations, 2015). The targets for SDG 7 to be achieved by 2030 are as follows:

- *"Target 7.1 - ensure universal access to affordable, reliable, and modern energy services.*
- *Target 7.2 - increase substantially the share of renewable energy in the global energy mix.*
- *Target 7.3 - double the global rate of improvement in energy efficiency.*

- *Target 7.A - enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology.*
- *Target 7.B - expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular, least developed countries, small island developing States, and land-locked developing countries, in accordance with their respective programmes of support"* (United Nations, 2015).

Even though energy access is covered by SDG 7, its pivotal role is recognised in the way it has implications for the achievement of several of the other SDGs such as the provision of good healthcare services, improvements in education, clean water and sanitation, poverty eradication, gender equality, economic growth, building sustainable communities and cities, climate action and promoting sustainable industrialisation (Rao and Pachauri, 2017).

To track progress, evaluate and inform policy, as well as hold stakeholders accountable to achieve the SDGs, a framework of indicators was developed and adopted in 2017. These indicators are useful for tracking the progress toward achieving the targets for the various SDGs. To track progress made with regard to achieving SDG 7, adopted indicators include:

- *"Proportion of global population with access to electricity and relying primarily on clean and affordable fuels for Target 7.1.*
- *The share of renewable energy in the total final energy consumption for Target 7.2.*

- *Energy intensity with regards to GDP and primary energy for Target 7.3.*
- *For Target 7.a, International financial assistance to developing countries to support research and development of clean energy technology and renewable energy generation.*
- *The number of installed generating capacity from renewable energy sources in developing countries*" (United Nations, 2017).

Sustainable Energy for All (SEforAll)

In 2011, the Sustainable Energy for All (SEforAll) initiative was launched by the UN Secretary-General as a partnership involving multi-stakeholders mainly governments of various countries, the private sector, philanthropies, civil society and financial institutions. The SEforAll provides a platform to bring together the top-tier leaders of the various sectors of society to deliberate on guidance for the initiative.

2.7 Conceptual and Analytical Framework

The framework adopted for this research is the logic framework developed by Quinn et al. (2018) for their work on the scale-up of clean household fuel for cooking. They draw on previous work by Rosenthal et al. (2017) discussing the salient factors and dimensions for LPG scale-up and adoption to develop a logic model that can be used for clean energy or fuel policy initiatives. Their model seeks to provide a general starting point to understand the various factors and dimensions that need to be considered in planning for the scale-up and adoption of clean fuel interventions or initiatives. The generalised model developed by Quinn et al. specifies five main dimensions that according to them influence clean energy adoption and as such should be given consideration in clean energy scale-up initiatives. These main categories that

are considered are enabling environment, energy industry structure and services, energy pricing and cost, factors influencing consumer demand and user and community needs and perceptions. They stress that these five areas - despite being interlinked in various ways - act as independent determinants of clean energy scale-up initiatives. The generalised logic model developed by Quinn et al. is presented in Figure 2.2 below. The logic model developed by Quinn et al. provides a vital starting point to understand and evaluate the various factors or dimensions that either act as barriers or enablers to the scale-up and uptake of LPG from the end-user perspective. Their model is applicable to understanding the uptake and scale up to other clean energy technologies for household energy access from the perspective of the users. The various factors considered under the model are presented below.

Enabling environment

The provision of an enabling environment for the promotion of the adoption and uptake of clean energy involves the provision of appropriate policy and regulatory frameworks as well as the right fiscal regime and political climate mainly by governments and all other relevant stakeholders.

Energy industry structure and services

The broader structures of the energy industry and how they function do influence the scale-up of clean energy. These structures and functions are influenced by the various policies and regulations instituted by the government as other key stakeholders within the energy industry. Other aspects under this category are not controlled by governments such as physical infrastructure, distribution, and the sustainability of supply.

Energy pricing and cost.

Key aspects include the initial setup and operation cost for various clean energy options (e.g., Electricity connection, LPG setup) as well as the cost of the alternative energy sources.

Factors influencing consumer demand

This focuses on aspects such as the knowledge of the end-user on the performance of the clean energy or fuel type, its use and anticipated benefits and the energy supply's reliability. The affordability and accessibility considerations of the energy supply are also factored in here. Other aspects considered under this factor include the setting, financing options available to the end-users and the socio-economic factors about the consumer that may either serve to be incentives for adoption or barriers.

User and community needs and perceptions

User and community needs, and perceptions deal with perceived affordability and safety issues concerned with clean energy technology. Other factors include awareness of the beneficial impacts of the adoption and use of clean energy, the perceived convenience associated with its use and any associated prestige. The emphasis on user and community needs, Stanistreet et al. (2019) explains, is to find out whether clean energy interventions, in this case, LPG use, do meet the needs of the end-user as this is a key influence on the sustainability of a clean energy intervention. They also posit that end-users are in a better position to identify enablers and barriers to the adoption and sustainable use of clean energy interventions and to help identify appropriate solutions when deciding on new interventions. The social and behavioural dimensions in relation to end-users have also been noted to have an influence on technology adoption (Dreibelbis et al., 2013). In line with the discussions about the importance of

user aspects in the scale-up of clean energy technology and adoption, Stanistreet et al. in their work suggest some changes to the logic model developed by Quinn et al to promote user aspects and in the scaling-up of clean energy. They suggest that user and community needs should be placed at the top of the model as opposed to their position at the base in the original model by Quinn et al. Placing user and community needs at the top of the model and as a starting point would ensure that these needs are prioritised in the discussions on the scale-up of clean energy technology. The Stanistreet revised model also rewords the user dimensions to exclude the word "perceptions" as its use downplays the significance of the knowledge and experiences of the end-users about the barriers and enablers of clean energy adoption and scale-up. The revised model used in Stanistreet et al.'s work is presented in Figure 2.3 below.

The generalised logic model is adopted as a starting point for this research which focuses on the use of a hybrid mini-grid use for the electrification of island communities. The research sought to examine how the various elements of the framework apply to the development of solar-PV hybrid mini-grid electrification systems for the island communities and explore how they influence the acceptance and adoption of the technology; energy uses and choices. The framework by Stanistreet et al. (2019) in itself is an improvement of the logic model for clean fuel scale-up first developed by Quinn et al. (2018). This research sought to inform, revise and add to the revised generalised logic model for clean fuel scale-up by Stanistreet et al., (2019) and while exploring its applicability to hybrid mini-grid adoption for the first time. This research thus goes ahead to add to the framework other dimensions that are equally important but may have been overlooked by the previous models., such as the importance placed on socio-cultural dimensions of renewable energy technology and energy access in general.

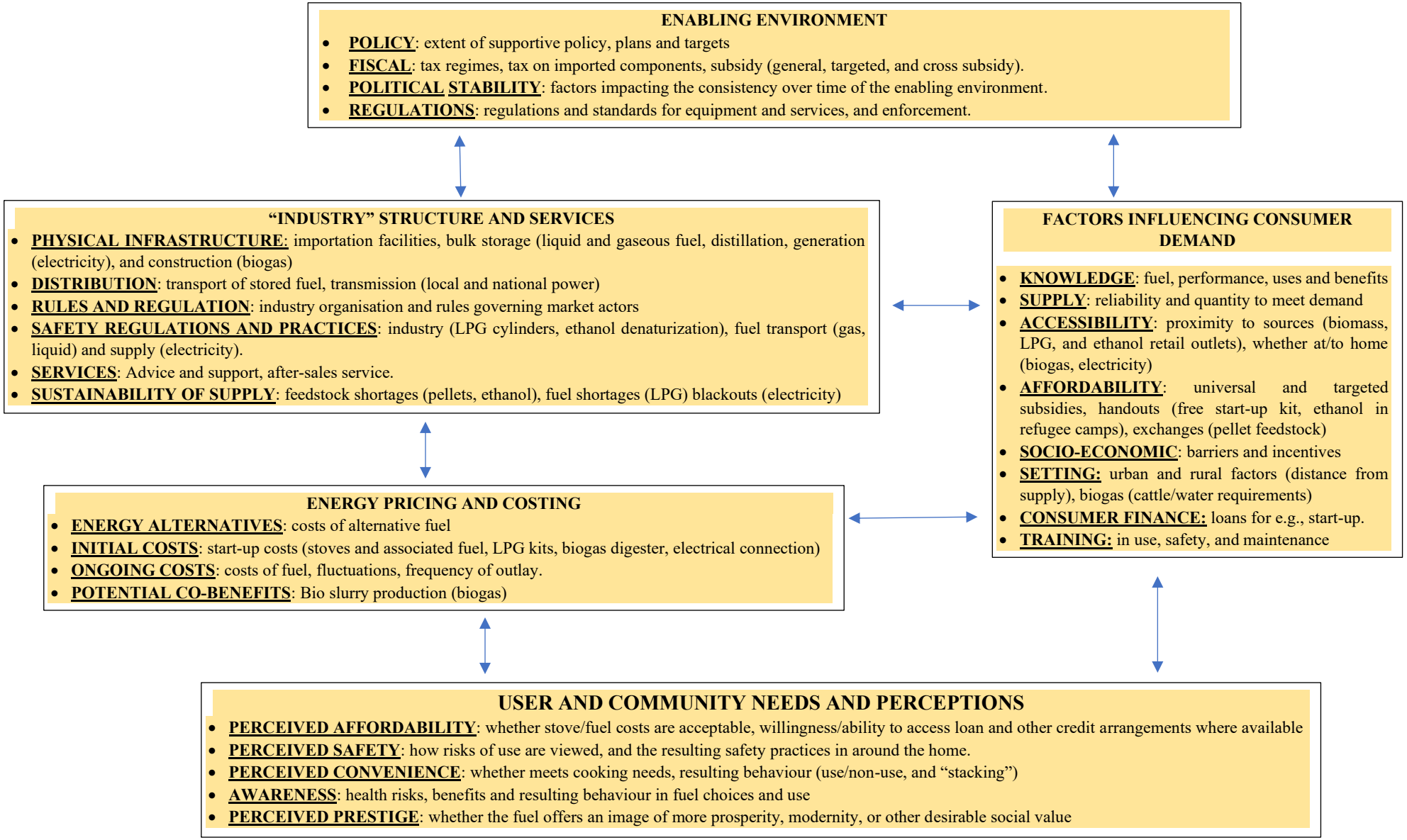


Figure 2.2: Generalised logic model for clean fuel scale-up developed by Quinn et al. (2018)

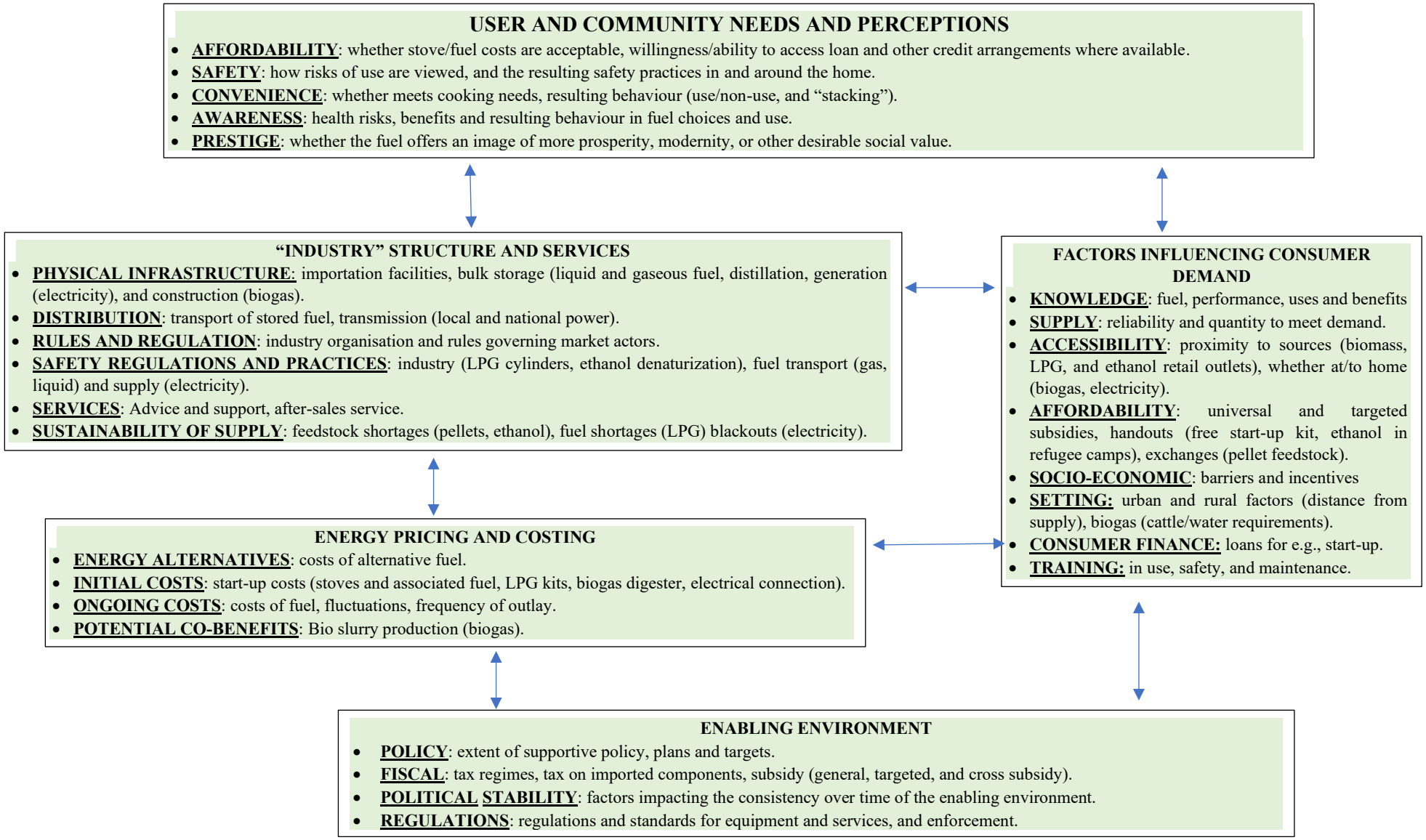


Figure 2.3: Revised generalised logic model for clean fuel scale-up by Stanistreet et al. (2019)

2.8 Gender and Socio-Cultural Dimension of Energy Access

Energy poverty has been shown to affect female household members the most, given that they are most often the ones that must spend time and use labour to search for and collect solid traditional fuels to meet energy needs within households, especially for cooking and heating. Women also spend several hours cooking with traditional solid fuels and are continuously exposed to smoke and other air pollutants emitted from the burning of traditional solid fuels (Oparaocha and Dutta, 2011). The health implications of continuous exposure to indoor air pollution from traditional fuel use are well documented and known to contribute to the death of about 3.8 million people annually and also results in an increased risk of illness such as tuberculosis, respiratory diseases, eye problems and impaired lung function (World Health Organization, 2021; Stanistreet et al., 2019; Barnes and Samad, 2018; Atagher et al., 2017).

Research also shows differences in energy use practices and preferences of energy sources exist between the different genders within communities (Asibey et al., 2021; Anfinsen and Heidenreich, 2017). Aryal et al. (2019) assess how clean energy use behaviour is different among male-headed households and female-headed households in Bhutan. Their research found significant differences in clean energy use based on the gender of the head of the household. In comparison to households headed by males, households with female (single, divorced, or widowed women) heads of households used energy that was significantly less clean. The difference in clean energy use could be attributed to access to higher income for male heads of households compared to the income of female heads of households. According to Choudhuri & Desai (2020), their study showed that households where women were significantly empowered in market participation and exercised more control over household expenditure decisions, due to

earning a salaried or higher income, were most likely to invest in the use of clean and modern cooking fuels.

Asibey et al. (2021) examined the responsiveness of Ghana's energy policies to gendered energy needs and the factors that influence energy choices of the different genders for productive uses in Ghana. They found out that overall energy policies in place fail to acknowledge and address gender-related energy needs and the factors that impact energy choices for productive uses. Their study also finds that energy needs, and energy preferences were gendered. Gender is noted to influence accessibility to electricity and other modern energy services by households as according to Ulsrud (2020) households headed by females (i.e. single women, divorced women and widows) had lower chances of obtaining electricity access compared to couples or single men and households headed by males. This could be attributed to the lower income levels of women. According to Winther et al. (2018) women have less influence on household decisions on sources of their energy and their use. Women in most instances benefit more in the household with access to modern energy services as it promotes better communication, safety, and fewer health issues than using solid fuels for cooking.

According to Brown and Cloke (2017) scholarship on achieving energy access targets has primarily focused on advances in particular technologies or the development of business, financing models to facilitate the uptake of various energy technologies, other market-led strategies and regulatory frameworks. This has resulted in less focus on the social and the political economy context of energy access. Similarly, Haque, Lemanski and de Groot (2021) argue that despite the crucial role of socio-cultural dimensions in energy access discussions and interventions, it is usually overlooked, downplayed and given the attention it deserves in scholarship, policy analysis and

discussions on strategies geared at global South energy transitions. According to Cloke, Mohr and Brown (2017), the preoccupation of project funders and implementers of energy access projects and interventions on the technical and financial aspects of energy projects may initially make implementation easy but less consideration for other aspects of such projects like the socio-cultural context of end-users, political economy and wider geopolitics usually results in the projects being unsustainable in the long term. Kumar (2018) points out that scholarship on the social and cultural aspects of energy access projects is key to enabling a holistic view of the impacts, either positive or negative, of these projects as well as the end-user perspectives on them as these are important factors that impact the outcome of the implementation of energy access projects. They also found out that socio-cultural norms about energy needs and priorities and the difference within households influenced the energy sources used and the choices made. As Elmustapha, Hoppe and Bressers (2018) point out, getting a comprehensive understanding of the socio-cultural norms and practices, especially within a regional context allows for the development of an enriched understanding of the dynamics at play in instituting the policies and strategies to promote solar energy technology and broader modern energy technology adoption. Evidence of the impact of the socio-cultural dimension on the behaviour and attitudes towards various modern energy services and technology adoption in general terms is provided by Agunyo, Bacwayo and Kizza-Nkambwe (2020). They point out that despite the benefits associated with resource recovery from the operation of waste-to-energy facilities, the cultural backgrounds and beliefs of people to a higher extent influenced their attitudes and perceptions towards the use of resources recovered from the waste-to-energy systems. Nuru, Rhoades, and Gruber (2021) also provide evidence in the case of mini-grid implementation for rural islands in Ghana, where social issues

like conflicts over the ownership and release of land intended for the mini-grid projects impeded the smooth implementation of the mini-grid projects on the islands. Delays in the delivery times of the projects were also noted to have been caused by various issues resulting from the social norms and practices of the beneficiaries. There is therefore the need for scholarship and project implementation to focus equally on the technical, financial and socio-cultural dimensions of energy access and transition projects (Nuru et al., 2021). The importance of the socio-cultural context of beneficiaries of energy access interventions and projects and the gap in the literature on these issues - especially in the global South - is what this research seeks to contribute to using the rural island communities in Ghana as a case study. The literature draws attention to the role gender dynamics and socio-cultural dimensions play in providing clean and affordable sustainable energy for all to achieve SDG 7 and therefore the need for energy strategies and policies to consider the gender and socio-cultural dynamics such as responsibilities, energy needs, preferences, and priorities.

2.9 Rural Electrification in Developing Countries

Barnes (1988) defines rural electrification as the provision of electricity access to rural and remote communities regardless of the generation, sources and technologies involved in doing so. Other definitions of rural electrification focus on providing electricity access with specific technology, i.e., central, or decentralised grid (Munasinghe, 1988). Looking at the various definitions, it is noteworthy that the meaning of rural electrification in the Global North will be different from that for the South, given the different circumstances in each case (Foley, 1992). However, it may be argued that there are some similar characteristics that all the other definitions relate to, i.e., rural communities are widely dispersed, there are fewer households as

compared with urban areas which means low load factors and thus low consumption (World Bank, 2012).

For this research, rural electrification is mainly used to refer to the provision of electricity access to rural and remote communities in low-income and developing countries. The benefits of rural electrification in most developing countries include significant reductions in particulate matter and other air pollutants in households. According to Barron and Torero (2017), their research evidenced that household electrification significantly reduces indoor air pollution as overnight kerosene use for lighting is replaced with electric lighting and the levels of indoor air pollutants were still noted to be low even after 2 years of electricity access. This reduction in indoor pollution goes a long way toward reducing respiratory infections for household members, especially children who are most vulnerable (World Health Organization, 2021; Quinn et al., 2018; Barron and Torero, 2014). As part of improved health care delivery due to rural electrification, reduced birth rates/fertility have been observed through the dissemination of information on reproductive health using information channels as well as entertainment benefits from the electricity for lighting and watching and listening to TV/radio (Mulugetta et al., 2019). Rural electrification also results in an increased and efficient means of production and other economic activities. In the household, more efficient production translated to more working hours to access markets. It also results in an increase in new work opportunities (Barnes and Samad, 2018; Westphal et al., 2017). It was also found that there are significant increases in the time spent doing non-farm work activities in the case of males and as well as an increase in total income mainly due to labour reallocation (Bernard and Torero, 2011 cited in Torero, 2016). Dinkelman (2011) points to the fact that electrification in households in South Africa has impacted positively female employment/economic

activities. She argues that time which hitherto was spent gathering wood for cooking is freed up with electricity access, thus allowing females the time to engage in other jobs or carry out other business and economic activities.

2.10 Current Trends in Rural Electrification Using Either Conventional or Renewable Energy Technology

2.10.1 Rural Electrification Strategies

Grid, Mini-grids And Standalone Systems

Rural electrification in developing countries has become of great interest to many international development agencies and governments as well as being the focus of a lot of research across the globe all in the bid to provide clean, affordable, modern, and sustainable energy as part of achieving sustainable development (Peters et al., 2019; Azimoh et al., 2017; Dagnachew et al., 2017). Electricity access through centralised grids is usually easily accessible in urban, peri-urban, and relatively easily accessible locations, which therefore leaves most rural and remote communities that lack access to these centralised grids with no option but to rely on low-quality traditional energy sources for their needs. Some of these energy sources include but are not limited to biomass or wood fuel for cooking, candles and kerosene for lighting (Dagnachew et al., 2017). The challenges associated with rural electrification due to location, population and energy demand limit the types of electricity-generating technologies that can be deployed in this location. Where it is not feasible to connect to the central grid, the use off-grid generation provides a better alternative. In deploying off-grid technologies, the use of locally available resources - in most cases - renewable energy resources provides more viable and realistic alternatives (Ulsrud, 2020; Azimoh et al.,

2017). In rural settings, some of the most readily available viable energy sources remain solar, biomass, mini-hydro, and wind. For off-grid rural electrification projects, the approaches that have been utilised can be categorised mainly into two; namely stand-alone home systems and localised grid systems as summarised by (Mandelli et al., 2016).[2] Stand-alone systems usually are deployed for individual households and utilise energy sources such as wind, solar and diesel generators. Localised grid (micro-grid/mini-grid) systems on the other hand have electricity-generating sources that utilise a distribution grid to supply electricity to its consumers in a location (Come Zebra et al., 2021; Azimoh et al., 2016, 2017; Aziz et al., 2016).

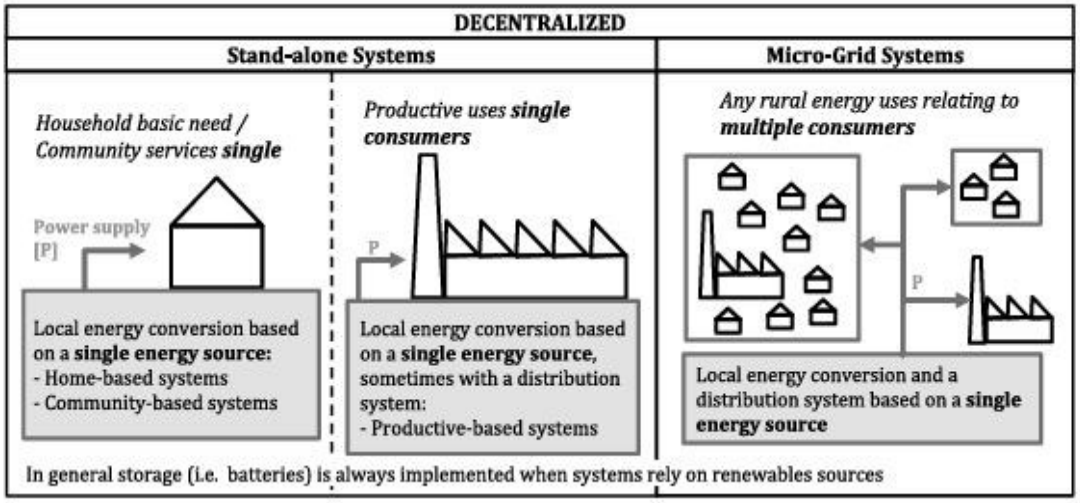


Figure 2.4: Diagram of Categories of Off-grid Electrification systems
Source: (Mandelli et al., 2016)

The choice of energy source for generating electricity in a particular rural community is dependent on the energy resource available within the community and how realistic and viable it is. The most preferred sources for powering stand-alone systems and localised grids are solar, wind, biomass, and diesel generators. The location limiting

[2] These may be categorised further depending on their capacity and sizing. These may either be mini-grids/micro-grids

factor associated with the use of hydropower does not make it practical and suitable for all forms of rural electrification. Fuel availability and the cost of diesel generators and their maintenance are limitations of the use of diesel generators for rural electrification (Aziz et al., 2016; Chowdhury et al., 2015; Zhou et al., 2015).

Off-grid electrification technology, especially mini-grids as earlier stated, remains a vital technology better suited for the electricity provision for rural and remote locations. The use of fossil fuel-powered mini-grids is convenient, but they raise concerns over high CO_2 emissions and the finite nature of the fuels and the associated costs. The use of renewable energy technologies for powering mini-grids minimises dependency on finite fossil fuels and ensures a reduction in CO_2 emissions but is dependent on reliable and affordable resource availability (Comello et al., 2017; Lewandowska-Bernat and Desideri, 2017; Bhattacharyya and Palit, 2016).

In the same vein, renewable and hybrid energy mini-grids stand out as having great potential for providing electricity to the millions in Sub-Saharan Africa lacking electricity access. The provision of electricity access using renewable energy stands to improve the lives of people through increased local employment, improved health care and a boost for economic activities and overall development. Mini-grids are increasingly proving to be technically and economically viable modern energy solutions for the millions who live in remote and rural areas and lack access to electricity (Cloke et al., 2017). The establishment and success stories of renewable and hybrid energy (hybridization with fossil-fuel generators) mini-grids have proved to result in substantial savings for end-users, as well as state-owned utility companies and governments while also minimising CO_2 emissions (Chowdhury et al., 2015; Akikur et al., 2013). For the successful and sustainable implementation of mini-grid schemes in any location, mini-grids are designed having given careful consideration

among others to the pertaining local conditions be they economic or environmental as well as the development of viable financial models all backed by suitable and enabling national policy and regulatory framework (Energy Sector Management Assistance Program, 2016).

2.11 Renewable Energy Technologies for Rural Electrification

2.11.1 Solar PV

Harnessing energy from the Sun has been a part of human lives for several thousands of years mainly for drying food and other items as well as heating (Shinn, 2018). Technological advancement, however, has made it possible and easy to harness solar energy for more complex uses such as electricity. Solar energy according to the International Energy Agency (2014) is the most abundant energy resource and has been receiving increased attention over the last few decades mainly because of climate change awareness and concern, the need for the pursuit of more sustainable energy sources aside from the current fossil energy sources and advancement renewable/green energy technologies. Solar is increasingly popular the world over given that it results in less environmental pollution and is also easy to maintain. The total global electricity generation from solar stands at 0.1% of global energy generation (International Energy Agency, 2014). Global solar installation capacity at the end of 2015 was 227 GW with countries such as Germany with the largest Solar PV installed capacity, followed by China, Japan, Italy and the United States (World Energy Council, 2018).

In harnessing solar radiation for energy generation, several technologies exist such as solar thermal, concentrating solar power and solar photovoltaic (PV) which is the most popularly used in electricity generation (Chu and Meisen, 2011). Solar PV works by

using an array of semiconductor-based solar cells. When light radiation interacts with the semiconductor it releases an electron, and this forms a current. The electrical current is harvested in the form of a direct current (DC). With solar PV, the electricity stops being generated when there is no sunshine, thus there is a need for storage or alternative means of electricity generation as a backup to ensure that electricity is available when it is most needed, which is at night. The combination of PV modules, batteries, inverters, and other electrical installations form the PV system. Available on the market are various solar PV technologies that vary based on cost and efficiency. The main solar PV end-user systems available are residential systems (standalone solar home systems, SHS), commercial systems, off-grid systems (increasingly geared to mini-grid systems) and utility-scale systems (International Energy Agency, 2014). Though Solar PV technology looks promising, the technology has with it some challenges such as:

- Limitations with regard to location and weather conditions.
- The low efficiency of the current PV modules on the market requires the development of cells with increased efficiency
- Research in technological advancement for modules with high efficiency is expensive. (Chu and Meisen, 2011).

2.11.2 Wind

The wind is a renewable energy resource that is used for rural electrification that is readily available irrespective of location. The energy from the wind flow is harnessed and converted into electricity, the quantity of electricity that can be generated at a particular place varies mostly dependent on the wind speed. The technology operates

on the basic principle that a wind turbine converts the kinetic energy in the wind flow into as the blades of the turbine are turned. This movement of the blades transfers energy to the rotor which in turn causes the shaft to spin thus converting the mechanical energy generated into rotational energy turning an electric generator. The amount of electricity a wind turbine generates is dependent on factors such as the swept area of the blades[3], the density of the air and most importantly the speed of the wind.

2.11.3 Hydro

Hydropower is a matured renewable energy technology in use globally. The installed capacity of hydropower worldwide in 2018 was 1,292 GW and it is currently utilised in over 160 countries. Hydropower electricity operates on the principle of rushing water turning the rotating turbines which then generate electrical energy in an attached generator (IHA, 2019; Yuksel, 2009). Hydropower-generating plants are of various sizes, ranging from large to small (Pico) depending on the capacity. In rural and remote locations where river streams exist with sufficient runoff, small-scale hydropower systems could be developed to generate electricity for the nearby communities where large-scale power generation or the central grid is not economically feasible (Zhou et al., 2015; Yuksel, 2009). Dependent on their capacity small scale hydropower systems are categorised as Pico (lower than 5 kW), micro (lower than 100 kW) and mini (capacity lower than 1MW), in comparison to conventional fossil-fuelled power plants, modern hydropower plants have higher efficiency in the range of 85%. Characteristics of hydropower such as being renewable, inexpensive, clean, and having low environmental impact make it a preferred option for many countries.

[3] Swept area of a wind turbine refers to the area that the blades of the turbine spin through

Hydropower requires high setup costs and when carried out on large scale issues with population resettlement and environmental impacts arise (Hossain et al., 2018).

2.12 Mini-grid and hybrid mini-grids systems

Off-grid/decentralised electrification seems to have gained great significance as a viable option for rural renewable energy penetration globally and improving electricity access given its key advantages such as making electricity available to local consumers in most remote and isolated locations unreachable with the centralized grid connection and ease of use with renewable/green energy technology (Ulsrud, 2020). In the push for this off-grid electrification agenda, micro/mini-grid systems are key. Mini/micro-grids are best suited for the electrification of these remote areas, where the electricity requirements of the locals are either beyond the capacity of solar home systems (SHS) or are added to them (Comello et al., 2017; Lewandowska-Bernat and Desideri, 2017; Bhattacharyya and Palit, 2016).

Mini-grids are defined by the European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF) as

> "*Involving small-scale electricity generation (from 10kW to 10MW), and the distribution of electricity to a limited number of customers via a distribution grid that can operate in isolation from national electricity transmission networks and supply relatively concentrated settlements with electricity at grid quality level*" (European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF), 2014).

The World Bank also defines mini-grids as "isolated groups of generation, distribution, storage facilities within a confined geographical space. They are usually locally managed, have less than 10 MW of installed capacity, serve small household loads, and serve an area of up to 50 kilometres radius" (World Bank, 2017). These definitions both make it clear mini-grids are decentralised grids usually utilised in the supply of electricity to local consumers, consisting mainly of electricity generation facilities, distribution networks and most probably storage systems. Mini-grids can be designed to work in isolation or be connected to the centralized grid.

Innovations in technology for mini-grid systems, renewable energy generation and electricity management platforms/services have resulted in cost reduction, increased effectiveness and reliability of mini-grids and renewable energy technology (Azimoh et al., 2016). Mini-grids may be configured in several ways. These may either be with a single-generation technology or a hybrid that integrates more than one generation technology (e.g., renewable, and conventional technology) which is drawing much attention as a promising future for mini-grids (Stockholm Environment Institute, 2016). Single-generation technology mini-grid systems are faced with challenges that are mitigated in with hybrid mini-grids. For instance, mini-grids with supplies from diesel generators alone are susceptible to disruptions resulting from fuel shortages and price increases. Other single renewable energy systems also face the risk of seasonal variability. However, with hybrid systems, these risks and challenges are mitigated. For instance, a solar PV-diesel hybrid system mitigates the risks associated with fuel supply, price increases and seasonal variability by combining the solar PV system (non-dispatchable because the energy source cannot be controlled by operators) with diesel generators (dispatchable systems) which are readily available and when solar

energy is not available at night when it is needed most (Alliance for Rural Electrification, 2014).

The Global Village Energy Partnership (GVEP) International lists the factors/features making mini-grids especially hybrid mini-grids attractive and promising as:

- Reductions in environmental pollution from energy generation because mini-grids especially hybrid mini-grids most often than not integrate renewable energy sources ranging between 75-99%. Thus, a major share of the energy generated is without any pollution.
- The reliability in electricity supply that hybrid mini-grid offers, as opposed to mini-grids powered by single-generation technologies, makes it attractive.
- The flexibility associated with mini-grids such as being able to install in remote locations, can be connected to the grid or not and its smaller scale also mitigates against challenges such as distribution loss associated with national/large scale grids.
- Due to its localised nature, local people can be trained and included in its operational, maintenance and management thereby dealing with issues associated with power theft and infrastructural damages (Global Village Energy Partnership International, 2011).

2.12.1 Community Size and Mini-Grid Access.

This section explores the relationship between mini-grids and the size of the intended beneficiary communities.

Community size and the design/planning of mini-grids

The ultimate beneficiaries of any electrification project are the community members. In choosing the best option for providing electricity access to any potential beneficiary community, it is best to take into consideration the population density to determine the demand load. Another important aspect to consider is the housing pattern, whether they are clustered or scattered. This will inform the choice of appropriate technology for the provision of electricity access i.e., mini-grid or standalone energy systems (Rawn and Louie, 2017; Alliance for Rural Electrification, 2014). In the scenario that a mini-grid system is the best option for electrification of a community with clustered housing patterns, information on the population density of the community will help in demand forecasting to accurately size the mini-grid system for the scheme. Accurate prediction of the demand load with supply will result in stable revenues, which increases the economic viability of the project.

According to the German Agency for International Cooperation (GIZ), (2016), inadequate information regarding electrical demand, load conditions of systems, and potential load growth as part of the sizing and design processes can result in the designing of either oversized or undersized mini-grid systems.

- Oversized mini-grid systems result when the capacity of the mini-grid is higher than the actual electrical demand. Investments for oversized systems tend to be higher as compared to returns as well as having higher operational costs and lower efficiency. Oversized hybrid mini-grid systems usually operate below their recommended load factor and usually result in energy losses as well as damage to components over time in some cases.

- Undersized mini-grid systems, on the other hand, have lower capacities than actual electrical demand due to inaccurate information on demand before setup. Mini-grids that are undersized result in unreliable, erratic supply and low electricity service quality.

Unreliable and erratic electricity supply resulting from both scenarios impact consumers negatively and result in increased dissatisfaction with the service. The strain placed on the system due to its undersized nature also affects the components thus potentially resulting in damage and ultimately increased operational and maintenance costs. Consumer dissatisfaction with service quality is more than likely to result in challenges with revenue collection (German Agency for International Cooperation (GIZ), 2016). Both scenarios do affect the optimum operation of mini-grids and thus hinder the supply of high-quality electricity with the associated higher costs of operation and maintenance, therefore there is the need to carry out accurate electricity demand assessment and sizing of the systems to ensure optimum operation.

Community involvement in mini-grids planning and operation

It is important to involve the communities, especially the community leaders and other representatives of the community members during the design and planning stages of mini-grid projects to ensure that the social and economic characteristics of those communities are taken into account (Kimera et al., 2014). Communities that are involved in mini-grid projects usually have a sense of acceptance and ownership and therefore facilitate their successful implementation. Community members could be trained and employed to maintain and repair the projects. Also, the involvement of community leaders will ensure effective revenue collection and supervision (Kimera et al., 2014; Global Village Energy Partnership International, 2011).

Population density vs tariff /returns on investment

The communities where mini-grids offer a good alternative for electrification are usually rural areas located further from the grid. These small and isolated populations/communities tend to have fewer economic activities and thus small economies which are less attractive to investors. Since these small rural isolated communities usually are further from urban economies and have small economies, private entities/investors hold back from investing in projects due to the perception that returns on investments in mini-grid projects through tariffs are difficult to achieve and rather invest in communities with large populations to effectively get the returns on their investments (Rawn and Louie, 2017). Another fact hindering investments in mini-grid schemes in smaller communities is that the payback times for investment in large communities are less due to the larger number of consumers contributing to pay off the cost as compared to the scenario in smaller communities (Rawn and Louie, 2017; S. Szewczuk, 2017). In instances where investment for mini-grid schemes/projects is mainly from aid or grants provided by NGOs and Development Agencies as is the case with most mini-grid projects in SSA, it, therefore, becomes economical for governments to site such projects in communities where larger populations will be covered under the scheme.

Though mini-grids are very promising for mitigating electrification challenges, especially in developing countries, they are not without some challenges which need to be appropriately addressed for increased performance. The Alliance for Rural Electrification (ARE) in their report on *Hybrid Mini-Grids for Rural Electrification: Lessons Learned* identify the following challenges:

- Poor maintenance of systems and use of untested technologies usually result in failed projects

- The absence of adequate primary renewable energy resources for proposed mini-grid projects does affect the success of the project.
- Lack of local involvement in projects (e.g., absence of local technical expertise could hamper the longevity of projects including repair and maintenance).
- The absence of supplementary programmes to promote economic activity and development may result in a lack of demand for the electricity generated and the subsequent failure/collapse of such projects.
- Unfavourable regulations and policies could also be a barrier to the promotion of mini-grids. E.g., high-cost import taxes on mini-grid/renewable energy equipment and technology could make the sector unattractive for investment by private entities.
- Poor financing schemes for mini-grid schemes and inadequate financial investment in developing schemes do make the promotion of these schemes for rural electrification difficult (Alliance for Rural Electrification, 2014).

2.13 Implementation and Diffusing Models for Rural/Off-Grid Renewable Energy Technology

According to Mandelli et al. (2016), energy uses can be grouped into three main categories; domestic household use, productive and economic activities meant to generate income, and community energy use for general well-being and security. The high cost involved in electricity generation and distribution systems becomes a limiting factor, especially in rural electrification where low-income levels and low demand pertains in addition to transmission losses which increase the cost further. For the successful implementation and operation of electrification projects for rural and

remote locations, there is a vital need to find a balance between recovering investments and consumer acceptance and their willingness to pay for electricity (Global Village Energy Partnership International, 2011). To achieve this, the appropriate financing and implementation models need to be utilised and these do vary between communities in deciding the best models/schemes to implement with several factors coming into play (Global Village Energy Partnership International, 2011). Pigaht and van der Plas (2009) argue that for successful implementation and operation of rural electrification projects especially off-grid projects local people should play active roles in the planning, development, and implementation of those interventions. This in a way makes them feel a part of the project and actively work to ensure its successful implementation.

2.13.1 Financing programs/schemes

The cost involved in planning, developing, and implementing rural electrification projects is a key challenge to the widespread penetration of rural electrification. This challenge is relevant for parties on both sides of the table (i.e., government and private investors on one side and consumers on the other side (Mainali and Silveira, 2011). Adequate capital is necessary for the successful implementation and operation of rural electrification projects. As Bhattacharyya (2013) points out there are various financial schemes/instruments that can be implemented to facilitate rural electrification success. These include subsidies, discounts, microcredits, and lease arrangements for rural consumers who are the end-users on one hand and on the other hand donor funds/grants, government debt financing, tax incentives, lending based on project cash

flows and asset-based lending for the government, agencies and private investors involved in the development of rural electrification projects.

Credit Financing

With the ever-increasing demand and need for rural electrification projects to improve lives and promote development, numerous financing models have been developed to cater for the issue of financing challenges, one of which is credit financing. These models are geared towards affording low-income earning rural dwellers the opportunity to have access to electricity. Some schemes captured under the credit financing model include leasing of energy-generating products, microcredit, community cooperatives loans and credit, loans from commercial banks and micro-finance institutions and revolving funds (Bhattacharyya, 2013; Mainali and Silveira, 2011). These are among some of the most utilised credit financing mechanisms in developing countries for financing rural electrification. For all the credit financing schemes, the underlying principle is that the company providing the service, or the product does so for the end-user on credit against collateral. The cost is spread out and payment usually is done in instalments instead of the full upfront cost which most cannot afford. In the leasing of energy-generating product schemes under credit financing for end-users, the service company provides the product and takes care of the upfront cost based on guarantees that the customer will pay monthly to cover the initial investment. The service provider retains ownership of the energy-generating system throughout the period and offers maintenance services (Bhattacharyya, 2013). Under the cooperative loans and credit scheme, individuals are usually able to borrow from cooperatives at better interest rates than from microfinance institutions and commercial banks pay for the upfront cost. The loans are then paid off later in

instalments or agreed on payment plans. In some cases, the cooperatives may procure the energy-generating systems on loans for interested members and have them pay instalments or agreed on payment plans.

Credit and loans from banks and microfinance institutions

One way of achieving this is by financial institutions (commercial banks and microfinance institutions) agreeing with energy providers to provide financial packages for their customers looking to purchase energy-generating systems without access to credit. Individuals could also approach these financial institutions to borrow funds to purchase a system with an agreed payment plan in place (Bhattacharyya, 2013; Mainali and Silveira, 2011). In some other cases, the governments in a bid to promote the penetration of rural electrification bear part of the initial setup cost or provide subsidies on the cost involved in setting up these energy generating systems and the community bear the balance that remains. This may be in the form of a monthly charge or tariff especially for renewable energy systems to cater for the remaining cost and the maintenance and operation of the system(s) (Bhattacharyya, 2013). In some cases, companies that market renewable energy products have in place hire purchase schemes that allow customers who cannot afford the high upfront cost of products to spread the payments in smaller regular payments over a period of time (Sovacool, 2014c).

Tax Incentives and Subsidies

Energy service companies involved in rural electrification projects may be given tax incentives as a means of indirectly reducing the initial setup cost involved in rural electrification projects. These may be in the form of tax waivers, and reductions on

import duty for equipment and energy generating systems (Mainali and Silveira, 2011).

2.14 Operational and Business models

Various models are available for developing, operating, and managing rural electrification mini-grids based on institutional and financial levels. Based on this, the approaches are categorised into four according to GVEP International and the Stockholm Environment Institute. These are:

- Community-based approach – under this approach, the mini-grid systems are owned, operated, and maintained by the community or community cooperative. The community remains in charge of management services such as tariff collection.
- Private sector operator approach – with this approach, private entities set up and operate the mini-grid systems and this may be in collaboration with the end-users or other investors
- The utility-based approach involves the setting up of the mini-grid system by a utility company. The operation, maintenance and management services are all handled by the utility company which may either be a public, a cooperative or a private utility company.
- The hybrid business model takes advantage of the other approaches and combines them in such a way as to maximize efficiency and effectiveness. In the hybrid approach, ownership, operation, maintenance, and management services may involve different entities (Stockholm Environment Institute, 2016; Global Village Energy Partnership International, 2011).

2.15 Challenges to Off-Grid Renewable Energy Implementation and Diffusion.

The implementation and diffusion of off-grid renewable energy for rural electrification have over the years had challenges that hinder their widespread implementation and penetration. This section reviews some of these challenges

2.15.1 Technical Challenges

Though renewable energy technology has evolved making it a good option for rural electrification several technical challenges still plague the sector; some of which are discussed below:

i. Lack of Skilled Personnel and Manufacturing Facilities

The number of technicians or skilled personnel engaged in renewable energy projects in Sub-Saharan Africa is limited and thus impacts the success and widespread penetration of renewable energy technology for rural electrification and electricity access in general. The successful design, manufacture, implementation, and maintenance of these systems require expert personnel who are few and far between. In addition to the few technical personnel, facilities for the manufacture of renewable energy technology are very limited and, in most cases, non-existent across most developing countries. Most companies providing renewable energy technology must rely on the import of their equipment and technology for deployment and maintenance which in effect adds to the cost of the technology (Aslani and Mohaghar, 2013; Nepal, 2012; Reddy and Painuly, 2004).

ii. Substandard Products

The high cost of setup for renewable energy systems remains a major concern for the industry, some practitioners in their bid to reduce the cost involved in deploying these systems procure equipment and products that are cheaper but end up being substandard. These cheap and low-quality products usually are less efficient in electricity generation and have shorter life spans as compared to the more expensive, high-quality products. These low-quality energy-generating products in a way affect the reputation of renewable energy technologies (Akinyele et al., 2018).

2.15.2 Financial and Economic Challenges

The current high cost of renewable energy technology as discussed translates to a high financial burden on the end-users. Service companies offering renewable energy services have to also deal with the high cost involved in procuring, implementing and servicing. Thus, the absence of financing and credit facilities for companies and end-users is a challenge that hinders the widespread uptake and adoption of renewable energy technology. The high initial setup cost makes renewable energy projects a higher risk if they are to fail in the initial stages than other conventional energy-generating technologies and projects (Zyadin et al., 2014; Nepal, 2012).

2.15.3 Stakeholder Engagement and Socio-cultural challenges.

It is vital to involve all stakeholders especially community stakeholders in the development, implementation, and operation of renewable energy projects. The non-involvement of these stakeholders usually results in the non-acceptance of projects.

Involving community stakeholders most often helps to dispel any misconceptions about renewable energy technology and allays any fears they have (Johannsen et al., 2020). According to Nuru, Rhoades and Gruber (2021) not appropriately engaging stakeholders and considering socio-cultural issues could result in delays and unsuccessful projects. According to Blechinger, Richter and Renn (2015), consumer behaviour and awareness of the benefits of projects, as well as the socio-cultural norms, can be barriers to the successful implementation of off-grid projects. Engaging with community members during the period before and after deployment helps to address any concerns or issues related to energy behaviour, choices, and decisions as well as any perceptions and beliefs (Nuru et al., 2021). According to Elmustapha, Hoppe and Bressers (2018) engaging stakeholders and increasing their awareness of the benefits and importance of energy access projects improves their trust and acceptance of the technologies and projects.

2.15.4 Policy, Legislative and Regulatory Challenges

The absence of a clear-cut legislative, regulatory and policy framework on renewable energy in most low-income countries remains a major challenge to increasing the penetration and adoption of renewable energy. These should be in place to support and promote the development and adoption of renewable energy technologies including mini-grids. There should also be transparent procedures in place for the licensing and monitoring of the activities of all entities involved in renewable implementation which is currently lacking (Zyadin et al., 2014; Nepal, 2012).

2.16 Conclusion

The chapter has presented relevant literature on energy access and the significance of socio-cultural dimensions for the successful implementation of energy access interventions in the context of this research. To sum up the review, energy research continues to evolve, and it is of interest in several academic disciplines, geography included. The contributions of geographers to energy research date as far back as the 1970s. Energy geographies research has covered research areas such as energy generation and environment impacts, low carbon energy transitions, urbanisation and the energy nexus, energy justice, gender and social aspects of energy access and consumption, community and household use of clean energy, and energy poverty to mention a few. Relevant literature on energy poverty, the importance of energy access and the measurement framework used as well as linkages between energy access and the SDGs especially SDG 7 have also been discussed. The chapter also presented the conceptual and analytical framework adopted to inform the research to explore how socio-cultural attributes of end-users influence their acceptance and use of energy access projects, in this case, solar PV hybrid mini-grids. Further discussions on renewable technologies for rural electrification were also presented together with the challenges associated with them. The various models for financing, diffusion/dissemination and operation of mini-grids were also presented. The review showed a gap in research in the global south in terms of less emphasis having been placed on the socio-cultural aspects of energy access as compared to the technical and financing aspects of energy access interventions despite its importance in ensuring the successful implementation of energy access projects and ultimately achieving targets of SDG 7.

CHAPTER THREE

BACKGROUND OF GHANA AND ITS ENERGY SECTOR

3.0 Introduction

This chapter presents a background on Ghana and gives a general overview of the status of the country's energy industry with emphasis on the available energy resources, electricity generation and distribution. It will provide details on the energy supply and demand patterns in both rural and urban areas of Ghana and helps to set out the energy situation in Ghana. The chapter is sectioned as follows: Section 3.1 sets the tone for the chapter with a general background of the Republic of Ghana, covering its location and population. An overview of the Ghanaian economy is also presented along with details on climate and vegetation. Section 3.2 presents an overview of the energy access situation in Ghana. Section 3.3 provides an overview of the energy resources currently available in Ghana categorising them into conventional/fossil energy resources and renewable energy resources. Section 3.4 presents details on the primary energy supply of the country. Overviews of electricity generation and distribution across the country are presented in sections 3.5 and 3.6 respectively, and energy consumption details are presented in section 3.7. The key stakeholders managing and influencing the energy sector are discussed in section 3.8. The legal and policy framework for Ghana's energy sector, with emphasis on renewable energy, is presented in section 3.8. Rural energy access is explored next with general rural consumption characteristics presented in section 3.9 and the policies and programs instituted to promote rural energy access discussed in section 3.10. The chapter concludes in section 3.12 with a summary of the key issues addressed in the chapter.

3.1 An Overview of Ghana

3.1.1 Location and Population

Ghana is a Sub-Saharan African country located on the west coast of the continent. Ghana is bordered on the East by Togo, in the north by Burkina Faso, on the western side by La Côte d'Ivoire on the west and finally to the south by the Gulf of Guinea (part of the Atlantic Ocean) (see Figure 3.1). Ghana was a former British colony and gained independence in 1957 and subsequently gained republic status in 1960. The country is divided into sixteen (16) administrative regions, each with its capital town as depicted in Figure 3.2. Ghana is described as a medium-sized country with a landmass size of 238,535 km² (Ghana Statistical, Service, 2017; Ghana Districts, 2019). The population of Ghana, according to data from the World Bank, was 30.82 million in 2021. This is an increase from 24.67 million in 2010 recorded by the Ghana Statistical Service (GSS) when the last major population census was carried out. This population in 2019 was a 23.4% increase on the figure from the last census and indicating an annual growth rate of 2.6%. These data are presented in Table 3.1.

Table 3.1: Population of Ghana and percentage growth rate

Year	Population (millions)	Growth rate (%)
1960	6,726,815	-
1970	8,559,313	27.2
1984	12,296,081	43.7
2000	18,912,079	53.8
2010	24,658,823	30.4
2021	30,832,019	25.0

Source: Ghana Statistical Service, 2021

Data collected on the population of Ghana over the years point to an uneven distribution across the administrative regions of the country. The Ashanti and Greater Accra regions, which are the most developed and urbanised, have the top two highest populations, whereas the Upper West, Upper East and North-East regions were the three regions with the lowest populations. The high populations in the two most developed and urbanised regions could be attributed to the high influx of people from the other regions (Ghana Statistical Service, 2021).



Figure 3.1: Geographical Map of Ghana
Source: Ghana Statistical Service, 2018



Figure 3.2: Map of Ghana showing the administrative regions and capital towns
Source: Ghana Districts, 2019

3.1.2 Climate and vegetation of Ghana

With renewable energy being the focus of the research, the climate of the location is vital and as such the climate of Ghana is vital to determining the potential of the renewable energy resources available in the country. In the case of this research, an understanding of the climate in Ghana will help appreciate the potential for renewable energy resources like solar PV and wind. Ghana's tropical climate varies in line with

the differences in its topography. The country has two main seasons, namely the rainy and dry seasons. The dry season is influenced by the dusty, hot and arid winds that blow from the Sahara Desert, which leads to cool nights, hot days, and low humidity in the north of the country occurring between December and March (USAID 2017). The rainy season is usually in two parts in southern Ghana, occurring from March to November, whereas the northern part has a single rainy season from April to October. The amount of rainfall increases as one moves from the northern part of the country to the south. The southwestern part is noted to experience the highest amount of rainfall throughout the country (Sekyere et al., 2021). The southwestern experiences rainfall above 1400 mm yearly, whereas the northern part experiences average rainfall below 800 mm per year. Changes in climatic conditions in recent years are noted to result in the southern regions, especially the southwest experiencing intense and more frequent rainfall whereas the northern parts of the country receive less rainfall and over shorter periods (Sekyere et al., 2021; Worqlul et al., 2019). Average annual temperatures in Ghana range around 26°C with the temperatures rising during the dry season and in the northern part (Asante and Amuakwa-Mensah, 2015; Baffoe-Bonnie et al., 2008). The conditions together with the varying rainfall seasons/patterns influence the vegetation distribution across the country. The north comprises Sudan and Guinea Savanna, whereas the south has vegetation such as the coastal savannah, deciduous forest, rain forest and the forest-savannah transition (Asare-Nuamah and Botchway, 2019).

3.1.3 Economy

Ghana's economy has seen rapid growth between 2017 and 2019, making it among the fastest-growing economies on the African continent. Since 2016, the industrial sector has been a major growth driver followed by the agriculture sector. Ghana is also a major exporter of commodities like cocoa, gold, manganese, timber, bauxite, and diamonds, which makes the country's forex earnings. The Ghanaian economy recorded GDP growth from US$ 47.7 billion in 2015 to US$ 65.3 billion in 2019 and a per capita GDP increase from US$ 1,721.00 to US$ 2,164.00 within the same period as is presented in Table 3.2. Export earnings were noted to have also increased from US$ 10.3 billion in 2015 to US$ 15.7 billion (Focus Economy, 2020).

Table 3.2: Economic Indicators and Data of Ghana (2015 – 2019)

Indicator	**Year**				
	2015	**2016**	**2017**	**2018**	**2019**
GDP (USD bn)	47.7	54.6	58.3	64.2	65.3
GDP per capita (USD)	1,721	1,926	2,014	2,173	2,164
Economic Growth (GDP, annual variation in %)	2.2	3.4	8.1	6.3	6.5
Industrial Production (annual variation in %)	1.1	4.3	15.7	10.6	6.4
Exports (USD billion)	10.3	11.1	13.8	14.9	15.7
Imports (USD billion)	13.6	12.9	12.6	13.1	13.3
External Debt (% of GDP)	42.2	38.8	38.4	36.3	-
Public Debt (% of GDP)	55.1	57.3	57.2	59.1	-

Source: (Ministry of Finance – Ghana, 2020; Focus Economics, 2020)

3.2 General Overview of Energy Access in Ghana

3.2.1 Electricity Access in Ghana

The availability and provision of modern energy services, such as electricity and clean fuel for cooking, are significant for human well-being and economic growth and development. Despite the importance of these modern energy services, it is estimated that 770 million people lack access to modern energy services. Most of the global population lacking access to modern energy services is located in rural parts of sub-Saharan Africa (75%), South Asia, and South America (International Energy Agency, 2020c).

The situation in Ghana is no different. Most of the nation's population that have access to modern energy services such as electricity and clean cooking facilities live in urban and peri-urban centres. The number of Ghanaians who readily have access to electricity has increased significantly over the past three decades. Ghana's electrification rate has increased from about 23.88% in 1990 to about 86.3% as of 2021, thus making the country one of seven countries (Gabon, Cameroon, Ghana, Côte d'Ivoire, Senegal, Namibia and South Africa) in sub-Saharan Africa with electrification rates above 50% (McKinsey & Company, 2015; World Bank, 2022). Data available from the World Bank (World Bank, 2022) indicates that about 93.8% of Ghana's urban population has electricity access compared to 70% of the rural population with access. With regards to clean cooking facilities, about 36.9% of the Ghanaian population utilise Liquefied Petroleum Gas (LPG) for cooking but only 0.4% of the population use electric cookers. In the absence of modern and cleaner cooking facilities, traditional solid fuels such as fuelwood, charcoal and biomass remain the most readily available option for the inhabitants to meet their energy needs (Ghana Statistical Service, 2022).

Ghana's national electrification rate has seen a significant increase from 23.88% in 1990 to 86.3% in 2021 (Figure 3.3) and this is a result of strong government policy aimed at achieving universal electrification in Ghana. Electrification in Ghana is based on two definitions; the percentage of communities nationwide that have electricity access (this could be through the grid or not) and the percentage of households across the country which have access to electricity (Energy Commission, 2021). The high increase in electrification was spearheaded by the National Electrification Scheme (NES) established in 1989 by the government of the time, with the objective of ensuring 100% electricity access by 2020 by ensuring electricity services were made available for un-electrified communities with populations of 500 people or more. In line with the NES, several un-electrified communities have also participated in the Self-Help Electrification Programme (SHEP) where the community members contribute to acquiring low-voltage meters and poles to facilitate their connection to the national grid. A success tale of the SHEP is that over 5000 communities across Ghana have been connected to the grid and provided with electricity access (Kemausuor and Ackom, 2017b). Even though the statistics on electricity access in Ghana are seen to be on the increase, as depicted in Figure 3.3, the reality seems to be slightly different. For instance, in urban areas where electricity access is high, several people/ households still lack access due to the high connection cost, and those who have been disconnected or unable to connect to the transmission lines due to their inability to pay for the high tariffs for electricity access. In rural areas, some communities that have transmission passing through their area are considered to have access to electricity but, in reality, they do not have the financial resource to enable them to connect to the electricity.

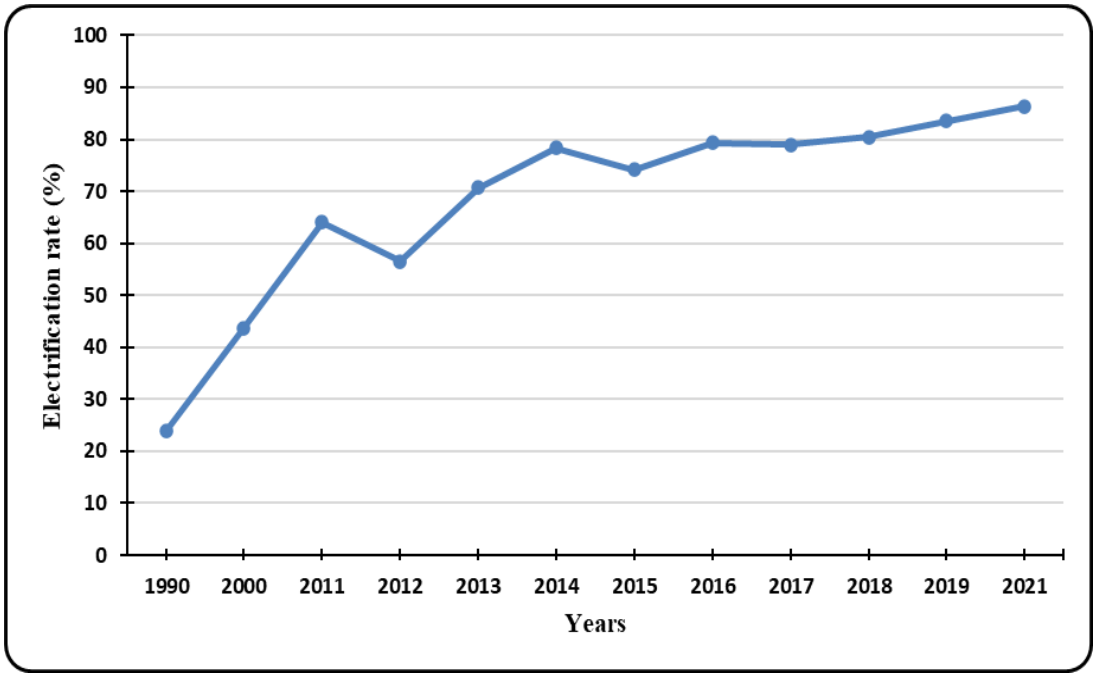


Figure 3.3: Ghana's Access to Electricity (% of population)

Source: Energy Commission, 2021; World Bank, 2022

3.2.2 Modern Energy for Cooking in Ghana

Most households in Ghana cook mainly with biomass, this is evident from the large percentage share of biomass in the country's final energy consumption. According to the Ghana Statistical Service's "Ghana Living Standards Survey (GLSS) Round 7", in 2017 about 67.9% of the population depend on biomass, consisting of wood, charcoal, animal waste, and crop residue, as fuel for cooking (Ghana Statistical Service, 2019). One of the key hidden costs with biomass use for cooking is time spent. Households spend a considerable amount of time collecting biomass (which can be physically draining and the burden of which often falls on women and children) and cooking using biomass in traditional stoves. According to Kimemia and Annegarn (2011) in South Africa, it took respondents between 1 to 3 hours to travel a distance of between 1 and 3 km to collect wood fuel which, in most instances, was carried on the head

mainly by women and children. The health implications of biomass use for cooking purposes include respiratory problems caused by exposure to emissions from these open fires due to the inefficient burning of biomass (indoor air pollution) (World Health Organization, 2021). Studies show that prolonged exposure to, and the inhalation of the particulates emitted from biomass combustion causes illnesses such as lung cancer and pneumonia, and these go on to cause about 4.3 million deaths annually (World Health Organization, 2021; Jewitt et al., 2020; Dickinson et al., 2019; Quinn et al., 2018). In most communities, women and children are the most affected when the stress associated with gathering biomass for cooking food is taken into consideration (World Health Organization, 2021; Stanistreet et al., 2019; Smith et al., 2013).

LPG usage nationwide is mainly limited to urban communities, reflecting the challenges with access to LPG refill centres and transport of LPG cylinders. The Ghanaian government is keen on promoting LPG usage as cooking fuel for most Ghanaians in a bid to eliminate the health impacts of biomass usage and reduce deforestation. In this regard, the government of Ghana set a target of achieving 50% LPG nationwide use by 2020. To achieve this target, the Energy Commission proposed some measures to be instituted. These measures include expansion of supply and storage infrastructure for LPG in all district and regional capitals to ensure ease of access, and a policy prioritising the Ghanaian market over export for gas produced in the country (i.e., from the Atuabo gas processing facility). Other measures proposed were an investment in the local production of LPG cylinders especially portable and affordable sized cylinders and the removal of any price distortions by the government. As of 2020 when the 50% usage target was expected to be achieved, LPG use across the country had increased to 25.3% from 18.2% in 2010 (Ghana Energy Commission,

2021). The population and housing census conducted in 2021 showed a further increase in LPG from the 2020 figure of 25.3% to 36.9% in 2021 (Ghana Statistical Service, 2022). The introduction of improved cookstoves (ICSs) onto the Ghanaian market is seeking to reduce the health risk associated with open fires for cooking. Though there are several manufacturers and distributors of these ICSs, their usage is largely limited to urban and peri-urban areas with little penetration in rural communities mainly. This is because, in many rural areas, fuelwood is available and free of cost, thus providing rural households with little or no incentive to invest in improved cooking stoves unless they are aware of the health implications associated with using biomass fuel on traditional cookstoves. The use of solar for drying purposes has always been a practice in Ghana, where food to be dried is put out in open space and exposed to sunlight. However, there is a need to research ways to modernise it and improve efficiency (Bawakyillenuo et al., 2021; Dickinson et al., 2019). Table 3.3 shows cooking fuel types and the percentage of households that use them based on either urban or rural locations and a national level.

Table 3.3: Household source of cooking fuel in Ghana, 2021

Source of cooking fuel	Urban (%)	Rural (%)	National (%)
Wood	11.0	62.0	31.1
Charcoal	27.9	16.0	23.2
LPG	51.4	14.8	36.9
Electricity	0.5	0.2	0.4
Kerosene	0.2	0.1	0.1
Crop residue	0.0	0.6	0.2
None, no cooking	9.0	6.3	7.9
Other	0.0	0.0	0.2
All	**100**	**100**	**100**

Source: Ghana Statistical Service, 2022

3.3 Energy Resources in Ghana

Ghana's energy sector can be categorised into three major subsections namely power, petroleum, and biomass. These sources of Ghana's energy can be categorised into conventional and renewable energy sources, where conventional consists of petroleum and natural gas whereas hydropower, solar and biomass are renewable sources of energy. Ghana is known to have large proven oil and gas reserves mostly offshore. As of 2015, the country's proven oil reserves were estimated to be about 0.66 billion barrels and natural gas reserves were around 0.80 trillion cubic feet (Energy Commission, 2016a; MoE, 2017). For several years the major source of electric power in Ghana was hydroelectricity. However, due to constraints in satisfying the increasing electricity demand in recent years, the power sector has had to make a major shift; depending significantly on crude and natural gas-powered plants (thermal plants) to increase the quantity of electricity generated for the electricity needs of the country (Eshun and Amoako-Tuffour, 2016).

3.3.1 Conventional/Fossil fuel energy resources in Ghana

Oil

Ghana's major oil discovery was in 2007 when commercial quantities were discovered offshore in the Jubilee field which first produced oil in 2010. Since then, other discoveries have been made including the Tweneboa, Enyenra, and Ntomme (TEN) fields that have also come on stream producing oil in August 2016, thus augmenting oil and gas production and gradually making it a key player in the oil and gas industry in Africa (Ghana National Petroleum Company, 2017). Based on the National Energy Statistics for 2019, about 72.11 million barrels of crude oil were produced from the

current active oilfields in the country and about 70.98 million barrels of crude oil were exported. The total crude oil imports for that same year amounted to about 830 kilotonnes (Energy Commission, 2020). Despite producing crude oil, it is worth noting that Ghana is heavily reliant on oil imports to meet the country's crude oil and petroleum product needs such as transport, and electricity generation. Finished petroleum products are sourced from the international market to meet energy needs (Energy Commission, 2019a).

Natural gas

Natural gas for powering thermal power plants in Ghana is mainly supplied by the Ghana National Gas Company's Atuabo facility which processes gas from the country's oil and gas fields, and imports from Nigeria through the West Africa Gas Pipeline Company (WAGPCo). The offshore oil fields produce natural gas which is then exported to a facility (Atuabo facility) to be processed and utilised in power generation. In 2018, the Atuabo gas facility supplied 58% of the total gas flow of 58,531 million standard cubic feet per day (mmscf), and the remaining 42% was through WAGPCo (Energy Commission, 2019). The Tema and Takoradi power enclaves used 35% and 54% of the total gas flow respectively, and the other 11% was used for non-power-related activities. The country's offshore oil fields produced 91,459.30 mmscf of raw (wet) gas, part of which was utilised in offshore petroleum operations and the rest exported to the national processing facility.

3.3.2 Renewable energy resources in Ghana

As part of the Government of Ghana's target of achieving 10% energy generation from renewable sources by the Renewable Energy Act (Act 832) formulated in 2011, several plans are underway to properly harness the renewable energy potential of the country. Plans included in the Scaling-up Renewable Energy Program (SREP) Investment Plan consist of the following key components:

- *"RE mini-grids and stand-alone solar PV systems: construction of 55 renewable energy-based mini-grids and 35,250 stand-alone PV electrification systems installed in 500 rural communities.*
- *Utility-scale solar PV/wind power generation: providing finance for Ghana's first private-sector utility-scale wind and solar plants that are expected to leverage substantial investments from the private sector.*
- *Technical assistance to scale-up RE: Capacity-building for key renewable energy players and policy support to the Government of Ghana.*
- *To increase the supply of renewable energy and modern biomass in the Ghanaian final energy supply to achieve at least 10 per cent penetration by 2020"* (Energy Commission, 2016).

Ghana by its location has vast renewable energy resources ranging from solar, wind energy, hydropower, and biomass. These resources when effectively harnessed and combined with the existing generation installations will contribute to significantly improving energy access. Renewable sources of electricity generation are being explored to increase electricity availability and access (Aboagye et al., 2021). At present, the most common renewable energy technology (RET) is solar PV although plans and studies are underway to establish wind farms on a pilot basis. As a result of the inadequate power supply and the ensuing power rationing between 2014 and 2016,

most private individuals and firms have invested in standby generators or solar home systems which they use as a backup in the absence of power from the grid. This can be a form of off-grid generation

3.3.2.1 Hydropower

Apart from the three main large hydropower plants in Ghana, numerous investigations and studies have been undertaken on the prospect of harnessing the small to medium hydropower potential of small rivers in Ghana. These studies have identified numerous potential small and medium-scale hydropower sites across the country. Table 3.4 presents a list of potential medium and small-scale hydropower sites across Ghana with capacity totalling 837 MW and a total annual average energy generation of 3,544 GWh. The government has intentions of supporting the development of these additional medium and small-scale hydropower capacities to increase the country's generation capacity. Feasibility studies are underway at some of these sites listed (International and Renewable Energy Agency (IRENA), 2015).

Table 3.4: Potential Small- and Medium- Hydropower Sites across Ghana

River basin	Potential (MW)	Average annual energy (GWh)
Black Volta		
Koulbi	68	392
Ntereso	64	257
Lanka	95	319
Jambito	55	180
Total:	**282**	**1,148**
White Volta		
Pwalugu	48	184
Kulpawn	36	166
Daboya	43	194

Total:	**127**	**544**
River Oti		
Juale	90	405
Total:	**90**	**405**
River Tano		
Asuaso	25	129
Sedukrom	17	67
Jomoro	20	85
Tanoso	56	256
Total:	**118**	**537**
Pra River		
Awiasam	50	205
Hemang	90	336
Abatumesu	50	233
Kojokrom	30	136
Total:	**220**	**910**
GRAND TOTAL	**837**	**3544**

Source: International and Renewable Energy Agency (IRENA), 2015

3.3.2.2 Solar energy

The Ghana Meteorological Services Agency has data from the last 50 years on solar radiation and sunshine hours within the country with a probable error margin of 15% for the irradiation data daily. In Kumasi in the Ashanti Region, the Mechanical Engineering Department at Kwame Nkrumah University of Science and Technology (KNUST) has equipment that is used to measure global and diffuse irradiance on an hourly basis, and the probable error at that location is 5%. From the data collected for several years, the monthly average solar irradiation in Ghana is estimated to range between 4.4 - 5.6 kWh/m2/day, this considers that the average irradiation duration

varies from 5.3 hours in Kumasi which is a semi-deciduous forest region to an average of 7.7 hours in Wa which is also in the dry savannah region (Aboagye et al., 2021). The northern part of the country Ghana, including parts of the Bono East and the Oti regions, has monthly averages of high irradiation readings between 4.0 - 6.5 kWh/m2/day. The other regions have average monthly irradiation readings varying from lows of 3.1 kWh/m2/day to highs of 6.0 kWh/m2/day. These readings indicate that there is a good potential to generate electricity from solar energy technologies in most parts of the country (Energy Commission, 2019b). Figure 3.4 shows the horizontal solar irradiation in Ghana. As of 2016, two (2) solar energy power plants had been integrated into the energy mix of the country. These are the VRA Solar and BXC Solar plants.

3.3.2.3 Biomass

Biomass refers to organic matter that is used in generating energy for various uses. Biomass includes plants, animals and municipal waste. Biomass accounted for 38.3% share of Ghana's primary energy supply in 2019, as such the use of improved cookstoves that are less polluting will help to minimise indoor air pollution in households and environmental damage from the high patronage of biomass across Ghana. Biogas is produced from municipal waste (organic material and animal waste) processed in digesters. The biogas produced is then used as fuel to generate electricity, for cooking and heating purposes (Energy Commission, 2020a).

3.3.2.4 Wind

Most parts of Africa have low wind speeds except in Southern and Northern Africa. Even though low wind speeds prevail in most parts of Sub-Saharan Africa, feasibility studies have shown that Ghana's south, especially the coastal areas, has good potential for wind energy generation. Average wind speed measurements range from 8 m/s to 9.9 m/s (Sun et al., 2020; Kemausuor et al., 2011). This potential is not yet harnessed and the proposed Ayitepa wind farm under construction near Accra will have an installed capacity of 225 MW with 75 turbines and with height ranging up to 140 m (Sun et al., 2020).

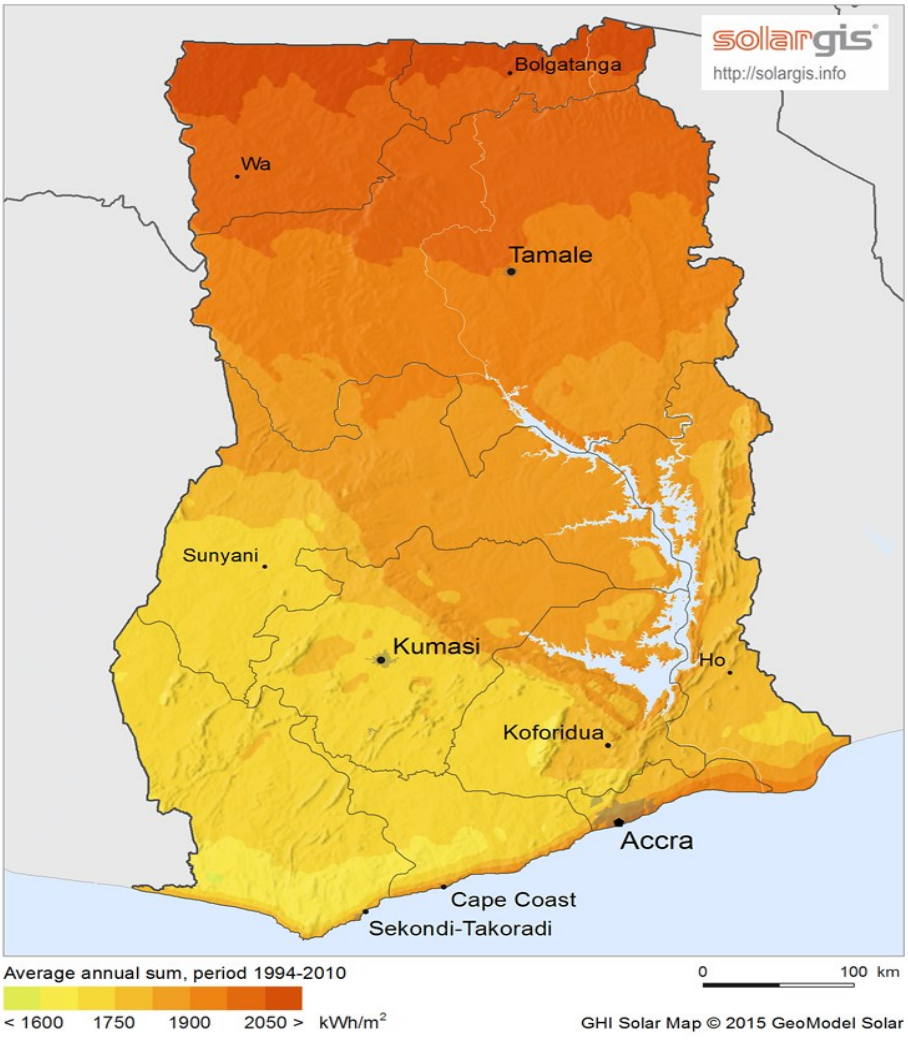


Figure 3.4: Horizontal Irradiation in Ghana
Source: Solargis, 2017

3.4 Primary Energy Supply

Primary energy supply refers to the amount of primary energy that is at the disposal of a country. The total primary energy supply consists of all energy supply sources, these include imported energy as well as energy production from natural resources. These sources may either be renewable energy sources or fossil fuel sources. The total primary energy supply for Ghana, as per the available statistics from the Energy Commission for 2019, was 11,159 kilotonnes of oil equivalent (ktoe). Oil as the major component, accounted for 4,276 ktoe (about 38.3%) while biomass, natural gas, hydro and solar accounted for 37.8%, 18.2%, 5.6% and 0.1% respectively of this total primary energy for 2019 (Energy Commission, 2020a). The percentage share of these primary energy supplies is presented in Figure 3.5. The high contributions of oil and biomass to the total primary energy supply are indicative of the high dependency on oil for electricity generation and transport whereas biomass is mainly utilised for cooking and heating purposes.

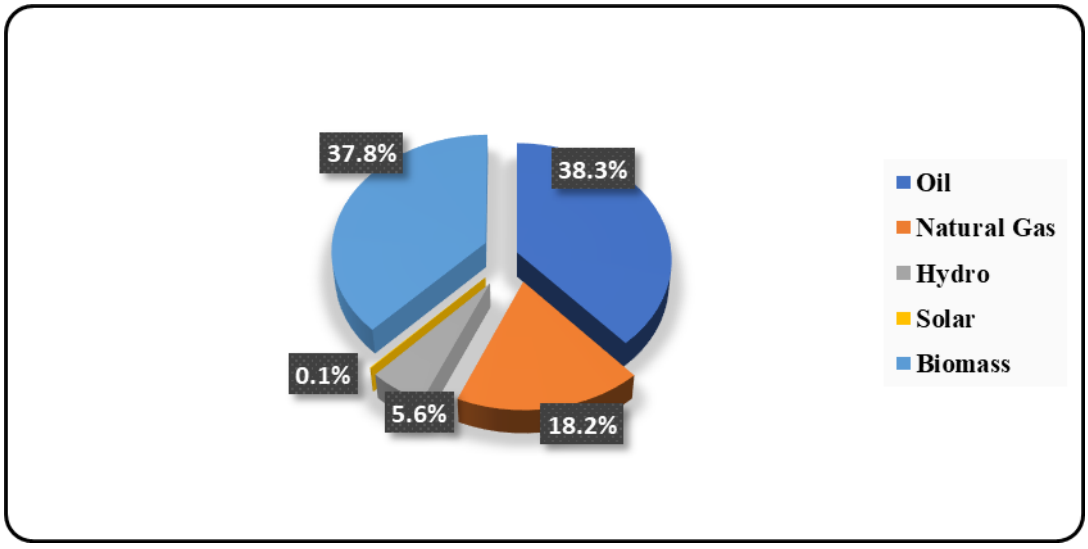


Figure 3.5: The percentage share of Ghana's primary energy supply for 2019
Source: Ghana Energy Commission, 2020

Large hydropower is used in Ghana and the major power plants are the Akosombo, Kpong and Bui hydroelectric power plants. These three hydro plants generated a combined power of 5,845 GWh in 2015 (Volta River Authority, 2017).

3.5 Electricity Generation

In Ghana, electricity generation is through two main means, these are hydropower generation and thermal generation. Hydropower plants are of different scales depending on their sizes and output. Ghana's first experience with hydropower generation was in 1965 with the construction and opening of the 1,040 Megawatt (MW) Akosombo hydropower plant operated by the Volta River Authority (VRA), which provides electricity for Ghana and neighbouring countries such as Togo and Benin (Volta River Authority, 2017). With the increasing electricity demand, two more hydropower plants have been constructed and are in operation, namely the Kpong Hydropower (160 MW) also operated by the VRA, and the Bui hydropower plant (400 MW) operated by the Bui Power Authority (Volta River Authority, 2017).

Thermal power generation is another major electricity generation means in Ghana. The thermal power plants are categorised based on the types of fuel utilised, these may be either:

- Steam-powered plants (using heavy oil, liquefied natural gas (LNG) or coal
- Combined cycle power plants
- Gas turbine power plants (using LNG) (KAPCO, no date).

According to the Energy Commission, the installed generation capacity in 2019 was 4961 Megawatt (MW) with an actual average available capacity of 4538 MW. Tables

3.5 and 3.6 lists the various electricity generation facilities in Ghana, and their installed and actual generation capacities in 2019.

Table 3.5: List of Electricity Generation of Plants in Ghana as of August 2019

PLANT	INSTALLED CAPACITY (MW)	TYPE OF PLANT	FUEL TYPE
Bui Hydro Plant	400	Hydro	Water
Amandi	190	Thermal	Gas/LCO
KarPower Barge 1	470	Thermal	HFO
Sunon Asogli Phase 1	200	Thermal	Gas
Sunon Asogli Phase 2 Stage 1	200	Thermal	LCO/Gas
Sunon Asogli Phase 2 Stage 2	360	Thermal	Gas/LCO
CENIT Power Plant	360	Thermal	LCO
Ameri Power Plant	250	Thermal	Gas
BXC Solar	20	Solar	Sunlight
AKSA	370	Thermal	HFO
Akosombo Hydro Plant	1,020	Hydro	Water
Kpong Hydro Plant	160	Hydro	Water
TAPCO - T1	330	Thermal	LCO/Gas
TICO - T2	340	Thermal	LCO/Gas
Mines Reserve Plant (MRP)	80	Thermal	Gas
Tema Thermal 1 Plant (TT1P)	110	Thermal	Gas/LCO
Tema Thermal 2 Plant (TT2P)	80	Thermal	Gas
Tema Thermal 2 Plant Expansion (TT2PP-X)	80	Thermal	Gas
Kpone Thermal Power Plant (KTPP)	220	Thermal	Gas/DFO
VRA Navrongo Solar Plant	2.5	Solar	Sunlight
Total Installed Capacity	**4275 MW**		

Source: Volta River Authority, 2020

HFO – Heavy Fuel Oil | DFO – Distillate Fuel Oil | LCO – Light Crude Oil

Table 3.6: Installed Grid Electricity Generation Capacity in 2019

GENERATION PLANT	FUEL TYPE	CAPACITY (MW)	DEPENDABLE CAPACITY (MW)
Hydro Power Plants			
Akosombo	Hydro	1,020	900
Bui	Hydro	400	360
Kpong	Hydro	160	140
Sub-Total		***1,580***	***1,400***
Thermal Power Plants			
Takoradi Power Company	Oil/Natural gas	330	300
Takoradi International	Oil/Natural gas	340	320
Sunon–Asogli Power (SAPP)	Natural gas	560	520
Tema Thermal Plant1 (TT1P)	Oil/Natural gas	110	100
Kpone Thermal Power Plant	Gas/DFO	220	200
Tema Thermal Plant2 (TT2P)	Oil/Natural gas	80	70
CENIT Energy Ltd (CEL)	Oil/Natural gas	110	100
Mines Reserve Plant	Oil/Natural gas	80	70
Karpower*	Heavy Fuel	235	220
Ameri Plant	Natural gas	250	230
Trojan	Diesel/ NG	44	40
Genser	Natural gas/ crude/	95	85
Sub – Total		***3,339***	***3,105***
Renewables			
VRA Solar	Solar	2.5	1.5
Safisana Biogas	Biogas	0.1	0.1
Meinenergy	Solar	20	16
BXC Solar	Solar	20	16
Sub – Total		*42.6*	*33.6*
Total		**4,961.6**	**4,538.6**

Source: (Energy Commission, 2020b)

3.6 Electricity Distribution and Transmission

Ghana's electricity distribution sector is run by three main utility companies. These companies consist of 2 state-owned catering for the majority of the electricity supply across the country and a privately owned company that supplies electricity to industrial customers.

- The Electricity Company of Ghana (ECG), which is wholly owned by the state and distributes and supplies electricity to 6 of the political regions of Ghana i.e., Central, Volta, Eastern, Ashanti, Western, Greater Accra regions.
- The Northern Electricity Distribution Company (NEDCo), a subsidiary of the Volta River Authority which is also state-owned distributes and supplies electricity to the north of Ghana mainly in regions like Brong Ahafo, Northern, Upper West and East regions.
- The Enclave Power Company (EPC) is privately owned and distributes and supplies electricity to 50 industrial customers and is in the Tema Free Zones Enclave.

The Ghana Grid Company (GRIDCo) operates a national interconnected transmission system. GRIDCo constructs, operate and maintain all transmission lines and substations across the country. GRIDCo oversees all transmission, mainly at 161 kV, and runs about 54 substations countrywide, from which it steps voltages down to 34.5 kV and 11 kV (Ministry of Energy, 2021). Figure 3.5 shows the national grid transmission map of Ghana. Electricity transmission from the generating plants to VRA is via an interconnected transmission network consisting of 69, 161 and 225 kV. The national transmission grid comprises transmission lines and substations (Figure 3.6). At the substations, the electricity is reduced to the appropriate voltage for bulk

off-takers (customers) and for end-users such as household consumers. Areas that are far off from the path of the national grid are most likely to have challenges with connectivity (GridCo, 2017; International and Renewable Energy Agency (IRENA), 2015).



Figure 3.6: National Grid Transmission Map of Ghana

Source: International and Renewable Energy Agency (IRENA), 2015

3.7 Energy Consumption

The total final energy consumption in Ghana for 2019 was 7,974.5 ktoe. As presented in Figure 3.7, the statistics show both petroleum and biomass account for 47.6% and 37.4% of the final energy consumed, while electricity composed of 15% in 2019. The 47.6% share of the consumed energy from petroleum products, which is about 3,794.0 ktoe is attributed to transport and electricity generation purposes. These petroleum products were mainly composed of diesel, kerosene, gasoline, liquefied petroleum gas (LPG) and residual fuel oil (RFO) (Energy Commission, 2020b). Meanwhile, the 37.4% share of biomass consumption (about 2,981.3 ktoe) was mainly for residential, commercial, and institutional cooking purposes. The sources of electricity generation were mainly hydropower, petroleum, natural gas, solar and biogas. Petroleum is the main energy source for transport whereas, for cooking purposes, the main sources are biomass fuel, LPG, and electricity (Energy Commission, 2020b).

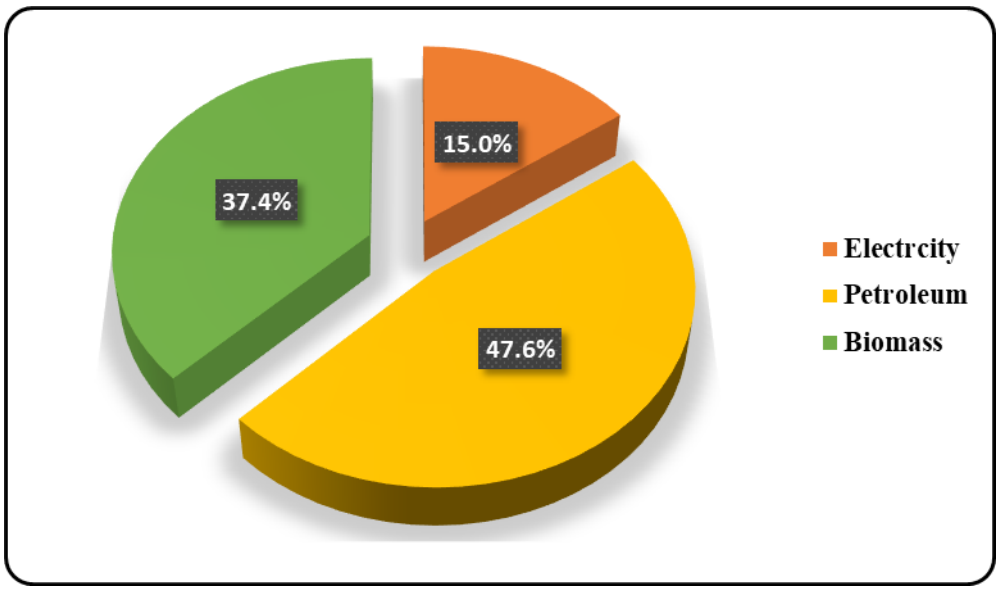


Figure 3.7: Final Energy Consumption by Fuel in 2019

Source: Energy Commission, 2020b

3.8 Key Stakeholders in Ghana's Power Sector

The energy and power sector in Ghana is managed and influenced by several actors/ stakeholders who are involved in the various aspects of the sector. For policy-making and implementation and regulation of the sector, the main stakeholders include The Ministry of Energy, The Energy Commission and The Public Utility Regulatory Commission (PURC) (Kumi, 2017). Figure 3.8 presents the overview of the key stakeholders in the power sector and how they interact as presented.

The Ministry of Energy

The mandate of the ministry is to oversee all power and energy-related activities across the country. The Ministry of Energy carries out its mandate in collaboration with other ministries and institutions where necessary such as the Ministry of Finance and the Ministry of Environment and Science (Ministry of Energy, 2018).

The Public Utility Regulatory Commission (PURC)

PURC is primarily tasked to serve as the regulator for all economic aspects of the country's energy sector. The PURC oversees tariff setting and approval before implementation, monitors the quality of energy services provided and ensures consumer protection(Public Utilities Regulatory Commission, 2022).

The Energy Commission

The Energy Commission's mandate is to be the regulator for all the technical aspects of Ghana's energy and power sector. It oversees the licensing and regulation of operators in the sectors as well as provides technical advice to the Ministry of Energy on energy-related policies (Kumi, 2017; Ministry of Energy, 2018). At the various

stages of the power sector different stakeholders influence the sector, these include generation companies, transmitters, distributors, and consumers at the end of the supply chain (Energy Commission, 2022).

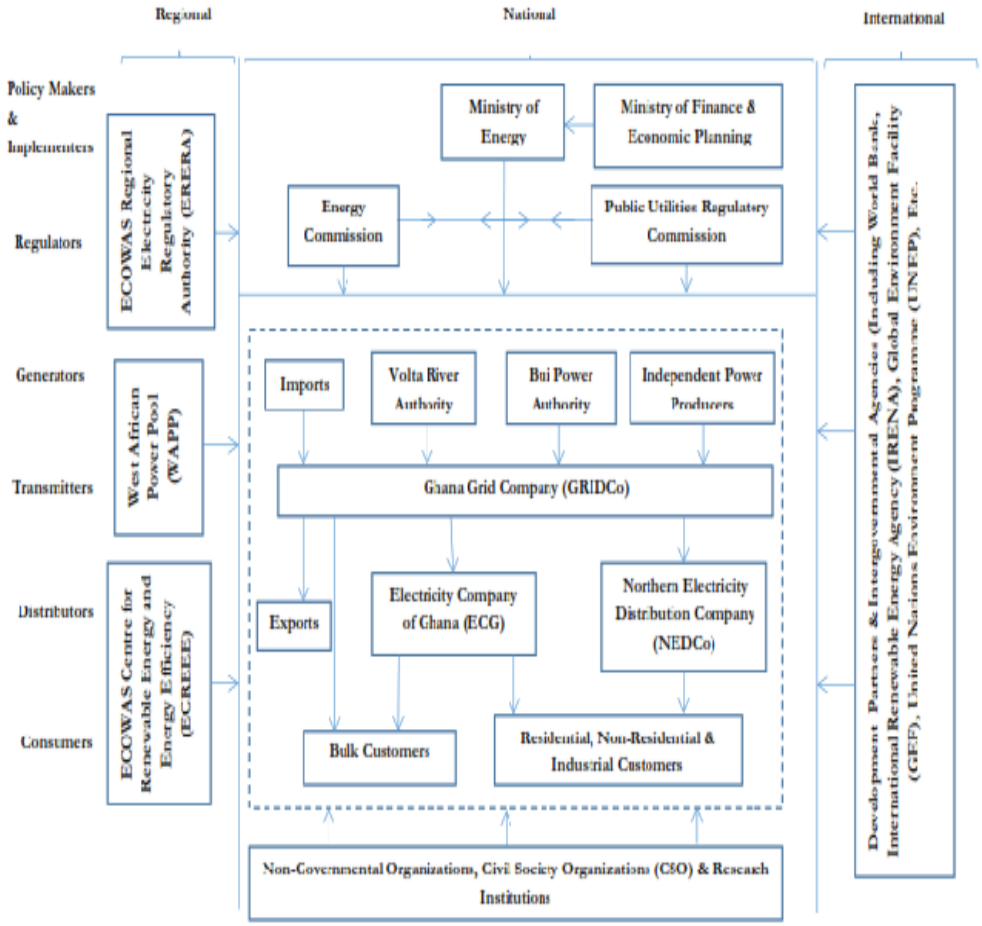


Figure 3.8: Stakeholders in Ghana's Power Sector

Source: Adapted from Kumi, 2017

3.9 Ghana's Legal and Policy Framework for Energy and Renewable Energy

3.9.1 Legal and Policy Framework

Ghana's energy sector, especially the power sector, is regulated and guided by a framework of laws, regulations and policies which facilitate the sector's operation,

growth, and adherence to best industry practices. The renewable energy sector benefits from tailored regulations and policies to promote its development. Some of these laws, policies and regulations are in their implementation and enforcement stages.

3.9.1.1 Legal Framework

The energy sector in Ghana is governed and regulated by several legal instruments that have been developed over the years as the sector has grown. The most relevant legal instrument that is specifically tailored to develop and harness renewable energy resources and technology in the country is the Renewable Energy Act passed in 2011 (Renewable Energy Act 832). The law has as its objectives:

- supporting the development and harnessing of renewable energy resources and technology for the development of sustainable energy.
- attracting investment, facilitating the development and generation of clean and sustainable energy.
- diversifying the energy supply mix for improved security as well as regulating the production and supply of biofuels and wood.

3.9.1.2 Policy Framework

The energy sector in Ghana is guided by several policies which provide a means for the government to guide and facilitate the energy industry's expansion and growth. The developing nature of the renewable energy sector in Ghana means it requires very favourable policies to facilitate its development. Policies on the energy sector which are relevant to research are summarised and presented in Table 3.8 below

Table 3.7: Relevant Renewable Energy Sector Policies in Ghana

Policy	Timeline	Policy Directive
The National Electrification Scheme (NES)	1989 – 2020 (ended)	To achieve 100% electrification by 2020 by extending electricity supply to all rural communities with populations 500 and above.
Renewable Energy Services Programme (RESPRO)	1999	To create a non-profit trust to manage and extend solar PV services to needy communities as an integral part of the national rural electrification programme. RESPRO has resulted in the installation and dissemination of PV operation instructions to the end-users and provided maintenance and replacement parts for the PV systems.
The Strategic National Energy Plan (SNEP)	2006	To establish the most feasible and sustainable way for utilisation, development, and judicious management of the country's energy resources
The Ghana Energy Development and Access Project (GEDAP)	2007	To promote the operational efficiency of Ghana's electricity distribution network and increase electricity access using several electricity delivery systems.
The National Energy Policy (NEP)	2010	To promote, develop and utilise renewable energy technologies and resources in Ghana
The National Energy Policy (NEP)	2010	Encompasses cross-cutting plans to manage the challenge of fast-growing energy needs for the national development agenda. The policy looks at renewable energy deployment, waste-to-energy management, and energy efficiency.
Ghana Sustainable Energy for All Action Plan (SE4ALL)	2012	To promote the use of modern energy services and facilitate the extension of these services to all.
Rural LPG Programme (RLP)	2013	To promote Liquefied Petroleum Gas (LPG) use in rural communities in Ghana to reduce the heavy dependence on biomass
Feed-in tariff for electricity from renewable energy sources	2013	Established feed-in tariff rates for electricity generated from renewable energy sources.
ECOWAS Regional Renewable Energy Policy (EREP)	2013	To boost the generation of grid electricity supply to improve energy security, electricity access in rural areas using renewable energy sources (wind, solar, bioenergy and small hydro) and provide clean and improved cooking methods.
Roof Top Solar PV Policy	2016	To operate a capital subsidy scheme for prospective beneficiary households to be given solar PV panels with a maximum capacity of 500 peak Watts. This is to lessen the demand on the national grid by providing 200 MW peak load relief by utilising solar PV
The Renewable Energy Master Plan	2019	To promote and develop renewable energy resources in the country for improved social wellbeing, and sustainable development.

3.10 General Characteristics of Rural Energy Consumption in Ghana

3.10.1 Energy for household cooking

The Ghanaian government has over the years made efforts to facilitate the increased usage of LPG through LPG promotional policies, including free distribution of LPG cylinders, and subsidizing the cost of LPG among others, however, its penetration of the Ghanaian households and its usage has been limited to urbanised areas, in particular cities, towns, and district capitals. According to Ahiataku-Togobo (2013) and Ahunu (2015), the low penetration of LPG in Ghana is due to reasons such as inadequate awareness of the benefits of LPG usage, LPG promotional programs predominantly focused on urban and semi-urban areas and leaving out rural areas. Other reasons cited for the low penetration of LPG include the higher cost of LPG compared to charcoal and fuel wood, the limited locations for refilling LPG which makes sustained usage difficult for beneficiaries, transport difficulty of LPG cylinders especially in rural communities, LPG safety concerns (Asante et al., 2018; Ahunu, 2015; Ahiataku-Togobo, 2013).

The small size of LPG cookers makes cooking difficult for large rural households that usually cook with large pots, thus they prefer to use the stone stoves which can easily be adjusted to fit the size of the cooking pot. The LPG stoves are then only used for small/medium-sized pots and when cooking for a fewer number of people. Cookstove and fuel stacking is common practice in most rural households, where households continue to use traditional stoves and less clean fuels even after they obtain new efficient cookstoves or have access to cleaner fuels, this is due to reasons like financial constraints, supply challenges with the cleaner fuel and preference for the traditional stove and fuels for its ability to cook particular types of food and quantities. Stove and

fuel stacking usually are associated with the users backsliding to the use of unimproved and cheaper stoves and fuels as discussed in Section 2.4 (Jewitt et al., 2020; Dickinson et al., 2019; Piedrahita et al., 2016; Masera et al., 2000).

As a result of these challenges, most rural Ghanaians continue to depend heavily on biomass (firewood, charcoal) for cooking purposes. The use of biomass for residential cooking is a contributing factor to the high percentage component of biomass in the country's final energy consumption in addition to commercial and institutional cooking. In 2021 biomass accounted for 54.5 % of the cooking fuels in Ghanaian households (Ghana Statistical Service, 2022). Electricity is not a popular alternative for cooking purposes in most Ghanaian households, as of 2021 only 0.4% of households nationwide used electricity as their cooking fuel and out of which only 0.2% were rural households. The low usage of electricity as cooking fuel is attributed to reasons like the erratic nature of electricity supply, high tariffs, cost of appliances and issues with accessibility, especially in rural areas (Ghana Statistical Service, 2022; Bawakyillenuo et al., 2021).

One of the key hidden costs of biomass use for cooking is time spent both on gathering the fuel and cooking. Households spend a considerable amount of time collecting biomass and cooking using biomass in traditional stoves which turns out to be physically draining. The health implication of biomass use for cooking purposes is exposure to the harmful emissions from these open fires due to the inefficient burning of the biomass (indoor air pollution). Studies show prolonged exposure to, and the inhalation of the particulates emitted from biomass combustion causes illnesses such as lung cancer, pneumonia, and others, and these go on to cause about 3.8 million premature deaths every year (World Health Organization, 2021). The continuous dependence on biomass especially charcoal and firewood pose a significant threat to

the environment by increasing the incidence of bush fires, and land degradation because most plants/trees cut for these fuels are not replanted (Ahiataku-Togobo, 2013).

3.10.2 Energy for household lighting

For most rural communities in Ghana electricity access, it is mainly utilised for lighting and entertainment purposes (watching TV and listening to the radio) and in some instances food storage (refrigerators). For rural communities without access, lighting is mainly by kerosene lanterns/ lamps and torch lights powered by dry cells. Most households in electrified areas also own kerosene lamps, torch lights, or rechargeable lamps as a backup in the event of a power outage due to unreliable supply which is a common occurrence within the past three years. Electricity access in rural communities has been shown to improve the kind of economic activities thriving in those communities. Improved lighting because of electrification also directly impacts positively on education, health and other aspects of life as has been discussed in Section 2.3 (Esper, et al., 2013).

3.10.3 Energy Use for Rural Economic Activities

For economic activities in rural areas in Ghana, the basic needs of energy are for agriculture, fishing, small industrial activities as well as goods and services. In rural settings, agriculture usually involves either manual tilling of farmlands, using draft animals or even fuel-powered tractors, the choice of which depends on income levels and the size of the farmland. Energy is still needed to irrigate the farmlands, and this can be done either manually, using diesel generator sets or even power from the grid.

Harvesting and processing of the produce from the farmlands also involve some energy usage. In fishing communities, premix fuel (gasoline mixed with lubricant) is used in fishing boats. The price of premix fuel is highly subsidised by the government of Ghana. For most rural people, small scale industrial economic activities include the operation of mills, wood processing, and small-scale manufacturing. Services and goods include transport, shops, communication centres (call centres, internet cafes) and mobile phone charging centres (United Nations Industrial Development Organization (UNIDO), n.d.).

3.10.4 Energy and Gender Considerations in Ghana

Even though energy issues involve everyone, women are one of the key actors in the household energy sector, with regards to their involvement in acquiring or gathering, energy use and management. With biomass making up the major share of energy used for cooking and heating in households in Ghana and other commercial activities, especially in rural communities, Ghanaian women are usually the ones impacted the most by indoor air pollution and the adverse health impacts of emissions from these fuels (Adjakloe et al., 2021; Pueyo et al., 2020).

In line with the discussions presented in section 2.8 on gender and socio-cultural dimensions of energy access, some of the key energy and gender issues in Ghana include the fact that women dominate the collection and use of fuelwood, charcoal, and other biomass for cooking purposes. Women and children were also at higher risk of increased exposure to indoor air pollution as a result of the use of biomass and the associated health implications. However, the dominance of men in the planning, management and decision making related to energy services limited the involvement

consideration of the views of women in these processes (Adjakloe et al., 2021; Asibey et al., 2021). According to Owusu-Manu et al. (2021) energy policy formulation and implementation in Ghana is dominated by males, thereby resulting in an underrepresentation of females in senior and management positions involved in energy policy formulation and implementation and the energy sector as a whole. They also found out that usually in energy policy formulation, gender mainstreaming analysis was poorly conducted. The Government of Ghana in addressing the challenges with energy and gender, and is committed to supporting the training and developing of the capacity of women involved in the energy sector; ensuring and promoting the involvement of women in energy policy formulation and implementation; promoting the use of energy modern services and fuels in households and promoting and providing clean renewable energy access in remote locations using off-grid systems (Agyarko, 2015).

3.10.5 Electrification and challenges

Ghana's national electrification rate was 86.3% as of 2021, this translated to 95.2% in urban locations and 72.6% in rural locations. Figure 3.3 in Section 3.2.1 presents the trend for Ghana's electrification rate from 1990 to 2021 whereas Table 3.7 below presents the regional distribution of electricity access in Ghana as of 2021. The Upper East region is noted to have a very low electrification rate as compared with the rest of the country. It is noteworthy that these figures on the number of people that have access to electricity may not be very accurate (World Bank, 2019). The availability of electricity infrastructure or connections may not necessarily mean there is ready access to all households. In some instances, the installations or connection points may be

available, but households may not be connected to them. In certain communities, the power lines may be available or even just pass through the community, but the households may not be connected and would not have access. In other cases, there may be a lot more people with access than the statistics report, this is the situation in several overpopulated communities. As Satterthwaite (2003) asserts, the proximity to a service does not necessarily translate to access to that service. For instance, in overcrowded locations like slums, it is quite difficult to properly estimate the number of households with access to electricity as not all households will have access to electricity and others obtain informal access due to affordability issues (Christley et al., 2021). According to Mensah and Birch (2021), the data from the metropolitan authority on electricity access in slum communities in Accra turned out to be less than the actual access rates found in their study. The data or statistics reported may not be a proper reflection of the situation on the ground, which Satterthwaite (2003) refers to as nonsense statistics. Some locations may be listed as fully electrified but in-depth assessment showed that not all households within those locations may be connected due to the high cost of getting connected, plus high ongoing tariffs. Other households may also have been disconnected because they do not have the means to pay for the high tariffs. With respect to the achievement of SDG 7 the data and statistics could give a false sense of the availability of reliable and affordable electricity access when in reality that is not the situation (Kumi, 2017; Akakpo, 2008).

Table 3.8: Electrification Rate by Region in Ghana, 2021

Region	Electrification rate (%)
Western	89.7
Central	91.7
Greater Accra	96.1
Volta	85.1
Eastern	88.0
Ashanti	88.5
Bono	85.2
Ahafo	76.0
Oti	72.9
Bono East	76.4
Western North	76.8
Northern	79.7
North East	72.1
Upper West	73.1
Savannah	59.5
Upper East	57.0

Source: Ghana Statistical Service, 2022

3.11 Policies and Programs in Support of Extending Rural Energy Access in Ghana

The policies and programs in support of extending rural energy access in Ghana include the following policies which have also been presented in Table 3.7 above.

- Rural LPG Programme (RLP)
- The National Policy of LPG Promotion
- The Strategic National Energy Plan (SNEP)
- The National Electrification Scheme (NES)
- The National Energy Policy (NEP)
- Ghana Sustainable Energy for All Action Plan (SEforALL)

3.12 Conclusion

This chapter has described the key geographical features, and economic and energy outlook of Ghana. Ghana's terrain is classified as being generally low, with a tropical climate and high temperatures for the majority of the year, and regular sunshine. Vegetation patterns across the country are influenced by the variations in the climates in the southern and northern parts of the country. Ghana has several energy resources, these are a mixture of fossil fuel energy resources (oil, natural gas) and renewable resources (biomass, solar, wind, and hydro). Of the renewable energy resources, biomass and hydro have been explored and exploited to some extent, with increased awareness of the need to harness renewable energy resources. Solar and wind are gaining attention and efforts are being made to exploit those renewable energy resources as well. Ghana's total installed electricity generating capacity was 4,275 MW in 2019, from sources such as thermal, hydro, and renewable energy power plants. As of 2021 86.30% of the population had electricity access which comprised 94.19% in urban locations and 67.35% in rural locations. With the increased awareness of the potential of renewable energy sources for increased energy supply, the government is actively working to harness as many renewable energy resources to integrate into the country's energy mix such as the development of solar PV systems and mini-grids for electrification in remote locations.

The chapter also discussed the various policies and programmes currently in existence to promote access to modern energy access in rural areas of Ghana as well as the policies adopted to facilitate the development of Ghana's renewable energy resources to ensure the country develops sustainably. The peculiar situation of rural communities in Ghana and their typical energy consumption characteristic were also presented to give a better understanding of the Ghanaian energy rural energy access situation.

CHAPTER FOUR

RESEARCH METHODOLOGY AND METHODS

4.0 Introduction

This chapter discusses the research approaches, methods design and techniques that have been adopted to address the research questions as well as achieve the objectives and overall aim of the study as set out in Section 1.3 as well as the rationale underlying the selection of these approaches. The chapter is structured as follows. Section 4.1 presents a discussion of the research philosophies underpinning the research. It also provides a discussion supporting the selection of a pragmatist approach for the work. In Section 4.2, the research methodologies and strategies are presented with explanations of the quantitative and qualitative research approaches used. Arguments in favour of the use of a blend of both quantitative and qualitative approaches (mixed methods approach) harnessing their respective strengths to achieve the objectives of the research are discussed. The research methods and designs utilised for the selection of study locations, study populations, ample size and participants for data collection are set out in sections 4.3 – 4.5. Detailed descriptions of the various sources of data required to answer the research questions as well as how the data is gathered processed and analysed are presented in sections 4.6 – 4.9. Sections 4.10 to 4.12 discuss positionality, ethical considerations and limitations associated with the study. A summary is provided in section 4.13 at the end of this chapter.

4.1 Research Philosophy

Research philosophy refers to the belief about how knowledge should be developed or how information or data regarding a research phenomenon should be collected, analysed, and utilised (Saunders et al., 2009; Galliers, 1991). According to Johnson and Clark (2006), the research philosophy assumed by the researcher indicated the significant assumptions about the researcher's perspective of the world around them. This serves as the basis for the selection of the research methods and strategy by the researcher. The chosen philosophy is influenced by the researcher's view of the relationship between the knowledge or truth and the process for developing that truth or knowledge. In exploring research philosophies through research paradigms, Saunders, Lewis and Thornhill (2009) put forward that Positivism, Realism, Interpretivism and Pragmatism are the main philosophies in research.

4.1.1 Positivism

In terms of the nature of reality or being (ontology), positivists believe that the external world is composed of a singular objective and tangible reality. For positivists, this reality is capable of being identified, understood, and measured. Regarding what constitutes valid knowledge (epistemology) positivists hold the view that knowledge can and should be objectively derived through observation and can be measured using properties which are not dependent or influenced by the instruments used or the researcher (Bryman, 2016). This knowledge when developed appropriately is certain and accurate truth. In the positivist view, the researcher's role is limited to the collection of "measurable" data and is distinct from the phenomena being studied with the results of positivist research being viewed as value-free and unbiased (Saunders et

al., 2015; Collis and Hussey, 2014). Positivists operate with the assertation that it is possible to separate the phenomena and the researcher (*dualism*) as well as follow strict procedures to ensure this separation to reduce any form of bias (*objectivity*) in the study. Positivists believe in the likelihood of establishing a cause-effect relationship in their research by using trends to make predictions to establish generalisations; thus, they assume the possibility of analysing the social world using scientific methods (Park et al., 2020; Grix, 2004). Positivist methodology focuses on generating or establishing associations such as causal relationships that they use to explain, predict, and control phenomena under study. As such positivist methodology focuses on research where the variables can be manipulated and controlled by the researcher. This way the research setting is set up such that any external factors are eliminated or minimised as much as possible. Positivists usually make use of data collection methods that gather numerical, quantitative data which can then be analysed statistically (Saunders et al., 2015). According to positivists, the internal validity of study findings is dependent on the result not being impacted by other factors except the independent variable whereas external validity focuses on the extent to which generalisations can be drawn from the study findings. The researcher mainly manipulates the variables and controls others that could threaten the validity of the research (Park et al., 2020).

4.1.2 Interpretivism

Interpretivism developed because of challenges with the use of positivism by social scientists and its inadequacy in meeting their research needs. The underpinning principle of interpretivism is the belief that social reality is subjective, not objective, and complex. Collis and Hussey (2014) argue that while positivism for social research

aims to measure social phenomena, interpretivism on the other hand aims to explore and understand the complexity of social phenomena. Ontologically, interpretivists have the belief that multiple realities exist, social reality is subjective as it is influenced by perceptions and is socially constructed as people create their own social reality. Epistemologically, interpretivists hold the view that knowledge is subjective and mainly derived from subjective evidence provided by research participants. Interpretivists also recognise the role of the researcher in the validity of the knowledge through interaction with the phenomena under study (Saunders et al., 2015; Collis and Hussey, 2014). Crotty (1998: 79) argues that "the object cannot be adequately described apart from the subject, nor can the subject be adequately described apart from the object.". Thus, the researcher interacts with phenomena and is not external to them.

To the interpretivists there is no distinction between the natural and social worlds and the researchers form a part of this social reality, as such researchers are not separated from the subjects under study. Interpretive research utilises various methodologies to explore and understand phenomena inductively (Saunders et al., 2015; Grix, 2004). Such methodologies include case studies, ethnography, and phenomenology. Interpretivists are of the belief that the social world is best understood from the perspective of the participants involved in the phenomena being studied and the involvement or interaction the researcher has with the research phenomena enables the researcher to better understand it (Cohen et al., 2003).

4.1.3 Pragmatism

According to Saunders, Lewis and Thornhill (2015), ontologically, pragmatists believe that reality can be viewed (the research question can be answered) from external or multiple perspectives. In terms of what constitutes acceptable knowledge (epistemology), pragmatists consider that integrating both observable phenomena and meanings that are subjective can provide acceptable levels of knowledge based on the research question and thus, they tend to focus on applied research (Morgan, 2014). Furthermore, values play a significant role in the interpretation of the results from both subjective and objective perspectives. Additionally, Burrell and Morgan (1982) accede that the techniques for data collection usually used by pragmatists are multiple or mixed designs, that is a combination of quantitative and qualitative. There is a debate framed within the context of choosing between the interpretivist and the positivist research philosophy since the ontology and epistemology competitive ring is unavoidable (Guba and Lincoln, 1994). Nonetheless, the argument of pragmatism is that the key determinant of ontology, epistemology, and axiology adopted by the researcher is the research question. One approach could be best suited to the others to answer specific research questions. Additionally, if the research decidedly does not recommend the adoption of either an interpretivist or positivist philosophy, then the pragmatist's view is perfectly possible (Collis and Hussey, 2014; Morgan, 2014).

From the pragmatist point of view, objective reality does exist outside of the human experience. This reality, however, is grounded in the environment and is unearthed via the human experience. Pragmatists argue that reality and knowledge are socially constructed habits and beliefs (Morgan, 2014; Tashakkori and Teddlie, 1998). Morgan (2014) argues that pragmatists overall accept and agree that every knowledge within the world is a social construct, however, there are instances of these social

constructions that align with individuals' (research participants') experiences and circumstances more than others. For pragmatists, the reality is valid as long as it aligns with the researcher's needs and addresses the research question. Pragmatists choose a research methodology and design that is the most appropriate to achieving the research aim as well as answering the research question (Collis and Hussey, 2014). Pragmatists are of the view that the knowledge-acquiring process is a continuum, situated in the middle of the paradigm continuum with the two opposite and mutually exclusive ends on the continuum being subjectivity and objectivity (Teddlie and Tashakkori, 2008a; Goles and Hirschheim, 2000). Pragmatism, therefore, combines the two poles of this continuum and thus offers a flexible approach to research design.

Tashakkori and Teddlie (1998) suggest that pragmatism is intuitively appealing due to the fact rather than engaging in debates about truth and reality, the researcher is able to investigate aspects of the research that is of value and interest, and in the various ways that are thought to be appropriate such that the results can achieve the objectives within the researcher's value system. In line with the research aim of examining the benefits and challenges of implementing solar PV-diesel hybrid mini-grid power systems as a suitable and economically viable means to provide electricity access to un-electrified rural island communities in Ghana, the research employed pragmatism as its most applicable research philosophy. The choice of a pragmatist philosophy is because it embraced both objectivity and subjectivity which was important to be able to gather objective data pertaining to the research problem as well as get the subjective perspectives of the participants on the research problem to address the research questions. Adopting a pragmatist approach also allows researchers to use mixed methods to study phenomena that were of interest and value to the research. With regards to the research problem, it allowed for the researcher to study aspects that were

of interest and value to the research. It also permitted the use of techniques that were best suited for gathering appropriate data to answer the research questions (Saunders et al., 2015; Morgan, 2014).

4.2 Research Approaches/Strategies

Creswell (2009) explains research approaches as being the procedures and plans to guide every step of research from the general assumption stages down to the precise and exact research methods for the collection of data, data analysis and interpretation. Bryman (2012) explains that there are two major research strategies/approaches namely: (i) quantitative and (ii) quantitative approaches. Creswell (2009), however, also includes mixed methods as a third approach given that it has become immensely popular with researchers. Creswell (2009) argues that these approaches are not entirely separate entities but describe them as different points on a continuum, with quantitative and qualitative approaches being at the extreme ends whereas the mixed-methods approach which is a blend of the elements of the two opposite ends is placed in the middle. The key elements researchers utilise in distinguishing between qualitative and quantitative approaches are the fact that qualitative research makes use of words, subjective meanings and opened-ended interview questions whereas the quantitative approach is based on measurements using instruments, thus the use of numbers and closed-ended types of questions.

According to Bryman (2012), quantitative research involves data collection with the use of instruments in the form of numbered or quantified data for statistical analysis and interpretation. This quantitative approach involves the testing of theories deductively with hypotheses to examine the relationships among variables under

study. The quantitative approach is supportive of structured data and thus enables the collection and analysis of large data in a logical manner as well as allowing for replication of the findings. Quantitative researchers have assumptions about protection from bias and control on alternative explanations limited to the hypothesis (Bryman, 2016; Creswell, 2009). Qualitative research approaches are more focused on words and the meanings derived and emphasise examining and comprehending the views, opinions and subjective interpretations people have about social phenomena and problems. Qualitative researchers are inductive in their approach to establishing interactions between research and theory, with the identification of patterns, relationships and themes in the data informing theories (Bryman, 2016; Creswell, 2009).

Tashakkori and Creswell (2007) define mixed methods as a research approach that makes use of a combination of both quantitative and qualitative methods for data collection, analysis, and interpretation. The key aspect of the mixed methods approach is the combination of quantitative and qualitative approaches with their elements complementing each other to overcome their singular shortcomings. The mixed-methods approach also combines the strengths of the individual approaches to promote a better examination and understanding of a research problem to adequately answer the necessary research questions (Saunders et al., 2015). According to Creswell (2009), pragmatism is not limited to any reality or philosophy and as such the mixed methods approach is based on that principle that is able to utilise both qualitative and quantitative assumptions for research. This implies that in seeking to understand social phenomena, the researcher or investigator should make efficient use of both quantitative and qualitative methods as each method complements the other to better answer the research questions (Creswell, 2009).

4.3 Research Design

Research design is defined by Kumar (2011) as the procedural plan that a researcher utilises in data collection, analysis and reporting to address a research problem accurately and objectively. As indicated in section 1.3 of Chapter 1, the overall aim of this study is to identify socio-cultural determinants influencing energy needs and choices to explore the applicability of solar PV-diesel hybrid mini-grid systems to provide electricity access to rural unelectrified island communities in Ghana. The research specifically set out to achieve the following set of specific objectives as presented in section 1.3:

- To assess the current energy sources and needs of the participants and the options renewable energy mini-grids offer.
- To determine the various socio-cultural factors that impact energy use and choices within households and the study communities, and the adoption of renewable energy mini-grid systems.
- To determine factors impacting equal access to clean, affordable, and sustainable energy in the communities.
- To review and assess factors promoting or impeding the development of renewable energy projects, precisely mini-grids as a viable option for improving energy access.

To be able to address the set objectives the research questions below were developed:

- Assess the current energy sources and needs of the participants and the options renewable energy mini-grids offer.

- Determine the various socio-cultural factors that impact energy use and choices within households and the study communities, and the adoption of renewable energy mini-grid systems.
- Determine factors impacting equal access to clean, affordable, and sustainable energy in the communities.
- Review and assess factors promoting or impeding the development of renewable energy projects, precisely mini-grids as a viable option for improving energy access.

In addressing the research problem which in this case was to find out how feasible solar PV-diesel hybrid mini-grid power systems are to provide rural island communities with electricity access, various forms of data were required, and these were to be gathered from diverse sources. The varying nature and sources of the data made the mixed methods approach best suited for collecting and analysing the data to be able to address the different research questions. Various research tools that are associated with both qualitative and quantitative research approaches such as surveys, interviews and focus group discussions were used in gathering data for the research. The mixed-methods approach used for this study offered the opportunity to gather both objective and subjective data. Thus, the data gathered offered the opportunity to understand the perspectives of the various stakeholders on the challenges of electricity access in rural communities and especially in island communities in Ghana. The use of a mixed-method approach also allowed the gathering of interesting data that would have been ignored if the research had relied only on either a quantitative or qualitative approach. Table 4.1 provides an overview of the links between the objectives, the research questions asked, and the data collection methods used.

Table 4.1: Overview of the research objectives, questions, data collection and their links

Research Objectives	Research Questions	Methods
Assess the current energy sources and needs of the participants and the options renewable energy mini-grids offer.	What are the current energy sources and requirements of the households especially women, children, and other vulnerable groups in the study locations? Do renewable energy mini-grid systems have the potential to meet the energy needs of households?	-Policy and Academic documents on Ghana's energy systems - Population and housing census data -Household questionnaire surveys -Household interviews -Open-ended interviews with key informants at the Energy Commission - Ghana, ECG Ltd, and Ministry of Energy - Ghana
Determine the various socio-cultural and economic factors that impact energy use and choices within households and the study communities, and the adoption of renewable energy mini-grid systems.	What socio-economic and socio-cultural factors influence energy use, choices, and the adoption of renewable energy systems	-Household questionnaire surveys -Household interviews -Interviews energy companies with companies -Academic documents in energy access in Ghana
Determine factors impacting equal access to clean, affordable, and sustainable energy in the communities.	What are the challenges with access to clean and affordable energy in rural and remote communities	-Interviews energy companies with companies -Academic and policy documents on Ghana's energy sector -Interviews with rural households
Review and assess factors promoting or impeding the development of renewable energy projects, precisely mini-grids as a viable option for improving energy access.	What are the appropriate institutional policies, structures, regulatory and legal frameworks in existence to promote renewable energy development? What challenges/ factors impact energy access using renewable energy?	-Policy documents on renewable energy in Ghana -Interviews with stakeholders (i.e., energy companies, NGOs, regulators, government officials, energy think tanks, etc) -Academic articles on energy access in Ghana.

4.4 Study Site Selection

Given the importance of access to modern energy services to human development, ideally for research of this nature, it would have been useful to collect data in all un-electrified communities across the country to get a comprehensive understanding of the issues in each community. This way conclusions could be drawn on the key themes or issues that influence electricity access in all those communities without electricity access. However, due to financial, time, and other resource constraints, this was not possible. It was therefore imperative that the study locations selected, and the questions asked to be representative enough of all the possible case scenarios while also being able to help to achieve the overall aim of the study. Given the constraints, four island communities in the Ada East District of the Greater Accra Region in the southeast of Ghana. These island locations were purposively selected from the list of rural/remote communities that had no access to electricity (un-electrified) from the Ghana Energy Commission's Energy Access Database (Ghana Energy Commission, 2020). In selecting the study sites, it was important to consider the possibility that the locations would not be provided with electricity access through the centralised grid as part of the national rural electrification policy and other electrification programs, as well as the remoteness of the locations. The main criteria considered for the selection of the research locations were that the locations should:

(i) be unelectrified remote rural communities with a focus on islands

(ii) have less likelihood of grid electricity connection within the next 8 years under the national rural electrification policy

Island communities are a good fit for these criteria, given that due to their locations it is not economically viable to provide electricity access using grid extensions from the

neighbouring mainland. The challenges with grid extension to non-island rural communities are less than those associated with island locations and grid connectivity could easily be achieved with the appropriate infrastructure and investment.

The identification of potential study locations started with desk studies to identify areas with island communities. There was initial interaction with staff of the Ghana Ministry of Energy to understand the issues associated with providing electricity access to island communities and identify potential research study sites. During the interactions, questions asked were about islands with solar PV systems or mini-grids as well as the regions of the country with a higher number of island communities. Two main regions were prominent i.e., the Greater Accra and Volta regions. Both regions had pilot hybrid mini-grids that could also be studied as part of the research. The Greater Accra region was purposively selected as the research study region based on time and financial constraints. Also, though the Greater Accra region overall has a higher electricity access rate, the region has several rural communities without electricity, most of which happen to be island communities. These island communities are among some of the poorest communities in the region. Within the region, the Ada East district alone has a little over thirty (30) island communities, most of which are without electricity access. These island communities have some of the lowest income levels in the district (Ghana Statistical Service, 2022). Due to resource constraints, only four island communities could be selected as study locations. Thus, the island communities of Pediatorkope, Alorkpem, Azizakpe and Aflive, all of which are in the Volta River were purposively selected due to their ease of access from the mainland as compared to the other islands within the region. Another reason for the choice of these islands as study locations was down to the fact that some feasibility studies were being conducted on the islands of Alorkpem, Azizakpe and Aflive for the development of mini-grid

systems to provide electricity to the inhabitants of these islands. Thus, the three communities were also selected for the study to understand the situation of the inhabitants before the implementation of the mini-grid system and the impact the development of the mini-grid will have on their lives.

Pediatorkope island on the other hand had been chosen for a slightly different reason. It is one of the first 5 island communities across the country that the government of Ghana piloted hybrid mini-grid systems to provide electricity access. The other four islands were Aglakope; Kurdokope; Atigagome and Wayokope. Pediatorkope island was selected as part of the study locations to gain insights into island inhabitants' experiences of the hybrid mini-grid system and how it has impacted their lives since it was first switched on. Following the successful development and operation of the pilot projects, the Ministry of Energy with financial aid from the African Development Bank and the Climate Investment Funds plans to develop 60 additional mini-grid projects on islands across the country by the end of 2022. The government with support from the Swiss government (SECO) is also set to develop 3 mini-grids in the Ada East district by the end of 2022. The beneficiary communities will be Aflive, Azizakpe and Alorkpem if the feasibility studies generate favourable results.

The study locations were only accessible by canoe or boat. Pediatorkope island, the only electrified study location has a health centre and a basic school. Children of school-going age from the other neighbouring islands attend the basic school either on Pediatorkope or Aflive islands. Across the islands, the major occupations were fishing and oyster mining. Some inhabitants (notably women) of the islands engage in trading activities either on their islands or in some instances in the neighbouring mainland towns of Big Ada, Ada Foah and Tsarley Korpey (Ghana Statistical Service, 2021). The predominant language spoken on the islands chosen as study locations is Adangbe

which is one of the common languages spoken by inhabitants of the south-eastern part of Ghana.

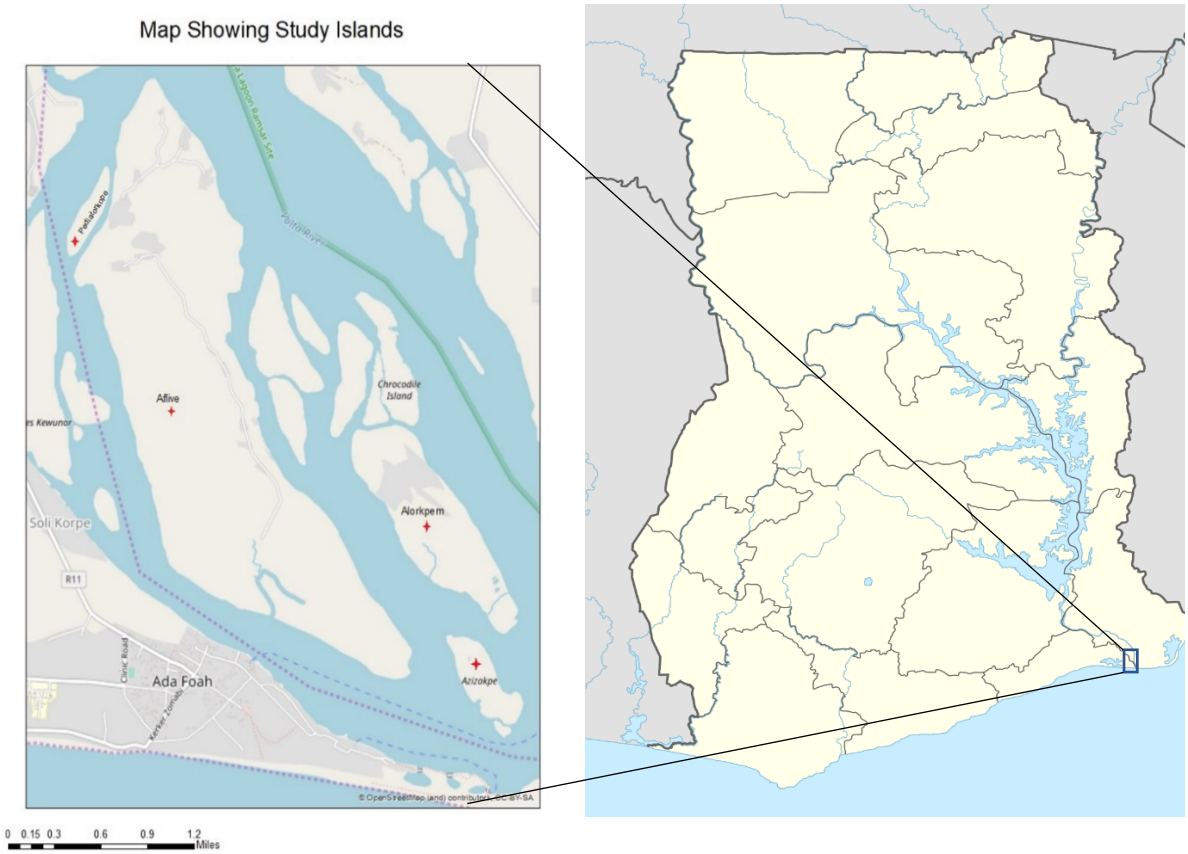


Figure 4.1: Map of Ghana showing study locations

4.5 Study Population and sample size

The study population in the context of this research study refers to the total units that can be used to address or provide solutions to the social phenomena being researched or investigated. Given that in the scope of this research, energy decisions, choices and demand were made at the household level in the various communities, answers to the research questions could be gathered through interactions with the various households. Households were therefore chosen as the basic units for the study population based on

the focus of the research on energy usage, decisions, and choices in the various study locations. Households in the context of this study were defined in accordance with the definition utilised by the Ghana Statistical Service

"Household - a person or a group of persons, who live together in the same house or compound, share the same house-keeping arrangements and recognize one person as the head of household" (Ghana Statistical Service, 2012). The households comprised of the various residents of each household and included men, women, and children. Data on the number of households in the study communities was not readily available from the East Ada District Assembly. Considering this, an estimation was made of the number of the households in the locations based on the average regional household size (number of persons per household) in the region based on data from the Ghana Statistical Service (Ghana Statistical Service, 2021).

Institutional stakeholders included government agencies, companies, NGOs, and energy think tanks with those involved in renewable energy and off-grid projects being targeted for interview. The main motive for interviews with these stakeholders was to get an insight into what the renewable energy landscape in Ghana looked like, the challenges faced, how renewable energy could be further promoted and perspectives on the prospects of renewable energy sources (aside from hydropower) becoming a key component in Ghana's energy mix. The data gathered from stakeholders with direct responsibilities in energy access served as a point of comparison for the household data and gave a broader perspective on the future of Ghana's energy industry. In determining the sample size for the household surveys, the formula used by Yamane (1973) was adopted as it is widely used in social science research (Tuptim, 2016; Menkiti and Agunwamba, 2015) i.e.

$$n = \frac{N}{1 + N * (e)^2}$$

where;

n – sample size,

N- the population size (number of households)

e – the acceptable sampling error

Ideally, the standard sampling error is 5% but as a result of limitations in cost and time, a 10% sampling error was used. Based on the 10% sampling error margin used, the sample size for the study locations is presented in Table 4.2 below.

Table 4.2: Study Population

S/N	Location	Total Households[4]	Sample size
1	Pediatorkope	266	72
2	Aflive	286	74
3	Azizakpe	217	68
4	Alorkpem	140	43
Total		**909**	**257**

4.6 Collection of Data

The collection of data for the research was carried out in two phases. Phase one was a pilot study which took place from April to May 2018. This offered the opportunity to visit the study locations and meet gatekeepers while also identifying the key stakeholders in the renewable energy sector and the energy sector in Ghana as a whole. The content of the questionnaires and interview questions used during the data

[4] Estimation of the total number of households in the study locations calculated based on the population as of 2018 and average household size reported in the 2010 Population and Housing Census for the Greater Accra region

collection was mainly informed by the aim and objectives of the study. The development of the household survey questionnaires and interview questions was partially started at the School of Geography, University of Nottingham and finalised on-site in Ghana after the specific study locations had been selected. It was important for the finalised version to be completed in Ghana after initial interactions with key stakeholders (e.g., staff of the Ghana Ministry of Energy) and after visits to the study sites as it helped to contextualise the survey questionnaire and the interview questions.

4.6.1 Household Questionnaire, Interview Questions Trial and Pilot

As part of the pilot phase, prior to finalising the survey questionnaires and interview questions, they were tested with a few people with diverse educational backgrounds (ranging from illiterate to highly educated people) to represent the educational background of the inhabitants of the study location. This exercise offered the opportunity to get feedback on the questions, resolve ambiguities with some of the questions as well as avoid repetitions as well as frame the questions better. The pilot testing of the interview questions also helped to get a sense of the time length to go through all the questions. This showed that for the educated respondents, less time was used as the questions were easily understandable and did not require further explanation whereas, for respondents with low levels of education, a lot more time was spent going through the interview questions as explanations had to be offered to clarify some of the questions. Thus, more time was allocated to interviewing a participant with less education to ensure the questions were well understood. The pilot also helped to frame the interview questions and survey questionnaire such that they would elicit the answers necessary to address the research questions. After the pilot some of the

changes made to the data collection instrument included amendments to questions on source of household and employment status to reflect the situation in the study locations, making the question on reasons for choosing a particular energy source open instead of a closed one. The question on the energy for cooking was also amended to reflect the use of multiple cookstoves in most households.

As part of the pilot phase, meetings were held with some of the institutional stakeholders to schedule appointments for their interviews at later dates as part of the data collection phase. The data collection was undertaken in the four island communities, and meetings were held with institutional stakeholders from October 2018 to February 2020. During the pilot phase, three research assistants were recruited who spoke the local language "Ga-Adangbe". The first research assistant had recently completed a master's degree program at the University of Education. The second assistant was a student at the Ada College of Education and the third assistant was a high school graduate. The first two assistants were selected based on their previous experience in administering questionnaires and knowledge of the local language. The third assistant was chosen as he worked as a boat skipper and could readily move the team around the island. His knowledge of the language and the communities also made him an asset to the team. After the recruitment of the research assistants, the overall aim and the specific objectives of the research were explained to them. This was necessary to give them a good understanding of the research to properly explain the purpose and context of the study to the participants without any misconceptions or misinterpretations. The assistants were also taken through refresher training in how to administer the questionnaire as well as the fact that participants were under no obligation to partake in the study.

4.6.2 Obtaining Approval and Entry to the Study Locations

In Ghanaian culture, Chiefs (Traditional rulers) and community elders serve as leaders for various communities, especially in rural and peri-urban communities and in some instances urban settings. These leaders serve as gatekeepers who need to be consulted to gain access to their communities. In this regard, the Traditional rulers and the community leaders in the study communities were consulted, provided an overview of the nature of the study, and formally notified of the intent of the research. The research assistants who were conversant with the culture of the study locations introduced the team to various Traditional leaders in each community and discussed the purpose and nature of the research with them. These visits also allowed familiarisation with the practices and culture of the communities. The consent and approval of gatekeepers were necessary to foster active participation in the research because the individuals and households approached had assurance that their leaders approved of the research. The traditional gatekeepers did not influence the recruitment of participants for the research. Their role was solely limited to granting access to their communities. In the meetings with the various gatekeepers, they were given information about the researcher including an introductory letter from the University of Nottingham which outlined the nature of the research. Permission and approval to enter the various communities to undertake the research were granted during the meetings with the leaders. After approval had been given, consent forms were co-signed by the researcher and gatekeepers, and a copy was retained by each party.

4.6.3 Selection of Participants for the Study

With the identification of the key stakeholders and participants for the study across the island communities completed as well as the relevant stakeholder institutions, the next stage was to determine the respondents to the survey questionnaire and participants in the interviews and focus group discussions.

Households

Sampling remains is a key aspect of the research process. As Onwuegbuzie and Collins (2017) note, by selecting elements of a population of interest, sampling enables the researcher to form generalisations about the wider population of interest and ensures the credibility and authenticity of the results or the interpretations. The sampling technique adopted by a researcher is dependent on several factors such as the research question, time, and resource constraints among others. In selecting participants for the household survey and interviews, a combination of two sampling techniques was used namely purposive sampling and snowballing sampling. This allowed participants in the various study communities from diverse age groups, educational and socioeconomic levels an equal probability of being chosen to participate in the research given they were willing and had capacity to participate in the research.

Jupp (2006) explains purposive sampling as a non-probability sampling that involves the selection of participants within a sampling frame or population of interest by the researcher using a number of criteria such as knowledge on the subject matter, willingness and capacity to take part in the research. Jupp also explains snowball sampling as non-probability sampling in which an appropriate respondent initially identified and selected by the researcher helps to identify another potential

respondent/participant. The new participant in turn helps to identify another and the process is repeated until sufficient data is gathered by the researcher. The two sampling methods were used to identify and select participants in the four study locations. On each of the four islands visited, the survey questionnaire was administered to any household the team visited where the members of the household were present and were willing to partake in the study. Snowball sampling was also used in several instances where participants encouraged other members of their households or other community members to take part in the study and on some occasions volunteered to help recruit other participants. The selection of participants was conducted to be representative of the different socioeconomic characteristics of the study communities. The various groups within the communities that were represented included age groups (from age 11 to 100); educational levels (from uneducated to tertiary); household size and income levels; and occupations.

Members of 36 households on Pediatorkope island were interviewed and answered the questionnaire surveys. Discussions were held with groups of women, men, and children. Ethical approval for the research and discussions with participants especially those under 18 years is presented in section 4.11. Interviews and questionnaire surveys were carried out in 32 households across the Aflive island, 42 households in Azizakpe and 34 households in Alorkpem. Separate focus group discussions were also held for various groups i.e., men, women, and children on all three islands as well. Participants were invited to the focus group discussion during the household interview. The key criteria for selection were based on the interest they exhibited in the subject and agreeing to participate in the focus group discussion. The rationale behind the focus group discussions was to help pick up on the issues that were peculiar to a group of people, in this case, women, men and children.

The rationale for interviewing children even though they are making no energy-related decisions in the household was to be able to gain insight into their energy needs, priorities and aspirations. This helped to examine whether the energy decisions made by the adults factored in their needs as well as whether their needs were met at all.

The number of participants interviewed in each study location is presented in Table 4.3. The interviews and questionnaire for the households were centred on issues such as:

- Energy needs of households
- Energy priorities and responsibilities of individuals in households
- Issues influencing energy decisions and choices
- Issues influencing electricity access in communities
- Perceptions and views on renewable energy use and energy access
- Willingness to sign up for mini-grid energy systems

Table 4.3: Number of participants interviewed in each study location

Community	Number of Households Interviewed	Number of People Interviewed
Pediatorkope	36	45
Aflive	32	49
Alorkpem	34	42
Azizakpe	42	62
Total	**144**	**198**

The research originally set out to interview respondents from 257 households across the four islands as discussed in section 4.5, however out of that number only respondents from 144 households (i.e., 198 participants) across all four islands were

available and willingly consented to participate in the study (Figure 4.3). This represented 56.03% of the initial sample size calculated for the study.

Institutional Stakeholders

Institutions which plan key roles in the energy industry in Ghana, especially with regard to renewable energy promotion such as Government regulatory bodies were identified as key stakeholders. Other private companies involved in the sale and installation of renewable energy systems especially off-grid solutions were also identified as stakeholders. The selection of participants from these institutions and firms for the interviews was made using purposive sampling. According to Jupp (2006), purposive sampling refers to a type of non-probability sampling in which the researcher makes decisions about participants in the study based on a range of criteria that involves specialist knowledge of the research problems, their willingness and capacity to be a participant in the study. Jupp further explains that with purposive sampling researchers are able to identify and choose participants that provide relevant and detailed data which help to answer the research question. The participants were selected from the Ghana Ministry of Energy, Ghana Energy Development and Access Project (GEDAP), The Delegation of German Industry and Commerce in Ghana (AHK Ghana) and the Renewable Energy Association of Ghana (REAG). Within these institutions, personnel or staff with higher grades were selected as they were the staff deemed to have specialist knowledge about the renewable energy and energy sector in general as well as their involvement in renewable energy development and promotion in Ghana. Other institutions selected include Franerix Solutions Ltd., GraMax Energy Group and Zola - ZEGHA Energy Ltd provide renewable energy solutions for off-grid electricity access using solar and wind. Black Star Energy builds and operates mini-

grids for remote communities in Ghana powered by solar PV systems. The list of Institutional stakeholders that were interviewed is presented in Table 4.4 below.

Table 4.4: Institutional Stakeholders Interviewed

Institution	Representative Interviewed	Number of People Interviewed
Ghana Ministry of Energy	Director of Renewable Energy Unit 2 staff of the Renewable Energy Unit	3
GEDAP	Senior Environmental Officer	1
AHK Ghana	Head of Competence Centre Energy and Environment Project Manager, Energy and Environment	2
Franerix Solutions Ltd.	CEO	1
Black Star Energy	Projects coordinator	1
GraMax Energy Group	Director of Operations	1
REAG	General Secretary	1
Zola - ZEGHA Energy Ltd	Operating Officer	1
Total		**11**

The interviews with these firms and institutions were centred on the following issues:

- The link between their work, renewable energy, and mini-grids in Ghana
- Government's policy and direction for renewable energy and mini-grids
- Community selection and system sizing criteria for the implementation of renewable energy mini-grid projects.
- The challenges faced in their line of work and the prospects of renewable energy and mini-grids in Ghana
- The extent to which community energy needs are factored in the sizing and deployment of mini-grid renewable energy projects.

The number of participants in the research and the methods used to gather data is presented in Table 4.5

Table 4.5: Data gathering methods used for each participant group

Group	Number	Method	Sampling method
Institutions	11	Interviews	Purposeful sampling
Study Communities participants	198	Interviews Household survey Focus Group Discussions	Purposive sampling and snowballing sampling

4.7 Data Collection Methods

Arega and Tadesse (2017) employed the use of a questionnaire survey to undertake their study on the willingness to pay for green energy by urban and pre-urban households in Ethiopia. This approach was also used by Alam and Bhattacharyya (2017) in their study on the willingness of off-grid customers to pay for electricity generated from hybrid mini-grids in Bangladesh. Thus, in this research, the use of semi-structured interviews and household questionnaires with a blend of open and closed-ended questions were adopted. The nature of the data required to achieve the research objectives confirmed that it was best to collect the data using both qualitative and quantitative methods as has been discussed earlier. Some of the data required to achieve the objectives were in qualitative form and the best way of collecting them was through the use of instruments such as interviews and focus group discussions. Others were more quantitative in nature and as such required the use of questionnaire surveys, whereas others were better collected by field observation. The study thus utilised the various mixed-methods instruments such as surveys, interviews, field observation and focus group discussions which maximises the strengths of these

different approaches. It is worthy of note that the language spoken in the study locations was Ga-Adangbe which the researcher did not either understand or speak, thus research assistants were recruited to interpret interactions from English to Ga-Adangbe and vice versa where necessary. In some instances, the respondents in the communities understand and could speak English and no interpretation was required.

4.7.1 Primary Data Sources

Interviews

The interviews conducted offered the opportunity to collect qualitative data as this allowed the participants to freely express themselves, their perceptions and opinions, their issues and challenges, the nature of their jobs, beliefs and practices using the open-ended questions asked. The interviews gave the respondents room to talk more than would be possible with the use of questionnaires. In conducting the interviews, any question that was not clear to the respondent was rephrased to offer clarity for the respondent (Creswell, 2009). This ensured that all questions were attempted by the respondents even if not fully answered thereby resulting in a high response rate. Appropriate background work was carried out to ensure the interview questions addressed the required data needs and were based on the research questions. Different interview questions were prepared for the household participants and institutional stakeholders given that different data was collected from them. To establish the reliability and validity of the interview questions, they were given to the research supervisors who provided insightful feedback on them (Teddlie and Tashakkori, 2008b). The interview guide was also tested during the pilot phase of the research to verify if the questions were appropriate for the research study setting, how easy they

were to understand and if they were appropriate to elicit the answers sought by the research questions.

Questionnaire

The use of a questionnaire made up of open and closed-ended questions was employed as it remains one of the most accepted and popular instruments for collecting quantitative data. Questionnaires have the benefit of enabling data collection quickly and cheaply and it is impacted less by the researcher's own bias thus making them very important in collecting research data about participants, their views, attitudes and ideas about research problems (Creswell, 2009). The household survey questionnaire was based on the quantitative data required for achieving the objectives of the study regarding energy requirements and cost and income level. Some relevant questions in the 2014 Ghana Living Standard Survey questionnaire instrument were modified and adapted for the questionnaire design. The questionnaire was subdivided into different sections which the researcher to collect the various forms of data required despite the different circumstances of the respondents (i.e., electrified, and un-electrified communities). The questionnaire was made up of both open and closed-ended questions. This made the data collection easy in that participants were able to easily choose an answer from the multiple-choice options that were provided for the closed-ended questions whereas the open-ended ones afforded respondents the opportunity to include more information on their views, attitudes and understanding of the issues under investigation. Open-ended questions here tended to provide vital information and insight for the researcher. The questionnaire was designed carefully to ensure that it mapped onto the various objectives to ensure their relevance, reliability and validity

for the study. They were then forwarded to the research supervisors for their expert input and comments. The questionnaire was also trialled out prior to undertaking the fieldwork to ensure they were easy to understand and could draw out the appropriate responses. The feedback from the trial and the expert input from the supervisors were then incorporated into an improved version of the questionnaire which was then used for the main fieldwork.

Focus Group Discussion

Focus group discussions refer to the gathering of people with similar backgrounds to discuss and share ideas on a subject or an issue of interest to generate data. Focus group discussions give the researcher the opportunity to understand the perspectives of the participants on the subject of the discussion (Mishra, 2016; Boateng, 2012; Wong, 2008). The focus group discussions helped to gather more data in addition to that collected using the interviews and the household surveys. Across the study communities, these focus group discussions were held for individuals who had been purposively selected during the household survey and interviews. Separate focus group discussions were conducted for groups of men, women, and children in each of the four (4) island communities. Men and women who during the household surveys and interviews showed interest in the research topic and agreed to participate were invited to participate in their respective focus group discussions. Ideally, children who exhibited knowledge and interest in the research topic should have been invited to the focus group discussions for the children but that was not the situation. The participation of pre-selected children in the focus group discussions was subject to the willingness of the parents or guardians to allow the children to participate and the

availability of the parents/guardians to be present during the discussion. Thus, the children who participated were those whose parents or guardians gave approval and were available to accompany the children to the discussions. Discussion guides were designed to facilitate the deliberations.

4.7.2 Secondary Data Sources

Data was also sourced from other secondary sources to enable the researcher to address the research problem. The secondary data used also helped the researchers to understand the extent of work that has been carried out on the subject matter and what gaps remain in the existing literature. Secondary data were also employed to help in the design of the questionnaire and interview questions. The data from the secondary sources include journal articles, government and other official reports, internet sources, census reports and books.

4.8 Fieldwork

4.8.1 Data collection in Study Communities

The data collection period was from October 2018 to March 2019 with a follow-up visit carried out in February 2020. Work in the first week of the fieldwork started with going through the scope and objectives of the research with the research assistants as well as going through the methodology that had been adopted for achieving these objectives. The next stage was discussing the questionnaire, interview and focus group questions to ensure that each question could be translated into the Ga-Adangbe language and draw out appropriate answers from them. This ensured that the entire team was on the same page with regard to the translation of all the questions.

The team then moved to Pediatorkope island to start the fieldwork. The Chief of Pediatorkope had an announcement made to the community detailing the purpose of the research team's presence, the nature and purpose of the research and how long the research team was going to be working in their community. The researcher and the research assistants together administered the first questionnaire and conducted the first interview in the house of the Chief of Pediatorkope and the next four households with each member taking the lead each time to ensure that everyone was conversant with how to administer the questionnaire and carry out the interviews. From there, the team split up into three, each consisting of two members and allocated a section of the community to administer the questionnaire and interview the respondents. For each household where the occupants were present, the team introduced themselves and requested the inhabitants to participate in the study. In instances where the households were empty or the occupants were not willing to participate, the team moved to the next available household.

In each household the team visited, the occupants participated in the study individually and their answers were kept confidential. They were also provided with copies of the consent and information sheets and translations were provided where necessary with the consent forms co-signed by the researcher and the participants with a copy retained by each party. The team noted down participants who could potentially be invited for the small group focus discussions. The selection criteria were mainly based on the level of interest in the questions they were asked as well as how they responded during the interview sessions. In households with children present, in all cases, the consent of their parent or guardian was sought first before they were engaged in any interactions. The selected participants for the focus group discussions were informed of the day and time for the discussion. Separate discussions were held for men, women, and the few

children whose parents and guardians allowed them to participate in the Chief's house. After the data collection on Pediatorkope island, the team then progressed to the other three island communities (Aflive, Alorpkpem and Azizakpe) conducting the survey and interviewing participants similarly to that in Pediatorkope.

4.8.2 Interviews with Institutional Stakeholders

Appointments for meetings with most of the institutional stakeholders were booked as part of the pilot phase of the fieldwork. Before the interviews with the institutional stakeholders, the scheduled appointments were confirmed via emails and calls. Calls were also made to confirm appointments for the interviews a day before the scheduled appointment. Participants who were not available for scheduled interview appointments had their interviews rescheduled to other times that were appropriate for them and the researcher. For every interview, after arriving and meeting the participant, the meeting was started by providing them with a brief overview of the aim of the research. Each participant was also provided with a copy of the consent and participant information sheet. The consent forms were co-signed by the researcher and the participants, and a copy was retained by each party.

4.8.3 Recording Data

Responses to all questions during the interviews and focus group discussions were audiotaped after permission had been sort from all the participants. The participants were made aware that if at any point during the interview they did not want to continue with the interview or did not want their responses recorded they could let the researcher

or the team member know, and the recording would be stopped, or the interview would end. All participants for the interviews were okay with it being recorded but a contingency was that if any participant objected to being recorded, handwritten notes were to be taken of their responses. The responses to the questionnaire were recorded on questionnaire sheets that had been printed. Though this made the work tedious, it was the most effective way of recording the data being collected. This was because the communities did not have access to electricity so the use of software on electronic devices (i.e., tablets) was not ideal.

4.9 Data Preparation, Analysis and Preparation of Results

Both qualitative and quantitative data were gathered in order to achieve the research objectives. The quantitative data from the questionnaire were entered into Microsoft Excel software. Excel was then utilised to generate descriptive statistics on themes such as household income levels, energy cost, cooking and lighting fuel choices in the form of tables, diagrams and graphs based on the data generated from the questionnaire responses. Another theme that was analysed using the quantitative data was the share of men and women involved in energy decision making and their various responsibilities. The individual energy preferences and priorities of the various household members were also analysed to establish if any patterns were evident. The qualitative data from the recorded interviews were transcribed by the researcher. The interviews that were carried out in the Ga-Adangbe language were first translated into English before being transcribed without making any changes to any part of the questions posed and the responses provided by the participants. The interviews that were carried out in English were transcribed verbatim. The data from the household

survey was used to generate the descriptive statistics for the research and this was analysed using Microsoft Excel. The interview data after transcription was coded using a combination of manual coding and the use of NVivo 12 software for some coding as well. The interview coding matrix from both the manual and NVivo coding is presented in Appendix VI. The thematic analysis of the data was carried out manually to draw out the key themes that emerged to establish the different interactions and relationships between the various themes arising out of the data. The discussions of the various themes when presented in this thesis, where necessary, are supported with quotations from the respondents from the interview transcripts.

4.10 Positionality

Rowe (2014) explains positionality as the stance researchers assume in relation to their study participants, the environment and the general context of the study. The positionality of the researcher is very important as it can impact the entire research process and the data collected. The positionality of a researcher can be categorised as being either that of an insider or an outsider in relation to the study context (i.e. the specific topic and the participants (Rowe, 2014). The perception the study subjects have of the research as being an insider or an outsider has the potential to either enhance or ruin the research process as well as the kind of data that is collected. Rowe (2014) suggests that a researcher being perceived as being closer, with similar experiences and expectations by the study participants enhances the entire data collection process. In the same light, Cotterill and Letherby (1994) also point out that when participants have a perception of the researcher as being an insider and share behaviours and experiences, they are less suspicious of the purpose of the research and

the researcher's intentions. The contrary view to this as argued by some researchers is that for a researcher's bias not to impact the research process it is best that the researcher assumes an outsider stance thereby creating a better understanding of the study and enhancing rigorous research (Sultana, 2007). The arguments on both sides point to the fact that the positionality of the research has a significant influence on the research and such appropriate steps must be taken to reduce any hindrances to rigorous research to the barest minimum.

Throughout the course of the research process, I was conscious of the significance of my positionality in the process (i.e., either enhancing or hindering) especially during the data collection phase. In this regard, I was positioned as both an insider and an outsider in that I was a Ghanaian conducting a study in a Ghanaian community in a part of the country I had visited several times and could relate to some of the experiences, attitudes, and behaviours of the participants. Despite the similar experiences I shared with the participants I was to a certain degree viewed as an outsider. I did not speak the local dialect, was not a native and had never encountered any of the participants prior to the study unlike the rest of the research team that spoke the local dialect and hailed from neighbouring towns. With these insider and outsider attributes, the research team were able to interact with the participants and their community leaders gaining their consent and support for the study. This enabled the participants to have no suspicions about the intention of the study rather all the participants that were approached were eager and enthused to partake in the study. During the interviews with participants on the unelectrified islands, some of the participants were of the view that we were undertaking the project to provide their islands with electricity. To manage this, the purpose of the study was explained to them and then they were requested to provide responses that were a true reflection of

their current situation. The other members of the team and I made sure to conduct the data collection in a professional manner gaining the trust and confidence of all participants.

4.11 Ethical Issues and Approval

In accordance with the University of Nottingham's policy on Research Ethics, approval was initially sought from the School of Geography's Ethical board on the way sensitive and ethical issues were to be handled. As the University's research ethics protocol rightly states, adhering to the highest standard of ethical conduct ensures that research integrity, honesty and accountability and other ethical behaviours are maintained. The key ethical issues that have been addressed in this research include access to and acceptance of the participants; informed consent of the participants; confidentiality of the information; anonymity, safety and wellbeing of all the participants especially participants aged below 18. In the conduct of the research, especially during the data collection stage, access to and the acceptance of the participants was required. To be able to access the study communities, the consent of the gatekeepers was sought. Written consent was sought from the District Chief Executive of the Ada East District informing the district assembly of the intent and the scope of the research and the communities involved in the study. Chiefs and community leaders in the selected study communities were contacted to gain their consent and permission to access their communities. The gatekeepers in the communities were given adequate details about the research study and information about the researcher as well as an introductory letter from the University of Nottingham to help allay any concerns. After consent had been given, consent forms

were co-signed by the researcher and the various gatekeepers, with a copy retained by each party. At the household levels, consent was sought from occupants for access to the household and subsequent participation in the survey and interviews.

Before participation, the informed consent of all respondents was sought by first translating the written consent form for them in the case of participants with little or no formal education. It was stressed that participation was not compulsory, and if at any point during the interaction they were inclined to discontinue, they were free to opt out. Participants were also made aware of their right to decline to answer any questions they did not want to. It was also made known to them that if they were uncomfortable with their response to any of the interview questions, they were free to request for their responses to be deleted. The written consent forms were co-signed, or thumb printed, and a copy was retained by each party. To maintain the confidentiality of information as well as the anonymity of the participants, participation in both the survey and interviews was undertaken on an individual basis, making sure other household members or participants did not hear each other's responses.

The data was securely stored by encrypting all the data files and no part of the data has been shared with anyone not directly involved in the research. The research assistants translated the questions into the Ga-Adangbe and translated the responses into English and all interactions were recorded provided the participants permitted it. To ensure the accuracy of the translations, the research assistants were trained to translate directly from Ga-Adangbe into English without making any adjustments to the responses provided. All recordings were compiled and stored on an encrypted drive at the end of each day's work by the researcher. This was to guarantee the security of the data collected by the research assistants. Transcriptions were carried out by the researcher and codes were assigned to participants which ensured that no personal information

was collected which could lead to the identification of participants. All paper copies of questionnaires were submitted to the researcher for secure storage after each day's work. During the transcription, all the interactions were transcribed wholly without any changes made to the sentence constructions of the translated responses. No personal details of the participants were used in any analysis or reporting to protect the anonymity of the participants. Appropriate steps were also taken to ensure the safety of all participants, especially children during interactions for the household surveys, interviews and focus group discussions. In interactions with children, a parent or guardian sat by to ensure that their wards were safe with the team. In ensuring the safety of the adult participants, all interactions were carried out in a safe environment.

4.12 Limitations

One of the limitations of the study was the challenge with language. The most popular language spoken in the study locations was the Ga-Adangbe language. Therefore, the interview questions and questionnaire had to be translated from English to Ga-Adangbe and most of the responses were also translated from Ga-Adangbe into English. The meaning of certain words was lost in translation and the tone of some of the participants' responses was not conveyed in the same manner and with the same intensity and passion. A common issue was the absence of a uniform term in the Ga-Adangbe language for energy. There were different terms for fuel and electricity but no common term for energy. Another limitation was the fact that the limited financial resources available meant only a limited number of communities were selected and the length of days that research work was undertaken in each community/ study location was limited.

4.13 Conclusion

This chapter has provided an overview of the various research strategies and approaches that were adopted to gather data in the study locations, the analysis and interpret the data to achieve the objectives of the research. This chapter also examined how using the mixed methods approach is a combination of both qualitative and quantitative approaches to gather the data needed and its analysis. The adoption of the mixed-methods approach led to harnessing the strengths of both the quantitative and qualitative approaches respectively to adequately address the research questions and achieve the research objectives. The techniques adopted for the identification of stakeholders and participants in the study were also discussed as well as the data gathering techniques namely interviews, household surveys, and focus group discussions. In addition, the chapter also explored the ethical considerations associated with the study and the security measures put in place to protect the data gathered and the anonymity of the participants in the study. Methodological limitations that influenced the study as well as the workarounds that were used to minimise their impact were also discussed in the chapter.

CHAPTER FIVE

CHARACTERISTICS AND ENERGY USES OF THE RESEARCH COMMUNITIES

5.0 Introduction

This chapter presents and discusses the energy use patterns in the study locations and their demographic characteristic as part of addressing objective one: *Assessing the current energy sources and needs of the participants and the options renewable energy mini-grids offer*. It outlines the unique demographic and socio-economic characteristics of the respondents and their households within the research areas and how their energy needs, and use are influenced in Section 5.1. The energy needs and use patterns of the participants in the various study locations are presented in Section 5.2. General discussions on the issues that stand out in the energy consumption discussions across the study locations and the influence of the participants' unique characteristics on their energy choices, needs and use are also presented in section 5.3. The chapter concludes with a summary of the discussion presented.

5.1 Characteristics of the Research Communities

The four study locations selected are representative of the rural communities especially rural island communities in Ghana. The participants share most of the general characteristics of rural households in Ghana and these are discussed in the ensuing sections.

5.1.1 Gender

A total of 198 people participated in the household surveys across the four islands of Pediatorkope, Aflive, Alorkpem and Azizakpe. Out of these, 105 (53%) were male and the remaining 93 (47%) females as depicted in Fig. 5.1 One of the themes emerging from the analysis of the result is the fact that energy needs and use were gendered and this is congruent with the research of Asibey et al. (2021) who found out that in Ghana, energy needs were gendered. In their study they found that most women are likely to opt for traditional solid fuels for cooking and other domestic needs whereas men were interested in modern energy services like electricity for productive purposes thus making them more economically empowered than women. The fact that major issues and decisions in most Ghanaian rural households such as energy use and decision-making tend to be dominated by male heads of household or household members, was reflected in the number of males that willingly participated in the household surveys and interviews compared to females (Adjakloe et al., 2021). Even in instances where heads of households were not male, it was noted that male household members had significant influence over the kind of decisions and choices that were made. The fact that the survey sought to understand the energy needs of the various households, including energy for cooking and heating water which usually are the preserve of women in traditional Ghanaian societies, could have been a contributing factor to the 47% share of the female participants. In most households across the research locations, female household members often offered for the males in their household to partake in the research instead of them citing reasons such as the men being the main decision-makers in the household and the leaders as presented in the quote below.

"…the men are the leaders in the house and decide on a lot of issues so they can partake in the interview, we support their responses…" (27-year-old female respondent, Pediatorkope).

Some female participants were coaxed by male household members to also offer their opinions by participating in the interview. The data on the gender of the respondents was relevant to help understand the different energy responsibilities, needs and priorities of the participants, as well as examine the role that gender plays in household energy decision making as explored in sections 6.1.1 and 6.1.2. As discussed earlier in section 2.8, gender significantly influences the energy choices for households as research has shown that female-headed households usually did not have equal access to clean energy sources as male-headed households (Ulsrud, 2020; Aryal et al., 2019). Traditionally, men and males in Ghanaian households are the decision-makers and dominate decision-making as Adjakloe *et al.* (2021) point out and this has an influence on how energy choices are made and the type of energy sources that are chosen.

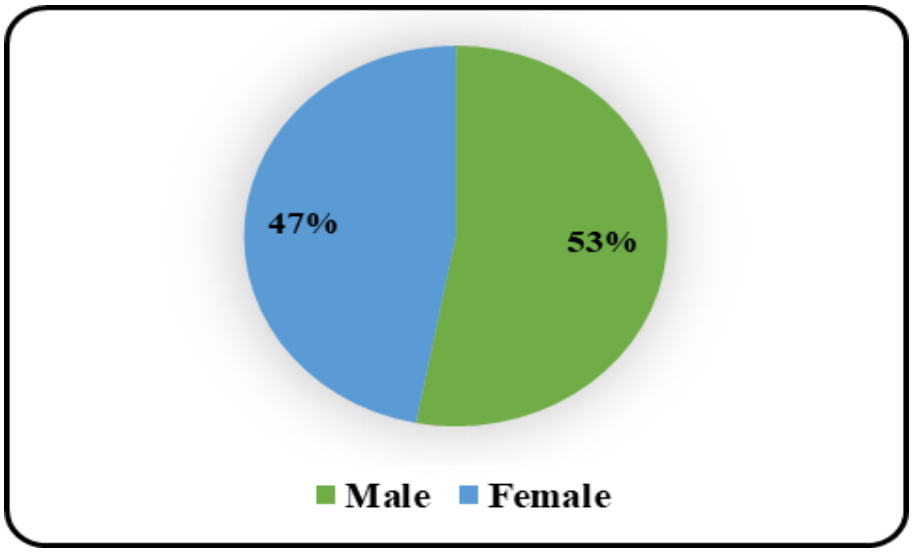


Figure 5.1: Gender distribution of the household survey participants
Source: Fieldwork, 2018/2019

5.1.2 Age

The participants in the household surveys and interviews ranged from ages 11 to 98 years. This wide age span was utilised to get a representative sample of the communities as discussed in section 4.6.3 and be able to gather the perspective of all willing participants who understood energy issues within their households and communities. The data as presented in Table 5.1 depicts that 62.2% of the respondents were within the age bracket of 11-40, whereas 19.2% of respondents ranged between 41 and 50 years and respondents who were aged 51 years and above accounted for 18.7%. This was representative of the broader trends across the country in the 2021 population and housing census where 38.2% of the 30.8 million population were between the ages of 15 and 35 years. The data on the ages of the participants helped to understand trends like the relationship between age and participants' energy priorities and aspirations. Regarding the relationship between age and energy needs and priorities of the respondents, it was noted that the majority of the participants aged below 30 years had as their top three needs and priorities: energy for lighting, communication, entertainment, and productive use as is captured in the quote below.

> *"...I need energy for light in my house, be able to charge my phone and also do my work, you know I am welder ... as for cooking food my wife takes care of that..."* (28-year-old male respondent, Pediatorkope).

The older respondents aged 30 and above, on the other hand, listed energy for economic activities and productive use, cooking, and lighting as their top three energy needs and priorities as indicated in the quote below.

> *"...my priority use for the electricity is to use a freezer to store the fish I sell for longer than I do now, that way I can make more money than I do now because sometimes I sell them cheaper because I don't have a freezer, ... I also need*

energy for cooking and light in the house in the night..." (43-year-old female respondent, Alorkpem).

Further discussions on the links between age and energy choices, needs and priorities are presented in section 6.1.2.

Table 5.1: Participants' Age Distribution

Age range	Percentage (%)
11-20	8.1%
21-30	28.3%
31-40	25.8%
41-50	19.2%
51-60	10.6%
61-70	6%
71+ years	2%
Total percentage (%)	100%
Total number of respondents	198

Source: Fieldwork, 2018/2019

5.1.3 Educational Level

Data on the educational levels of the participants helped to understand the energy needs and aspirations of the participants. As Inglesi-Lotz and Morales (2017) found in their analysis of data available from 11 developing and 10 developed countries, increased educational levels showed a positive impact on energy consumption in developing countries due to the increase in income and increase in energy needs and aspirations to catch up with their developed counterparts. With respect to the developed countries, they found that increase in education level impacted energy consumption negatively as there is less increase in energy aspirations compared to developing countries. Wang et al. (2020) also find that in the Guangdong Province of China, higher educational levels translated into increases in energy consumption even

though there was increased awareness, energy behaviour was not in accordance with the awareness. Thus, high education levels translated to an increase in energy use and aspirations which could be attributed to an increase in income levels and increased energy use aspirations as indicated in the quotes below. As illustrated in the quote below as the educational level of the respondents increased, their energy needs, and aspirations were noted to equally increase

> *"... I will be starting my studies at Accra Technical University next year and I would be happy if by then we have electricity so that when I come home, I can use a laptop for my studies"* (22-year-old male respondent, Azizakpe).

The results from the survey indicate that 44.4% and 41.9% of the respondents had basic and high school education respectively. Around 2% of these respondents had some form of tertiary education and the remaining 11.6% had no classroom education as presented in Table 5.2 below. It was noted that the respondents with higher educational levels had a lot of understanding of issues about modern energy access and renewable energy. Also, higher educational level was noted from the results to have a link with high-paying jobs and increased income, thereby offering the opportunity to be able to afford access to modern energy services as illustrated by the quote below.

> *"... some of the houses were not able to pay to be connected to the mini-grid because of the money involved and the tariff to be paid every month,...most people do not make a lot of money from their jobs, so the connection fee and monthly bill is a lot for them, my job is not the best paying job but it helps me to be able to afford to pay for my electricity and buy appliances like a TV set and a fridge..."* (35-year-old male respondent (Teacher), Pediatorkope).

This is congruent with Wang et al.'s (2020) findings that increases in respondents' income levels due to higher education and better-paying jobs resulted in a higher demand for new goods and services and thus significant increases in energy consumption. According to ÖzçiÇek and Ağpak (2017), their findings also show that higher education level has a positive impact on the acceptance and desire to use modern and renewable energy sources in households. Thus, the higher the education level of people and the better they understand the need for access to renewable energy sources and the increased possibility that they will adopt such technologies. Educational level was also noted to influence household sizes, it was observed that families with higher educational levels usually had smaller household sizes, whereas the household sizes of respondents with lower educational levels and no education were usually large.

Table 5.2: Educational Level of Research Participants

Educational level	**Percentage (%)**
Illiterate	11.6%
Basic school	44.4%
High school	41.9%
Tertiary education	2.0%
Total percentage (%)	100%
Total respondents	198

Source: Fieldwork, 2018/2019

5.1.4 Household size and monthly income

The survey data depicted that the household sizes ranged from 2 to 15 persons, with 72.8% of the respondents coming from homes with a household size of between four to seven people with an average household size being 5.5. This was higher than the national average household size of 3.6 reported by the Ghana Statistical Service

(2022). Table 5.3 presents the household size distribution of the respondents. The average monthly household income as shown by the survey data ranged between GH₵ 1.00 to above GH₵ 2001.00 (US $ 0.14 –$ 300)[5]. As is shown in Table 5.4, some 77.3% of the respondents had average monthly household incomes of GH₵ 500 ($ 75) and below. This translates to earnings of $ 2.5 and below daily, which is below the higher poverty line of $3.20 daily earnings. The monthly household earnings were observed to be almost half that of the national monthly household income of GH₵ 900.00 (US $ 135.00) (Sasu, 2021). This provides a clear indication of the level of poverty in the research communities and is a reflection of the 25.5% poverty rate across the country (World Bank, 2021). Household size was noted to affect household income and this, in turn, influenced the choice of energy services and sources for meeting their needs. Smaller households were noted to have more disposable income compared to larger households and as such, they could afford to spend a lot more to get access to cleaner modern services as illustrated by the quote below.

> *"… we are not many in this house, just 3 of us, so we were able to save up before they completed the mini-grid, so we could afford to be connected when it was completed"* (32-year-old female respondent, Pediatorkope).

This response was also in agreement with the findings of Zou and Luo (2019) that in rural communities in China that income influenced the energy consumption levels of households levels where increases in household income resulted in households transitioning from using traditional solid fuels or energy sources to more efficient non-solid fuels and energy sources in line with the energy ladder concept. Given the high cost associated with renewable energy technologies in comparison to the generally

[5] Exchange rate of GH₵ 1.00 = US $ 0.15

lower rural household income, the absence of the availability of financing and credit option to consumers is a barrier to modern energy access (Bhattacharyya, 2013).

The response stated above also showed that increases in disposable income within households allowed for households to switch to cleaner non-solid fuels and modern energy services in line with the energy ladder concept of transitioning to more efficient energy sources with increases in household income (Poddar et al., 2021; Perez and Zepeda, 2016; Sovacool, 2014b).

Household size was also noted to influence energy choices. In large-sized households, the respondents were noted to choose energy sources and fuels that could cater for their energy needs at affordable prices depending on their household size as the quote below illustrates.

> *"…we are about eight in this house, we cannot afford to cook for everyone with the LPG stove, it can only small quantities of food, that is why we use the stone stove…"* (58-year-old female respondent, Aflive).

This was congruent with the literature on cookstove stacking behaviour and the reasons behind them such as the capability of the cookstoves to cook the quantities of food required (Jewitt et al., 2020; Dickinson et al., 2019; Piedrahita et al., 2016). The above-quoted response is congruent with the findings of Özcan et al. (2013) who found that increases in household size results in an increase in energy consumption, they also found that with increased household size, there was a decrease in the use of cleaner non-solid fuels and preference for traditional solid fuels as illustrated in the quote above. Additional discussions on the effect of household income and size on energy access and priorities are presented in section 6.1.3.

Table 5.3: Household Size Distribution

Household Size	Percentage (%)
2 persons	2.0%
3 persons	5.6%
4 persons	16.7%
5 persons	20.7%
6 persons	19.2%
7 persons	16.2%
8 persons	9.6%
9 persons	4.0%
10+ persons	6.0%
Total percentage (%)	**100%**
Total number of respondents	**198**

Source: Fieldwork, 2018/2019

Table 5.4: Average Monthly Household Income

Average Monthly Household Income (GH₵)	Percentage (%)
1-50	0.5%
51-100	17.2%
101-500	59.6%
501-1000	15.7%
1001-2000	1.0%
> 2001	0.5%
Unknown[6]	5.5%
Total percentage (%)	100%
Total number of respondents	198

Source: Fieldwork, 2018/2019

[6] refers to those who were either not sure of their average monthly household income or those who were not willing to disclose their household income.

5.1.5 Occupation

28.3% of the 198 respondents were engaged in trade, sales, and business-related occupations, 20.7% of the respondent were involved in fishing-related activities (fishing, fish-mongering); 22.8% of the respondents were either dependents or unemployed. The remainder of the participants were in other occupations such as agriculture; tradesmen (mechanic, carpenter, mason), hospitality and other services. Table 5.5 presents the distribution of the occupations of the respondents. Further discussions on the influence of occupation, household size and income on energy access, needs and priorities are presented in sections 6.1.3 and 6.2. It was noted that respondents who had occupations with high monthly income could afford to pay for access to modem energy services. This was in accordance with Quinn et al.,'s (2018) work which lists socio-economic characteristics as a factor that influences consumer demand. The occupations of some respondents were observed to increase their awareness about modern energy services, especially renewable energy sources and their willingness to adopt these technologies as the quote below illustrates.

> *"I am an electrician, so I know that solar energy is an easy way to provide electricity to the islands than connecting to the centralised grid and it is also good for the environment… I bought the solar system I have and installed it by myself…"* (30-year-old male respondent-Electrician, Alorkpem).

Table 5.5: Percentage Distribution of Respondents' Occupation

Occupation	Percentage (%)
Trade/Sales/Business related work	28.3%
Agriculture	4.0%
Artisans (mechanics, carpenters, mason, etc.)	11.1%
Fishing related activities	20.7%
Services	8.1%
Student/Dependent	4.5%
Educational professional	2.5%
Unemployed	18.3%
Pensioner	2.5%
Total percentage (%)	**100%**
Total respondents	**198**

Source: Fieldwork, 2017/2018

5.2 Energy Use in the Research Communities

The four island communities used for the research had a lot of similar characteristics. Across the communities, majority of the respondents were noted to be employed in the informal sector working in occupations such as fishing, agriculture, artisans and sales as pointed out in section 5.1.5. Fishing seemed to be a very popular occupation in the locations mainly due to their proximity to the sea and river. Household income levels and education levels were also noted to be low across the communities as shown discussed in sections 5.1.3 and 5.1.4 respectively. These characteristics were a reflection of the household income and education levels as well as occupations in rural communities across the country as reported by the Population and Housing Census conducted by the Ghana Statistical Service in 2021(Ghana Statistical Service, 2022). The similar characteristics these research communities share with the other rural and

remote communities across the country make for the generalisability of the research findings of the research in those contexts as well.

The energy sources for the study communities varied for each island community. Pediatorkope had a hybrid mini-grid electricity system in operation as part of the Ghanaian government's pilot project for mini-grid development. The other 3 islands (Aflive, Azizakpe and Alorkpem) on the other hand, had no mini-grid electricity access like Pediatorkope. Some residents who had the means and could afford standalone solar systems had them installed for lighting purposes and powering household appliances like radios, tv, fans and charging phones as depicted in images b and c in Figure 5.3. Water filtration systems and lights that were powered by standalone solar systems had also been installed on the islands (Figures 5.2 and 5.3d). The data on energy use across the study islands is presented in the next sections.



Figure 5.2: Community water filtration system in Aflive powered by a standalone solar system
Source: Fieldwork, 2019/2020



(a) Solar home system on the roof of the Chief's palace in Alorkpem



(b) Solar home system in Alokpem



(c) Solar home system used by a resident in Aflive



(d) Solar street light in Azizakpe community

Figure 5.3: Pictures of Solar Homes Systems and solar light in use in the three unelectrified communities
Source: Fieldwork, 2018-2020

5.2.1 Pediatorkope Island

The hybrid mini-grid system in Pediatorkope consists of a solar PV plant with a capacity of 39 kWp, an 11kW wind turbine and a backup diesel generator plant for supplying all connected households on the island with electricity.

A picture of the Pediatorkope mini-grid generation site is shown in Figure 5.4. The beneficiary households pay a tariff for the electricity consumed. The tariff paid is also categorised into tariff bands dependent on the consumption of the individual households. In instances where the battery systems are fully charged, and there is excess electricity generated, households use the available electricity at no charge at all.



Figure 5.4: Picture of the hybrid renewable energy generation site on Pediatorkope island

Source: Fieldwork, 2018

The results showed that in Pediatorkope 82.2% of the respondents had electricity access via the hybrid mini-grid system which they used for lighting, phone charging and several other uses while some 17.8% of the respondents did not have electricity

access and as such relied on other energy sources for their energy needs as presented in Figure 5.7. For the households not connected to the mini-grid, their sources of energy for lighting according to the respondents, included battery-powered torchlights, solar rechargeable torchlights, and kerosene lanterns. For the 17.8% of the respondents without access to electricity, their reason was their inability to pay for the cost of being connected to the mini grid and the monthly costs for energy used. Table 5.6 presents the average monthly energy expenditure of the participants in Pediatorkope. Participants on Pediatorkope island listed their uses of the electricity from the hybrid mini-grid as lighting, powering radio and television sets as well as fans. Others used the electricity for their economic activities such as powering refrigerators and freezers for shops and powering a mobile phone charging shop.

Responses regarding the reliability of the hybrid mini-grid system indicated that, on average, the mini-grid electric system provided electricity for 22 hours, and it was impacted by the changes in the weather. When probed further it was pointed out that on cloudy days and rainy days the power did not stay on for 24 hours as evidenced by the quote below

> *"... within the last 7 days, the light has gone off a number of times... it can go off in the day and the night... when it goes off it can last for between 2 – 5 hours..."* (48-year-old male focus group participant, Pediatorkope).

Some other participants also pointed out that on some days, especially on rainy days, they could not use high-consuming household appliances due to the low voltage as evidenced by the quote below.

> *"...on some days, especially when it rains the electricity is not able to power the freezer that I use for my shop and the iron too"* (40-year-old female participant, Pediatorkope).

Some respondents also reported turning off their power whenever it rained but they did not mention any specific reason for doing that. It is noteworthy that most respondents had other sources of energy for lighting apart from the main sources which they relied on as backup in the event of issues with the main source. These other sources include torchlights and lamps that are either battery-powered or rechargeable and kerosene lanterns as evidenced by the quote below.

> *"…on the nights when the electricity from the mini-grid goes off, we have rechargeable torch lights and lamps that we use to light up the rooms"* (47-year-old male participant, Pediatorkope).

Some respondents also pointed out they had to limit their electricity use for fear of not ending up with huge electricity bills as captured below.

> *"…sometimes we also want to use household appliances like the people in Ada who connected to the centralised grid, but we are worried that if we do that, we can't pay the bill"* (24-year-old male respondent, Pediatorkope).

This was contrary to information gathered from interactions with officials of the Ministry of Energy when asked about the capacity of the mini-grid system to meet the needs of the people in Pediatorkope, they pointed out they had never recorded usage near the capacity of the mini-grid system as captured in the following quote.

> *"…actually, the Pediatorkope system has never been used close to its capacity and in some instances, the consumers use electricity for free when the battery for the systems is fully charged…"* (Staff, Ghana Ministry of Energy, Accra).

This showed that while the consumers limited their electricity use due to the tariff, the operators of the system considered that their maximum use of the electricity from the mini-grid system was below the capacity of the system. This showed that metrics that the ministry used to measure and track the electricity use from the mini-grid system

were not always reflective of the situation on the ground. This was in agreement with Satterthwaite's (2003) argument about “nonsense statistics” explaining that statistics on developmental issues may not always be true representations of the problems on the ground and as such the need for further investigations to understand the issues involved.

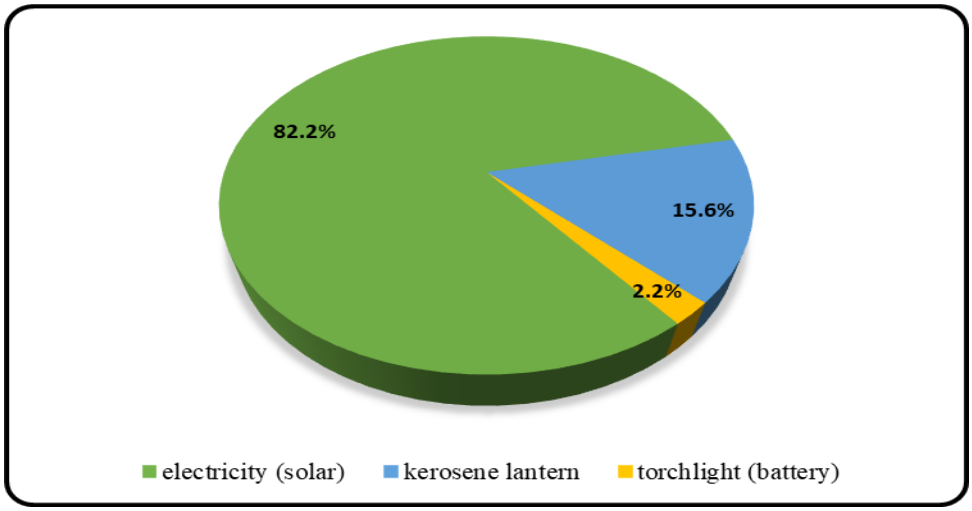


Figure 5.5: Primary Energy Source for Lighting in Pediatorkope
Source: Fieldwork, 2018-2019

The monthly energy cost of the respondents in Pediatorkope as derived from the survey ranged from GH₵ 5.00 ($ 0.75) to GH₵ 100.00 ($ 15.00). From the data, it was shown that households on the island on average spent GH₵ 34.31 ($ 5.15) monthly to cater for their energy needs. Table 5.6 presents the average monthly energy cost for the respondents in Pediatorkope. The results show that various appliances were in use in households on Pediatorkope island. The appliances consist mainly of radios, fans, television sets and others as presented in Table 5.7. The most popular appliance was a radio set with 40 respondents from Pediatorkope island owning a radio set in their household. For most of them, it was the main medium through which they got informed of events happening outside their communities. Some respondents had a combination

of these appliances, and it was evident from the responses that they could afford to use these appliances due to their above-average income levels.

Table 5.6: Average Monthly Energy Cost of Respondents in Pediatorkope

Average Monthly Energy Cost (GH₵)	Percentage (%)
1 – 10	3.6 %
11 – 20	9.8 %
21 – 30	13 %
31 – 40	18.9 %
41 – 50	35.8 %
51 - 60	7.8 %
61 – 70	4.6 %
71 – 80	0 %
81 – 90	0 %
91 – 100	6.5 %
Total percentage	**100 %**
Total number of respondents (n=45)	**45**

Source: Fieldwork, 2018/2019

Table 5.7: Appliances used by participants in Pediatorkope

Household Appliance	Number of participants who own it
Radio	40
TV	17
Fan	22
Fridge	13
Steam iron	6
Water Heater	1

With regards to energy for cooking, three key types of cookstoves that were in use by the households visited in Pediatorkope were three-stone stoves, coal pots, and LPG cookstoves (Pictured in Figure 5.6). From the data, it is noted that some 85% of the

respondents had a three-stone stove as their main cookstove. The choice of the three-stone stove by most of the respondents was based on reasons such as its ease of use, affordability, readily available fuelwood and the ability to cook large quantities with ease. It was observed that about 70% of the respondents in Pediatorkope were engaged in cookstove stacking of some sort. These respondents had more than one cookstove which was used as and when the need arose. The reasons for cookstove stacking behaviour exhibited in the community echoed similar reasons attributed to stove and fuel stacking behaviour from a range of different regions outlined in literature (Dickinson et al., 2019; Piedrahita et al., 2016; Masera et al., 2000). The stacking behaviour exhibited and the reasons given were congruent with the findings from research in Nigeria by Jewitt, Atagher and Clifford (2020) where the stove or fuel stacking is usually undertaken to cater for different cooking needs and to accommodate changes in the access and supply of any fuels for cooking. Most of the households had both a three-stone stove and a coal pot. Respondents explained their preference for the stone stove was due to the ease with which they could cook large quantities of food, as opposed to cooking with the less polluting stoves which they explained were only suitable for cooking smaller quantities of food. Other reasons as evidenced in the quote below include the consideration of how fast the stove-cooked food and the taste of the food cooked on different cookstoves:

> *"...for me, I have the coal pot and the stone stove, but I always prefer the stone stove because it cooks the food faster than the coal pot and even the gas stove... and I forgot the food tastes better as well when cooked with the stone stove."* (63-year-old female participant, Pediatorkope).

None of the households that took part in the study used electricity for cooking purposes. Some expressed a desire to be able to cook with electricity but mentioned

concern about an increase in their energy expenditure as the main reason for not doing so as illustrated in the quote below:

> "*...sometimes I wish I could use a rice cooker and a microwave oven like people in Accra and the mainland do but if I do that, I cannot pay the bill and also, I don't know if I can even use the electricity from the mini-grid for that."* (38-year-old female focus group participant, Pediatorkope).



A) Coal pot



B) Three-stone stove



C) LPG Stove

Figure 5.6: Pictures of the main cookstoves used by the respondents in the research area

5.2.2 Azizakpe Island

Azizakpe, unlike Pediatorkope island, there was no access to electricity for its inhabitants at the time of the research visits (05/2018 – 03/2020). The Ghana Ministry of Energy, however, had undertaken feasibility studies for the implementation of a

hybrid mini-grid project like that in Pediatorkope by the Government of Ghana with support from the Swiss Government. Though this project is yet to be rolled out, a solar home system (SHS) had been installed in the Chief's residence as a pilot, which according to the Chief, was primarily used to power lights, a radio and to charge mobile phones. As part of finding out the energy needs and use patterns among the respondents, questions were asked about the sources of energy for light (i.e., primary, and other sources). The data from the responses on primary energy sources for lighting on Azizakpe Island as presented in Figure 5.7 indicate that without access to electricity some 45.2% of the respondents used kerosene lanterns as their primary source of lighting, followed by 30.6% relying on battery-powered lamps and torchlights. Around 22.6% also relied on rechargeable lamps, which required electricity to charge or were solar rechargeable lamps. It is noteworthy that over 80% of the respondents in Azizakpe also had backup sources of lighting energy. The other sources of energy for lighting varied across households on the island, however, they mainly consisted of kerosene lanterns, candles, and battery-powered torchlights. Household appliances used by the participants mainly consisted of battery-powered radios for most of the households and some solar rechargeable ones. Some individuals (12) also had mobile phones, which they charged either on the mainland or Pediatorkope, as presented in Table 5.8 below.

Table 5.8: Appliances used by participants in Azizakpe

Appliance	**Number of participants who own it**
Battery operated radio	39
Mobile Phones	12

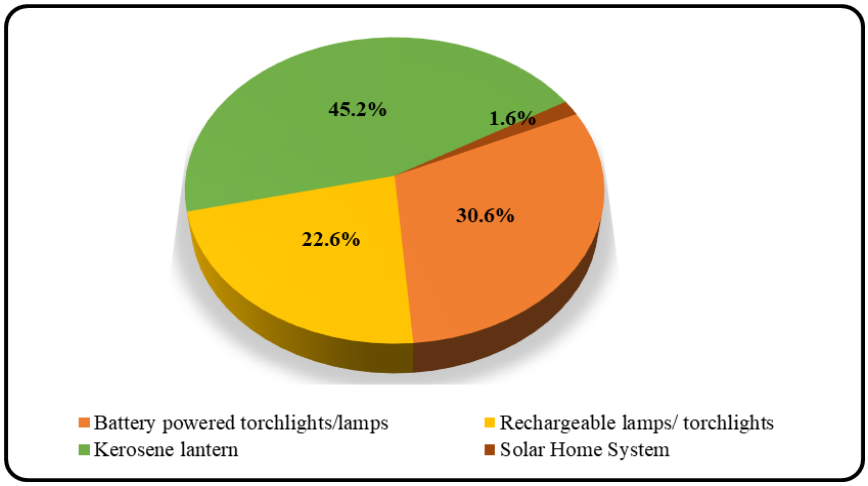


Figure 5.7: Primary energy sources for lighting in Azizakpe

Source: Fieldwork, 2018-2020

The data on fuel for cooking across the four islands showed that 77.4% of the respondents used three-stone stoves (fuelwood) as their preferred cookstoves, whereas 19.4 % and 3.23% preferred to use coal pots and LPG stoves respectively. Similar to the situation in Pediatorkope, about 87% of the respondents engaged in some stacking of cookstoves, except for the remaining 13% who had just one cookstove, comprising either three-stone stoves or coal-pots. One of the reasons the respondents, quoted below, gave for their choice of the cookstove includes the cost associated with cooking with modern cleaner fuels, i.e., LPG, compared to cheaper or free biomass. As echoed by Jewitt et al. (2020) and Dickinson et al. (2019), the cost associated with the initial setup, maintenance and fuel of improved cookstoves and LPG stoves encourages the stacking of stoves and fuel and possible backsliding to the reliance on biomass.

> *"…the three-stone stove cooks faster and is cheap, also it can cook a lot of food than the coal-pot. As for the LPG, it is good, but I don't have the money to buy the stove, the cylinder and be refilling it every time…"* (45-year-old female respondent, Azizakpe).

Another reason the respondents gave for their choice of biomass over other cleaner modern cooking fuels, quoted below, was how readily available the wood fuel (biomass) was and at no cost in comparison to the other cooking fuels where there was the cost to have the stove and regular fuel cost.

> *"…the wood for the three-stone stove is everywhere on the island but for the charcoal and LPG, you have to buy, and also you can only get it from Ada, mainland…"* (37-year-old male respondent, Azizakpe)

Though other respondents practised cookstoves and fuel stacking behaviour, they expressed a preference for cleaner stoves because of the ease of use and the convenience that comes with it. This is echoed by Gould and Urpelainen (2018) who find that in India, despite the practice of stacking behaviour people still preferred the use of modern cookstoves like LPG stoves because of their ease of use and convenience. Some of the responses in support of this are quoted below.

> *"I prefer using the coal-pot because it is easy to light and does not produce a lot of smoke like the three-stone stove. I still have the three-stone stove, but I don't use that much because the smoke makes my eyes hurt…"* (31-year-old female respondent, Azizakpe).

> *"...we use the LPG in my house because it is easy to use and does not make a mess, sometimes you just want to heat water but if you only have the three-stone stove or coal-pot, it is a lot of work lighting it just to heat water for instance"* (21-year-old male respondent, Azizakpe).

5.2.3 Aflive Island

The island of Aflive also has no electricity access for its inhabitants. It is one of the islands that are set to have mini-grids deployed as part of the Governments' electricity expansion through mini-grids. The data from the respondents as presented in Fig 5.8 show that concerning primary energy source for lighting, out of the 49 respondents in Aflive, 53.1% had kerosene lanterns as their main source of lighting, while some 30.6% and 12.2% relied on battery-powered torchlights, rechargeable lamps respectively. Two households (the Chief's residence and another household) representing 4.1%, used their installed solar home systems (SHSs) for lighting and sometimes charging their mobile phones. The users of the SHSs commented on the fact that the reliability of their systems was affected by the weather. On average, the fully charged batteries could provide them with electricity for about 10 hours. One such respondent in answering the question on reliability and variation is quoted as saying *"…the power of the solar is not so strong when it rains, or it is cloudy for many hours during the day."* (27-year-old male respondents, Aflive).

The reasons attributed to the various choices of lighting energy sources include the affordable nature, availability, and the convenience of the source in each respondent's perspective. In a similar fashion as with the other islands, most households had other sources of energy for lighting as backup sources. These backups varied and included candles, kerosene lanterns and torchlights. Battery-powered radio sets were noted to be the most common appliance in households on the island, although some inhabitants had mobile phones which they had charged on the mainland every couple of days.

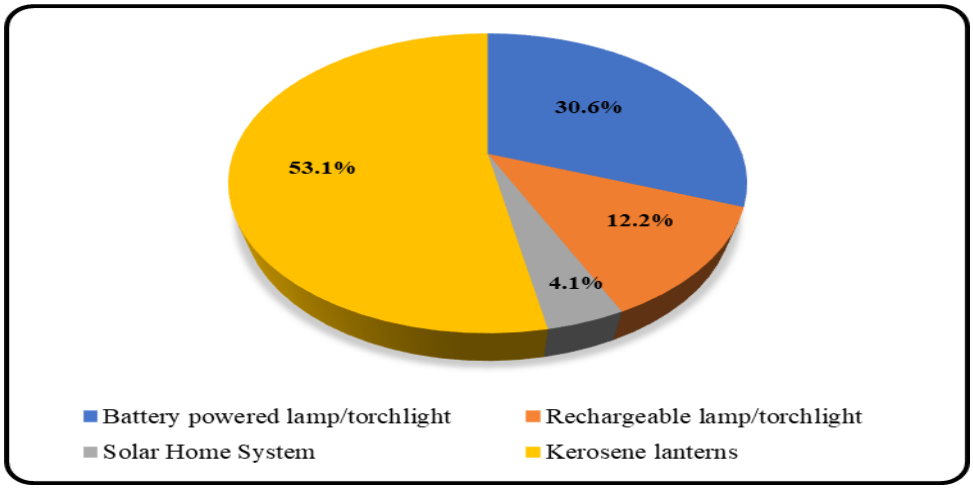


Figure 5.8: Primary Energy Source for Lighting in Aflive
Source: Fieldwork, 2018 - 2020

Cookstoves in use by households in Aflive were the same as those used on the other islands within the study area comprising mainly of three-stone stoves and charcoal coal pots. A majority of the 49 participants on the island (53.1%) responded that the three-stone stove was the main cookstove used in their households while the remaining 46.9% used coal pots as their main cookstoves. Several households were noted to have multiple cookstoves, however, in contrast to the trends on the other islands where most of the households used multiple cookstoves, about 61% of the households interviewed used only one cookstove, with 55% of that number only using the three-stone stove. Some of the responses to the query, quoted below, about the reasons underlying the choice of using one cookstove were the initial cost of the cleaner stoves and the convenience associated with their choice of stoves. As Dickinson et al. (2019) point out, the initial setup cost and fuel cost of cleaner stoves were a barrier to their adoption by households with lower incomes.

> *".. you see the three-stone stove can cook everything and the wood also cost nothing but with the coal-pot and gas, you have to spend a lot of money to buy*

them and the fuel which I don't have so I use just the three-stone stove…" (50-year-old female respondent, Aflive).

Another common reason that was cited to have influenced fuel and cookstove choice as evidenced in the quote below was the capability of the cookstove of choice to cook the quantity of food required and to the desired level.

"We are only 3 in my house, so the coal pot is able to cook for all of us, that's why we use only the coal-pot because we don't need the other ones like some of the other houses who are many" (43-year-old male respondent, Aflive).

5.2.4 Alorkpem Island

The situation in Alorkpem was like that in the other two unelectrified island communities discussed earlier. Except for three households that have SHSs to provide them with electricity access, the rest of the community is without access. The three households with electricity access were the residence of the Chief of the island and an electrician's house, both of which had solar home systems for powering lights, and the pastor of a local church who also had a solar home system which was used to power lights and household appliances like a TV set, radio, fan, and a sound system. As presented in Figure 5.9, out of the 42 respondents, the share of primary energy for lighting was 33.3% for kerosene lanterns, 21.4% for battery-powered lamps/ torchlights and 7.1% for solar home systems. Interestingly, 38.1% of respondents used rechargeable lamps/ torchlights. These lamps were powered by either electricity or solar but most of them were solar rechargeable lamps. This share of the source of energy for lighting had seen an increase from below 12% during the first visit to the island in December 2018 to 38.1% in February 2020. The adoption and use of solar

rechargeable lamps and torchlights on the island had been given a major boost by a private company which had sold various solar rechargeable products (lamps/ torchlights of various sizes) under a hire purchase scheme to the interested inhabitants of the island. The cost of the products, depending on the type, ranged between GH₵ 100.00 and GH₵ 200.00 (i.e., $ 15- $ 30). The beneficiaries made agreed weekly instalment payments until the cost of the lamps was fully paid.

In addition to the primary energy sources for lighting, most households had other sources of energy for lighting, which according to their responses were mainly kerosene lanterns, battery-powered torchlights/lamps, candles and in some cases petrol generators (The Chief's residence and 2 churches). Responses on household appliance use indicated the most common ones were radios, mobile phones and the households and churches that owned solar home systems and petrol generators had other appliances such as fans, a TV set, sound system and musical instruments that were powered by the electricity generated. Table 5.9 presents data on the appliances used by respondents in the Alorkpem community.

Table 5.9: Appliances used by participants in Alorkpem

Appliance	**Number of participants who own it**
Radio	24 (14 - battery powered)
Mobile Phones	8
TV	1
Soundsystem	1
Musical instruments	4

Source: Fieldwork, 2018 - 2020

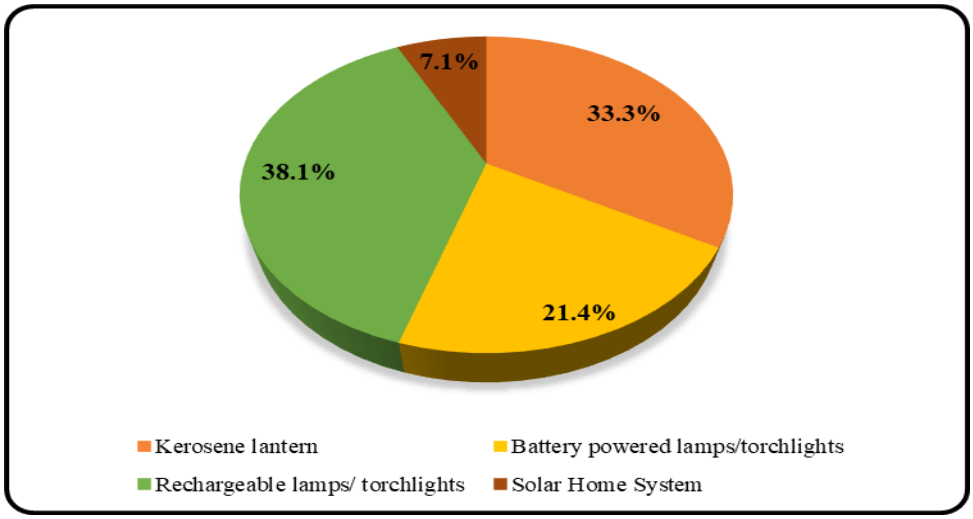


Figure 5.9: Primary energy for lighting in Alorkpem

Source: Fieldwork, 2018 - 2020

The choice of energy for cooking according to the responses was dependent on reasons such as affordability, availability, convenience, safety, ease of use, the quantity of food cooked and its suitability for cooking certain types of food. Safety concerns regarding possible explosions and burns with the use of LPG stoves have been noted by Abdulai et al. (2018), Asante et al., (2018) and Dalaba et al. (2018) to influence their adoption and use. As Stanistreet et al. (2019) also point out, households in choosing cookstoves consider factors such as ease of use of the stove, its ability to cook the quantity of food required and the level preferred. The data depicts that 63.4% of the respondents used three-stone stoves as their main cookstoves, some 34.1% and 2.4% (i.e., 1 household) also used charcoal coal-pots and LPG stoves respectively. Most of the households had multiple cookstoves with about 63.4% of the respondents owning and using more than 1 cookstove in their households, while the remaining 36.6% had just 1 cookstove in their household. The most common combination of cookstoves was the three-stone stoves and the charcoal coal pots. Queries regarding the reasons for the low patronage of LPG stoves as compared to the other islands brought to the fore safety concerns about their use. According to some of the respondents, quoted below, a faulty LPG

stove had caused a fire in the past and because the inhabitants had been put off patronising LPG stoves as.

> *"...you know some time ago, a house was burned down and the people in it got severely hurt due to a faulty LPG cylinder that had caught fire…because of that everyone is scared to use LPG on this island and no one even uses and LPG stove and cylinder."* (42-year-old female respondent, Alorkpem).

> *"...LPG stove is very dangerous, a small leak can cause a fire that will burn down the house and even kill you, we have seen that before…"* (29-year-old male respondent, Alorkpem).

5.3 Discussion

Discussions in the preceding sections have been based on the results from the fieldwork about the socio-economic and demographic characteristics as well as the energy use patterns of respondents and their households. The results indicate that a high percentage of the heads of households in the four island communities were male which is typical of rural Ghanaian households. Traditionally, men and males in Ghanaian households are the decision-makers and dominate decision making as Adjakloe *et al.* (2021) point out. Given that energy issues and use were classified as key issues, the majority (53%) of the respondents were male. There was a significant number of female participants (47%) which can be attributed to the fact that the research also queried energy sources for cooking and heating which are predominantly undertaken by females in rural households. It was observed that in a lot of instances, female household members offered for the males in their household to partake instead

of them, they only agreed to participate when the team explained their interest in their opinions on the subject matter.

The data indicated that about 97.9 % of respondents on the four islands had no education or were educated up to only high school level, which is likely to limit their prospects of landing high-earning jobs as education is known to affect income positively (Van Vu, 2020; Alves, 2012). The majority (49%) of these respondents were engaged in fishing-related and trading activities which yielded low earnings while some 18% were unemployed. The fishing practices in the island communities were mainly artisanal fishing and petty trading which usually yield very low income. With these low-earning jobs and livelihoods, household income is bound to be low which was the case across these islands relative to other towns which had more economic activities and thus higher-earning livelihoods. Individuals with high-earning jobs have more disposable income which they could then spend on getting access to modern energy services and fuels like solar rechargeable lamps, electricity from solar home systems and the mini-grid system and LPG, but that was not the case with individuals and households with low earnings.

Educational levels also influenced household sizes and income with families with higher education tending to usually have smaller families, while the less educated usually had large family sizes. The large household sizes, 75.7% with 5 or more household members were indicative of the low educational levels within the communities. The higher educational level also had an impact on energy preferences, consumption, and aspirations. That is to say, it had a positive impact on energy preferences and demand, mainly clean modern energy services and an increase in overall energy demand (Inglesi-Lotz and Morales, 2017). Household sizes also impacted the energy option that households were limited to. For instance, large

households usually need cookstoves that can cater for cooking in large quantities and from the results, most respondents from large households responded they used the three-stone stove for cooking because it was better and easy for cooking in large quantities. From the results, it was evident that education level had an impact on energy consumption and choices, as participants with higher educational levels had small household sizes and could be affordable to pay for electricity access and cleaner fuels for cooking and also attributable to their higher earnings.

Most of the households engaged in cookstove stacking where they had more than one cookstove which they used as and when the need arose. In instances where cooking was for a few people, either coal-pots or LPG stoves were used, and when cooking in large quantities, the three-stone stoves were used to reduce costs. The main reasons behind the stacking of stoves were to cater for the varying cooking needs and provide backup for instances where it was not practical to use a particular stove. One example mentioned was the inability to use wet fuelwood or biomass on rainy days, so respondents thus switched to the use of coal pot or an LPG stove as well as using the three-stone stove to cook in large quantities. Stove and fuel stacking is often associated with backsliding (reverting to the use of traditional solid fuels after transitions to cleaner and improved fuels and or a return to unimproved cooking practices). Likewise for cookstoves stacking, there is the tendency to backslide to the use of open and polluting stoves like the three-stone stove, and this results in continuous exposure to the household air pollution produced from the fuelwood or biomass burning and the health implications thereof (Jewitt et al., 2020; Dickinson et al., 2019; Piedrahita et al., 2016). When queried about the reasons for the cookstove or fuel backsliding, the reasons given included the fuel cost, cookstoves not being able to cook food as wanted and safety concerns (i.e., the explosion of LPG cylinders) These agreed with the

literature on the underlying reasons for fuel and cookstove stacking and backsliding behaviour (Jewitt et al., 2020; Ochieng et al., 2020; Dickinson et al., 2019; Piedrahita et al., 2016; Ruiz-Mercado and Masera, 2015).

5.4 Conclusion

The chapter has presented a discussion on the energy use patterns and some characteristics of the respondents and their households. These have shown that the four island communities are typical rural settings where poverty levels are high, inhabitants mostly have low educational levels and large household sizes. Discussions about how respondent characteristics influence energy use and choices were presented. The energy sources and uses across the four (4) island communities were also discussed. With the lack of electricity access in three of the study locations, most of the inhabitants were left with no choice but to rely on traditional solid fuel to satisfy their energy needs due to high poverty levels as these sources create high levels of household air pollution, their use is associated with health risks. The case of Alorkpem, where most households have purchased solar rechargeable lamps, indicates that with the right financing schemes the inhabitants will be willing to adopt modern energy technologies. Chapters 6 and 7 present detailed discussions of the energy uses within the islands of study.

CHAPTER SIX

FACTORS INFLUENCING ENERGY CHOICES AND THE UPTAKE OF RENEWABLE ENERGY (HYBRID MINI-GRIDS) FOR RURAL ELECTRIFICATION

6.0 Introduction

This chapter presents discussions on the key themes that emerged from the research. These themes were gender roles and energy decision making; intrahousehold energy priorities and responsibilities; determinants of energy choices; economic, technical, and political dimensions of rural modern energy access with particular emphasis on mini-grids for electrification of rural island communities. Section 6.1 discusses the socio-cultural themes of gender roles and energy decision making, intra-household energy priorities and responsibilities and energy choices. Discussions on the economic, technical, and political dimensions of modern energy access in the context of rural island communities are also presented in sections 6.2, 6.3 and 6.4 respectively. A conclusion of the chapter is presented in section 6.5.

6.1 Socio-Cultural Dimensions Of Energy Access

Energy choices of consumers across the globe are dependent on social, economic, technical, and other factors which influence how these consumers seek to meet their energy needs (Rahut et al., 2017; Jones et al., 2015). This study showed that the energy needs, choices, and willingness to adopt renewable energy technologies were influenced by various factors among them the socio-cultural dimensions of the

societies to which the end-users belong. In discussing the socio-cultural factors that influence household energy access and uptake of renewable energy technology, the key categories used by Quinn et al. (2018) are adopted to structure the themes that emerged from this research. Using these categories to structure the discussion also helped to determine if they agree with the themes that emerge on the factors that influence energy access in the research areas and the adoption of hybrid renewable energy mini grid and renewable energy technologies in general for rural electrification. The key categories related to socio-cultural dimensions of energy access set out in Quinn et al.'s (2018) model are "Factors Influencing Consumer Demand" and "User and Community Needs and Perceptions". Other categories set out in the model are "Enabling Environment"; "Industry Structure and Services"; "Energy Pricing and Costing" which are discussed in relation to Political dimensions; Technical dimensions and Economic dimensions of energy access and adoption of hybrid renewable energy mini grids respectively.

6.1.1 Gender Roles And Energy Decision Making

One of the key themes that run throughout the research and was noted to significantly influence energy choices and the adoption of renewable technology is the theme of gender roles and the impact on energy decision making in rural households and communities. In typical Ghanaian rural households, female members generally have responsibility for carrying out the domestic chores involving cleaning, cooking, and washing. The husbands and other male members on the other hand in most cases assume the role of breadwinners and heads of households. Males mostly engaged in household activities that involve manual lifting and "manly" activities in the household

whereas the females in the house provide care (Brown, 1996). According to Quaye et al. (2016), male dominance in decision making in households in Ghana especially in rural communities is a common occurrence. This dominance is attributed to the men in households usually being more educated than the women and being more economically empowered as compared to the women. They find that due to these advantages, men dominate the control of productive assets like agricultural land and involve women less in decision making processes on various issues. This dominance by the male household members tends to be seen in other spheres of Ghanaian society, household energy decision making inclusive.

As pointed out in discussions in section 2.8 and the literature on gender and decision making, men tend to dominate in decision making in rural households (Adjakloe et al., 2021; Quaye et al., 2016). Through the interviews conducted as part of the research, male household members were noted to be the key decision-makers for issues in the various households. As such for important decisions such as choosing energy sources for energy needs in households, most of the decision-makers were noted to be male. Even in instances where the male members were not the heads of the households, they were consulted to a certain extent before decision making. These observations are evident in the quotes presented below.

> *"...for the energy sources we use in the house because I am the one who pays for all of it, I decide on everything alone..."* (34-year-old male respondent, Azizakpe).

> *"My husband is the one who decides on the type of energy we use in our house… even for cooking, he decides the fuel we should use since he is the head of the household"* (30-year-old female respondent, Pediatorkope).

This is also evident from the data on the number of males and females who were responsible for making decisions regarding energy choices in their respective households as presented in Table 6.1 and Figure 6.1. The findings from the interviews showed that the majority, that is 71.7 % of the decision-makers for energy issues were male. Thus, males dominated energy decision making in most households across the research area. This finding that males dominate decision making, in this case energy decision making, was noted to be a common occurrence across the Ghanaian society especially in rural settings and not limited to the study areas of this research

This finding was noted to be in agreement with the findings of other research that had been carried out on gender roles and decision making in Ghana. Adjakloe et al. (2021), find out that male dominance in the energy decision-making process limited the involvement of women and the consideration of their opinions in decision making related to energy choices and uses. According to Quaye et al. (2016), the dominance of males in Ghanaian society is down to the socio-cultural practices and the higher level of education and economic empowerment they possess in comparison to females. Ayaa and Peprah (2021), also find out that with respect to investment and financial decision-making Ghana, males tend to dominate whiles females and women are less informed and involved in the process.

In some households across the research area, energy decisions were noted to be jointly made (both males and females) as evidenced by the response below. Respondents from households where energy decisions were jointly made constituted 19.7% of the total respondents for the research. In the households where energy decisions were jointly made, it allowed for the energy needs and concerns of both females and males in the households to be adequately factored into the decision-making process. A response pointing to the energy decision being made jointly is presented below:

"…when we want to choose the type of energy we will use, my husband discusses with me then we will decide together" (27-year-old female respondent, Aflive).

In other households, even though some form of joint decision making was carried out, it was dependent on the uses of energy or fuel. For instance, the woman of the household would decide on cooking fuels whereas the man decides on the other energy sources for the rest of the household. A response capturing this is provided below.

"I decide on the energy for the light and radio alone, but my wife is the one who chooses what she wants to use for cooking even though I pay for all of it…" (40-year-old male respondent, Alorkpem).

The respondents from households where females were the key decision-makers constituted 8.6% of the total number of respondents. Even in those instances, the female decision-makers in some way consulted the other household members before finalising their decisions. This is captured in one of the responses quoted below.

"…sometimes I decide on my own and in some cases, I speak to my children about it before I decide on what we should use…" (58-year-old female head of household, Pediatorkope).

Table 6.1: Energy Decision-Makers Across the Islands

Decision-makers	Pediatorkope		Azizakpe		Alorkpem		Aflive		Total	
	No.	%	No.	%	No.	%	No.	%	**No**	**%**
Females	7	15.6	8	12.9	1	2.4	1	2.0	**17**	**8.6**
Males	35	77.8	43	69.4	31	73.8	33	67.3	**142**	**71.7**
Joint	3	6.7	11	17.7	10	23.8	15	30.6	**39**	**19.7**
Total	**45**	**100**	**62**	**100**	**42**	**100**	**49**	**100**	**198**	**100**

Source: Fieldwork 2018/2019

When questions about gender and decision making related to energy choices and uses were posed to participants during the focus group discussions for women, some of the participants pointed out they would prefer joint decision making on issues in their households especially energy-related issues to ensure that their concerns and opinions were fully considered in energy-related decisions that were made at the household level as evidenced by the quote below.

> *"...sometimes it will be good if the men consulted us the women on some of the issues in the house, including energy issues so that we can all decide together..."* (36-year-old female focus group participant, Azizakpe).

The views of some male participants during their focus group discussions on decision making were different, a lot of the men felt they factored in the concerns of their wives when making decisions on energy choices and uses as captured by the quote below.

> *".. in my house, I decide alone, but I consider my wife's concerns because she tells me about the issues that bother her and all, so for instance when I am choosing the type of cooking fuel we should use in the house, I think about her concerns that she would have talked about in the past as well."* (40-year-old male focus group participant, Aflive).

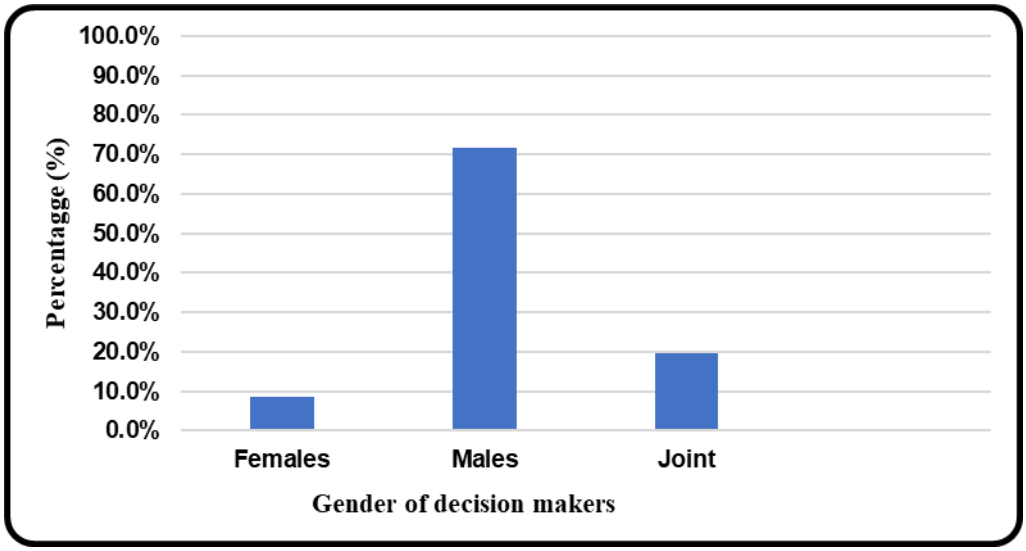


Figure 6.1: Percentage Share Of Energy Decision-Makers In The Research Communities

Source: Fieldwork, 2018/2019

The high number of male decision-makers in households in these rural communities was indicative that even though cooking and boiling were predominantly acknowledged as the role of women and females in the household a lot of male household members were also deciding on the sources of cooking fuels. These male members were deciding on energy for uses that they mostly were not directly involved in. As such, there was a high probability that the well-being and concerns of those directly using these energy sources may not have been prioritised in the decision-making process. For instance, a male head of household who made energy decisions alone may decide that a three-stone stove should be the main cookstove in the household, however, because he would not be the person collecting the fuelwood or doing the cooking, he therefore would not have first-hand experience of the challenges associated with collecting the fuelwood and using this stove to cook. That male head of household deciding on the energy source also is unlikely to be conversant with the time involved in searching for and gathering fuelwood which could have been put to some other meaningful use. Also, the male deciding on the energy source to be used

has limited involvement in cooking with the three-stone stove and will not be exposed consistently to the smoke and other particulate matter produced, and its knock-on negative long-term health implications.

Linking back to the logic model set out in section 2.7 as the conceptual framework for the research, gender roles and their influence in the decision making related to energy choices and uses fall under the user and community energy needs element. This has a significant influence on the household energy needs and not fully involving other household members in the decision process could result in their needs not being factored in the energy choices that are made.

6.1.2 Intrahousehold Energy Priorities and Needs

The discussion on gender roles and decision-making as presented in section 6.1.1 brought to the fore another key theme which is intrahousehold differences in energy priorities and responsibilities. These differences in energy needs, priorities and responsibilities of the various household members were noted to have significant influences on energy choices and use. As Johnson et al. (2019) elaborate, the provision of modern energy services impacts males and females differently and as such different household members would have different experiences i.e. their energy needs, aspirations and priorities.

The results of the research revealed that different household members had diverse energy needs and priorities across the entire study area. These needs and priorities were noted to vary based on factors such as age, educational level, and gender of the individual as well as their location and household income levels. Initial discussions about how these factors influence energy needs and use are presented in section 5.1.

Knowing and understanding the energy needs and priorities of various household members helps to make energy decisions that take into full account the varying energy requirements in households (Johnson et al., 2019). It was noted that younger people were more likely to prefer to have energy for lighting, charging a mobile phone and entertainment (radio/tv) as their top energy priorities as captured by the quote below.

> *"for me my energy priorities are energy for lighting, charging my mobile phone and power for the radio… and my wife wants to start a shop so we will need electricity for that too"* (30-year-old male participant, Pediatorkope).

Older females (mostly mothers and married women) were noted to prefer to have energy for cooking, lighting, and powering a refrigerator as their top energy priorities as indicated by the following quote.

> *"… as a woman, one of the important things I have to do is to make sure there is food for my family so that is my priority, as for the other things like the TV and my phone I like them, but they are not as important as the having fuel to cook and take care of my family"* (56-year-old female focus group participant, Pediatorkope).

For most older males, energy for lighting and for powering radio and tv sets were at the top of their energy priority list. The details of the diverse energy priorities are presented in Table 6.2 and Figure 6.2, and it can be noted that 85.9% of female respondents had cooking and food storage using refrigerators as their topmost energy priorities. In contrast to this, 87.7 % of male respondents had other energy needs such as lighting and entertainment (tv or radio) as their topmost energy priorities. In analysing these results, it is evident that if only the male household members were allowed to make decisions on energy sources and choices, given that they have different energy priorities from those of the other household members, the choices

made will most likely be biased towards their energy priorities and this reflects the issues with male dominance in household energy decision-making in general (Adjakloe et al., 2021; Shrestha et al., 2020; Permana et al., 2015).

Table 6.2: Gender-Based Energy Priority of Respondents

Groups	Pediatorkope (%)	Azizakpe (%)	Alorkpem (%)	Aflive (%)	Total
Females (cooking top priority)	72.7	82.1	94.4	95.8	85.9%
Males (cooking top priority)	26.1	8.8	4.2	12.0	12.3%
Females (other priorities)	27.3	17.9	4.5	4.2	14.1%
Males (other priorities)	73.9	91.2	95.8	88.0	87.7%

Source: Fieldwork, 2018/2019

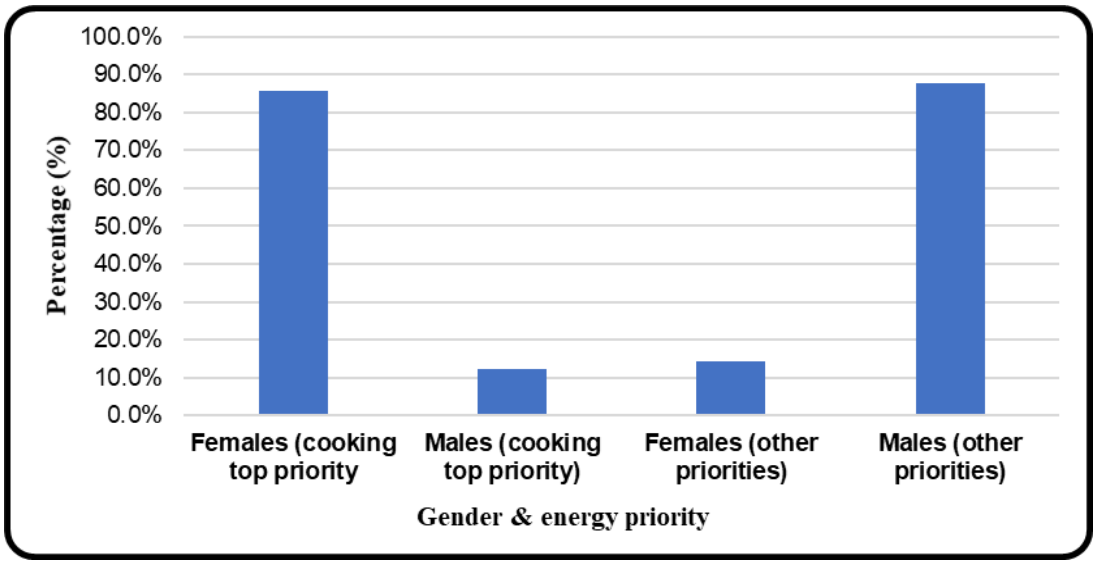


Figure 6.2: Gender-based energy priority of respondents

Source: Fieldwork, 2018/2019

Participants were queried about their energy priorities and those of other people within their households, specifically whether or not they thought their priorities were similar to those of others. Some participants indicated that they were of the view that their

energy needs and priorities were likely to be the same as those of their other household members as indicated by the quote below:

> *"…we all want electricity for light, tv and radio… and I'm sure everyone in my house likes the same things so they won't be different…"* (22-year-old male respondent, Azizakpe).

Other participants agreed that the energy needs, and priorities would be different because different household members used energy for different things as indicated by the following quotes.

> *"…our energy needs, and priorities cannot be the same because you know the women like to cook and watch tv but as a man, I prefer to listen to the radio and sometimes watch tv … and charging my mobile phone is also very important …"* (38-year-old male respondent, Pediatorkope).

> *"…the energy needs of various household members are definitely different, men, women, and children all use energy in different ways, so we cannot say that their needs and priorities are the same"* (40-year-old female respondent, Aflive).

The results from the surveys and interviews show a link between age and participants' energy priorities and aspirations. The majority of younger participants, aged below 32 years were noted to have as part of their priorities and aspirations energy for uses like lighting, entertainment, and communication such as powering TV and radio sets and charging mobile phones. This is indicated by the quotes below.

> *"…as a young person, I am conversant with technology so I would like electricity to charge my phone because it is linked to my work, also electricity to power a tv or radio so I can stay up to date with news in Ghana and the world. There are others but these are my top ones"* (26-year-old male participant, Azizakpe).

"I want to be able to charge and use my phone, to connect with others on social media and have light in the house…" (21-year-old female participant, Pediatorkope).

The older participants had other energy uses like electricity for lighting and other productive uses among their top energy priorities. Older women were noted to have energy for cooking, lighting, and the use of a refrigerator as part of their top energy priorities and aspirations. The older men mostly had energy for lighting, radio sets and cooking. For intrahousehold energy responsibilities, most men in male-headed households were noted to be predominately responsible for paying for household energy whereas females were mostly in charge of either purchasing or collecting the fuels that were used. The quotes below are indicative of these differences in energy responsibilities.

"…my husband is the one who decides on the energy that we use in the house, like for cooking and he pays for it; myself and the children either collect the wood or buy the charcoal that we use for cooking" (35-year-old female respondent, Pediatorkope).

The point elaborated here agreed with the discussions on gender roles presented in section 6.1.1. Relating the influence intrahousehold energy priorities and responsibilities has on energy choices to the framework set out in section 2.7, it falls under two elements in the model. Intrahousehold differences in energy priorities determine what the energy needs of a household would be therefore it is under the scope of the user and community needs. The energy needs and priorities of various household members are determinants of their energy demand, and as such can be classified as a factor that influences energy demand and is therefore placed under the factors influencing the demand element.

6.1.3 Household Size and Income Levels

Household size is a key determinant of household energy choices and consumption, as well as the adoption of renewable energy technology. The household sizes within the study area were noted to be influenced to some extent by factors such as educational level, household income, religious beliefs and other socio-cultural practices of that household as has been discussed earlier in Chapter 5. The choice of the type of energy sources in each household for meeting energy needs was to a high extent dependent on the number of household members. Larger households tend to use more energy to meet their needs in comparison to households with smaller sizes. In their findings, Pandey and Chaubal (2011) and Özcan et al. (2013) show that households with a larger number of members tend to prefer and use cheaper traditional solid energy sources which usually are not entirely clean energy sources. The data from this research aligns with their finding as it was noted that across all four (4) islands of the study area, most households (73%) with a high number of occupants (above 5 members) were most likely to use the three-stone stove and fuelwood as their preferred cooking stove and fuel respectively in contrast to households with a smaller number of occupants (between 1 – 5 household members) who preferred to use charcoal coal pots and LPG stoves for their cooking.

Likewise, with regards to energy for lighting purposes, in as much as the source of lighting to be used in a household was determined by the resource availability (i.e., whether there was electricity access or not), the choices were also noted to be influenced to some extent by the size of the household. Thus, smaller households in the unelectrified communities were most likely to invest in the purchase of solar rechargeable lamps when they could afford it, whereas, in larger households, the use of solar lamps benefitted only a small portion of the household since they could only

afford to buy 1 or 2. Thus, in larger households it was not viewed as a "good investment" even if they could afford to procure it rather they preferred to spend less on lighting sources like kerosene lanterns, which were cheaper, and every household member could have one to themselves for their lighting needs. The responses of some respondents presented below were indicative of the fact that investing in solar lamps limited the number that could be acquired and would benefit only a few of the household members but with kerosene lanterns, they could afford to provide for each household member.

> *"…the cost of the solar lamp is high and, in my house, all eight (8) of us can't use it in the evening at the same time but that money for the solar lamp can also be used to buy maybe 4 or 5 kerosene lanterns and also buy kerosene so that everyone will have light in their room in the night..."* (45-year-old male respondent, Azizakpe).

> *"As for the solar lamps they cost about 150 Ghana cedis but when you buy them not everyone in my house can use them at night for light and you will still have to use another light"* (27-year-old female respondent, Aflive).

On the Pediatorkope island, which had electricity access, the cost of electricity access increased with increasing household size, as higher household size meant high electricity use and thus increased cost. This is evident from the quote of a response presented below.

> *"...you see there is light on this island, but I don't have enough money to bring it to my house, I have to pay the connection fee and then every month pay the light bill. We are six (6) people in my house…, if I connect the electricity and pay the bill, the small money I get from my fishing to feed my family will not be*

enough…., that is why the government should help those of us who are poor…" *(*48-year-old male respondent, Pediatorkope).

The results also pointed to the fact large household sizes meant that less disposable income was available to households and as such they were less likely to be able to afford and commit to investing in modern energy services such as solar home systems or even solar rechargeable lamps. Larger households with less disposable income mostly relied on traditional solid energy sources for their energy needs, which have been shown from extensive research to have health implications in the long term. The results on the effect of household size on income level agree with the findings of Meyer and Nishimwe-Niyimbanira (2016) in South Africa, which points to the fact that larger household sizes had low-income levels and usually their income levels were noted to be below the poverty line. With reference to the logical framework set out in section 2,7. household income and size were noted to be key determinants of energy demand in agreement with the argument by Meyer and Nishimwe-Niyimbanira (2016) and is therefore considered to be a factor that influences energy demand in the conceptual framework.

These findings point to the significance of the socio-cultural dimensions of energy access. Socio-cultural aspects of society such as gender roles, intrahousehold priorities and aspirations as well as household income and size have been shown to impact how households decide on energy. These findings are not limited to the research locations and equally agree with the findings of other researchers in the same light in the broader global south context such as Adjakloe et al., (2021) (gender roles); Johnson et al., (2019) (intrahousehold energy needs); Meyer and Nishimwe-Niyimbanira, (2016) (household size).

6.2 Economic Dimension of Energy Access

An in-depth analysis of the economic and demographic characteristics of the participants in both the electrified and unelectrified communities indicates that the economic status of the various households influenced the energy needs and aspirations as well as the choices that were made to meet those energy needs and aspirations. The energy sources chosen to meet needs, and households' ability and willingness to adopt renewable energy technology such as the connection to the solar PV hybrid mini-grid or the purchase of a solar home system or a solar rechargeable lamp, were dependent on the prevailing economic circumstances of the households. The factors that were prominent from the survey and interviews included household income; access to credit facilities; the cost of installation or setup as well as operational and maintenance costs associated with the renewable energy technology of choice.

Household income is a vital determinant of the type of energy choices that were made in every household across the study area. Middle-income households, who also had high levels of education, secured jobs and earned a regular source of income (salary) were noted to have invested in gaining electricity access and various household appliances in Pediatorkope. In the case of the unelectrified islands, middle-income households were more willing to invest in electricity access and cleaner cooking fuels. Other households with less-educated members, lower and irregular income sources, on the other hand, were noted to be less likely to commit to spending high amounts beyond their means to meet their energy needs. This group expressed satisfaction with being able to meet their needs with traditional solid fuels. Thus, there was less likelihood of them investing in energy technology which was perceived to be costly and as such would use up a large proportion of their already meagre income. It was obvious therefore that to be able to invest in modern energy services to meet

households' needs, the availability of adequate disposable income to cater for the associated cost of setup or tariffs where applicable was necessary. In Pediatorkope where electricity access by the hybrid renewable energy mini-grid was readily available, households not connected to the mini-grid were noted to be mostly households with low and irregular income. This was mainly due to the inability of those households to raise the installation/connection fee and the tariff that had to be paid for the electricity used. Many of the households connected to the Pediatorkope mini-grid system were in a financial position to pay the installation fees and had regular incomes that allowed them to pay the electricity bill or received remittances such that they could pay for the tariff they were charged. The household income data from Pediatorkope showed that most of the beneficiaries of the mini-grid had higher income levels than those who were not connected, and the households connected were able to afford to buy more "luxury" household appliances than their counterparts who could not afford to pay to be connected to the mini-grid. When the respondents were asked about the equality of electricity access in Pediatorkope, about 60% of the respondents agreed that despite the availability of electricity, access was not equal as some of the households were not connected to the mini-grid due to their low-income levels even though they would have loved to enjoy the benefits of having electricity access. Responses from some participants in Pediatorkope who did not have access to electricity due to their inability to pay the initial setup fee and tariff are presented below:

> *"…when they did the solar, I didn't sign up because connecting to the solar is expensive and my income cannot pay for that"* (53-year-old male respondent, Pediatorkope).

Other participants pointed out that electricity access and the use of other modern non-solid fuels were expensive and would exhaust a larger proportion of their household incomes essentially making them energy poor. Thus, they resorted to alternative cheaper and less clean energy sources for their needs as captured in the quote presented below.

> *"…we would like to have electricity in our house too, but the cost is too much, the kerosene lantern that we use is cheaper, meanwhile the electricity from the mini-grid is expensive and that would use up all the little money that I get from my work"* (33-year-old female respondent, Pediatorkope).

Other respondents who had electricity access, acknowledged that despite the benefits of having electricity to meet their energy needs, it required a substantial and regular income to enable a household to connect and pay the tariff for the electricity used regularly. About 40% of the participants in Pediatorkope pointed out that electricity access within their community is not equal because the income levels prevented a lot of households from accessing electricity even though they would have preferred to have access. The quote below illustrates the point of unequal access.

> *"…the electricity from the solar system is cleaner than the kerosene lanterns which we used to use before, it allows us to watch tv, use the radio and charge our mobile phones unlike in the past when we had to go all the way to the mainland to charge our phones…I understand that it is not everyone that can afford to connect because of the money you have to pay…. some people cannot connect because of the money you have to pay, I think that based on that the access is not equal"* (39-year-old male respondent, Pediatorkope).

Participants also confirmed that their energy use was dependent on the tariff band that they signed up for and that was tied to their income levels given that with lower household income, they could only afford to pay for electricity access for limited uses as captured by the quote below.

> *"…I use my solar electricity for light and to charge my mobile phone, others have the type that they can use to watch tv but the price for that was too high for me…"*[7] (47-year-old male respondent, Pediatorkope).

On the islands of Aflive, Azizakpe and Alorkpem, it was clear that the households that had installed solar home systems had income levels higher than the average household income levels within their communities. There were other households, however, that had income levels higher than the average household income but had not invested in solar home systems. They were hopeful that the government would soon proceed with its plan of providing them with electricity access through the development of renewable energy mini-grid systems on their respective islands just as had been implemented in Pediatorkope. A response illustrating this point is quoted below.

> *"…I will hold on with buying a solar system, for now, I am sure in some months or a year from now the government will install a system like the one in Pediatorkope, then we can all get electricity from it, that will be cheaper…. The government officials were here a while back to speak to us about the project, so we are waiting for them…*" (32-year-old male focus group participant, Azizakpe).

Another respondent pointed out that even though they could afford to buy a small-sized solar home system, they would rather wait to connect to a mini-grid when it has

[7] Referring to the different tariff bands operated for the Pediatorkope mini-grid system

been implemented to save them any operational and maintenance costs as opposed to owning a solar home system.

> *"I have checked the price of a solar system before and I can save to buy it, but I have to also pay for any repairs of the system but when the government implements the mini-grid, any repairs on that are paid for by the government and I only pay for the electricity I use… so that is cheaper"* (Male participant, Aflive).

Household income levels were noted to impact the choice and use of other clean fuels like LPG for cooking and solar rechargeable lamps as well as solar home systems for lighting. Participants on the unelectrified islands further expressed their opinion on the fact that income status impacted their energy choices and willingness to sign up for electricity access and other modern energy services. Key issues raised included the fact that households needed a certain amount of money to be able to sign up and adopt modern energy services such as electricity and LPG. This agreed with the energy ladder concept in that households are only able to transition to modern energy sources (electricity and LPG) with an improvement in economic status. With improved economic status households can move from the use of traditional solid fuels (biomass) to cleaner non-solid fuels (LPG and electricity) (Poddar et al., 2021; Perez and Zepeda, 2016; Sovacool, 2014b). Thus, with lower household income, it is near impossible for households to invest in cleaner energy sources and move up the energy ladder. Responses illustrating these are quoted below.

> *"… I hear you need about 10,000 Ghana cedis if you want to have the small solar system in your house, there is no way my husband can afford that… I hope that the government will soon come and implement a mini-grid like the*

Pediatorkope one that we can all afford." (26-year-old female respondent, Aflive).

"…the solar home system is good and useful but the money that you need to pay to install it is very high for some of us to afford…" (40-year-old male respondent, Azizakpe).

For cooking fuels, some participants indicated they preferred to use the cheap readily available alternative of biomass (fuelwood, coconut husk) compared to LPG which had an expensive setup kit and required regular refilling to use as the quote below expresses.

"…we prefer to use the three stone stoves because the wood is easy to get and you don't spend so much money….as for the LPG, it is expensive and refilling it when it's finished is stressful" (36-year-old female respondent, Azizakpe)

A response from a participant who had benefited from a discounted solar home system pointed out that even with the discount he had received, the amount he paid was still high for most households in the community to be able to afford to invest in it.

"…the solar system that I have in my house is supported by an NGO, I paid part of it so that they will install it for me… about 4,800 Ghana cedis…. with the money involved I agree that very few people and households can afford to get it on this island and other islands" (52-year-old male respondent, Alorkpem).

Several respondents expressed interest in investing in renewable energy technology for lighting and electricity access if appropriate pricing mechanisms and credit facilities were made available to them. An example is when several households in Alorkpem (an un-electrified island) purchased solar rechargeable lamps through a hire purchase scheme offered to them by a private company that engaged in the importation

and sale of solar rechargeable lamps and similar products in Ghana. The company visited the island with their products, mainly solar rechargeable lamps, and marketed them to the local population. They pointed out the benefits of investing in their products as opposed to the use of kerosene lanterns and also offered flexible payment terms through their hire-purchase scheme.

The cost of these lamps ranged between GHC (Ghanaian cedis) 100 and GHC 200 ($ 15 – 30) dependent on the type of product purchased. As per the terms of the hire purchase agreement, flexible weekly instalment payments were made by the beneficiaries until the cost of the products was fully covered. This credit facility made it possible for the beneficiary households to invest in renewable energy sources for lighting (i.e., solar rechargeable lamps) over a period instead of having to pay the full cost upfront. The availability of appropriate credit facilities and subsidies on modern energy technology has been shown to impact how poor households decide on the type of energy sources or technology to meet their energy needs (Zerriffi, 2011). Thus, the active participation of the residents of Alorkpem in the hire-purchase scheme for the solar rechargeable lamps showed that with the availability of appropriate financing and credit facilities to rural households, they are willing to invest in modern energy services as captured by the quote below.

> "…w*hen the company representative presented the solar rechargeable lamps to us I liked them but my problem was the cost, I wondered how I could come up with the 200 Ghana cedis to pay for 1 or even 2… but then they explained that we can pay for it in small amounts every week, maybe 10 Ghana cedis every week and as for that I can try and pay so I bought it…"* (45-year-old female participant, Alorkpem).

The potential economic benefits of investing in an energy source and technologies also determine the extent to which beneficiaries are willing to go to access those benefits. Some respondents were willing to take loans to invest in solar home systems or connect to the mini-grid (when implemented) if they were sure that they could utilise the electricity available for profitable business ventures such as purchasing a freezer to boost their businesses as well as preserve and sell their fish catch.

> *"when they completed the solar mini-grid and told us how much it will cost to connect and the average tariff to use it, I thought of buying a freezer which will help me to store and sell a lot more things in my shop. I decided to take a loan from the microfinance company in Kasseh to be able to connect to the mini-grid and buy a freezer for my shop… it has helped to increase my sales…"* (32-year-old female participant, Pediatorkope).

Households' willingness to adopt and use renewable and modern energy technologies and fuels to meet their energy needs is therefore to a great extent influenced by their awareness and understanding of these technologies and the potential benefits they stand to derive from their usage. As Adjakloe et al. (2020) point out, awareness of the benefits derived from access to modern energy services and renewable energy technology significantly influences the willingness of households to adopt and invest in these modern and renewable energy technologies.

It is evident from the preceding discussions on the economic dimensions of energy access in communities that economic status has a significant impact on access to electricity through the solar PV hybrid mini-grid system and other modern energy services. Factors such as the high investments required for the uptake and use of modern energy technologies and fuels in comparison to cheaper or free alternative energy sources and fuels; the high initial setup cost and the regular ongoing cost of

fuel purchase and tariffs; and the potential benefits to be derived influence whether rural households would be able to invest part of their income to transition to the use of modern non-solid energy sources. These economic dimensions of access were common in most rural and remote locations where income levels tend to be low. These factors are congruent with the factors covered under the "Energy Pricing and Costing" category in the framework i.e., cost of alternative energy fuels; start-up and ongoing cost; and potential co-benefits as presented by both Quinn et al. (2018) and Stanistreet et al. (2019). In continuing with the development of the model as Stanistreet et al. (2019) did and by applying the model to the use of solar PV hybrid mini-grids for the electrification of rural islands, this research suggests some additional adaptations to the "Energy Pricing and Costing" category of the model. This research suggests the inclusion of "Financing and credit options" as a factor in that category as with the availability of appropriate financing and credit options, consumers were willing to adopt renewable energy technologies. It is also suggested that the category is renamed to "Energy Pricing and Financing" to reflect the financing aspect instead of the "Energy Pricing and Costing" originally used.

From the interactions with institutional stakeholders that operate in the renewable energy sector, it was noted that the cost associated with the importation of equipment and setup had an impact on the number of people who are willing to sign up for their products and services. This is captured in the quote presented below:

> "… *when the cost of importing our equipment and installation is high, we have no choice but to pass it on to the customer, since we began our operations about 3 years ago, we have noted that it is the cost that hinders some of our customers from signing up for our services*" (Renewable energy professional, Kumasi).

Some of the institutional respondents pointed to the fact that their respective companies had some financing schemes in place for their customers who were willing to use their services but needed flexible payment methods. This is captured in the quote below:

> "*...not all of our customers are able to afford our products, so we have come up with flexible payment schemes which allow them enough time to pay for the products they are interested in and without straining their finances*" (Renewable energy professional, Accra)

6.3 Technical Dimensions of Energy Access

Throughout the research, some technical issues regarding renewable energy technology especially solar PV that was raised as influencing their uptake were noted as the "complexity" of renewable energy technologies, variability in the supply, and the required technical knowledge to install and maintain them. These technical issues/factors were noted to have come up as influencing the adoption and uptake of renewable energy technologies for electricity access in the study areas as well as the country from the perspective of both industry professionals and end-users. Given the high illiteracy rate and low educational levels of inhabitants of the research areas, the perception that renewable energy technology was complex among most participants was not surprising. However, it is unfortunate that this influences some households not to adopt these modern energy technologies even though they were affordable. For instance, a respondent was of the view that products like solar rechargeable lamps were very expensive and not durable as captured by the quote below.

> *"... some people have solar charging lamps which they paid a lot of money for, about 150 Ghana cedis, but I have heard that they only last for a few months then they get damaged…that is what I heard"* (39-year-old male focus group, Aflive).

After explaining the hire purchase scheme that had been introduced to the residents of Alorkpem, they realised they could afford it and that the instalment payments made it easier to cover the cost. Another significant issue is that of insufficient numbers of technical professionals with the required technical knowledge to set up, maintain and repair renewable energy technology, especially solar PV systems. This according to information gathered from the interviews with professionals working within the renewable energy space limits how much work they can carry out, their coverage and their ability to provide the required after-sales and maintenance servicing of their clients.

> *"…we currently have a few technicians and that has limited our coverage at the moment to Accra and a few other regional capitals and, remember we also have to be able to maintain the systems we install for our clients…"* (Renewable energy professional, Accra).

The limited number of professionals with the appropriate level of knowledge in these technologies is usually restricted to the urban areas, most of whom are unwilling to work in rural communities. The advancing trends of the technologies also make it such that repair works in the event of breakdowns are limited to a few technical professionals who are versed in these technologies whereas several other technicians who may be able to undertake installations and general maintenance are unable to carry out any repair work when need be. It was pointed out that the use of unqualified

professionals for the installation, maintenance and repair work in renewable energy technologies had the potential to compromise the quality standards of installations. This is illustrated by the quote below.

> *"…. technology is always evolving, and the renewable energy technologies are no exception, this is a good thing because it makes the systems efficient but also it creates a small challenge for us when it comes to the repair and maintenance of the systems that we install for customers. Not all the staff are conversant with the advancing technologies so only a few of them can actually carry out the repair works. Our company always ensures that our staff are always qualified for the type of work they that is why we are continuously training other staff to be able to conduct repairs on installed systems"* (Renewable energy professional, Accra).

This agreed with Akinyele et al.'s (2018) point on the importance of using qualified renewable energy professionals and contractors for installations, especially for decentralised grids, to avoid expensive system failures and damage to property in the long term. Another technical issue that kept coming up during the research was the variations in electricity supply in Pediatorkope from the solar PV hybrid mini-grid systems. About 72% of the respondents reported variations in their supply within 7 days prior to partaking in the research interviews. Most participants reported variations in their supply, electricity going off, which usually happened on cloudy or rainy days with some participants even reporting they had to turn off their appliances to avoid any damage to them. However, they also reported that on sunny days there were fewer or no outages at all.

"The power goes off for some time on the days that it rains, or it is very cloudy. If I can remember correctly, in the past week it went off on two days… for less than 1 hour but I do not know why, but it happens sometimes" (Female respondent, Pediatorkope).

Industry participants pointed out that access to and the availability of the latest renewable energy technologies, parts and specialised equipment were vital to the successful installation of efficient energy generation systems for customers. The absence of local manufacturing options meant that companies had to always rely on imported equipment and parts to be able to provide services and carry out repair work. Some of these imports attracted high import duties that to a large extent increased their operational cost and the consequent high cost for the end-users (Nepal, 2012; Reddy and Painuly, 2004). This argument is in agreement with discussions presented in section 2.15.1 and a response from one of the interviews quoted below illustrates this point.

"I would say 90% of the components for our renewable energy installations, either solar home systems or mini-grid, are imported and these take time to arrive in the country and the added cost means that customers have to pay more. If we could produce the parts locally, the cost will be less, and our turnover time would also be quicker…" (Renewable energy professional, Kumasi).

This was congruent with similar findings by Shukla et al. (2017) and Azimoh et al. (2017). Shukla et al. (2017) find that the availability and access to locally manufactured components and equipment help to boost the scale-up of renewable energy technologies in their research on renewable energy in South Asian countries. Azimoh et al. (2017) also find in South Africa that the supply deficit of spare parts and

components posed a huge challenge to the sustainability of the hybrid mini-grid system implemented in Tsumkwe, South Africa.

Another issue cited by the industry participants as a hindrance to the successful operation of the renewable energy sector in Ghana was the use of substandard parts and materials for installations. They explained that this was due to the high setup cost of renewable energy systems and mini-grids especially for good quality materials, as some practitioners in a bid to reduce their operational cost, resorted to cheap substandard components. These cheaper and substandard components and materials were noted to compromise the quality and durability of the installations and in the long run, result in breakdowns or failures. One of the responses illustrating this point is the quote below.

> *"the components we used for our work are expensive, but some practitioners try to use cheaper substandard materials for their work to reduce their cost. By using substandard materials, they reduce the quality and some of these systems have been known to cause major problems which to some extent impacts the reputation of renewable energy technologies and people's willingness to adopt them"* (Renewable energy practitioner, Accra).

The technical aspects of modern energy access using renewable energy, especially through solar PV hybrid mini-grids were noted to align with the factors covered under the "Industry Structure and Services" category in the Quinn et al model for scale-up of clean household energy for cooking. This research suggests the addition of "Competence of Practitioners" to the "Industry Structure and Services" category in the adapted version of the model for hybrid mini-grid systems as presented in Figure 7.1 This is an important factor given that the qualification of practitioners was noted to have a significant impact on the successful implementation of mini-grids and

renewable energy technologies as a whole. The findings regarding the technical dimensions of hybrid mini-grid adoption discussed in this section were noted to be in line with the arguments presented by Akinyele et al. (2018) on the influence of technical factors on the successful implementation of microgrids in Nigeria. These technical dimensions were also noted to be applicable to the adoption of other modern energy services in a lot of rural areas. They were not limited to the study locations as pointed out by the industry professionals who were interviewed as part of the research.

6.4 Political Dimensions of Energy Access

Politics plays a significant role in the adoption and uptake of renewable energy technologies. As Urmee and Md, (2016) argue the commitment of government is critical for the growth of the renewable energy industry, especially for the provision of modern energy access to rural and remote locations. They elaborate that the institution of transparent and comprehensive national policies on renewable energy for rural electrification promotes the growth of the market and serves and incentivises private entities to invest in the sector. Interactions with the renewable energy industry stakeholders revealed that the Ghanaian government had made various policy commitments as well as set in motion plans and targets for renewable energy development across the country. This has made it attractive for private companies to invest in the renewable energy industry to facilitate its growth. Some of the policies that have been introduced that are on par with existing policies around the world include net-metering; feed-in-tariff for electricity from renewable energy sources; and the guidelines for the Renewable Energy Purchase Obligation (REPO). Responses elaborating on these supportive policies from the government are quoted below.

"The government is doing a good job by indicating to various stakeholders especially investors and private companies that it is committed to the development of the country's renewable energy sector and prepared to make the sector profitable for them to invest…It started with the passing of the Renewable Energy Act in parliament in 2011 and since then there have been other policies the most recent one is the renewable energy master plan. I hope it does not end there but they continue to provide support to the sector" (Renewable energy sector practitioner, Accra)

"Government's policy is gradually attracting investment in the sector, the renewable energy master plan, for instance, has in place various measures to ensure that the sector remains profitable for investors, the introduction of feed-in-tariffs the renewable energy purchase obligation ensure that when we invest in renewable energy generation, we can at least recover our investments" (Renewable energy sector practitioner, Accra).

The interactions also revealed that licensing regulations had also been introduced to deal with technical challenges such as the use of sub-standard material and unqualified personnel as discussed in section 6.3. These regulations sought to ensure that the use of sub-standard materials and parts was minimised, and practitioners were appropriately licensed for the types of jobs they carried out. The challenge with effectively regulating the sector to avoid the challenges with sub-standard materials and unqualified practitioners was the limited enforcement capability of the regulatory agencies mainly the Energy Commission. With respect to the importation of sub-standard materials, it was revealed that the enforcement of the regulations on the standards for renewable energy technology materials and parts was non-existent at the

country's ports. This resulted in numerous cheap and sub-standard materials ending up in the country. The quote below captures this argument.

> *"…. government has put in place regulations to deal with the issue of unqualified people and the importation of cheap and sub-standard materials like inverters and solar PV modules, but they don't enforce it at the ports, so the substandard materials still come in causing many problems after they have been used installations"* (Renewable energy sector practitioner, Accra).

The availability of financial support from the government was revealed during the interactions with the industry stakeholders to have the potential to attract investment, boost the development of renewable energy in Ghana and reduced the cost passed on to end-users. Government fiscal support could be in the form of the removal of excise duty on imported materials, subsidies for rural communities benefiting from mini-grids and renewable energy technologies as a whole and tax waivers for renewable energy companies. It was pointed out that the financial incentive from the government at the time of the interviews was not comprehensive enough and needed to be amended. This is captured in the response quoted below

> *"…it's confusing sometimes, when you import a complete solar home system you have the import duty waived but when you import an inverter or other individual components you must pay import duty on those. Surprising and confusing because something like the inverter can only be used for electricity generation so why charge import duty on it. Government has to address those issues"* (Renewable energy sector practitioner, Accra).

Some renewable energy industry participants also pointed out that the financial support could also incentivise companies to explore local manufacturing of parts. The

government could also support companies through partnerships to get into the manufacturing of components for renewable energy technologies.

> *"If the government will be willing to partner with the private sector or provide financial support to companies, it will attract investment into the establishment of manufacturing facilities to produce the parts and components needed locally and in the long term boost the growth of the industry"* (Renewable energy sector practitioner, Accra).

The interactions with the industry stakeholders also revealed that the kind of political statements that are made about renewable energy technologies, especially solar PV and mini-grids directly or indirectly promoted or hindered the adoption and development of renewable energy technologies across the country. In instances where politicians have made election promises of providing un-electrified communities with electricity access via the grid, it has led to the residents losing interest in the adoption and uptake of renewable energy technologies for electricity generation. However, in most cases, these promises end up not being fulfilled and the poor rural residents are left with no electricity even though they could have signed up for appropriate schemes to gain electricity access using renewable energy technology or even purchased renewable energy products like solar rechargeable lamps that would better their lives. In other instances, while some politicians canvas for votes through the promotion of renewable energy technology through the donation of products like solar rechargeable lamps for their constituents, others promise grid connectivity and discredit the benefits of off-grid connectivity using renewable energy. This, therefore, dissuades some rural inhabitants from investing in renewable energy to improve their lives. The above-discussed political factors aligned with the factors captured under the "Enabling Environment" category in the models presented by both Quinn et al. (2018) and

Stanistreet et al. (2019) as key factors that can promote or hinder clean fuel scale up. The political factors that have been shown to influence the uptake of renewable energy (hybrid mini-grids) were also congruent with the findings of Akinyele et al. (2018) on the policy and political factors that influence the sustainable implementation of microgrids. These political factors that influence energy access were not limited to the research locations but were also noted to be relevant to energy access in the many rural and remote communities across Ghana and the Global South in general.

6.5 Conclusion

The chapter sought to discuss the factors that influence the energy decisions, adoption and uptake of renewable energy technology with an emphasis on hybrid mini-grids within the study areas. The discussions were mainly based on the household survey data and the transcriptions from interviews with the various household participants and institutional stakeholders. The chapter discussed the socio-cultural and behavioural dimensions of rural energy choices and decisions focusing on household size and socioeconomics, gender and decision making and energy priorities and the influence on energy choices and the adoption of renewable energy technology involved more than just the availability of the energy resource or technology. The various themes were related to the conceptual framework to see how it related to and the adaptions necessary were suggested. Other factors such as technical, economic, and political and their influence on energy decision making and uptake of renewable energy technology were discussed.

CHAPTER SEVEN

IMPACT OF SOCIO-CULTURAL AND ECONOMIC FACTORS ON THE FEASIBILITY OF MINI-GRID IMPLEMENTATION FOR RURAL ELECTRIFICATION

7.0 Introduction

This chapter analyses the influence of the socio-cultural and economic factors identified earlier in Chapter Six on the perception, choice, adoption, and use of renewable energy mini-grids as well as on life in the study island communities and remote locations in general. The chapter makes use of the data gathered from the household surveys and the household interviews as well as the interviews with institutional stakeholders. Section 7.1 discusses the impact the implementation of the solar PV hybrid mini-grid system in Pediatorkope has made on the community. It discusses three key areas: impacts on household activities, communal services, and economic activities. In section 7.2, the seasonal variations in electricity from renewable energy sources are examined from the perspective of participants in Pediatorkope (electrified community) and other participants that had access to solar home systems in the other study island communities. The perceptions of participants on renewable energy and mini-grid implementation for rural electrification are explored in section 7.3. Section 7.4 examines the extent to which the socio-cultural and economic factors identified in chapter six influences electricity access and uptake of renewable energy technology. Section 7.5 presents a conclusion to the chapter.

7.1 Impact of the Mini-grids in the Electrified Community (Pediatorkope)

Interactions with participants and industry professionals helped to understand the various ways in which electricity access has impacted and benefitted the electrified island of Pediatorkope. The hybrid mini-grid system in Pediatorkope consists of a solar PV plant with a capacity of 39 kWp, an 11kW wind turbine and a backup diesel generator plant for supplying all connected households on the island with electricity. These impacts are examined according to various activities such as household activities, agricultural activities, social and communal services, and religious activities.

7.1.1 Household Activities

The main household uses of electricity derived from the solar PV hybrid mini-grid system on Pediatorkope island were noted to be for lighting and entertainment purposes. The finding on the uses of electricity point to lighting as the main followed by entertainment as depicted in Table 7.1.

7.1.1.1 Lighting

All the participants who had access to electricity mentioned lighting as one of the major uses of their electricity access with 96% of the 45 respondents using their electricity access for lighting as depicted in Table 7.1. The improved lighting has also brought about a significant reduction in accidents in households, which occurred sometimes with the use of kerosene lanterns or candles. The improved lighting in the beneficiary households also resulted in reductions in indoor air pollution due to

exposure to the smoke from kerosene lanterns and candles. Indoor air pollution resulting from exposure to smoke and fine particulate matter ($PM_{2.5}$) is known to cause acute respiratory infections, especially in children, who are most vulnerable (Barron and Torero, 2017). The provision of lighting with electricity access has allowed household members to stay up longer than they previously did. Children were able to stay up in the evenings to study more than they were able to in the past when they used kerosene lanterns and candles. Interactions revealed that for some participants, the availability of electricity for lighting had resulted in improvement in the grades of their children. These responses are captured in the following quotes:

> *"... before the mini-grid was made here, my children were always playing in the evening when it got dark and only use the lantern to study on a few occasions but now they can stay up and study longer after school and they are doing well in school, the youngest one was top of her class in the last term…"* (38-year-old male participant, Pediatorkope).

> *"In my case I let my children know they can only watch the tv after they have studied in the evening, and it is helpful, they used to sleep early when there was no electricity and seem to be doing well in school…"* (40-year-old male focus group participant, Pediatorkope

Table 7.1: Main use of electricity from the hybrid mini-grid system in Pediatorkope

Electricity use	Frequency	Percent (%)
Lighting	43	96
Entertainment	40	89
Education	15	33
Economic activities	10	22
Cooking	0	0
Agriculture	0	0

Source: Fieldwork, 2018/2019

Depending on the size of the household and the number of rooms, some sections of the household were left unlit with the supply of light being limited to the living area and the bedroom, or the bedrooms and the courtyard/kitchen. Most households prioritised the supply of light to the bedrooms, the living area/room, the courtyard, and the kitchen in that order. Many of the electrified households had electricity providing lighting in their bedrooms and the living areas/rooms while the courtyards and kitchens were not connected. Thus, households with no supply of light for the courtyards and kitchens relied on their secondary sources of lighting energy such as kerosene lanterns, candles, and rechargeable lamps (for those that could afford them). The prioritisation of the provision of lights to the bedrooms and living areas could be attributed to the decision-makers in the households deciding on the supply points, based more on their personal energy priorities with less consideration of the priorities of the entire household.

> *"I decided that we have the lights in the bedrooms and the living room…. when the women want to go the kitchen, they can quickly light a candle or a kerosene lantern for that since they will be there for long in the night"* (35-year-old male participant, Pediatorkope)

In this way, the kitchen which was the preserve of the female household members and not a priority of the male household members was noted to be neglected and not considered much of a priority in agreement with the discussions on intrahousehold differences in energy priorities influencing energy choices presented in section 6.1.2. Thus, the male decision-makers in this instance decided on the access points for lighting based on their energy priorities, which were mainly the bedrooms and the living areas. The provision of electricity has also resulted in an increased sense of

security given that most households are well-lit at night and people can move around safely at the night. The quote presented below captures a response to this.

> *"...the light makes it safe to move around in the night and not worry about getting hurt because you couldn't see or anything like that"* (40-year-old male focus group participant, Pediatorkope).

7.1.1.2 Entertainment

On Pediatorkope island, the community with electricity access via the hybrid mini-grid system, entertainment was one of the major uses of electricity in the various households that participated with 89% of the 45 respondents indicating entertainment among their electricity uses. Before the community was provided with electricity, the main forms of entertainment in the evenings were limited to mainly conversations, singing and dancing sessions and storytelling. With the provision of electricity access, community members can engage in various forms of entertainment, ranging from watching tv shows, listening to radio and music, and charging and use of mobile phones. Thus, the provision of electricity access has increased the options for entertainment for the various households that are connected to the mini-grid system. These entertainment options help the communities to stay informed and connected to the outside world without feeling cut off.

As pointed out in section 6.1.2, most male respondents (73.9%) in Pediatorkope had other energy uses apart from cooking being their topmost priority, which consisted mainly of entertainment, communication, and economic activities with the provision of electricity access. These increased entertainment options, however, tend to affect the communal spirit and the involvement in communal entertainment activities

negatively as a few respondents pointed out. One such response is presented in the quote below.

> *"…the electricity access is very good for the people and the community but now everyone stays in their homes watching tv unlike before when the children will play outside and tell stories in the evenings"* (65-year-old male participant, Pediatorkope)

Most people now either watch tv or listen to the radio in their household and spend less time socialising with other community members outside of their households in the evenings unlike before. This could also affect participation in traditions of storytelling and other activities. Other respondents also expressed concern that with electricity access, most children tend to stay up late watching tv.

7.1.1.3 Cooking

The main cooking fuels in the study communities as was noted in section 5.2 were wood fuel and charcoal. Despite the benefits that stand to be derived from cooking with electricity and LPG such as the reduction in exposure to smoke and respiratory infections, none of the respondents reported using electricity as their cooking fuel, a few participants reported that they did use LPG for cooking but for most of them that was not their primary cooking fuel. Some respondents expressed the desire to use rice cookers, microwave ovens, toasters and other devices powered by electricity to cook but the cost discouraged them from doing so. No respondent was noted to be using electricity for cooking purposes in Pediatorkope as presented in Table 7.1 outlining the energy uses. As such the implementation of the mini-grid could be noted to have not significantly made any changes in the choice of cooking fuels in the community as

they continued to rely on the cooking fuels they used before the implementation of the mini-grid system.

7.1.2 Communal services

Electricity access on Pediatorkope island facilitated the provision of several communal and social services to the community. These services include healthcare, potable water, and education. The provision of these has helped to improve the lives of the inhabitants of the island.

7.1.2.1 Healthcare

Pediatorkope has a health centre which is vital to ensuring the health and wellbeing of the inhabitants of the island. The health centre is connected to the hybrid mini-grid in the community to provide it with electricity. The provision of electricity to the health centre has enabled the health workers to attend to several health conditions that previously they referred to the Ada East district hospital on the mainland. The facility is now also able to store vaccines and other medication. The quote below captures a response to the importance of electricity to the provision of health care delivery in the Pediatorkope community.

> *"...because we have electricity on the island now, we can store some of the vaccines and medication that we use for our work unlike before the island was provided with electricity access"* (Community health nurse at Pediatorkope).

The provision of electricity access to the Pediatorkope community has also made it convenient and easy for health workers to move into the community. In the past before the implementation of the mini-grid project, most of the health workers assigned to the

health centre either requested to be posted elsewhere or preferred to live on the mainland in Ada and commute to Pediatorkope via canoes. A response from a resident in Pediatorkope is quoted below illustrating how electricity access on the island has made it more attractive for some health workers to move into their community.

> *"Some of the nurses live on the island now, so when anybody is sick or a pregnant woman is in labour, we just go to get the nurses to take care of them… but before the electricity, none of the nurses stayed on the island so when someone needed urgent care in the night or when they close, we went to Ada or waited till morning…"* (35-year-old male respondent, Pediatorkope).

Having some health workers living in the community has been beneficial in that in medical emergencies, the health professionals can provide the initial care before they are referred to the Ada East District Hospital in Kasseh.

7.1.2.2 Education

In the opinion of most of the respondents, the provision of electricity through the mini-grid system has enhanced the standard of education within the community because children can read for longer periods in the evenings and overall learning has been enhanced with the connectivity to the mini-grid. In some instances, teachers are able to provide additional tuition for students in their final years of study and preparing for their final exams. Previously without electricity access, the students could not benefit from additional tuition in the evening or read for longer periods in the evenings. The response quoted below captures this point.

"...with the provision of electricity, we can organise evening classes for the final year junior high students so that are adequately prepared before their BECE (final exams)" (Teacher, Pediatorkope).

The situation with teachers not wanting to move into the community was similar to that of the healthcare workers. Before the implementation of the mini-grid system very few teachers accepted postings to the island and even when they did, they stayed in the neighbouring mainland towns and commuted to work on the island. However, the electricity access from the mini-grid has attracted some teachers to move to the island.

7.1.2.3 Potable Drinking Water

Water is vital for the survival of every community. The quality of water supply to communities translates to good health, sanitation, and hygiene in the community by limiting the exposure to water-borne illnesses (Hunter et al., 2010). The research communities have water purification systems that provide the inhabitants with potable water. In Pediatorkope, the water purification system is connected to the hybrid mini-grid system, whereas on the other study islands of Aflive, Azizakpe and Alorkpem the water purification systems are powered by standalone solar PV systems as pictured in Figure. 5.4. The water purification systems are placed at easily accessible points within each community where every member of the community has access to them and can get their potable water from them. Water for other domestic uses like laundry and cleaning was derived from the surrounding river. The respondents attested to the fact that the water from the water systems was cleaner than the water they got from either the river or dugout wells. Some responses elaborating on this are quoted below.

"The water from the purification system is very clean, you can drink and cook without doing anything to it. In the past, we would have to boil the water from the river before we drank or cooked with it if we didn't want to get sick" (21-year-old female participant, Aflive).

"...the taste of the water from the water purification system is even better than that water that we used to use from the river, so it has helped us" (27-year-old male participant, *Alorkpem*).

Access to potable water from the purification systems was revealed to be most beneficial to women and children who mostly had the chore of getting water from the river or the dugout wells for their various households.

7.1.3 Economic activities

The implementation of the hybrid mini-grid project in Pediatorkope has brought with it benefits for individuals who are business-minded and have taken advantage of the electricity access to establish small ventures to generate income on the island. As depicted in Table 7.1, some 22% of the 45 respondents on the Pediatorkope island had started some business venture and others were expanding and growing their businesses with the implementation of the mini-grid project. These ventures include retail shops, a drinking bar, a cold storage facility and a mobile phone charging shop. A significant change for the existing retail shops was the fact that they now can stay open longer into the night, which in turn resulted in increased income.

"... before the mini-grid, I used to close my shop when it got dark in the evenings but with the light, even when it is dark people still come to buy things, so I close

late now and my income has gone up" (29-year-old female participant, Pediatorkope)

One of the retail shop operators had acquired a freezer to enable her to sell chilled drinks and frozen products and their response is captured in the quote below.

"…. I thought of buying a freezer which will help me to store and sell a lot more things in my shop. I decided to take a loan from the microfinance company in Kasseh to be able to connect to the mini-grid and buy a freezer for my shop… it has helped to increase my sales…" (32-year-old female participant, Pediatorkope).

A cold store had been set up by some inhabitants where catch from their fishing activities was stored and sold together with frozen meat. The response from the operator of the cold store was that the facility had given an added boost to their fishing business. Their response is quoted below.

"…. People have also used the light to expand their businesses and shops… we bought a freezer so the fishermen can now store their fish catch as well. This way they don't always have to sell their fish for cheap. The mini-grid has been beneficial to us, and I can say it is a good technology." (30-year-old male respondent, Pediatorkope)

A mobile phone charging shop was set up by a resident to meet the need of those without electricity access but who needed electricity to charge their phones on Pediatorkope island and the other unelectrified islands. The response of one of the participants in the newly established mobile phone charging shop is quoted below.

"One of the young men in the community even set up a mobile phone charging business and people come from the nearby islands that have no electricity to charge their phone there too" (63-year-old male participant, Pediatorkope).

Agriculture is a significant part of rural economies, and some respondents anticipated that they would be undertaking the irrigation of their farms using electricity access from the mini-grid. However, the cost of the electricity usage stops them from doing so and as such, no member of the community utilises electricity for irrigation purposes.

7.2 Variations of electricity generated from renewable energy technology.

The variable nature of some renewable energy resources and the electricity generated from these sources especially solar, and wind has been the key argument for the adoption of hybrid renewable energy systems so that when electricity generated from the renewable energy resources is not enough to power the mini-grid, a backup generator is turned on to power it (Agrawal et al., 2016; Olatomiwa et al., 2016; Adaramola et al., 2014). To get a sense of the reliability of the electricity supply participants were asked about variations in supply from the mini-grid system in Pediatorkope and the solar home systems some residents had on the other three islands. As depicted in Table 7.2, 70.6% of the respondents (51) who had electricity access from renewable energy resources indicated that there was variation in their electricity supply at different times of the year. The main reason the respondents assumed was the cause of the interruption of supply was the lack of adequate solar irradiation to generate enough electricity for their needs during the rainy season and on cloudy days. Some of the responses citing this reason for the variation in their electricity supply are presented in the quotes below.

"Most times during the dry season, the light does not go off, but it mostly goes off during the raining season, sometimes it can go off and come back about 3 times in the days during the raining season" (42-year-old male respondent, Pediatorkope).

"The solar system that I have in my house works all right just that in the rainy season the power is not strong like the days that it is not raining, and the sun is shining bright" (98-year-old male respondent with access to SHS, Alorkpem).

Other participants reported their supply was interrupted when they used high-consuming household appliances for longer periods. In such instances, the voltage was either too low to power some of their appliances or the electricity did not last for 24 hours.

"…I use the light for my shop, sometimes when I have the freezer on for long, the light will go off but on other days it does not go off... I think sometimes the power is not enough that is why it goes off" (32-year-old female respondent, Pediatorkope).

"I have noticed that in the times where I have both my fridge and iron plugged on the light will go off in a short time… I am sure they take too much of the power so now when I want to iron, I turn off the fridge and turn it back on when I finish. In the rainy seasons too, the light goes on and off a number of times during the day the operator at the mini-grid site told me when there is not enough power then he turns on the generator" (28-year-old male respondent, Pediatorkope).

For some households, respondents reported that they switched off their supply whenever it rained heavily.

"The days that the light mostly goes off are when the sun is not shining a lot or if there is rain… also we turn off the light when there is heavy rain so that our appliances do not get damaged" (75-year-old female participant, Pediatorkope).

For the households with access to the Pediatorkope mini-grid, their supply was restored when the diesel generator at the plant was powered on in instances where the solar system was not generating enough electricity.

Some 25.5% of the participants with electricity access also reported that they did not notice any variation in their electricity supply throughout the year. Their responses are quoted below.

"I have not really noticed that the light goes off… maybe it's because I use just the light which I put on only in the night time" (43-year-old male respondent with access to SHS, Aflive).

"In the last 7 days, the lights have not gone off, I am sure it is because of the good weather now but it goes off sometimes for a few minutes or hours and then it comes back. That is not a problem for us because we still get to use electricity which the other nearby islands are not fortunate to have" (29-year-old male respondent, Pediatorkope)

When contacted for comment on the variations in the electricity generated for the mini grid system, a technician from the managing company for the Pediatorkope facility pointed out that, the system was set up as a hybrid one to combat variability issues with the renewable energy resources as captioned in the quote below.

" A key issue challenge with using renewable energy resources like solar and wind is the variation in the energy generated, thus we designed this system as a hybrid system to combat that. This way when there isn't enough energy from

the renewable energy sources (i.e., solar and wind), we turn on the diesel generator to get enough electricity for the people on the island." (Renewable energy professional, Accra).

Table 7.2: Reliability of electricity supply in the study area

	Nature of supply			
	Uninterrupted supply	**Interrupted supply**	**No Supply**	**Unknown**
Respondents with access (n=51)	13	36	0	3
Per cent (%)	25.5	70.6	0.0	5.9

Source: Fieldwork, 2018/2019

7.3 Perceptions of Renewable Energy and Hybrid Mini-grids

The perception of the public especially those of beneficiary communities on renewable energy technology is very important to the effective development of RETs, their acceptance and the intended increased electrification with these renewable energy technologies (Ribeiro et al., 2018). According to Wall et al. (2021), the perception, beliefs and awareness about renewable energy technologies and their benefits significantly impact the adoption of renewable energy by consumers. Djurisic et al. (2020) elaborate further that their findings show that the perceptions and attitudes of consumers impact significantly the adoption of renewable energy technologies however awareness about the technologies has significant potential to change perceptions about them. The household interviews sought to understand the perceptions of the participants from both the communities with and without electricity access. The perceptions of the participants in the study area varied with the majority

of the respondents agreeing that renewable energy technology was indeed beneficial for the extension of electricity access to rural communities like theirs and that it had improved their lives. Some of the responses that were provided are captured below.

> *"The solar energy is very good, it is easy to use because before we used to light kerosene lanterns to provide light in our house and sometimes candles but with the solar mini-grid, we do not worry much about all of those options ...."* (31-year-old male respondent, Pediatorkope).

> *"...It will be nice to have a mini-grid as they have in Pediatorkope so we can also enjoy light, I know it will be very useful and nice because even the solar rechargeable lamp in the house makes life easy for us since we do not have to worry about lighting the kerosene lanterns now."* (26-year-old male respondent, Alorkpem)

Interactions also revealed that despite the beneficial uses of renewable energy technology the high cost involved in their adoption and setup deterred some participants from considering it as an option for their energy needs. The quotes presented below capture the responses on these points.

> *"...it is very useful, now the children can study in the evening, we can also watch tv and listen to the radio like everybody in the country... my only problem is that it is not cheap so some households in our community cannot have the light because they cannot afford the money. When this project was being developed, I remember the team from the ministry of energy said it will provide electricity for everyone but if some people cannot enjoy it because they do not have money then we still have some work to do...*" (57-year-old female focus group participant, Pediatorkope).

"I have been using the solar light for almost 2 years, I bought the first one on this island. I will say it is very useful and convenient but the cost of buying the things to install it is too high. When I bought mine, I wondered if I had wasted my money, but I do not regret it because I am enjoying it. Not everyone can afford to pay that amount, that is why the government should help" (45-year-old male respondent, Aflive).

Another interesting point that was raised in a focus group discussion in Pediatorkope was the limited capacity of renewable energy technology (solar PV) to meet all the energy needs and aspirations of the beneficiaries. It was revealed from the responses that it was a bit discouraging despite the other beneficial uses. Some of the responses on the limited capacity of the hybrid mini-grid system in Pediatorkope during the interviews and focus group discussions are quoted below.

"The mini-grid has been very helpful to us if I am being honest…but I think that we are not being treated fairly if we pay the government says that we pay the same tariff as those on the mainland who have electricity from the grid but cannot use the electricity for all the things that we want. If I use a fridge in my house, I will end up using all my money to pay for the electricity and it cannot support other high consuming appliances..." (30-year-old male focus group participant, Pediatorkope).

"The mini-grid has been helpful and benefitted households and the community in many ways, just that I wish I could use household appliances like rice cooker and blender, but my husband says that the power is not strong enough to power it." (32-year-old female respondent, Pediatorkope)

The response captured above gave an insight into the perceptions that the respondents had about renewable energy technology and its role in improving their lives. Therefore, to effectively provide products and services to meet the energy needs of the unelectrified island communities using hybrid mini-grid systems, it is important to factor in their perceptions of renewable energy technologies (RET) in line with how it affects their willingness to adopt RETs. Products and services that do not address the needs of the communities will most likely not be appreciated. Any concerns raised as was the case with the high cost (either as tariff and connection fees or setup cost) associated with RET during the study, should be adequately addressed with appropriate and affordable financing schemes to make it attractive and enable people to sign up for the service and products. Relating these findings to the conceptual framework set out for the research by Quinn et al. (2018) and Stanistreet et al. (2019), it is noted that perceptions influence the demand and adoption of hybrid mini-grids and renewable energy technology as a whole. Thus, the perceptions align with the "Factors That Influence Consumer Demand" category in both models. In extending the model, this research, therefore, suggests the addition of "Perceptions" to the "Factors That Influence Consumer Demand" category given that it plays a significant role in determining whether people are willing to adopt renewable technologies or not. The significance of the perception of end-users about renewable energy technologies is also shared by industry professionals. A quote capturing this is presented below:

> *"... the views and perceptions of consumers have a strong impact on whether they will be willing to buy into the service and products that we offer. We always make sure that we address any concerns our customers have to avoid creating any negative impressions or perceptions"* (Renewable energy professional, Accra).

7.4 Implications of the Research Findings

Chapter Six presented discussions on the key factors influencing the energy choices and adoption of hybrid mini-grids in the research communities. These factors were classified as being socio-cultural, economic, political, and technical and aligned with other research conducted to identify influences on the success of renewable energy projects, especially mini-grids. Azimoh et al., (2017) who sought to identify the factors that facilitate or challenge the successful implementation and functioning of a mini-grid installation in South Africa found that socio-economic, technical, and political issues were significant in either facilitating or hindering the successful implementation of the mini-grid. The findings were also in agreement with those of Come Zebra et al. (2021) who in their review of hybrid mini-grids in development found that political, technical, economic and environmental factors had significant impacts on the successful implementation of mini-grid systems. The findings are noted to align with the various categories of the model for the scale-up of clean energy fuels by both Quinn et al., (2018) and Stanistreet et al., (2019) while also suggesting improvements to the revised model by Stanistreet et al. (2019) which is also an improvement of the original work by Quinn et al., (2018).

The revised version of the model for the application to the uptake and scale-up of hybrid mini-grids (Figure 7.1) for electrification based on the empirical findings from this research is discussed in this section. This study has shown from the perspective of rural island communities that factors influencing energy choices and the uptake of hybrid renewable energy mini-grids are multidimensional and not restricted to only the technical or financial aspects. The findings of the research, therefore, draw attention to the need to change the approaches used currently in electricity access projects for rural and remote locations, especially through renewable energy resources,

more precisely hybrid renewable energy systems and the adoption of modern and clean energy sources.

First and the most popular factor influencing the energy choices is the cost of access to off-grid renewable energy services and other forms of clean energy resources, especially among low-income households. Low-income households tend to be mainly based in rural communities where access to electricity remains a challenge. For a lot of these residents in rural communities, the high initial cost required to sign up for off-grid modern energy services or clean modern fuels such as LPG and the absence of consumer credit facilities remained a significant barrier (Zou and Luo, 2019; Bhattacharyya, 2013). Their economic status, therefore, was a barrier to them moving up the energy ladder from the use of traditional solid fuels to modern non-solid fuels to satisfy their energy needs (Poddar et al., 2021; Sovacool, 2014b). To overcome this challenge there is a need to come up with innovative financing schemes such as loans and hire-purchase schemes to help cater for the energy needs of the people in these rural areas. Such schemes will help to extend access to renewable systems and make them affordable to poor rural inhabitants. The financing schemes would help spread the high initial setup cost associated with the signup for hybrid renewable energy mini-grid systems and renewable energy technologies while making them available to the rural poor who need them the most.

In discussing the importance of the socio-cultural influences on energy choices and the adoption of hybrid renewable energy mini-grid technology, the study adopted the logical model presented by Quinn et al. (2018) and Stanistreet et al (2019) for the scale-up of clean fuel uptake. The importance of the social needs of beneficiaries when deciding on the best approach to provide renewable energy systems in rural and remote locations cannot be underestimated. Stanistreet et al. (2019) argue in their work on the

upscale of LPG use in Cameroon that the “User and Community Needs” category was noted to not receive the level of attention it deserved in the presentation of the model by Quinn et al. (2018) (Figure 2.2). As a result of the “User and Community Needs” category not being prioritised, it was placed at the bottom of the hierarchy. In Stanistreet et al.’s (2019) revision of the same model, they moved the “User and Community Needs” category to the top of the model (Figure 2.3). This they argue is to prioritise the user and community needs as the first step to understanding the peculiar energy needs of individuals, households, and communities. In the case of this research, prioritising and understanding the energy needs of users and communities helps ascertain whether or not hybrid mini-grid systems and other renewable energy systems have the capability to meet the energy needs and aspirations of the users and their communities. The study agrees with the prioritisation of the “User and Community Needs” over the other categories as done in Stanistreet et al.'s (2019) version of the model and the movement of the “User and Community Needs” category to the top of the model.

Both versions of the model for the scale-up of clean fuels by Quinn et al. (2018) and Stanistreet et al. (2019) consider some social aspects of energy needs and demands but a lot more attention is paid to other aspects such as the technical aspects which align with the “Industry Structure and Services” category; the Financing aspects, which align with the “Energy Pricing and Costing “ category and the Political aspects which echo factors under the “Enabling Environment” category. However, this study has sought to dive deeper to understand the various socio-cultural factors that could influence energy choices, needs, demands and access to modern energy services and the uptake of hybrid renewable energy mini-grid systems and renewable energy technologies in general at the household and community levels. Understanding and

prioritising the socio-cultural dimensions of energy access in the various rural communities and households helps us to understand what their user energy needs are. It also helps us to understand and appreciate how diverse and different the energy needs of rural people are from those of urban dwellers. It also helps to better understand the influences that socio-cultural practices, gender roles and the differences in energy priorities have on energy needs and choices. This research presents a revised version (Figure 7.1) of Stanistreet et al.'s (2019) logic model which in itself is an extension of the original model by Quinn et al. (2018) and applies it to hybrid mini-grid scale-up and uptake. The revised model presented by this research explores the various factors that influence the successful uptake of hybrid renewable energy systems and renewable energy systems in the context of rural locations. A key implication of the research for future energy research and energy access intervention projects is the need to consider the influence that gender roles and intrahousehold differences in energy priorities have on energy choices and decisions. This will help to understand how energy decisions are made in the rural context and the best way to factor these into projects aimed at addressing energy access. The diverse nature of energy needs in rural and remote communities as well as the important influence that socio-cultural factors have on the success or failure of off-grid energy projects draws attention to the need for a multi-dimensional approach to providing electricity access in these communities. Given the importance of the socio-cultural needs of the beneficiaries as discussed, the successes of these multi-dimensional approaches for electricity access will be dependent on a shift from a “top-down” approach, where the planning and decision making is carried out without much involvement of the end-user to a “bottom-up” approach, where the beneficiaries are actively involved in planning and decision-making phases and their energy needs are properly factored into the

development of modern energy access and electrification projects. This approach is presented in the adaptation of the logic model in Figure 7.1 (suggested additions highlighted in red) showing the "User And Community Needs" at the top of the model. This points out that to better facilitate the uptake of renewable energy technologies, especially off-grid solutions, the user and community needs, and aspirations should be the starting point and they should be a priority throughout the process.

Based on the preceding discussions on the factors that influence the adoption of the renewable energy system, another key finding this research draws out is the significant role that the perceptions of consumers have on the success or otherwise of renewable energy projects. The finding points to the fact the views and perceptions of end-users influence whether they will accept and signup for energy access projects or not. This also shows that despite the significance of the technical and economic dimensions of energy access, the perceptions of the end users are vital to the success of energy access interventions in rural communities. The perception of the community members about projects could be the difference between increased uptake for a service or a decrease regardless of the finances involved. For instance, as presented in section 7.3, the perceptions of cost and benefit within the communities influenced how willing the consumers were to sign up for energy services. Negative perceptions about renewable energy technology and modern energy services also influenced their adoption and uptake negatively. An example is when due to an LPG fire in the past, respondents in one of the communities were adamant to use LPG for cooking. Another perception about renewable energy that was prominent and influenced uptake was the view that renewable energy did not have the capacity to meet their energy needs and this seems to be a commonly held view. Perceptions like this have the tendency to deter people from adopting renewable energy technology regardless of the cost involved. Thus, as

part of improving access, it is important to address these issues with perceptions and the influence on the adoption and uptake of renewable energy technologies.

With regards to the "Energy pricing and financing category" of the revised logic model, the major implication of this research on the model is the addition of financial investment and management for renewable energy projects. Given that capital is critical at every stage of energy access projects especially off-grid projects, it is important to provide appropriate financial mechanisms to cater for challenges with capital at both the end-user and project implementation levels (Bhattacharyya, 2013). To help with the challenges with capital at the project level, supplier credit, loan facilities from financial institutions and financial support from the government (i.e., tax incentives and subsidies) can be implemented to lessen the financial burden of the setup cost associated with these projects. At the end-user level, a mechanism that can also be used is leasing/hire-purchase agreements where the payment for the cost of access or a product is spread for a period where small regular payments are made instead of initial lump sums.

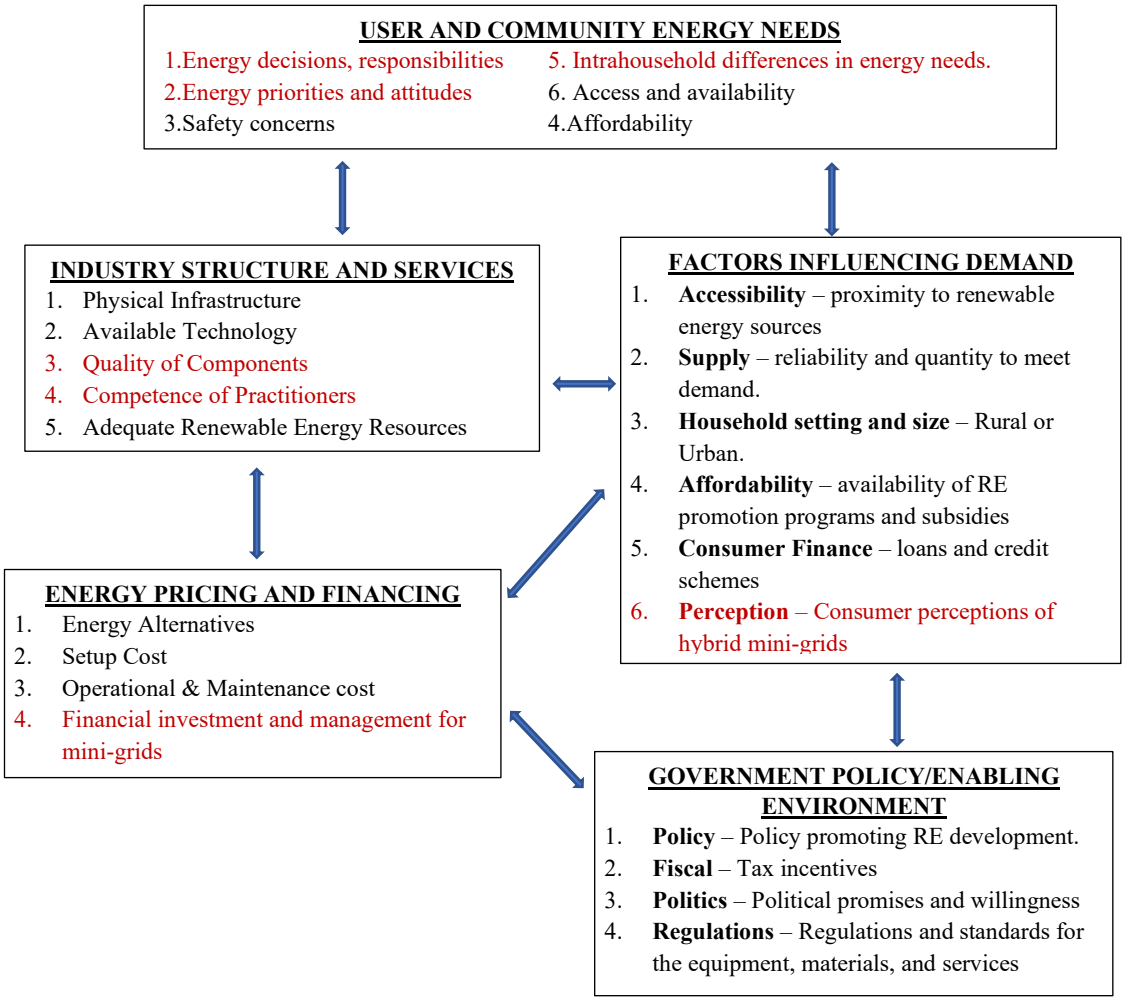


Figure 7.1: Revised logic framework for the uptake of the hybrid renewable energy system. Adapted from Quinn, (2018) and Stanistreet et al. (2019)[8].

7.5 Conclusion

The chapter has explored how the socio-cultural and economic factors that were identified in the study impacted the successful implementation and the uptake of hybrid mini-grid systems for electricity access extension to rural and remote communities. The discussions explored how access to electricity or the lack of it

[8] Additions and adaptations highlighted in red

impacts life in rural communities. Households who had access to electricity indicated there had been improvements in their lives with the hybrid mini-grid and solar home systems. Several participants had started some business ventures with access to electricity. Improvements in communal services such as security, education and availability of potable water were noted. The chapter also discussed the variability of renewable energy technologies and the perceptions of participants about renewable energy and hybrid mini-grids were presented as well as some of the factors that limit their adoption. Discussions on the implications of the findings of the study were also presented. Key among these was a shift in the current approach to electrification of rural communities, which prioritised the technical and financial aspects of access to the detriment of the socio-cultural considerations of the end-users as well as the need to develop innovative financing mechanisms to address the financial challenges of rural consumers. The end-user perception of renewable energy technologies was also noted to have a significant influence on the success of energy access interventions in rural communities. It was noted that user and community needs and socio-cultural dimensions of communities should be prioritised, and the end-users should be allowed to participate in the planning, designing and decision-making phases of off-grid electrification and other modern energy services projects or interventions.

CHAPTER EIGHT

CONCLUSION

8.0 Introduction

Despite the efforts being made to provide modern clean energy access to people globally and achieve SDG 7, there are still about 770 million people lacking access to electricity and some 2.5 billion others who also lack access to clean cooking facilities relying on traditional solid fuels as their primary cooking and heating fuels (International Energy Agency, 2020c). The majority of the global population without access to modern services like electricity and clean cooking fuels are located in Sub-Saharan Africa. Existing research and scholarship addressing the energy access situation globally make arguments for the use of renewable energy technologies as viable options for improving electricity access in low-income countries, particularly within Sub-Saharan Africa (SSA). The majority of the scholarship and interventions have mainly focused on the technical and financial aspects of the issue thereby resulting in less consideration for the social and cultural context of the issue (Bhattacharyya and Palit, 2016; Sovacool, 2014a). Most interventions have also placed less emphasis on the role that stakeholders and end-users play in facilitating the successful implementation of energy access projects (Sovacool et al., 2016). In this regard, the gap in research and discussions regarding energy access, renewable energy and decentralised mini-grids in Sub-Saharan Africa has mainly focused on technical development, financing, and delivery mechanisms with less on the social, cultural and end-user behaviour context like the energy needs, priorities, and aspirations and the influence these have on the sustainability of energy access interventions (Cloke et al., 2017).

The research sought to explore rural energy access and identify the socio-cultural, economic, technical, and political determinants influencing energy needs and access to the adoption of solar PV hybrid mini-grid systems in rural island communities in the Ada East District of southern Ghana drawing on Quinn et al.'s (2018) framework for the scale-up of clean fuels. This aim was achieved through the following objectives:

I. Assessed the current energy sources and needs of the participants and the options renewable energy mini-grids offer (Chapter 5).

II. Determined the various socio-cultural factors that influence energy use and choices within households and the study communities, and the adoption of renewable energy mini-grid systems (Chapter 6).

III. Determined factors impacting equal access to clean, affordable, and sustainable energy in the communities (Chapters 6 and 7).

IV. Reviewed and examined factors promoting or impeding the development of renewable energy projects, precisely mini-grids as a viable option for improving energy access (Chapter 6).

This chapter presents a conclusion to the research. The chapter also discusses the limitations of the research and makes recommendations for a better understanding of the socio-cultural determinants of energy access and use in rural settings to better provide sustainable modern energy solutions to improve the lives of the beneficiaries.

8.1 Summary of Key Findings / Achievement of objectives

The key findings of the research were structured around the broad themes of user and community energy needs, socio-cultural determinants of energy access and demand,

other determinants of energy access and demand (i.e., technical, economic, and political) and use within households and communities.

8.1.1 User and Community Energy Needs

The first objective of the research was to assess the energy needs and the sources of the participants within the study locations. This was to understand what the energy needs, priorities and aspirations were, how they were met at the time of the research and the energy sources that they depended on. The data to help achieve this objective was gathered through a combination of household surveys and interviews with the various participants. The findings from the study presented in sections 5.2 and 7.1 revealed that energy needs were structured around the household and individual energy needs on one hand and the communal energy needs on the other. Household and individual needs were mainly centred around lighting, education, entertainment, cooking, and economic activities.

For the islands without electricity access, Aflive, Alorkpem and Azizakpe, the main cooking fuel was revealed to be biomass. About 80 % of the participants used biomass consisting of wood fuel, charcoal, and coconut as primary cooking fuel. Some people reported using LPG cookers, but these were limited to a few households that could afford to invest in them. Other households simply did not use them because of safety concerns and the perception of "danger" associated with LPG in the community. Over 60% of the participants in both Aflive and Azizakpe relied on kerosene lanterns and candles as their primary energy source for lighting. In Alorkpem several households were noted to have invested in solar lamps when offered favourable payment terms while others relied on kerosene lanterns for lighting. Community energy uses mainly

centred around the standalone solar system that powered the water purification systems in the communities. Participants' energy aspirations included having electricity access and being able to use various household appliances to boost economic activities and start new ones to better their lives.

For Pediatorkope island, with electricity access, the energy needs of the participants were found to be like those of the other islands. Participants' energy needs were mainly centred around household and individual uses as well as community uses. For the households with electricity access (82.2% of participants) via the hybrid mini-grid, electricity was the primary source of energy for lighting. Other households without access (17.8% of participants) relied on kerosene lanterns for their lighting. The electricity was also used to power radio and television sets as well as charge mobile phones for entertainment, communication and keeping abreast with happenings in the outside world. Even with electricity access, none of the participants reported using electricity for cooking purposes due to the cost and issues with variations in the supply. The primary cooking fuel was mainly biomass (wood fuel, charcoal, and coconut husk) and a handful used LPG. The availability of electricity in the community allowed the health centre to be able to store and preserve medications and vaccines and improved healthcare delivery within the community. Numerous economic activities have been boosted and others started because of the availability of electricity. Some residents had invested in acquiring refrigerators and freezers to boost their retail shops and fish and meat sales. A resident had set up a mobile phone charging shop for individuals without electricity within the community and from the neighbouring island. Demographic characteristics were revealed to have impacts on the energy needs, uses and aspirations of the participants. However, these are noted to be interlinked with other factors to impact energy demand and use.

8.1.2 Socio-Cultural Determinants of Energy Access

Socio-cultural factors emerged as a key theme in the research and were also a key objective (objective two). Exploring and identifying the socio-cultural influences on energy access was a key means of understanding how these factors affected energy access and the adoption of renewable energy technologies. Exploring these factors also contributed to filling the gap in research on the various dimensions of energy access discourse in sub-Saharan Africa especially, within rural and remote communities (Cloke et al., 2017; Sovacool et al., 2016).

The study revealed that household size is a vital socio-cultural determinant of energy needs, and thus impacts the adoption of renewable energy technologies. The number of household occupants was found to have a link to income availability within households and influenced investment in renewable energy technologies. Larger households that had limited disposable income were less likely to invest in renewable energy technologies which came with high setup and operational costs. Larger households were also found to be less likely to use modern non-solid fuels like LPG for cooking because of the cost associated with its usage and therefore relied on solid fuels like biomass for their cooking needs. Thus, with a larger number of occupants, households were less likely to move up the energy ladder transitioning from a reliance on traditional solid fuels toward modern non-solid fuels (Meyer and Nishimwe-Niyimbanira, 2016; Özcan et al., 2013; Pandey and Chaubal, 2011).

Gender roles and energy decision making also emerge as a key sub-theme of the broader socio-cultural theme in the research. Decision making on choices of energy sources was noted to align with gender roles in households. In most households, males assumed the roles of breadwinners and leaders of the households whereas female members were primarily tasked with conducting domestic chores and providing care.

Males dominated most decision making in households and energy decisions and choices were not an exception, resulting in less involvement of female household members in the decision-making process, especially on energy. This dominance was found to be because of a combination of cultural practices and the fact that males tended to be more educated and economically empowered in households than females (Adjakloe et al., 2021; Quaye et al., 2016). Most men were also reported to spend very limited time in the kitchen and instead spent a lot more time in the courtyard or the living room. In these spaces, they could enjoy more of the benefits of electricity access like watching TV and/or listening to the radio than when the household did not have access, while the female members spent most of their time in the kitchen being exposed continually to the air pollution produced from the use of solid fuels like biomass (Johnson et al., 2019).

Another key point that emerged under the broad socio-cultural theme was the differences in intrahousehold energy priorities and their influences on household energy demands and needs. (Johnson et al., 2019). The careful consideration of the differing needs and priorities of various household members is important to ensure that people are not being provided with energy that does not meet their needs. The study revealed that for most households, males were the decision-makers (71.7%), and it was shown that in most cases, decisions related to energy were made based on the priorities of the decision-maker with minimal consideration given to the needs and priorities of other household members. The study also showed that the majority of women participants wanted decision-making, especially on energy-related issues, to be jointly made. With regards to cooking fuels, the choice of fuels was noted not to conform strictly to the energy ladder concept where it is expected that as the income status of households improve, they move towards clean modern non-solid fuels and away from

traditional solid fuels. The study showed that participants instead exhibited fuel stacking of various forms mainly due to reasons such as the quantity of food that a cookstove could make, the cost and availability of fuels, variations in the supply of fuels and the need for backup sources (Jewitt et al., 2020; Dickinson et al., 2019; Ruiz-Mercado and Masera, 2015; Masera et al., 2000).

The other key theme that emerges from the research that is of great significance is the end-user perception of renewable energy technologies. As Urpelainen, (2016) points the perceptions and views of end-users be they positive or negative impact on whether renewable energy projects are successful or not. In the case of this research, the consumer perceptions were found to have a significant influence on their willingness to adopt renewable energy technologies and modern energy services.

8.1.3 Technical, Economic and Political Determinants of Energy Access

Factors that emerged under the technical factors theme and influenced energy access and the uptake of hybrid mini-grids and renewable energy as a whole included the limited number of qualified practitioners in the renewable energy space; the use of cheap sub-standard materials and components which ultimately resulted in failure of renewable energy projects and delays and difficulty in procuring parts due to the absence of local companies that manufacture these parts (Shukla et al., 2017). Under the economics theme, some of the factors that were noted to influence access and adoption of renewable energy technologies were the high cost of technologies due to the cost of importation and taxation; the availability of credit and financing facilities was noted to influence investment in renewable energy technologies for both companies and end-users. The running cost associated with renewable energy

technologies and other modern energy services like LPG was revealed to influence their adoption. Political factors that were noted to influence energy access and adoption of renewable energy technologies in the research communities and across Ghana were the establishment of robust policy, regulatory and enforcement regimes, and the provision of appropriate fiscal and financial incentives to attract investments into the renewable energy sector.

8.2 Implications of the research findings

The research sought to draw attention to the need to prioritise the socio-cultural dimensions of scholarship and discussions on energy access and the adoption of renewable energy technologies. The research has broader implications for policy and energy access projects to prioritise the needs of end-users and their peculiar social and cultural practices to facilitate the sustainability of renewable energy projects and ensure that interventions meet the needs of the end-users, particularly in the context of rural and remote location like islands in sub-Saharan Africa. The research also has implications for Quinn et al.'s (2018) logic model for the scale-up of clean fuels and its applicability to renewable energy technologies. By applying the model to explore the adoption of hybrid renewable energy mini-grid systems as part of the research, it was shown to be applicable but with some adaptations. Notable among them was the movement of the "User and Consumer Needs" category to the top of the model, thereby prioritising the category and setting it as a starting point to understand the issues that influence the adoption of hybrid renewable energy mini-grid systems. Other adaptations that are suggested are the addition of some other factors under the various categories to better represent the significant factors that impact the adoption of hybrid

renewable energy mini-grid systems and renewable energy technologies in general as presented in Figure 7.1.

This research contributed to the gap in the literature on the links between different age groups and household energy uses, particularly in the context of developing countries. Most of the available literature was based on the energy requirements of elderly people usually in developed countries. There is very limited literature on the household energy requirements and needs of the various age groups of household members as well as how age influences household energy use. This research shows that the energy needs and priorities of the different age groups in a household are different and as such consultations are important to ensure that each member's needs are met. This research also made contributions to the research gap on the influences of intra-household energy needs and priorities on energy choices. As a key theme, it was shown that differences in intra-household energy needs and priorities of various household members were vital to ensure that their needs and priorities were catered to avoid energy choices that are not needed or even beneficial to the end-users. The research further showed that the consideration of intrahousehold energy needs, and priorities were critical to ensuring the sustainability of renewable energy projects and modern energy services when adopted as they would be tailored toward the needs and priorities of household members.

8.3 Limitations

There were some limitations of the research, which are listed below:

- Initially, plans were for the research to explore other island communities with greater differences between them and contrast the different types of mini-grid

systems that could be implemented but this wasn't possible as the roll-out of such systems was slower than anticipated as well as time and resources constraints.

- The research also considered the possibility of designing and simulating hybrid mini-grid systems for the unelectrified communities based on the information on their energy needs but this was left due to time and financial constraints.
- The COVID-19 pandemic started during the last phase of the fieldwork for the research. As such it impacted the final phase of research fieldwork that was carried out. Originally, it was planned that discussions will be held with some development agencies like United Nations Development Program (UNDP) and German Agency for International Cooperation (GIZ) representatives in Ghana but that was not possible due to the pandemic. Planned follow-up meetings with government officials were also impacted.

8.4 Recommendations

The recommendations of the research are aimed at suggesting ways the energy access situation could be improved with the application of renewable energy technologies such as hybrid mini-grid systems. Other recommendations suggest areas for further research.

The research found that the differences in intra-household energy needs and priorities influenced how energy for meeting needs and priorities were decided on. It also revealed that in rural settings, gender roles also had an impact on energy decisions and ultimately gender equality and empowerment of women and girls. It is therefore recommended that scholarship and projects on energy access in rural settings prioritise

the influence of gender and intra-household energy dynamics. Given the powerful influence that end-users wield in the sustainability of energy access projects, especially renewable energy projects, it is recommended that communities would be more closely involved in projects from the planning, designing and implementation through to the operation phases. One other recommendation that this research would make is that in the Ghanaian context, government and the private sector explore the possibility of local manufacturing of renewable energy technology parts and components as this would in a way reduce the associated high price tag of adoption of renewable energy technologies. To continue filling the gap in the literature on the socio-cultural dimensions of energy access in developing countries, it is recommended that there should be additional research on energy needs and priorities and how these influence demand and users' willingness to invest in energy access and renewable energy. Additionally, there should be further research on the application of the Quinn et al. (2018) model to the scale-up of renewable energy technologies.

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APPENDICES

I. HOUSEHOLD QUESTIONNAIRE AND INTERVIEW GUIDE

HOUSEHOLD QUESTIONNAIRE

INTRODUCTORY NOTE

Hello, my name is Kwabena A. Gyan-Amponsah, I am a researcher from the School of Geography at the University of Nottingham, UK

I am conducting research on the use of hybrid renewable energy mini-grid systems for electricity provision in your community. I am interested in gathering information on the different types of energy sources the different households within the community use for lighting, cooking, and entertainment. I am also interested in learning about the various ways you currently access energy/electricity, the cost you incur in doing so and who the key decision-makers are in each household and how other household members are impacted

I will appreciate your participation in this short interview, which should only take about 30 minutes. All the information provided will be kept confidential.

SURVEY INFORMATION

1. Community/Village _____
2. Date of Interview _____
3. Time of Interview
4. Household Number _____
5. Respondent ID _____
6. Name of Team member _____

SECTION A: DEMOGRAPHIC INFORMATION

1. **Sex** [ ] Male [ ] Female

2. **Age** _____

3. **Educational level:**
   a. None [ ]
   b. Basic school [ ]
   c. High school [ ]
   d. Vocational training [ ]
   e. Diploma [ ]
   f. Degree level [ ]
   g. Postgraduate level [ ]

4. Employment Status & Occupation

   _____

5. Main material of the floor of your household (observations to be recorded):
   a. Natural floor _____
   b. Wood planks _____
   c. Tiles/terrazzo _____
   d. Cement _____
   e. Woollen carpet _____
   f. Linoleum/rubber carpet _____

6. Main material of the roof (observations to be recorded):
   a. Thatch/ palm leaf roof_____
   b. Bamboo _____
   c. Wood planks _____
   d. Metal _____
   e. Wood _____
   f. Brick tiles _____
   g. Roofing shingles _____
   h. Asbestos roofing sheets_____

7. Main material of the exterior walls (observations to be recorded):
    a. No walls _____
    b. Mud _____
    c. Bamboo with mud _____
    d. Plywood _____
    e. Reused wood _____
    f. Cardboard _____
    g. Cement _____
    h. Stone with cement _____
    i. Bricks _____
    j. Cement blocks _____
    k. Wood planks/shingles _____

8. How many rooms in this household are used for sleeping?

    _____

9. Ownership of the house?
    a. Rent [ ]
    b. Own [ ]
    c. Family house [ ]

10. Head of household _____
11. Relationship to respondent _____
12. Sex of head of household _____
13. Age of head of household _____
14. Employment Status of head of household
    a. Unemployed [ ]
    b. Permanent employment [ ]
    c. Temporary employment [ ]
    d. Entrepreneur/Self -employed [ ]
    e. Pensioner [ ]
    f. Student [ ]

15. Number of occupants in the household. Total number:

a. 0-1 _____
b. 2-16 _____
c. 17-55 _____
d. 55+ _____

16. Main source of household income?

a. Salary [ ]
b. Sale of products and goods [ ]
c. Proceeds from the provision of services [ ]
d. Support from family and friends/remittances [ ]
e. Other (Specify)___ [ ]

17. Average total monthly income from all sources

a. GHS 0 - 100 [ ]
b. GHS 101- 500 [ ]
c. GHS 501- 1000 [ ]
d. GHS 1001 – 2000 [ ]
e. GHS 2001 over [ ]

SECTION B – HOUSEHOLD ENERGY

1. Do you have electricity in this household?
    a. Yes [ ]
    b. No [ ] >>> B.7
2. What is the source of your electricity?
    a. Grid connected [ ]
    b. Generator [ ]
    c. Solar/other renewable energy source [ ]
    d. Combination of any of the options above_____

3. How much does the electricity cost your household averagely in a month?

    _____

4. Within the last week (7 days) how many hours of electricity were available in your household daily on average from your main source?
    a. During the day;

        _____

    b. During evenings;

        _____

5. Does the reliability of your main source of electricity vary depending on the time of day or year?
    a. Yes [ ]
    b. No [ ]

6. If yes, what factors would you attribute these variations to?

    _____

    _____

    _____

    _____

    _____

    _____

    _____

7. What is the main source of lighting for this household?
    a. Electricity (Grid) [ ]
    b. Electricity (Generator) [ ]
    c. Kerosene lamp [ ]
    d. Candle [ ]
    e. Battery powered Torch light [ ]
    f. Rechargeable Torch light [ ]
    g. Firewood [ ]
    h. Other (specify)

    _____

8. Any reasons underlying your choice of energy source?

    _____

    _____

    _____

    _____

9. Do you have any other secondary or tertiary lighting sources that you rely on in the absence of the main source?

    _____

    _____

    _____

10. Which household appliances do you have in your household?

    _____

    _____

    _____

    _____

    _____

    _____

    _____

11. Which members of the household have the following responsibilities?

Energy source	Decision maker (Who buys and when)	Who pays	Who purchases/ collects the fuel	Who makes use of these sources of energy	How much is spent in a month (averagely)
Electricity					
Kerosene					
Gas					
Wood					
Charcoal					
Sawdust					
Crop residue					
Animal waste					

12. Do you cook in your household? (Includes cooking food and boiling water)

a. Yes [ ]

b. No [ ]

13.

What does your household use for cooking (cooking food and boiling water) most of the time?	Main Cookstove	2nd cookstove	3rd cookstove
	a. Electric stove [ ] b. LPG stove [ ] c. Kerosene stove [ ] d. Coal pot [ ] e. Solar cooker [ ] f. Three stone stove with chimney [ ] g. Three stone stove without chimney [ ] h. Other, specify_____	a. Electric stove [ ] b. LPG stove [ ] c. Kerosene stove [ ] d. Coal pot [ ] e. Solar cooker [ ] f. Three stone stove with chimney [ ] g. Three stone stove without chimney [ ] h. Other, specify _____	a. Electric stove [ ] b. LPG stove [ ] c. Kerosene stove [ ] d. Coal pot [ ] e. Solar cooker [ ] f. Three stone stove with chimney [ ] g. Three stone stove without chimney [ ] h. Other, specify _____

14. What are the main fuel sources for your household cooking?

Main cookstove	**2nd cookstove**	**3rd cookstove**
Wood [ ]	Wood [ ]	Wood [ ]
Charcoal [ ]	Charcoal [ ]	Charcoal [ ]
Electricity [ ]	Electricity [ ]	Electricity [ ]
LPG [ ]	LPG [ ]	LPG [ ]
Kerosene [ ]	Kerosene [ ]	Kerosene [ ]
Sawdust [ ]	Sawdust [ ]	Sawdust [ ]
Crop residue [ ]	Crop residue [ ]	Crop residue [ ]
Animal waste [ ]	Animal waste [ ]	Animal waste [ ]
Animal waste [ ]	Animal waste [ ]	Animal waste [ ]
Other _____ _____	Other _____ _____	Other_____ _____

15. Any reasons determining your choice?

_____

_____

_____

16. Who makes the decisions regarding the types of energy sources and the type of energy technologies/devices that are utilised in the household?
    a. Lighting _____
    b. Cooking _____
    c. Heating _____
    d. Entertainment (radio, tv, etc.) _____

17. What would you say are the top five (5) most important things you use energy for? energy needs?

_____

_____

_____

_____

18. Does your energy use differ from those of the other members of your household?
    a. Yes [ ]
    b. No [ ]

19. If Yes, how do they differ?

_____

_____

_____

20. Would you say your energy needs are being met with your current household energy status?

_____

_____

SECTION C: COMMUNITY ENERGY

1. Does your community have access to electricity?
   a. Yes [ ]
   b. No [ ] >>> (proceed to 6)

2. Does your community benefit from the electricity access?

   _____

3. Would you say there is equal access to electricity within your community?

   _____

   _____

   _____

4. Are there are any factors that impact equal access to electricity in this community, (wealth, superiority, etc.)

   _____

   _____

   _____

5. Can you name some of the ways your community currently benefits from the access to electricity

   _____

   _____

   _____

6. Do you think your community could be better off with electricity access?

   _____

7. In what ways do you think your community could benefit with access to electricity?

   _____

   _____

   _____

II. GUIDE FOR FOCUS GROUP DISCUSSIONS

INTRODUCTORY NOTE

Hello, my name is Kwabena A. Gyan-Amponsah, I am a researcher from the School of Geography at the University of Nottingham, UK

I am conducting research on the use of hybrid renewable energy mini-grid systems for electricity provision in your community. I am interested in gathering information on the different types of energy sources the different households within the community use for lighting, cooking and entertainment. I am also interested in learning about the various ways you currently access energy/electricity, the cost you incur in doing so and who the key decision-makers are in each household and how other household members are impacted. I will appreciate your participation in this focus group discussion which should only take about 30 minutes. All the information provided will be kept confidential.

QUESTIONS FOR FOCUS GROUP DISCUSSION

- What benefits do you think electricity access brings to your community?
- Is there variation in your energy supply and how does it affect your energy use?
- What are the things that will promote or prevent you from having access to modern energy services such as electricity and LPG?
- How are energy decisions taken in your households and would you want a change?
- Are energy needs and priorities the same for every member of your household?
- Would you invest in renewable energy technology if discounts or hire purchase schemes are offered?
- Do you think energy access is equal for all within your community?

III. GUIDE FOR INTERVIEWS WITH INSTITUTIONS AND OTHER STAKEHOLDERS

STAKEHOLDER INTERVIEWS

INTRODUCTORY NOTE

Hello, my name is Kwabena A. Gyan-Amponsah, I am a Ph.D. researcher from the School of Geography at the University of Nottingham, UK

I am researching the use of hybrid renewable energy mini-grid systems for electricity provision in rural island communities. I am interested in gathering information on your institution's engagement in the energy sector particularly the renewable energy space. I am also interested in learning about issues that promote or act as barriers to the development of the renewable energy space in Ghana with an emphasis on electricity access in rural and remote locations.

I will appreciate your participation in this short interview, which should only take about 30 minutes. All the information provided will be kept confidential.

INTERVIEW INFORMATION

1. Institution Name _____
2. Date of Interview _____
3. Time of Interview _____
4. Participant ID _____
5. Role of participant _____

INTERVIEW QUESTIONS FOR RELEVANT INSTITUTIONAL STAKEHOLDERS

- What exactly do you do in the renewable energy industry?
- Do you have any mini-grid renewable energy projects?
- Do you plan on undertaking any mini-grid renewable energy projects?
- Are any of your existing renewable energy projects hybrid?
- Do you have in place any criteria for the selection and implementation of renewable off-grid projects in remote communities (community size, types of settlement, etc.)?
- What factors determine the capacity of mini-grids installed in rural communities?
- What (if any) financing and development schemes do you have in place for the communities?
- What do you say are the technical challenges you face in your operations?
- Do you require any financial incentives to effectively carry out your work?

IV. RESEARCH PARTICIPANT CONSENT FORM

CONSENT FORM FOR PARTICIPATION IN RESEARCH INTERVIEW

I agree to participate voluntarily in this research project conducted by Mr. Kwabena A. Gyan-Amponsah, PhD researcher from the School of Geography at the University of Nottingham, UK. I understand that the research is to gather information about the energy sources, uses and costs incurred in the community as well as the key decision-makers in energy choices.

My participation in this research interview is voluntary basis. I understand and agree that I will not be paid for my participation. I may withdraw and ask to discontinue participation at any time I deem necessary without any consequence to me.

- I understand that most interviewees in will find the discussion interesting and thought-provoking. If, however, I feel uncomfortable in any way during the interview session, I have the right to decline to answer any questions or to end the interview.
- Participation involves being interviewed by a member of the research team. The interview will last approximately 30-45 minutes. Notes will be written during the interview.
- I understand an audiotape of the interview and dialogue will be made. I am free to object to being taped if I am not comfortable with that.
- I understand that the researcher will not identify me by name in any reports using information obtained from this interview and that my confidentiality as a participant in this study will remain secure. Subsequent uses of records and data will be subject to standard data use policies which protect the anonymity of individuals and institutions.

- Other people (community elders, other community members and other members of my household) will neither be present at the interview nor have access to raw notes or transcripts. This precaution will prevent my comments from having any negative repercussions.
- I understand that this research study has been reviewed and approved by the Ethics Panel in the School of Geography at the University of Nottingham.
- I have read and understood the explanation provided to me. I have had all my questions answered to my satisfaction, and I voluntarily agree to participate in this study.
- I have been given a copy of this consent form.

_____	_____
Signature/ Thumbprint	Date
_____	_____
Printed Name	Signature of Investigator

For further information, please contact:

Mr Kwabena Amponsah Gyan-Amponsah (Researcher)

Email: kwabena.gyan-amponsah@nottingham.ac.uk or gyanamponsahka@gmail.com

Tel: +233269190900 / +447765444934

V. RESEARCH PARTICIPANT PRIVACY NOTICE

RESEARCH PARTICIPANT PRIVACY NOTICE

Privacy information for Research Participants

For information about the University's obligations with respect to your data, who you can get in touch with and your rights as a data subject, please visit:

https://www.nottingham.ac.uk/utilities/privacy.aspx.

Why we collect your personal data

We collect personal data under the terms of the University's Royal Charter in our capacity as a teaching and research body to advance education and learning. Specific purposes for data collection on this occasion are to determine the energy needs or use patterns in the community and perceptions on renewable energy use to assess the challenges and benefits of providing electricity using solar PV-diesel hybrid mini-grids.

Legal basis for processing your personal data under GDPR

The legal basis for processing your personal data on this occasion is Article 6(1e) processing is necessary for the performance of a task carried out in the public interest.

How long we keep your data?

The University may store your data for up to 25 years and for a period of no less than 7 years after the research project finishes. The researchers who gathered or processed the data may also store the data indefinitely and reuse it in future research. Measures to safeguard your stored data include:

- The data gathered will be anonymised to protect the identities of the participants.
- The anonymised data will be password protected and stored confidentially in secure locations.

Who we share your data with?

Extracts of your data may be disclosed in published works that are posted online for use by the scientific community. Your data may also be stored indefinitely on external data repositories (e.g., the UK Data Archive) and be further processed for archiving purposes in the public interest, or for historical, scientific, or statistical purposes. It may also move with the researcher who collected your data to another institution in the future.

VI. INTERVIEW CODING MATRIX

Name (Codes)	Description
1. Socio-Cultural Dimension Matrix	
Gender roles and energy uses	Gender roles in rural households and how it affects energy choices and uses
Gender and energy responsibilities within households	The energy responsibilities of the various genders in households
Energy needs	
Individual needs and how these needs are met	
Household energy needs and how these are met	
Energy Priorities	Priority needs (i.e., lighting, cooking, entertainment, etc..)
Are energy priorities the same?	
Differences in energy priorities and the impact on energy choices and how needs are met	
Energy Aspirations	Future energy needs
Awareness of renewable energy technology (RETs)	Awareness of RET and benefits
Do not know about RETs	
Understand RETs	
Awareness about the benefits of RETs	
Do not understand the benefits of RETs	
Understands the benefits	

Source of energy source	Reason for the source of energy chosen
Convenience	
Cost	
Availability	
Ease of use	
Functionality (able to cook large quantities of food)	
Stacking	
Less smoke to deal with	
Concerns about safety	
Household size and income	How do household size and income influence energy choices and use
Household size and energy needs	
Household size	
Influences on household size	
Energy source meets the needs of the household	
Large household uses more energy so cheaper options used	
Household income and energy	
Determinants of household income	
Education	
Employment	
Impact of household income on energy needs and choices	How does household income impact energy use and choice
Can invest in modern energy technology	
Can’t invest in modern energy technology	

Can invest in modern energy technology if appropriate financing schemes are available	
Perceptions about RETs	
Reliability of RETs	
The capacity of RETs to meet needs	
The cost associated with RETs	
Safety concerns	Fires from LPG use
Exaggerated benefits of RETs	
Taste of food cooked with modern cookstoves	
RETs are beneficial	
RETs bring convenience to remote locations	
User Experience	
Positive and negative experiences	Previous experiences impact energy decisions
Habit and historical use	Difficulty in breaking habits of users regarding energy sources
Timesaving	Time spent gathering fuel and preparing food
Time savings made or not when collecting and preparing fuel	
Time savings made or not when cooking	
Time savings made or not when cleaning	
Ownership of projects	
2. Economic Dimension Matrix	
Cost of investing in modern energy technology	Affordability of RETs

Cannot afford to invest in modern energy technology and RETs	
Cannot afford to make regular payments for energy use (tariff)	
Not willing to invest	
Other financial commitments and priorities	Housing, childcare, education, etc.
Prefer the cheapest option	
Waiting for modern energy technology to be free or offered at a cheaper amount	
No willingness to pay	
Willing to pay	
Household income	
Availability of finance at the end-user level	Appropriate financing schemes
Loans	
Credit-Hire purchase schemes	
Availability of finance at the project level	
Supplier credit	
Loans from financial institutions	
Subsidies and discounts from the government	
3. Technical Dimension Matrix	
User-friendliness of Tech	Ease of use compared to other traditional energy sources
Quality of materials for installations	
Technical knowledge	Adequate number of people with the right level of knowledge
Set up and installation cost	
Durability of RETs	

Number of qualified professionals in the RET space	Does the number of qualified professionals influence the work in the sector
Access to RETs and equipment	Impact of import technology and equipment in the absence of local manufacturing facilities
Supply chain	Impact of challenges on the supply chain
Weak supply chain	
Strengthen supply chain	
After-sales support/maintenance	
4. Political Dimension Matrix	
National policies	Enabling national policies
Regulatory regimes	How effective is the regulation of the renewable energy sector and the energy sector as a whole?
Effective	
Not effective	
Financial incentives and subsidies for RETs	Availability of financial incentives to support the development of RET
Available	
Not available	
Limited offers available	
Adequate offers available	
Need to mobilize financial institutions to fund RET projects	
Trust in Governments	How well do end-users trust politicians?
Mistrust in the promises of government officials	

Trust government officials wholly	
Government interest and commitment to investing in RETs	
Government-funded programmes to improve the development of RET projects	

VII. COVID-19 IMPACT STATEMENT

The COVID-19 pandemic started when the final phase of the fieldwork for the research was underway. I had to cut short the fieldwork in Ghana short so that I could return to England before restrictions were announced. I wrote parts of the thesis during the COVID-19 lockdown but could not do as much because of the stress and anxiety surrounding the whole pandemic and having to work from the house instead of the library where I was used to working. As an international student, I was also concerned about the well-being of my family in Ghana and its impact on them. Later at the beginning of 2021, I got infected with COVID-19 and was unable to work for about 3 weeks. I also suffered bouts of extreme tiredness, brain fog and reduced concentration for about 2 to 3 months even after testing negative which I later found out to be due to the COVID-19 infection earlier. These issues had an impact on the length of time it took for me to write my thesis for submission.