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Assessing Benefits and Barriers to Deployment of Solar Mini Grids in Ghanaian Rural Island Communities

Jude T. Nuru
Antioch New England Graduate School

ANTIOCH UNIVERSITY

NEW ENGLAND

Department of Environmental Studies

DISSERTATION COMMITTEE PAGE

The undersigned have examined the dissertation entitled: “Assessing Benefits and Barriers to Deployment of Solar Mini Grids in Ghanaian Rural Island Communities,” presented by Jude T. Nuru, candidate for the degree of Doctor of Philosophy, and hereby certify that it is accepted.*

Committee Chair: Jason L. Rhoades, Ph.D.
Core Faculty and Director of the International Service Program, Antioch University New England

Committee Member: James S. Gruber, Ph.D.
Core Faculty and Director of the Doctoral Program in Environmental Studies, Antioch University New England

Committee Member: Benjamin K. Sovacool, Ph.D.
Professor of Energy Policy at the Science Policy Research Unit (SPRU) and Director of the Sussex Energy Group at the University of Sussex.

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Date Submitted to the Registrar’s Office:

*Signatures are on file with the Registrar’s Office, Antioch University New England.

Assessing Benefits and Barriers to Deployment of Solar Mini Grids in Ghanaian Rural Island Communities

by

Jude T. Nuru

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Dedication

I dedicate this dissertation to my children Ryan Maalu Nuru, Melanie Saama Nuru, and Ronny Faareh Nuru for them to grow up, appreciate the value of formal education, and seek it to the best of their abilities.

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Abstract

Researchers, policy makers, and development partners are increasingly concerned about the challenges of climate change and lack of energy access facing countries in sub-Saharan Africa. While the majority of people in sub-Saharan African countries lack livelihood diversification skills and are vulnerable to climate change, energy poverty is also widespread, particularly in the rural areas where it is difficult and expensive to extend grid electricity. In the face of these two challenges, it has been envisaged that since sub-Saharan Africa is endowed with variety of renewable energy resources such as solar, wind, and biomass, their deployment could help address both climate change and energy access in the region. While the deployment of renewable energy could offer benefits for rural populations in the region, barriers to their deployment are inevitable. There has been limited research on co-benefits and barriers to renewable energy deployment in sub-Saharan Africa. This dissertation combines climate compatible development and social construction of technology theoretical frameworks as the analytical framework alongside mixed methods including surveys, semi-structured interviews, focus group discussions, and direct observations to identify the benefits and barriers to the deployment of solar mini grids in Ghanaian rural island communities. The island communities were created in 1965 as a result of the construction of Ghana's largest hydro-electric dam and they have remained so until 2015 when the World Bank Group funded the provision of solar mini grids in five communities. Major benefits that emerged include adaptation benefits such as creation of jobs and business opportunities; mitigation benefits such as replacement of kerosene use and reduction in deforestation; and development benefits such as improvement in healthcare delivery and school performance. Key barriers identified include infrastructural, socio-cultural, and technical barriers. Based on the findings, the study concluded that solar mini grids could address both climate change and energy access in the region and as such, more resources should be channeled towards their deployment, while steps are also taken to address both the technical and socio-cultural barriers. Given that the Ghanaian islands share many similarities with other sub-Saharan African rural contexts, the results are transferable to other rural areas in the region.

Key words: Ghanaian island communities, solar mini grids, co-benefits, climate compatible development, social construction of technology.

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Chapter 1

Introduction

Climate change and energy access are among the major challenges facing Sub-Saharan African (SSA) countries. While these two challenges are not peculiar to countries in SSA alone, certain conditions prevalent in the region raise greater concerns for policy makers and development partners. In terms of climate change, the factors that give cause for concern are two-fold. First, countries in SSA are vulnerable to climate change due to lack of livelihood diversification strategies (Stern, 2007). Particularly people in SSA lack the ability to adapt to sudden disruptions caused by climate change to their routine economic activities due to limited or complete lack of the resources required to make appropriate adjustment to their lives. Climate change is a contributing factor to widespread poverty among rural populations in the region (Zerriffi & Wilson, 2010). It is likely that the impact of any potential disaster in the region resulting from climate change will potentially be greater than other regions with stronger economies. Second, the livelihood of the majority of the people living in SSA is heavily dependent on natural resources (Food and Agriculture Organization, [FAO] 2007). It has been projected, however, that people whose survival is contingent on the climate are at greater risk from increasing climate variability than those with diversified means of livelihood (Adger et al., 2007; Conway, 2009). Under these circumstances, unless concrete strategies are deployed, climate change will exacerbate the prevailing vulnerabilities in SSA (Boko et al., 2007).

As far as energy access is concerned, the proportion of population without access to electricity in the majority of SSA countries is greater than 75% (International Energy Agency [IEA], 2014). There are three factors that account for the low electricity access in SSA. First, due to the difficulty of transporting electricity via the grid to the rural areas, many rural communities in SSA remain unelectrified (Kanyarusoke et al., 2016). This is true where most rural communities in SSA are isolated from the mainland areas by vast bodies of water, which makes it extremely difficult to extend the grid electricity there, especially transporting the required logistics to facilitate electricity extension (Nuru et al., 2020). Second, the scattered settlement patterns that characterized rural SSA also makes it very challenging for grid extension (Othieno & Awange, 2016). Third, the above two challenges obstructing grid extension to the rural areas in turn affect costs and as such, energy sector actors, especially the private sector, often do not find it lucrative to invest in rural electrification in SSA. As a result of these challenges, nearly half of the countries in SSA are energy poor (World Bank Group, 2017), as more than half a billion people living in the region are without electricity (IEA, 2014). According to Africa Development Bank [AfDB] (2016), the lack of energy access is a major crisis facing SSA, as access is only a quarter of the region's total population compared with 50% in South Asia and 80% in Latin America. Deichemann et al. (2011) also revealed that the average electricity access in SSA's rural communities is only about 3% compared to 65.5% in Latin America and the Caribbean, and 55.7% in the South and Southeast Asia.

A relationship between climate change and energy access exists, as access to energy can mitigate the level of exposure to climate change vulnerabilities. While lack of access to energy affects peoples' ability to adapt to climate change (Sumiya, 2016), having access to energy can strengthen local communities to build adaptive capacity and resilience against climate change vulnerabilities (Murphy & Corbyn, 2013). Availability of energy for productive use such as irrigation, for example, can enhance productivity among populations that depend on rain-fed agriculture and safeguard food insecurity resulting from climate change (Burney et al., 2010; Burney & Naylor, 2012). In addition, electricity can provide access to clean water and improve healthcare (Johnson et al., 2017).The widespread energy poverty in SSA thus suggests that the population, especially those in the rural areas, are incapable of empowering themselves to build resilience against the growing climate change vulnerabilities in the region.

Given the above two major challenges facing SSA, it has been suggested that since the region is blessed with variety of renewable energy (RE) resources such as biomass, solar, wind, and hydropower in exploitable quantities, their exploitation could be beneficial (Kammen & Kirubi, 2008). The World Bank Group (2017) in a study concluded that off-grid and mini-grid RE systems constitute an antidote to SSA's electricity poverty. Similar studies have concluded that RE remains the most suitable energy option to electrify rural SSA (Pueyo et al., 2016; Othieno & Awange, 20106). Othieno and Awange further suggested that SSA's energy poverty is not predicated on scarcity of energy resources, but rather a lack of the appropriate technology to harness her abundant RE resources to assuage the situation.

This dissertation argues that, it is not enough to suggest that SSA countries are endowed with plentiful RE resources and their exploitation will automatically solve the energy crisis in the region. I posit that while there could be potential benefits to RE exploitation in the region, significant barriers are also likely to exist. As such, it is important to understand the potential benefits that can stem from RE deployment, as well as the barriers that can possibly impede the realization of these benefits in the region from the perspectives of stakeholders. Understanding stakeholders' views is particularly vital, because they are the people who are directly involved with the projects and are better placed to identify the actual benefits from and challenges of RE projects. This dissertation is designed within the context of SSA and therefore has a broader regional focus. Its specific goal, however, is to better understand the benefits of solar mini-grid systems in Ghanaian rural island communities within the context of climate change and development with larger implications for SSA rural areas . It is also intended to identify barriers to the deployment of the solar mini-grid systems in the rural island communities and strategies to overcoming the barriers from the perspectives of stakeholders. To accomplish the goal of this dissertation, the study is designed to answer the following three questions:

1. What do stakeholders identify as the benefits of solar mini-grid systems to rural island communities within the context of climate change and development?
2. What do stakeholders identify as the barriers to deployment of solar mini-grid systems in the rural island communities?
3. What are the stakeholders' suggested strategies for overcoming the barriers to the deployment of solar mini-grid systems in the rural island communities?

Preview of Dissertation Chapters

To contribute to a better understanding of the benefits and barriers to solar mini-grid systems, as well as the strategies to overcoming the barriers, the dissertation is divided into five standalone chapters, which are interconnected and feed into one another. While Chapter 1 and Chapter 5 form the general introduction and main conclusion for the dissertation in its entirety, Chapters 2 – 4 are written and presented in a manuscript format to be submitted to separate peer-reviewed academic journals for publication. As a result, each manuscript-styled chapter has its own title, abstract, introduction, methods, results, discussion, conclusion and policy implications, and reference sections. Additional details on the structure of the dissertation are provided below.

Chapter 2 explores two theoretical frameworks applied in the dissertation. It synthesizes *climate compatible development (CCD)* and *social construction of technology (SCOT)* theoretical frameworks for assessing the benefits and barriers to deployment of RE in rural SSA. A desk study approach has been utilized to identify aspects of these two frameworks that provide the tools for understanding the benefits and barriers to RE deployment in SSA. It argues that while there are benefits to deploying RE in rural SSA, significant barriers also exist and as such, understanding both the benefits and barriers at the same time requires a comprehensive theoretical framework. Given that existing theories fall short of providing adequate analysis of both issues, an integrated framework is developed from the two theories, which can be applied to assess pre-deployment and post-deployment of RE in SSA. While CCD can help us understand the benefits of solar mini grids such as livelihood diversification or access to social services, these benefits can only be realized when barriers such as socio-technical factors are addressed from the standpoint of SCOT. This integrated framework provides the basis for the research in Chapter 3 and Chapter 4.

Chapter 3 begins by highlighting the gravity of climate change and lack of energy access in SSA. It shows that solar mini-grid systems can address climate change impacts and energy access challenges at the same time in rural communities. Using a CCD framework as a guide, it applies a survey to reveal that solar mini grids can deliver tri-benefits - adaptation, mitigation, and development - to rural households in SSA simultaneously within the context of climate change and development. The survey was administered in three Ghanaian rural island communities. The survey covered a total of 105 household respondents with 35 in each community. The survey included but was not limited to questions about households' socio-economic and demographic characteristics, importance, and benefits of the solar mini grids. It found that an increased deployment of solar mini grids in SSA would save policy makers and development partners substantial amount of resources that would have otherwise been expended on different projects towards the achievement of separate goals for adaptation, mitigation, and development. The findings further support the potential of RE technologies to deliver such co-benefits and underscore their suitability to rural areas in the developing countries.

Chapter 4 investigates the barriers and strategies for overcoming the challenges to deployment of solar mini grids in rural SSA. It builds on Chapter 3 and highlights that while solar mini-grid systems offer several benefits for rural populations in SSA, their deployment face significant barriers. A SCOT framework guided the research design and analysis here. Semi-structured interviews, focus group discussions, and direct observation approaches were used to collect the data. It argues that the barriers to solar mini grids in SSA transcend technical and financial concerns. It further contends that while there have been technological advancement and increased financial support from development partners, the deployment of RE technologies in SSA continues to face significant barriers embedded in the socio-cultural contexts of rural communities. Thus, understanding the socio-cultural contexts is as important as the technical and financial impediments to RE deployment in SSA.

Chapter 5 presents the overall conclusion for the dissertation. It summarizes and integrates the findings and policy implications from the three immediately preceding chapters to draw an overarching conclusion for the study. The study concludes that while benefits were realized from the solar mini-grid systems, socio-technical barriers were also encountered and as such, it is important to consider both technical and social factors when deploying RE in SSA. There is a complete reference list for the entire dissertation, as well as appendices showing a survey instrument, semi-structured interview guides, , raw data and copy right permission.

Ethical Concerns

Ethical concerns have been addressed by following established ethical guidelines for conducting social science research. The ethical guidelines adhered to in this dissertation ranged from respect for participants' rights through regard for groups and institutional values to accurate reporting of results. To do this, I first obtained approval from the Antioch University Institutional

Review Board prior to the data collection. Second, I upheld confidentiality and anonymity by not disclosing names and addresses of respondents, as well as other personal identifiers in the report and to third parties. To safeguard the identity of respondents , I transcribed the interviews all by myself. Third, prior to the start of each interview session, a respondent's informed consent was obtained for participation and recording the interviews. In addition, I gave them the option to withdraw from the study up to the point of the data analysis. Fourth, I took steps to encrypt all the data and safely kept the original transcripts.

Contributions of the Dissertation

Considering there is scarcity of research on RE, as well as lack of practical application of the two theoretical frameworks applied in this study in the energy sector within SSA, this dissertation offers three main contributions. First, the dissertation contributes to the scholarly literature on RE deployment in SSA, particularly solar mini-grid systems, which are a novelty in the sub-region. The review of extant literature revealed limited research on solar mini grids in SSA. Thus, this dissertation adds and extends the limited scholarly information about solar mini-grid systems in SSA.

Second, it contributes to the advancement and applicability of CCD and SCOT theoretical frameworks applied in the dissertation. In reviewing the literature, I was unable to find any evidence of an integrated application of CCD and SCOT theoretical frameworks specifically in the energy sector within SSA. This dissertation represents an important effort to apply both theories in a single study to understand the benefits and barriers to the deployment of solar mini-grid systems in rural communities in SSA. Its contribution to theoretical synthesis in general is significant.

Third, this dissertation contributes to energy access and development policy. It draws the attention of policy makers and development partners, donor agencies to the fact that RE deployment has the potential to deliver multiple benefits for rural populations in the developing countries within the context of climate change and development. It highlights the need to prioritize and allocate limited resources to RE projects like the solar mini-grid systems that can deliver tri-benefits concurrently for rural people with the potential to tackle both climate change and lack of energy access at the same time. It further points out how the unresolved socio-technical barriers can be addressed.

Limitations of the Study

This dissertation was designed as a single country case study, which limits its generalizability. Its broader framing within the SSA regional context, however, compensates for the limitations arising from the narrowing of the data collection to a single country in the region. Thus, the results are still transferable to other rural contexts within SSA and by extension rural communities in other developing countries for the following reasons. First, the Ghanaian rural island communities share similar socio-cultural and geographical characteristics with other rural areas in Africa and the developing regions. Typically, rural populations across the developing regions of the world depend largely on natural resources and lack skills diversification to enable them to adjust and response to any climatic catastrophe. Second, much like the Ghanaian rural island communities, many rural areas in other parts of SSA face similar problem with means of access to the communities, and equally lack basic infrastructure and social amenities like clean water and energy. Third, there is generally low access or complete lack of access to electricity in many SSA rural areas. Consequently, the use of traditional energy sources is widespread in the rural areas much like the situation in the Ghanaian rural island communities. Given these similarities, the results of this study may be transferable to other rural communities in SSA lacking in infrastructure and with similar socio-cultural contexts.

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Chapter 2

A Synthesis of Climate Compatible Development and Social Construction of Technology Theoretical Frameworks.

Abstract

This paper synthesizes climate compatible development and social construction of technology theoretical frameworks for assessing the benefits and barriers to deployment of renewable energy in rural sub-Saharan Africa. Renewable energy deployment is considered a viable strategy that can help address climate change and lack of energy access in rural sub-Saharan Africa. While there are benefits to deploying renewable energy in sub-Saharan Africa, significant barriers also exist. Understanding both the benefits and barriers at the same time requires a comprehensive theoretical framework. Existing theories are, however, incapable of facilitating analysis of both issues at the same time. There is therefore the need to integrate two or more theories that can be applied to analyze both benefits and barriers concurrently. The integrated framework developed in this paper can be operationalized to assess the benefits and barriers to deploying renewable energy in rural sub-Saharan Africa in two major ways – pre-deployment assessment and post-deployment assessment. The climate compatible development component of the integrated framework is to help us understand that there are benefits such as livelihood diversification, reduction in carbon emissions, and access to social amenities associated with the deployment of renewable energy projects. However, as made clear by social construction of technology, these benefits can only be realized when barriers like funding challenges are addressed and political commitment shown by political actors.

Key words: Renewable energy deployment, sub-Saharan Africa, climate compatible development, social construction of technology, integrated theoretical framework

Introduction

In the last two decades researchers, policy makers, and international development organizations have demonstrated growing concern about the myriad of challenges bedeviling sub-Saharan Africa (SSA) and the need to address them (Othieno & Awange, 2016; World Bank, 2017). Even though the problems facing SSA are many and varied, two challenges that are of utmost priority in the region are climate change and energy access. Addressing these two challenges will invariably result in other problems being solved. On one hand, there are serious concerns that SSA countries would find it difficult to cope with growing climate change vulnerabilities due to weak adaptive capacity (Stern, 2007). The reason being that, predominantly the region's economic activities are climate dependent and as such, disproportionate climate change impacts are anticipated in the years ahead (Adger et al., 2007). On the other hand, SSA is said to bedeviled with acute energy poverty. The International Energy Agency (IEA, 2011a), for example, reported that the over 1 billion of the world's population that still lacks access to electricity, about a fifth of this population lives in SSA. It has been estimated further that about 600 million people, approximately 70% of the total population in SSA have no access to electricity (IEA, 2014).

A question that arises from the two problems highlighted is: What opportunities exist in the region that could be tapped for electricity generation, as well as in meeting climate change adaptation, mitigation, and development goals? Some studies have suggested that since SSA is endowed with enormous RE, their deployment could offer the region several benefits within the context of climate change and development (Kammen & Kirubi, 2008; Adkins et al., 2010; Szabo et al., 2011; Yadoo & Cruickshank, 2011). While RE potential in SSA is not in doubt, an analysis of benefits and barriers to their deployment in the region is necessary. Understanding the benefits of RE could provide motivation for policy makers, government agencies, and development partners to increase allocation of resources towards their deployment. In the same vein, knowing the barriers could help stakeholders of RE deployment in the region take steps towards remediation of the barriers. There are existing theoretical frameworks that can offer analytical tools to help us better understand the benefits and barriers to the deployment of RE in SSA. In the section that follows, a review of the concept of theory and its importance in social science research is done. It then follows with an analysis of two theoretical frameworks that can help us better understand the benefits and barriers to deployment of RE in SSA.

Meaning and Justification for a Theoretical Framework

There has been growing diversity and pluralism of theories within social science following Talcott Parson's attempts at formulating an overall general theory for the study of societies (Dahms, 2011). Despite the multiplicity of theories that exist in the social sciences, there is no known universal definition of a theory. Indeed, leading scholars within the realm of social sciences have been unanimous about the non-existence of a "one-fit all" definition of a theory (Gioia & Pitre, 1990; Mintzberg, 2005; Eisenhardt & Graebner, 2007; Abend, 2008; Sovacool & Hess, 2017). With this understanding, the intention is not to render an exhaustive analysis nor an attempt to provide a universal meaning of a theory here. I will, however, refer to a few scholarly explanations of a theory that have relevance to this paper.

While highlighting the varying interpretations relating to theory and the difficulty about having a conclusive definitive meaning of a theory, Abend (2008, p.179) maintained that a theory is "an overall perspective from which one sees and interprets the world." Put in a different way, a theory is a general lens through which interpretations are made about the world. Sovacool and Hess (2017, p.708) offered a more comprehensive explanation of what constitute a theory including such referents as "theoretical construct, conceptual framework, analytical tool, heuristic device, analytical framework, concept, model or approach to technology and society". Taken together and contextualizing these views within the remit of this paper, a theory thus provides a useful lens for the researcher to distill information relevant to the goal of a given research. It is a meaningful tool, which helps a researcher understands and interprets the world. A theory provides an analytical framework for interpretation of a social phenomenon. Given the importance of a theory in social science research as highlighted here, understanding the benefits and barriers to the deployment of RE in SSA would require a comprehensive theoretical framework. Two theoretical frameworks suitable for a concurrent analysis of both benefits and barriers are Climate Compatible Development (CCD) and Social Construction of Technology (SCOT). These two theoretical frameworks will be analyzed in more detail later.

Methods

This paper utilizes a desk study approach (Payne et al., 2007) to identify relevant theories for assessing the benefits and barriers to deployment of RE projects in rural SSA. The desk study method results in a wider coverage of search domains in less time. Admittedly, not all materials found were relevant and specific to the purpose of the study. In identifying the appropriate theoretical frameworks, an extensive literature review was conducted to select theories that fulfil the aim of this study. The review focused on conceptual and theoretical frameworks in both peer-reviewed and grey literature sources covering climate change and development policies. Given the focus of the study, the protocol for inclusion of study materials has two criteria. First, a theoretical framework chosen should at least provide explanation on the means through which climate change adaptation, mitigation, and development goals could be achieved concurrently in SSA within the context of climate change and development. Second, a theoretical framework selected should at a minimum, give guidance on a range of factors that could promote or hinder technological development to achieve adaptation, mitigation, and development goals. The two theoretical frameworks that met the inclusion criteria were: climate compatible development (CCD) and social construction of technology (SCOT). While CCD provides information on strategies that can be pursued to achieve adaptation, mitigation, and development benefits concurrently, SCOT helps with an explanation of socio-technical factors that can enhance or obstruct the deployment of renewable energy technologies in SSA to realize CCD's goals. These two theories have met the selection criteria stipulated above.

The literature search was done in two major ways: through Google Scholar, and an Advanced Search of over 259 databases managed by Antioch University New England. The following keywords were used: "climate compatible development" and "social construction of technology." The search for "climate compatible development" returned a total of 1600 documents. The titles and abstracts of the documents were scanned to identify those that address the three dimensions of climate change – adaptation, mitigation, and development. Only 25 articles met this inclusion criteria and were shortlisted for the review under climate compatible development framework. The titles of the rest of the articles had just one term in them either "climate" or "development." These were not included. Also, the search for articles with "social construction of technology" generated over 2000 articles. Examination of the titles and abstracts revealed 14 which met the inclusion criteria and those were shortlisted. Again, those documents not included had either only "social" or "social construct" or "technology" but not all the three key words in one title. In the section that follows, each of the two theories is described in more detail to reveal their core tenets before synthesizing them into an integrated framework.

Climate Compatible Development

Given the predicted climate change vulnerabilities coupled with the lack of energy access in SSA, it is imperative for policy makers in the region to consider projects that generate triple benefits: adaptation, mitigation, and development within the context of climate change and development (Adger et al., 2009; IPCC, 2007; Suckall et al., 2014). This is precisely the central theme of CCD – the need to deploy projects that yield adaptation benefits, mitigation benefits, and development benefits (Mitchell & Maxwell, 2010). Mitchell and Maxwell constructed the CCD theoretical framework, describing it as “development that minimizes the harm caused by climate impacts, while maximizing the many human development opportunities presented by a low emission, more resilient future (2010 p. 1).”. Thus, CCD is anchored on the three pillars of adaptation, mitigation, and development. This stance of CCD is supported by evidence that climate change no longer has links with mitigation and adaptation only, but it does have serious impacts on development (Reid & Huq, 2007; Lemos et al., 2007; Stringer et al., 2014). It therefore seeks to promote projects that yield these triple benefits at the same time. Central to CCD is the need to ensure coherence between climate change goals and development objectives in ways that reduce negative impacts of climate change and yet promote development opportunities presented by low carbon emissions projects. Fundamentally, CCD endeavors to break the existing boundaries that flank mitigation, adaptation, and development, while building synergies among them (Mitchell & Maxwell, 2010). Mitchell and Maxwell have been motivated by the idea that climate change is a complex issue, which has ushered in dynamic development agendas for policy makers and governments particularly in developing countries. It has an emphasis on making climate change strategies and development goals compatible.

CCD stresses that any attempt to delink adaptation, mitigation and development could result in substantial duplication and trade-offs between the three components of CCD (Suckall et al., 2014). For example, intensification of tree plantation as a mitigation strategy to reduce carbon emissions (mitigation) without consideration for local farmers' livelihood diversification (adaptation) could result in trade-offs between mitigation and adaptation goals (van Oostena et al., 2018). Mitchell and Maxwell maintained that unless policy makers consider the principles of CCD, they will end up having disappointing results where some problems will be resolved while others get exacerbated. At the core of CCD is synthesizing and integrating the three strategic areas that have been isolated in the past. Figure 2.1 illustrates the framework diagrammatically. The framework is an intersection of the individual strategies with overlaps existing between them. At the center of the intersection is CCD.

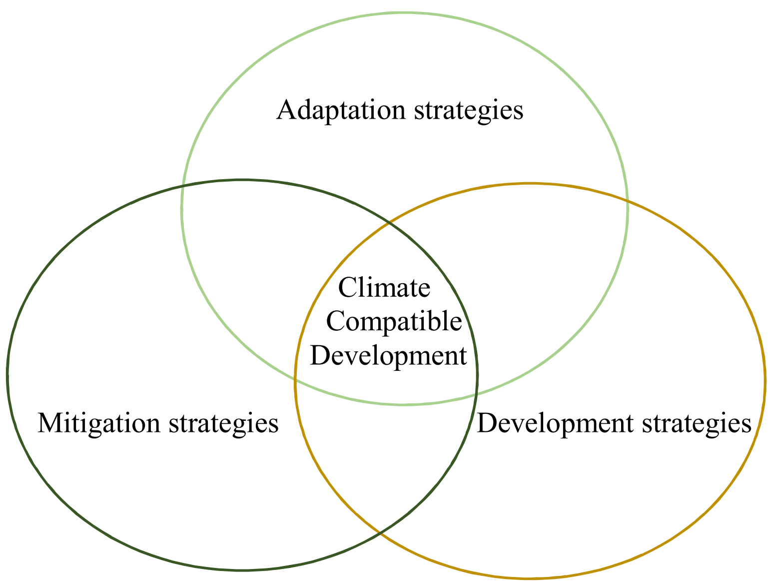

Figure.2.1. Climate compatible development framework. Source: Adapted from Mitchell & Maxwell (2010)

Primarily, CCD is a transformational theoretical framework, which implementation requires promoting emission free technologies and at the same time, addressing poverty, bridging the inequalities gaps, and building resilience (Nunan et al., 2017). It is aimed at advancing strategies that build resilience (adaptation), reduce carbon emissions (mitigation) without development goals being compromised. As climate change delivers threats and opportunities at the same time, CCD theoretical framework objective is to minimize those threats and utilize the many opportunities. The major appeal of CCD is for policy makers to undertake projects that are cost-effective and can yield multiple benefits. To demonstrate how CCD is best suited to analyzing the benefits to deployment of RE in SSA, the three components embedded in the framework are discussed below with some practical illustrations from the region.

Adaptation strategies

Adaptation strategies in the context of CCD are "projects that have the potential to reduce risks, moderate and take advantage of climate impacts at all scales" (Mitchell & Maxwell, 2010, p.3). Under the concept of CCD, adaptation strategies are meant to promote livelihood diversification, create opportunities for learning new skills and innovative ideas, limit reliance on natural resources for survival, bridge inequality gap and ensure equal participation in decision making process by all stakeholders. Climate change vulnerabilities have been projected to increase in the developing regions of the world including SSA due to weak adaptive capacity (Stern, 2007). The reason why SSA in particular is predicted to be hardest hit by climate change vulnerabilities is because the region's economic activities are largely climate dependent and hence disproportionate climate change impacts are highly anticipated (Adger et al., 2007). Consequently, most SSA countries lack the capacity to respond to changes in the climate, since the means of livelihood in the region are contingent on natural resources. To address the situation, CCD advocates adaptation strategies that would strengthen the adaptive capacity of people in poorer countries. RE deployment is one of such strategies recommended by the framers of CCD. Access to energy via RE projects can help rural people develop new skills to enable them respond to climate change impacts. Acquiring new skills can help them refocus on other sectors of the economy rather than the current sole reliance on natural resources. In my view, the dominant practice where livelihoods in poorer regions are dependent on rain-fed agriculture is not sustainable in the wake of climate change.

A practical example of an adaptation strategy that resulted in the achievement of triple benefits within the context of CCD framework is exemplified by Burney et al's study (2010) in the Republic of Benin.

In the Republic of Benin, climate change has been affecting the amount of rainfall that enables farmers grow their crops. With donor support from the World Bank Group, some affected communities were provided with solar-powered irrigation pumps (Burney et al., 2010). The intervention enabled the farmers to plant their crops without much rains. The project enhanced their adaptive capacity, as their earnings increased. With proceeds from their farms, beneficiary households were able to purchase many "goodies" of life for themselves such as television sets, mobile phones, motorcycles (Burney & Naylor, 2012). The authors added that farmers were able to send their children to school. Situating these benefits in the CCD framework, triple benefits were achieved simultaneously with a single project implementation (Suckall et al, 2015). The initial objective of the project was to assist the local farmers adapt to climate change, yet the project yielded mitigation and development benefits as well. Mitigation and development goals were achieved alongside adaptation goals, in that the solar-powered irrigation mitigated carbon emissions, and the beneficiaries economically empowered. The initiative enabled families to send their children to school, thereby promoting development at both community and household levels.

Mitigation Strategies

Mitigation strategies in the context of CCD refer "to those development initiatives that either eliminate the release of greenhouse gases (GHGs) into the atmosphere or minimize them (Mitchell & Maxwell, 2010, p.3)." As Mitchell and Maxwell (2010, p.2) further noted, "mitigating the emissions of GHGs means using less energy, generating more energy from low-emissions sources, protecting carbon stores such as forests, encouraging the development of low-emissions technologies, and providing incentives to discourage high-emissions investments." The major concern about emissions relates to the energy sector because it contributes the highest amount of GHGs emissions (Sims, 2004). Even though other sectors, for example the agriculture sector, can contribute to emissions (Peskett, 2010) and at the same rate help reduce emissions, none can compare with the energy sector in terms of adding emissions to the atmosphere . Thus, CCD's emphasis on promoting low carbon technologies in the energy sector for achieving adaptation, mitigation, and development makes it an ideal theoretical framework for analyzing RE benefits in SSA.

As far as mitigation is concerned, CCD recognizes emissions reduction as a less priority to developing countries that, if any at all, contributed the least to climate change. That notwithstanding, developing countries have a responsibility to pursue projects that mitigate climate change in line with CCD principles. It is believed that when land use change and forest degradation are considered, the contributions to global emissions of developing countries such as Indonesia, Malaysia, Myanmar, and the Democratic Republic of Congo cannot be ignored (Mitchell & Maxwell, 2010). CCD does not compromise on emissions reductions regardless of which country is involved. It largely promotes the utilization of carbon free technologies, of which RE features prominently.

To illustrate how a mitigation program could result in adaptation and development benefits too within the CCD framework operationalization, a case on Guyana is presented below.

The case study was conducted by Ellis et al. (2009). The government of Guyana pursued a rain-forests preservation program. The project was implemented through a global program known as "Reducing Emissions through Deforestation and Forest Degradation – REDD+ (Ellis et al., 2009)." The implementation of the project attracted payment from REDD+. The primary goal of the project was to create forest carbon sinks leading to emissions reductions. However, adaptation and development benefits were also achieved. The payment made to the government was used for developing RE projects, enhancing adaptive capacity of communities affected by flooding, and for providing healthcare and educational facilities. Within the context of CCD, a mitigation project was planned in a manner that also yielded adaptation and development benefits simultaneously. That is the core foundation of CCD, ensuring that mitigation projects also deliver adaptation and development goals. Overlapping of the three strategic goals is at the center of CCD.

Development strategies

Within the CCD framework, development strategies are policies that aim to promote access to basic social services such as healthcare, education, clean energy for cooking, and improvement in general standard of living (Mitchell & Maxwell, 2010; Fisher, 2013). Adherents of CCD, however, warned that even though closer linkages exist between adaptation and development, it does not always hold that all developments equal adaptation and vice versa (Suckall et al., 2014). Proponents further cautioned that when rolling out development projects, policy makers should balance their priorities such that projects designed to bring development do not incidentally result in GHGs emissions.

A study that highlights how a development project also resulted in adaptation and mitigation co-benefits was conducted by Adkins et al., (2010) in Malawi. Adkins and colleagues evaluated the use of light emitting diode (LED) lanterns by rural dwellers in the southern region of Malawi to identify any benefits thereof. The study communities were beneficiaries of the Millennium Village Project jointly initiated by the Earth Institute at Columbia University and the UN Development Programme (Suckall et al., 2014). The primary objective of the project was to promote rural development. Prior to the implementation of the LED project, the villages were using hurricane lamps that emitted harmful fumes detrimental to health (Adkins et al., 2010). The study, however, found that the switch from hurricane lamps to LED lanterns resulted in significant cost savings. Besides, it was observed by the authors that some households reported engaging in some income-generating activities. The intervention also extended livelihood programs in the evenings and school children could study longer hours in the night (Adkins et al., 2010).

The above study showed that, even though the LED lanterns project was originally designed to deliver development, in the end mitigation and adaptation objectives were accomplished. In terms of mitigation benefits, the study reported that while the hurricane lamps previously emitted carbon dioxide, no emissions were observed from the LED lanterns. Likewise, for adaptation, livelihood diversification became apparent as beneficiaries engaged in more income generating activities than before. In effect, the lanterns created additional avenues for earning incomes and hence the communities diversified their sources of revenue rather than relying on farming alone.

From the analysis of CCD key components with illustrations from developing countries including SSA, it is evident that the CCD theoretical framework is indeed well suited for assessing the benefits of RE deployment in SSA. The practical examples have amply shown how RE projects in some parts of the region actually yielded the triple benefits being espoused by the CCD theoretical framework (adaptation, mitigation, and development). Apart from CCD, there are other theories that also call for an integration of mitigation, adaptation, and development. These include low-emissions climate resilient development, climate resilient pathways, green growth, and low carbon development (Nunan, 2015). All these concepts which are collectively referred to as low emissions development strategies (LEDS) are defined as "forward-looking national economic development plans or strategies that encompass low-emission and/or climate resilient growth" (OECD/IEA, 2010, p. 11)

Despite the seeming affinity between CCD and the LEDS, as their common theme is emissions reductions towards fighting climate change, CCD's distinctiveness is discernable. CCD is overtly more development centered than the other theories and as such, its application to assessing the benefits of RE in SSA is more relevant, as countries in the region are still developing. Certainly, countries in the region need to implement pro-development policies to catch up with development without compromising on the need for low emissions. It is therefore no wonder that most evaluative studies using CCD as a framework were conducted in developing countries (see Stringer et al., 2014; Tanner et al., 2017; Harkes et al., 2015; Suckall et al, 2015; Quan et al, 2017). This is where the relevance of CCD to analyzing the benefits of deploying RE projects within the context of climate change and development is significant. CCD's suitability over the other theoretical frameworks referenced above, to analyzing RE deployment in SSA is anchored on four major reasons namely: (1) CCD being a pro-development approach, (2) emphasis on RE technologies as viable strategies to emissions reduction, (3) suitability to the needs of developing countries and (4) attractiveness to donor agencies and development partners because of triple benefits components (Suckall et al, 2015). It is important to consider a detailed analysis of these four factors.

First, CCD is pro-development and more suitable for addressing climate change and development challenges in developing countries. CCD will have greater appeal and gain more attraction to policy makers in developing countries. Development is of utmost priority in the least developed countries (Flamos, 2010) to the extent that policy makers and politicians are more likely to favor a framework that is development oriented. Though not a good basis, it is argued that developing countries contributed less, if any at all, to global emissions and are not likely to prioritize emissions reduction programs devoid of development component (Mitchell & Maxwell, 2010). A framework that stresses development first while also recognizing the need to address climate change is more attractive and easier to market in the least developed countries and by inclusion SSA. The developing countries need to be assured that adoption of a given framework will address both climate change and development and inure to their benefit (Suckall et al., 2014). As Mitchell and Maxwell (2010, p.1) articulate, "policy makers must promote growth and social development whilst building climate resilience, cutting emissions or keeping them low".

Second, this paper's focus on climate change and RE technologies is consistent with CCD's emphasis on building climate resilience and reducing emissions through deployment of RE technologies. For example, there is a common thread running through an underlying concern of this paper about how to simultaneously address climate change vulnerabilities and lack of energy access in SSA without releasing greenhouse gases and CCD's central focus on reducing energy poverty in developing countries without increasing emissions (Mitchell & Maxwell, 2010). More appropriately and more than any theoretical framework, CCD offers a potential answer for addressing these related concerns – a potential solution lies in RE deployment.

Third, the framers of CCD were motivated by the need to craft a framework to specifically address climate change and energy poverty in developing countries. CCD's theoretical anatomy is region-specific. It has rightly identified issues like climate change, energy poverty, water crisis, and food security as challenges of developing regions and proposed RE as a solution (Mitchell & Maxwell, 2010). In this sense, it has been crafted and tailored to be applied by anyone seeking to address climate change and energy poverty in developing countries. Unlike other frameworks that are generic in content, CCD is specific about the countries of its operationalization. Indeed, there is an alignment between IEA's (2014) energy poverty statistics of 1.3 billion people without energy access in the developing regions and CCD's central focus on reducing energy poverty in developing countries without increasing emissions. Undisputedly, CCD's framework was designed for developing countries, as the advanced countries are more concerned about adaptation and mitigation than development (Suckall et al., 2014). It is no wonder that about a decade since its formulation, CCD's application has only been recorded in developing countries (see Tompkins et al., 2013; Stringer et al. 2014; Suckall et al., 2014, Suckall et al., 2015).

Finally, CCD will also be more attractive to donor agencies because of its emphasis on achieving triple wins concurrently (Suckall et al., 2015). Increasingly donor agencies and international development partners such as the World Bank Group, Africa Development Bank, United States Agency for International Development, Netherlands Development Organization are facing resource constraints to execute multiple projects across the length and breadth of the globe (Pilato et al., 2018). Under such circumstances, operationalizing a framework that can yield multiple benefits through a single project implementation will be economically prudent to the donor agencies and development partners. Within the CCD's framework RE projects, for example, can yield co-benefits for adaptation, mitigation, and development in poorer countries (Suckall et al., 2014). CCD as a framework can potentially help the donor agencies and policy makers in prioritizing and allocating scarce resources to projects that have the potential to yield multiple benefits simultaneously.

Despite being a useful framework for analyzing the benefits to the deployment of RE in SSA, CCD has suffered a number of criticisms. Critics of CCD have identified three major shortcomings associated with it: its very conceptualization; how the three components are valued when addressing trade-offs; and lack of explicit policy governance structure within it (Ficklin et al., 2018). On the issue of conceptualization, it is argued that it is difficult to distinguish CCD from other concepts such as "climate resilient pathways; green growth; and low carbon development" and that it was conspicuously missing in the IPCC's Fifth Assessment report (Ficklin et al., 2018). For Ficklin et al., given its close affinity with other epistemic communities, enough clarification should be provided on its distinctiveness from other theories. Contrary to this criticism, CCD is distinct from the other models mentioned above based on its cautious development first approach, as well as its greater leaning towards helping developing countries to address climate change and energy poverty. The proponents of CCD have been explicit about its core orientation, which sets it apart from other purely climate-based approaches. On the issue of CCD being a value-laden concept couched in economic narratives, it has been argued that to be able to address trade-offs, there ought to be a universal unit of measurement to determine the value of each component. Doing so is, however, not possible due to the complexity attached to the interpretation of what constitutes development. Again, CCD has been explicit about what it considers as development. It clearly identifies access to clean energy, healthcare, education and other social amenities as constituting development.

The third major criticism leveled against CCD is that it is bereft of a policy governance component (Ficklin et al., 2018). Critics raise questions such as how is CCD implementation governed? Will new institutions and governance structures emerge to coordinate the implementation of CCD? Opponents argued that CCD implementation across different sectors certainly creates conflicts in governance. Associated with this last piece of criticism, the opponents argued that achievement of positive environmental results are predicated on choices made by different political actors (McCarthy, 2004) who do so in line with those acting at the global level. The critics maintained that political institutions are not well defined within the CCD framework. This last piece of criticism is undeniable because the role of political actors can either be conducive or inimical to RE deployment in developing countries. As it shall become apparent later in this paper, while political action or the lack of it could impede RE deployment in the developing regions, it is through politicians that the several barriers to RE deployment could be addressed in the developing countries including those in SSA. Such barriers could range from social, political, economic to technical factors. This is a big gap that needs to be filled by integrating CCD with another theoretical framework capable of helping us understand the potential socio-technical factors that can hinder the execution of RE projects in SSA.

Importance of Theoretical Integration in Social Science Research

While CCD remains a useful analytical framework for assessing the benefits to deployment of RE in SSA, it is less well positioned to assessing the barriers to the deployment of RE projects in the region**.** This goes to underscore the fact that while a number of theories can help explain the benefits or barriers to the deployment of RE in SSA, there is no single theory that can assist with analysis of both the benefits and barriers at the same time. Relying on a single theory may lead to an incomplete analysis of both issues. Under such circumstances, theoretical integration is necessary to fill the gap. Indeed, there have been calls for theoretical integration in the scholarly literature. Stern (2014) advocated theoretical integration as an optimal approach towards theory building. Sovacool and Hess (2017, p.745) captured same view nicely when they posited that, "We need more examination of the epistemological underpinnings of theories and more nuanced ways of comparing, contrasting, and synthesizing them." Sovacool and Hess further stressed the need for theoretical integration as an avenue for a researcher to deal with disciplinary bias and activate an in-depth analysis of research data.

In this context, this paper seeks to synthesize two theoretical approaches into an integrated theoretical framework for analyzing the benefits and barriers to RE deployment in rural communities in SSA and in other developing regions of the world. An important observation made by Sovacool and Hess (2017) about theoretical integration is making sure that the theories chosen for integration are ontologically and epistemologically interconnected. With that being observed, the two theoretical frameworks: climate-compatible development (CCD) and Social Construction Technology (SCOT) chosen for integration are ontologically interrelated, because they are both rooted in social constructivist paradigm. CCD is the idea that policy makers in developing countries should pursue projects that can yield adaptation, mitigation, and development benefits concurrently within the context of climate change and development (Mitchell & Maxwell, 2010). SCOT underscores that technological development is not determined by technical factors alone, but by an interplay of both technical and social factors (Pinch & Bijker, 1984). Thus, the two theoretical frameworks are undoubtedly compatible. SCOT nicely complements CCD by enhancing a better understanding of the socio-technical barriers to RE deployment. Before delving into the integration of CCD and SCOT, it is important to review the latter's framework to highlight its general structure and specific components. The SCOT theoretical framework is presented in the next section.

Social Construction of Technology (SCOT)

While CCD can help provide insights into the potential benefits of RE, it is less well appropriate to explain stakeholders' perspectives regarding the problems associated with the deployment of RE projects in SSA. Social construction of technology (SCOT), one of the theoretical frameworks under the broad spectrum of sociotechnical approaches, will be used to complement the CCD. Apart from its relevance to analyzing what the various stakeholders or social groups would identify as problems with RE projects deployment in rural SSA, SCOT is also suitable for eliciting stakeholders' views on what they would proffer as solutions to the problems identified. In the analysis that follows, the historical background of SCOT, its basic tenets and some key concepts embedded in it, as well as some criticisms against it are analyzed.

The term sociotechnical emanates from the idea that technology and society do not stand-alone, but co-evolve and complement each other (Geels, 2004). A number of theories that are useful for explaining sociotechnical change exist. Sovacool and Hess (2017) have identified several theoretical frameworks that largely lean towards analyzing sociotechnical systems. While most of the theories have common attributes that qualify them as sociotechnical, some of them are more closely related by disciplinary orientation and prior collaboration among proponents. Sovacool et al. (2018, p. 1072) have outlined five of such approaches that are broadly related and yet distinct in specific areas. These approaches are: Multilevel Perspective (MLP), Actor Network Theory (ANT), Social Construction of Technology (SCOT), Technological Innovation Systems (TIS) and Large Technical Systems (LTS). All of these approaches are bounded by identical traits that render them truly sociotechnical (Bijker et al., 1987). I will briefly address the elements that consolidate them, as well as those that set them apart before focusing on SCOT.

The first modality that characterizes what could be referred to as the classical sociotechnical frameworks listed above is the incorporation of technology into the domain of social studies of science. The early 1980s saw a dramatic turn towards technology by many sociologists and historians (Forman, 2007), propelled by political antecedents in Europe, especially UK under the leadership of Margaret Thatcher (Woolgar, 1991). The second common feature shared by all the classical sociotechnical approaches is a Hughesian metaphorical concept of "seamless web" (Hughes, 1986). The term "seamless web" in the sociotechnical context connotes an idea of an unrestrained interaction between science and technology in a manner that any perceived boundaries between the social and the technical were created by social actors engaged with a given technology rather than any predetermined factors (Bijker et al., 1987). The "seamless web" of technological development stresses that technology and society are intricately intertwined in determining the success or failure of a given technology. In this sense, the technical, social, economic, and political factors are inseparable in explaining technological development. The notion of a "seamless web" thus feeds into the "social constructivist" perspective, which holds that the social context tends to shape a given technology through the actions of various actors (Bijker et al., 1987). This holds true for RE technologies deployment in developing countries including SSA, where socio-cultural factors tend to influence projects execution. A third identical trait underlying the classical sociotechnical frameworks is the pursuit of both empiricism and theory. The primary goal of the sociotechnical theorists is to understand the interaction between actors and technology through empirical study of the social processes through what Geertz (1973) referred to as "thick description". It is not surprising that most, if not all sociotechnical theories, were formulated following practical observation and analysis of how the social world influenced and shaped technological developments (see for example Callon, 1987 study on Electricite' de France; Pinch & Bijker, 1984 study on the development of the bicycle).

While the classical sociotechnical frameworks are bounded by certain commonalities, there are subtle differences among them. Bijker et al. (2012, p.14) nicely capture this variation in the following quote: "Stressing these commonalities does not imply that we do not recognize important differences. Indeed, we frequently warn over-enthusiastic students who often want to combine elements from the different approaches into one common theoretical framework to be careful." While, for example SCOT stresses on relevant social groups, ANT considers both humans and nonhuman forces in shaping a technological change. Also, whereas LTS is less opposed to technological determinism, SCOT is outrightly ant-deterministic, a trait also shared by MLP (Sovacool & Hess, 2017). Pinch and Bijker (1984), two pioneers of the SCOT school of thought for example, argued that the belief in a technological determinism is a myth. Furthermore, ANT is more receptive to political action than its counterparts (Sovacool and Hess, 2017). And while TIS deals more with microlevel technological innovations, LTS leans heavily towards large scale technologies (see Hughes, 1987). The following quote from Bijker et al. (2012, p.13) further highlights the differences existing among the sociotechnical approaches discussed here despite their strong affinity. "We can recall asking Bruno Latour, Michel Callon, and John Law (Proponents of ANT) whether they really believed the slide projector in the conference room should be treated as an actor equivalent to the excited sociologists and historians gathered around it". As Bijker et al. (2012) observed, regardless of these differences, the commonalities among them are much more important when thinking about an integrated constructivist approach towards analyzing technology. Indeed, all of them are concerned with how people interact with and apply technology.

On the basis of Bijker et al's (2012) advice against collapsing all the approaches into a unified framework, I will focus on SCOT. I chose SCOT, because it is suitable for analysis of the socio-technical factors that can shape the deployment of RE in SSA from the perspectives of stakeholders. Compared with the other affinal theories, SCOT's leaning towards technological indeterminism renders it most appropriate, as socio-cultural factors strongly hold sway over technical factors in shaping RE development in SSA (Bailis et al., 2009). Given that the goal of this paper is to develop an integrated theoretical framework for assessing stakeholders' perspectives of the benefits and the barriers to the deployment of RE technologies, SCOT is thus most appropriate for my analysis. Also, I want to stress that it will complement CCD, because while SCOT is capable of addressing the sociotechnical factors (barriers) that can influence the deployment of RE in SSA, CCD is less suitable for that aspect of the analysis. As with the other sociotechnical theories, SCOT is both a theoretical and a methodological approach that originated from the related fields of Sociology of Scientific Knowledge and Sociology of Technology (Bijker et al., 2012). Advocates of SCOT believe that technology does not determine human activities, rather it is the actions of people that shape technological development (Pinch and Bijker, 1984). For the "SCOTists", a piece of technology can only be well understood within the social contexts that the technology is being used. Using the SCOT framework can help us understand the socio-cultural factors that can promote or stifle the deployment of RE projects in different societies within SSA. For example, SCOT can be used to explain why the deployment of RE could be a success or a failure within certain sociocultural contexts, whereas CCD can only address the benefits.

SCOT is a theoretical framework that has relevance to the study of different technologies. In other words, the approach lends itself to broader technological applications including RE projects. Following its emergence, it soon became an integral part of science and technology studies (Bijker et al., 1987). SCOT considers multiplicity of factors such as technical, social, economic, and political when analyzing a piece of technology. Using the SCOT framework can help us understand how the above sociotechnical factors can shape the deployment of RE projects in SSA. The primary focus of SCOT is its emphasis on the different meanings and interpretations stakeholders assign to a technology (Sovacool et al., 2018). Thus, various social groups and stakeholders who are the users of technology are the ones that define and shape a technology. As far as SCOT is concerned, an explanation for an acceptance or rejection of a technology should be sought from the social world. Sovacool (2006), for example, pointed out that public acceptance of RE technologies is not only determined by the technical systems in place, but social influences as well. Under SCOT, both technical and social factors play out equally in determining the success or failure of a given technology (Pink & Bijker, 1984).

By the core tenets of SCOT, a successful development of an emerging technology is not predicated on resource abundance and technological advancement, but rather by a panoply of different conditions such as the technical, social, economic and political factors stated previously. A clear example supporting this view was a study conducted by Goldthau and Sovacool (2016) on the development of shale gas resources in Eastern Europe. It is worth mentioning here that despite the environmental consequences and the attendant protests, shale gas exploitation has already revolutionized US energy market and transformed the country from being a net importer of energy to a net exporter of energy since 2010 (Yergin, 2012). Given that the shale gas exploitation has reshaped the US energy market and to some extent geopolitics, by means of hydraulic fracturing technology, similar outcomes could be expected from other shale gas resource-endowed countries. In their study of the evolving shale gas landscape in Romania, Bulgaria, and Poland, Goldthau and Sovacool (2016), however, found that neither resource abundance nor technological advancement is driving the market in these countries studied. It is rather the opinion of various stakeholders that account for the extent to which the shale gas resources could be exploited in those countries and by extension other countries that are similarly endowed.

The SCOT theoretical approach is underscored by key concepts which are worth digesting (1) interpretative flexibility, (2) relevant social groups and (3) closure and stabilization. *Interpretative flexibility* implies that there are varying interpretations to a technology and the way that a given technology is interpreted is socially constructed (Pinch & Bijker, 1987). Pinch and Bijker further explained that because technological problems can be identified by social groups in a defined social context, technological design could vary. While some groups might appreciate RE projects as being useful to their economic wellbeing, others could discount such projects as interfering with the existing social structure in place. In other words, the nature of technology and associated problems are subject to different interpretations. *Relevant social groups* suggest that different social groups assign different meanings to a technology (Bijker, 1995). In the same way, the social groups also identify different problems with the technology with varying expectations as solutions to the problem (Pinch, 1996). Pinch &Bijker (1984, p.41), for example argued that “a problem is defined as such only when there is a social group for which it constitutes a problem.” *Closure and stabilization* in the process of technological development is attained when there is a mutual agreement among stakeholders that a problem that emerges from the development of a technology has been addressed. The involvement of different social groups in technological development often imply that there are bound to be conflicts and disagreements over solutions to same problem. In the process, however, consensus will be reached. It is that stage in the technological development when social groups agree that a problem has indeed been eliminated and the technology is stabilized (Bijker et al., 1987). In other words, conflicts and disagreements usually precede closure and stabilization.

Despite its usefulness in helping to understand the factors that can make and unmake a new technology, SCOT has attracted some criticisms. An ardent critic of SCOT is Winner (1993), who argued that proponents of SCOT are fixated on pointing out various interest groups that play a part in the emergence of a given technology to the neglect of inherent qualities of the technological change itself. In other words, "SCOTists" ignore certain in-built qualities of a piece of technology that could contribute to its success or failure. Winner further criticized SCOT for its silence on technological ethics relating to nuclear power technology. Klein and Kleinman (2002), also criticized SCOT for overlooking power relations – a question of which social groups' views are included or excluded or what power does each social group possess to influence the process.

Notwithstanding the criticisms leveled against it, the SCOT framework, in my view, still stands as an important analytical tool for deciphering the social, political, economic, technical, and socio-cultural challenges associated with any emerging technology. Using such a framework will help policy makers identify the socio-cultural issues that underlie the technical constraints. Understanding the non-technical hurdles impeding technological development could help policy makers devise appropriate strategies to clearing the impediments. The SCOT approach has demonstrated that for any new technology to succeed both technical and social conditions must be present. By this understanding, it can be fairly concluded that technological success is a function of an interplay of social and technical factors. What I have accomplished thus far has been a distinctive presentation of two separate theoretical frameworks that are to be transformed into a powerful integrative approach to facilitate an in-depth analysis of RE technologies deployment in rural communities in SSA.

While CCD has been shown to be appropriate for interpreting stakeholders' perspectives of the benefits associated with RE projects in rural communities, SCOT is undisputedly well-suited for making sense of the socio-technical factors that could promote or hinder RE projects deployment from the insights of relevant social groups who often constitute the stakeholders. As such, a synthesis of the two approaches is next presented. The purpose of synthesizing CCD and SCOT is to have a composite analytical framework for anyone who want to explore the benefits that rural communities can derive from RE projects, as well as an understanding of factors that could pose challenges for both development partners and beneficiary communities within the context of climate change and development. Though the proposed framework is primarily targeted at researchers conducting research on the benefits and barriers of RE technologies in SSA, the synthesized approach could be useful to academics, students, and professionals undertaking research relating to any technological development in rural communities in other developing regions of the world.

Towards an Integrated Approach for Assessing Benefits and Barriers to Deployment of Renewable Energy Projects in Rural Communities in SSA

Towards this end of the analysis, it is imperative to synthesize aspects of the two theoretical frameworks discussed above to have an integrated approach for assessing the benefits and barriers to deployment of RE projects in SSA. This has become necessary because, though useful frameworks, CCD and SCOT approaches are, by themselves incomplete, and therefore blending aspects of both for holistic analysis of the deployment of RE projects within the context of climate change and development is ideal. Drawing on both CCD and SCOT, a concerted approach that would allow for a systematic analysis of the benefits and barriers to the deployment of RE projects in rural SSA is depicted in table 2.1.

Table 2.1
An Integrated climate compatible development and social construction of technology Framework

Benefits	
Adaptation	Strategies meant to promote livelihood diversification, create opportunities for learning new skills and innovative ideas, limit reliance on natural resources for survival, bridge inequality gap and ensure equal participation in decision making process by all stakeholders.
Mitigation	Strategies promoting less energy use, generating more energy from low-emissions sources, protecting carbon stores such as forests, encouraging the development of low-emissions technologies, and providing incentives to discourage high-emissions investments.
Development	Strategies that promote access to basic social services such as healthcare, education, clean energy, and improvement in general standard of living.
Socio-technical factors/barriers	
Political	Lack of political will to support RE projects Unstable political institutions Ineffective law enforcement system
Economic	High unemployment rates among citizens Poor salaries and generally low incomes
Infrastructure	Lack of funding opportunities for RE projects and infrastructure Less focus on off grid RE development in rural areas Lack of or irregular maintenance of existing RE infrastructure
Regulatory	Non-existing policies to promote RE deployment and use Poor incentives for prospective RE investors and customers
Financial	No funds for RE projects implementation Absence of subsidies for RE projects in rural communities Financial institutions' unwillingness to support RE deployment Limited international agencies and donor support

Technical	Unavailability of RE technical expertise in developing countries Immature RE technologies in developing countries Absence of technical institutions for training RE technicians
Research & Dev't (R&D)	Limited support for RE research and development No fundraising activities for RE research & development
Socio-cultural	Negative beliefs, values, and practices towards RE projects Lack of information about the benefits of RE projects by local people Poor acceptance of RE projects by rural people

The strength of this integrated framework is its ability to enhance our understanding of the benefits and barriers to the deployment of RE in SSA at the same time. While using a SCOT focal lens can help provide insights into certain actions/or inactions of stakeholders that might impede the deployment of RE in SSA, explaining the benefits through a CCD frame can have positive impact and drive action towards promotion of RE deployment in the region. In order to meaningfully demonstrate how the CCD-SCOT framework works, it is helpful to provide an illustration that contextualizes the various components embedded in the integrated framework (Figure 2.2).

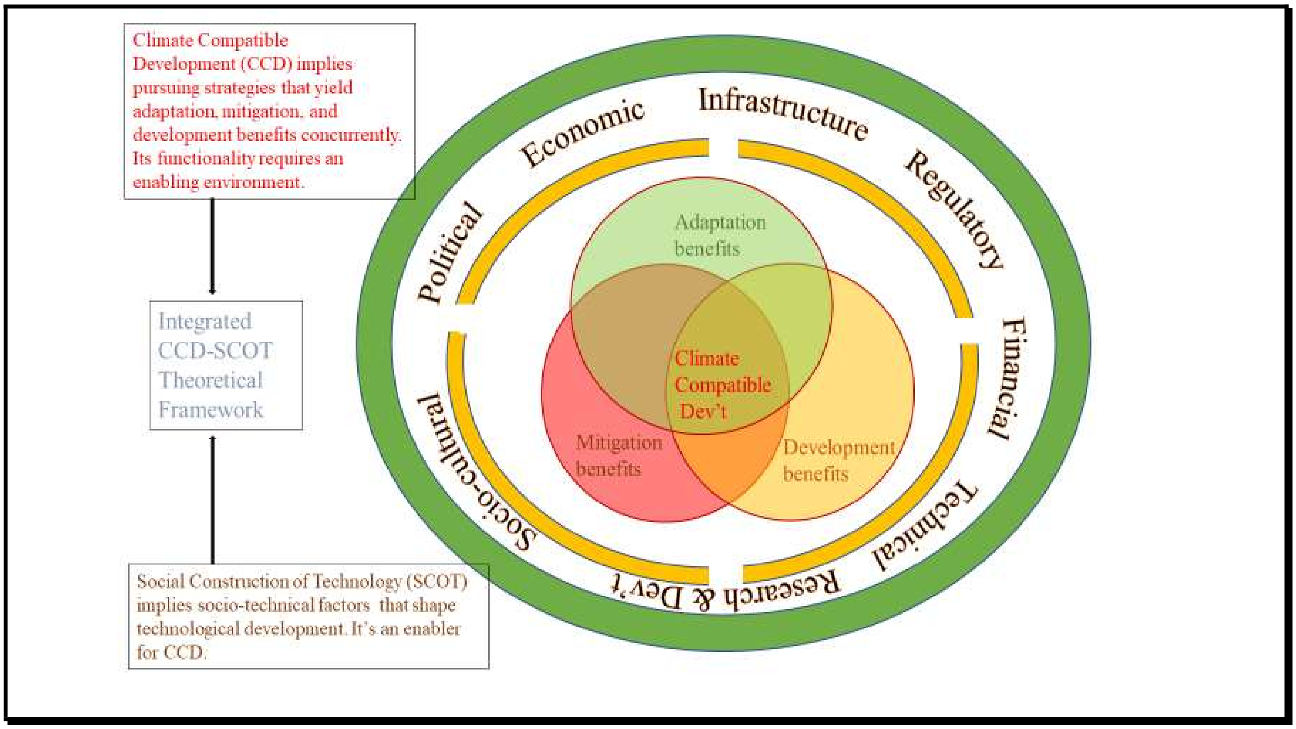

Figure 2.2. Integrated Climate Compatible Development and Social Construction of Technology Theoretical framework. Source adapted and modified from Mitchell & Maxwell (2010), Bijker & Pinch (1984).

Political factors

Taking the political factor for example, the sub-continent of SSA is no doubt endowed with enormous RE potential, however, the political will to promote RE in the region is woefully lacking. A South African Feed-in-Tariff policy, for instance, failed on grounds of lack of political commitment (Haselip et al., 2011). The lack of political will among SSA governments could be addressed when the benefits of RE such as livelihood diversification (adaptation), preservation of forests (mitigation) and access to basic social services (development) are fully explained to them through a CCD lens. In this case, while SCOT framework can help us identify that the non-commitment on the part of politicians towards RE development in the region is a barrier to RE deployment, CCD framework would highlight the multiple benefits that could be derived from RE deployment. As Flamos et al. (2010) noted, development is a topmost priority in SSA, and as such, politicians are more likely to better understand a framework anchored on development. Typically, governments in SSA tend to support fossil-fuel based investments than RE projects (Amigun et al., 2008). However, if political actors in the region begin to realize that investing in RE could also create business and employment opportunities for the citizens, especially those in the rural areas, RE projects would begin to receive significant governmental support. Politicians might initially be adamant to RE projects, but when the full-scale benefits of RE are explained to their understanding, they would begin to create conducive atmosphere for their deployment.

Economic factors

One of the barriers to the development of RE in SSA that can be deduced from a SCOT framework is an economic problem of low income in the region that prevent people from utilizing RE. Take for example, the cost of 50watts solar panel is about US$400 together with other accessories, meanwhile about 90% of rural people in SSA earn below US$50 a month (Othieno & Awange, 2016). This means that the majority of people cannot afford to pay for the cost of electricity generated from RE sources. Besides most of the population in the region are not gainfully employed whereby deductions for loan payment could be made at source. Despite the economic hurdle of low income among rural people in SSA, the problem could be addressed by weighing the multiple benefits that rural people stand to gain from RE projects. Within a CCD framework, deployment of the RE projects could benefit the people in the form of economic empowerment as access to energy would enable them to learn new skills. Some people could gain employment by being engaged to work for the organizations executing the projects. This could also go a long way to bridge the inequality gap between rural people and their urban counterparts. Mitigative benefits could be derived as well when rural people are empowered economically and are able to switch from cutting down trees as fuel to using energy from RE sources. There could be associated development benefits too from using clean energy such as improvement in healthcare and access to educational facilities.

Infrastructural factors

Viewing the lack of modern energy infrastructure to support RE projects in SSA could be a barrier from a SCOT perspective. Govinda et al. (2010) maintained that the absence of adequate infrastructure such as transmission lines to facilitate the deployment of RE remains a major barrier in SSA. The existing electricity infrastructure in SSA is obsolete, which cannot support modern energy technologies like RE (Energy Information Administration, 2011). As a region, SSA lacks regional grid connectivity which is an impediment to the deployment of RE projects in the region (IEA, 2014). The deployment of RE projects, for example large scale solar and wind farms, usually require vast areas of land, which is available in rural SSA, however, the lack of grid infrastructure in the rural areas is problematic (Ohunakin et al., 2014). Obviously, the lack of infrastructure is a barrier in the context of SCOT. To address the problem of infrastructure, governments in the region must be made to recognize that developing the infrastructure to facilitate the deployment of RE in rural SSA would generate multiple benefits within a CCD framework. Most people cut down trees for energy and also depend on rain-fed agriculture (FAO, 2007) because they lack alternative sources of livelihood. In addition, rural people in the region depend on unhealthy energy sources such as animal dung, crop residue all of which affect their health (Sustainable Energy for All [SE4ALL], 2012]. However, if the energy infrastructure is developed to provide clean energy from RE sources, they would no longer depend on unhealthy energy sources, thereby improving their health.

Regulatory factors

SSA no doubt has plentiful RE potential, but ineffective policy formulation and implementation regarding RE deployment in the region is a huge barrier (Mohammed et al., 2013) under SCOT. Weak regulatory and institutional support for RE development in SSA remain a significant hindrance, because existing governmental support in the form of subsidies favor conventional energy sources (Ohunakin et al., 2014). To advance the course of RE in SSA, the sector needs some regulatory support in the form of subsidies and incentives to create an even playing ground (Fischer et al., 2011). In few instances where some non-governmental organizations (NGOs) have championed the development of RE in SSA, their efforts failed because they did not receive the necessary institutional and regulatory support (Othieno & Awange, 2016). Addressing the regulatory barrier could be made possible if the governments in the region are informed about the benefits of RE projects to rural communities in the context of CCD framework. Given the widespread climate vulnerabilities in the region, governments should be made aware that enacting policies to promote RE projects in the rural areas would not only generate development benefits as in improvement in the standard of living, but there would be adaptation and mitigation benefits as well. Adaptation benefits could result from the projects when rural people switch from reliance on natural resources to acquiring new skills and doing businesses. Also, mitigation benefits could emanate from the projects when there is a stoppage or reduction in kerosene and fuelwood use.

Financial factors

Also, within a SCOT framework, funding could pose a huge barrier to RE deployment in SSA, because the economies of most SSA countries are generally weak and most of the citizens cannot afford to pay for the cost of electricity generated from RE sources (Mohammed et al., 2013; Othieno & Awange, 2016). There is also a general lack of credit facilities to support investment in RE technologies (Mohammed et al., 2013). The lack of funding opportunities and low-income levels in SSA constitute a huge financial hurdle in the context of SCOT framework. To overcome the lack of funding opportunities for RE, the governments, donor agencies, development partners, and investors have to be convinced that channeling funds into RE deployment could create multiple benefits ranging from reduction in deforestation, opportunities for businesses, improvement in healthcare and general economic growth (Mitchell & Maxwell, 2010). It would take an explanation of the CCD components (adaptation benefits, mitigation benefits, and development benefits) embedded in the integrated framework to motivate stakeholders to embrace the idea of investing in RE in SSA.

Technical factors

It has been asserted that unlike other jurisdictions where RE development commenced around the 1970s, countries in SSA have only recently embraced the technology (Othieno & Awange, 2016). Thus, RE technologies are a novelty in SSA and have not yet reached maturity to compete favorably with the more mature fossil-fuel based technologies (Fischer et al., 2011). Consequently, people with the requisite skills to champion the course of RE projects in SSA are not readily available (Uyigue & Archibong, 2010). In addition, African leaders are guilty of nepotism when considering people for jobs requiring technical expertise. All these problems outlined here are technical barriers to the deployment of RE in SSA when viewed from a SCOT standpoint. Once a substantiation of the lack of technical expertise as a barrier to RE deployment by a SCOT frame is made, the issues can only be addressed when the benefits of developing the technical expertise in the region are contextualized within a CCD framework. For policy makers to spearhead the establishment of technical institutions to resolve the challenge of RE technical know-how deficit in the region as revealed by a SCOT framework, they must be made to understand the multiplicity of benefits associated with such investment from a CCD perspective. Policy makers should be informed that establishing technical institutions to train personnel to support the RE sub-sector could create a chain of employment opportunities, especially for the youth.

Research and Development (R&D) factors

To promote RE deployment, there is the need for R&D schemes in the region, but this is not the case as R&D centers exist in only few SSA countries while the practice is completely absent in most African countries (Govinda et al., 2010). The absence of well-resourced R&D centers in SSA specifically dedicated to the promotion of RE development is a barrier (Othieno & Awange, 2016). The few countries where R&D centers exist, inadequate budgetary allocation usually render them ineffective (Othieno & Awange, 2016). Again, the problem of limited R&D centers to promote RE development in SSA could be resolved if the benefits of RE are made well known to all stakeholders in the region. The poor attitude and less attention given to the sector might be due to misinformation or lack of information on the multiple benefits that can be derived from such projects. A CCD framework is an excellent tool for explaining the benefits.

Socio-cultural factors

As a further illustration of an operationalization of a CCD-SCOT integrated framework, let us consider how certain socio-cultural issues could pose as barriers to RE deployment in SSA in a SCOT context and the way by which an explanation of the benefits via a CCD lens could help to overcome such barriers. Mohammed et al. (2013), for example argued that the practice where cooking is mostly done in enclosed areas in many SSA rural communities is not suitable for tapping wind energy. Under such scenario, limited or no ventilation outlets are provided to vent the smoke when cooking indoors (Othieno & Awange, 2016). The situation could pose serious health hazards to the respiratory systems of most women and children who are always at the mercy of such practices (Mohammed et al., 2013). While these socio-cultural practices could be understood as barriers to the deployment of RE from the viewpoint of SCOT, they could be addressed by a CCD-grounded explanation. For example, if rural communities are made to believe that cooking with firewood in an enclosed area has negative implications on their health, but the situation could be resolved through the use of solar cookstove in a well-ventilated environment, they are more likely to embrace RE solutions. Oftentimes, rural people in SSA are adamant to social change for lack of information about the benefits of a novel practice. As Govinda et al. (2010) suggested, there is a huge information gap on the potential benefits of RE in SSA. It has been pointed out that a whopping 90% of rural population in SSA who form the majority in the region are generally unaware of the substantial benefits to be derived from RE sources (Othieno & Awange, 2016).

Following from the illustrations, applying a CCD-SCOT integrated theoretical framework to analyzing the benefits and barriers to the deployment of RE in SSA has the added advantage of enabling an understanding of both issues simultaneously. While, for example, through a SCOT framework we could better understand that a lack of political commitment on the part of politicians could be a barrier, an explanation of the benefits from a CCD standpoint could help overcome such a sociotechnical barrier and pave the way for smooth deployment of RE projects in the region. The above integrated framework can be used to assess both the benefits and barriers to development of projects in SSA and in the other developing regions of the world. The framework can be operationalized in two ways. First, it can be applied to assess the perceived benefits and barriers prior to the actual deployment of RE projects in rural communities from the perspectives of stakeholders including donor agencies, development partners, government agencies and the beneficiary communities themselves. In this regard, rural communities without access to electricity could be studied to identify what would be the likely benefits and barriers to deployment of RE projects. The outcomes would then guide policy makers and development partners to prioritize the allocation of scarce resources to communities where the projects would yield multiple benefits with less obstacles to deployment. The second way by which the integrated framework could be applied is to use it to assess the benefits and challenges of utilizing RE projects in communities where the projects have already been deployed. The outcomes of such assessment would also guide policy makers and donor agencies to prioritize extending such projects to similar communities. This way, the development partners and government agencies would learn from the results and make the necessary changes to the projects when deploying in other communities.

Application of CCD-SCOT Integrated Framework to a Specific Case Study

The aim of this section is to demonstrate how this integrated CCD-SCOT framework can be applied using a specific case study. The case study shows how socio-technical barriers ranging from political to socio-cultural have been addressed in Kenya, after the government realized the benefits that could be derived from the projects. According to Njugunah (2018), as of 2013, Kenyan national electricity access stood at 32%, but increased to 73% in 2018 due to massive RE projects deployment, supported by measures put in place to address some of the socio-technical barriers highlighted in the SCOT framework. The outcome of the increased deployment of the RE projects yielded adaptation, mitigation and development benefits in the context of CCD. In this case study, I will analyze strategies instituted by the government to address political, regulatory, technical, financial, infrastructural, and socio-cultural barriers that paved the way for RE deployment in the country from a SCOT perspective. I will also point out specific benefits yielded from the initiatives using a CCD lens.

Prior to 2004, the Kenyan government had no explicit policy in place to guide the deployment of RE projects in the country, which was obviously a barrier, as there was no political commitment. However, in 2004, the government crafted a comprehensive energy policy document known as Sessional Paper No.4 on energy with specific guidelines on RE deployment (Government of Kenya, 2004). The policy contains short to long term RE development goals and features initiatives such as promotion of solar energy; standardization of RE development, incentives packages for local manufacturers of solar panels and accessories; severe punishment for anyone who interferes with the construction of solar energy facilities (Mas'ud et al., 2016). In addition, the government passed an Energy Act in 2006 (Government of Kenya, 2006). A whole section of the Act is dedicated to the promotion and development of RE in the country. The Minister responsible for RE development was charged to channel resources into the building of in-country capacity to take on the task of developing RE projects such as biodigesters, solar systems, hydro, and wind turbines. As part of her regulatory measures to promote RE, the government also granted tax concessions to entities willing to venture into the business of either locally manufacturing solar PV accessories or importing them into the country (Othieno & Awange, 2016). A national policy requiring most public institutions to install solar rooftops was introduced which resulted in about 150 public institutions harnessing solar power for their electricity needs (Jacobson, 2004). This amounted to approximately 360 kilowatts of solar energy capacity, whilst the rural communities alone had an installed capacity of electricity in the region of 6 megawatts (Jacobson, 2004). It has been estimated that about 30, 000 households in

Kenya purchase and use small solar systems annually (Martinot et al., 2002). In 2003 alone, sales of solar home systems exceeded the target sales by 220, 000 units, while there were about 7000 solar thermal units for use in the agricultural sector for food processing (Jacobson, 2004).

As underscored by the SCOT framework, lack of technical expertise is a huge barrier to RE deployment in SSA. To overcome this problem, the government of Kenya established technical programs for training indigenes on manufacturing and maintaining RE accessories (Mas'ud et al., 2016). The government also engineered a partnership between locals and foreign expertise that created a window for transfer of technical knowledge in RE. An example of such collaboration exists between the Dutch Ubbink and Kenya's Chloride Excide Company (Mas'ud et al., 2016). The technical joint venture resulted in production of solar cells locally. Indeed, the partnership has greatly addressed the technical barrier to RE deployment in Kenya, but which continues to be a nightmare for many other countries in the region. Now local people in Kenya are producing and installing solar panels throughout the country.

The government of Kenya has also instituted measures to address a socio-cultural barrier to RE deployment in SSA. The involvement of local people, especially rural dwellers, in the RE manufacturing chain and use of local materials to construct solar cookstoves, for example, has cleared a socio-cultural barrier obstructing RE development in the country (Mas'ud et al. 2016). With their involvement, the local people now appreciate the importance of RE. Public education has also been used to address a problem regarding acceptance of a new technology by rural people in SSA by highlighting the health benefits of RE utilization. Research and development, which has been a barrier in most SSA African countries has been tackled in Kenya. The government has established a solar academy responsible for R& D in solar energy (Magenta

Global Pte Ltd., 2015). Higher institutions of learning have been tasked to research into green energy options (Othieno & Awange, 2016).

Furthermore, funding support for RE projects was unavailable which remained a huge barrier until the government established the RE Fund to address the problem of funding (Magenta Global Pte Ltd., 2015). In addition, government set up a financing scheme purposely to fund RE projects. The scheme allows, for example, potential users of solar energy to access credit facilities from any commercial bank in the country if purchases of equipment are to be made from local manufacturers (Magenta Global Pte Ltd., 2015). The government sought financial support from Belgium to construct the largest wind farm in Africa in 2013, estimated to have cost $760 million (Kiplagata et al, 2011). Similar financial support had been sought from the World Bank for expansion of RE projects in rural communities in SSA (Njugunah, 2018).

Within a CCD framework, adaptation, mitigation and development benefits are discernable from the increased deployment of solar projects in Kenya. In terms of mitigation benefits, the mass utilization of solar energy in the country translated into reduction in fossil-fuel consumption, implying less carbon emissions. Adaptation benefits are visible in the creation of employment for the indigenes who ventured into the business of manufacturing and maintaining the solar panels and accessories. From a development point of view, access to clean energy means significant health benefits for those who utilize the solar systems. A huge benefit of the projects from a CCD stance is skill diversification among locals who initially lacked the expertise in RE technology. It thus created employment opportunities for the indigenes who acquired the technical expertise from their foreign counterparts.

Again, the triple benefits drawing on CCD framework are apparent here. The local people who had been trained on how to manufacture solar cookstoves have diversified their skills and would no longer rely on only rain-fed agriculture or remained jobless as it has always been the case with many people living in rural SSA. Numerous employment opportunities have been created to enable them to strengthen their adaptive capacity. That way, they can respond to and adjust to changes in the climate as their sources of income increase. Mitigative benefits are also obvious as solar cookstoves are widely being used in the country, thereby reducing the practice of cutting down trees for cooking purposes. Development wise, using clean energy has a lot of development benefits for the rural people especially. Women and children living in households that use the solar cookstove are being protected from indoor air pollution during cooking.

Also, the policy that allows local manufacturing entities to access credit facilities from banks has both adaptation and development benefits. As an adaptation benefit, the scheme allows local manufacturers to expand their businesses to earn more income, which means empowering them economically and building their adaptive capacity. Once people are able to grow their businesses and earn additional income, there is a likelihood of acquiring certain assets to improve their overall standard of living.

Conclusion

The aim of this paper was to synthesize two important theories into an integrated theoretical framework, which would be used for assessing the benefits and barriers to the deployment of RE projects in rural communities in SSA and by extension, other developing regions in the world. The integrated CCD-SCOT framework can be applied to the study of RE technologies in the developing regions around the world. Given the multiplicity of theories existing in the social sciences, and the difficulties in identifying appropriate theory to guide one's research, theoretical integration has become necessary. Theoretical integration is particularly needed when the use of one theoretical framework is inadequate to help with a thorough analysis of the phenomenon under study. Understanding of the benefits and barriers to the deployment of RE in SSA is a complex social phenomenon that requires a composite theoretical framework to enable an in-depth analysis.

While a number of theories can help explain the benefits and barriers to RE deployment in SSA, using one theory can only produce incomplete analysis of both issues. Thus, the integrated CCD-SCOT framework developed in this paper provides a comprehensive framework that can be utilized to assess both the benefits and barriers simultaneously. The two are compatible and complementary theoretical frameworks in that they are both rooted in a social constructivist paradigm. In a CCD context, RE deployment in SSA can yield adaptation, mitigation, and development benefits. However, the deployment of RE could be hindered by certain socio-technical factors which are explainable by a SCOT framework. Such socio-technical barriers could range from technical to socio-cultural factors that could be addressed by explaining the benefits that are likely to result from RE projects for rural people. It is by explaining the benefits to key stakeholders like policy makers and politicians that the barriers could be addressed. When political actors are made to appreciate that deploying RE projects in rural communities has the potential to empower rural people economically, reduce their reliance on natural resources, create skills diversification, and improve their health that policies could be initiated to undo the barriers and pave the way for smooth deployment of the RE projects. The politicians for example, need to clearly understand and appreciate the many benefits of the RE projects in rural areas within a CCD lens before they would be motivated to look for the necessary funding, which is a huge barrier in a SCOT framework. Also involving local people in the process of deploying RE projects addresses a socio-cultural barrier and triggers several benefits for the people themselves.

There are some implications in terms of contributions of the paper. First, the integrated framework enhances the two original theories' applicability to the context of RE in SSA. The core tenets of each theory have been retained and extended to create room for operationalizing them for analysis of the benefits and barriers to RE deployment in SSA. Second, the paper has added to the few existing examples of theoretical integration. The practice of bringing together two or more separate theories to facilitate the study of a complex social phenomenon, like RE deployment, is a burgeoning area that needs more scholarly contributions. Third, with the newly integrated theoretical framework, it is possible for any researcher assessing the benefits and barriers to RE deployment in SSA to be able to do so using this unified framework. With this framework, it is practicable to conduct a thorough assessment of both the benefits and barriers of RE deployment in SSA at the same time. Using a CCD-SCOT integrated framework can enhance our understanding that establishing technical institutions to train people to manufacture and service solar energy accessories locally could strengthen the adaptive capacity of the local people, reduce their vulnerabilities to climate change, reduce dependence on unhealthy energy sources, and improve healthcare. For future research, this paper has created an opportunity and a necessity. Conducting further research using the integrated CCD-SCOT framework is needful as that can help deepen our understanding of factors surrounding the potential and actualized deployment of RE in SSA. There is little doubt that the theoretical synthesis provided here has set a pace for empirical research to be carried out into the benefits and barriers to RE deployment not only in rural SSA, but also in other developing regions of the world. Future empirical studies can help refine and reshape the theoretical understanding proposed here.

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Chapter 3

Assessing adaptation, mitigation, and development benefits of solar mini grids in Ghanaian rural island communities

Abstract

While the majority of people living in sub-Saharan Africa depend on rain-fed agriculture and remain vulnerable to climate change, energy poverty is also pervasive, as about 70% of the population in the region lives without access to electricity. Given these two major problems, and a vast renewable energy resource base in the region, renewable energy deployment is considered a viable strategy to address climate change and energy poverty. This paper uses climate compatible development framework to assess the benefits of solar mini grids to Ghanaian rural island communities in sub-Saharan Africa. The study applied a survey to identify the benefits of solar mini grids to rural households. The survey finds that solar mini grids can deliver adaptation, mitigation, and development benefits to rural households simultaneously within the context of climate change and development. Consistent with these three dimensions, the benefits identified include engagement in alternative income generating activities, preservation of fish in fridges without cutting trees for smoking, and improvement in educational performance and healthcare delivery. The study concludes that renewable energy projects can address both climate change and energy access concurrently in the developing countries. We argue that an increased solar mini grids deployment in sub-Saharan Africa would save policy makers and development partners substantial resources that would have otherwise been expended on different projects to achieve adaptation, mitigation, development goals separately. We further contend that the potential of renewable energy solutions to yield such co-benefits underscores their suitability to rural areas in the developing countries.

Key words: Climate compatible development, solar mini grids, tri-benefits, Ghanaian island communities

Introduction

Sub-saharan African (SSA) like many developing regions in the world is beset with a legion of developmental problems. Climate change and lack of energy access are, however, two daunting challenges affecting overall progress in the region. Research has shown that SSA countries might not be able to cope with escalating climate change vulnerabilities due to weak adaptative capacity (Stern, 2007), as majority of the people living in the region depend on rain-fed agriculture (Food and Agricultural Organization [FAO], 2007). Over reliance on natural resources is a conduit for climate change vulnerabilities (Adger et l., 2007). While climate change continues to pose threats to the development fortunes of many SSA countries, energy poverty is also prevalent in the region.

Countries in SSA are faced with energy poverty as 70% of the population in the region have no access to electricity (Power Africa, 2018). According to International Energy Agency (IEA, 2014), less than 15% of the people living in SSA have access to electricity. The lack of energy access in the region is underscored by acute electricity deficit and the attendant widespread use of traditional cooking methods such as firewood and charcoal (SE4ALL, 2012). Indoor air pollution resulting from traditional cookstoves is a leading cause of death among women and children in the developing countries (IEA, 2006; World Bank, 2011; Martin et al., 2013; Barnes, 2014). Estimates show that about 10 million women and children will likely die from indoor air pollution from traditional cookstoves by 2030 (Sovacool, 2012). The search for firewood by women carrying children along exposes them to health hazards such as snake bites, bone fractures, lacerations, foot and back damage (Masud et al., 2007).

Given the climate change vulnerabilities and energy poverty in SSA, exploitation of renewable energy (RE) resources is envisaged as a remedy to address these two challenges and unlock development opportunities in the region (Kirubi et al., 2009). SSA's underdevelopment is linked to low energy access and the development of the sub-continent's abundant RE resources such as solar, wind, biomass *inter alia* could facilitate development. The scattered settlements that characterized rural SSA makes RE, especially mini-grid and off-grid solutions, the most viable energy options to addressing energy poverty in the region (Sovacool, 2014; World Bank Group, 2017). It has been suggested that electrifying rural SSA communities is achievable through off-grid RE solutions similar to the strategies used by the telecommunication industry to accomplish rural communication in the region (Szabo et al., 2011).

Unlike the developed regions of the world where strategies to climate change often revolve around adaptation and mitigation, developing regions including SSA still have several development challenges to address. Social amenities such as access to portable water and clean energy for cooking are lacking in rural communities due to lack of energy. Under such circumstances, it is imperative for policy makers and development partners to explore avenues by which climate change and development could be addressed concurrently. Climate compatible development (CCD) is a theoretical framework that seeks to address adaptation, mitigation, and development in the developing countries simultaneously (Suckall et al., 2015).

Mitchell and Maxwell (2010) proposed the CCD theoretical framework, describing it as, "development that minimizes the harm caused by climate impacts, while maximizing the many human development opportunities presented by a low emission, more resilient future (p.1)." Mitchell and Maxwell argue that adaptation, mitigation, and development goals can be achieved

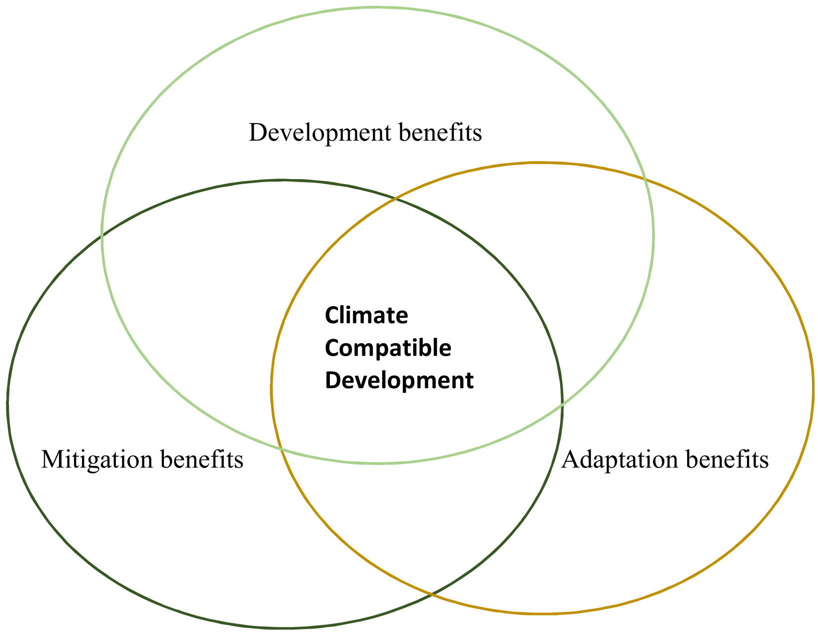

Figure 3.1. Climate compatible development framework. Source: Adapted from Mitchell & Maxwell, 2010.

through a single project . Mitigation strategies under CCD imply generating energy from low carbon technologies, while adaptation strategies suggest promoting livelihood diversification, creating opportunities for business and new skills, limiting dependence on natural resources, and ensuring equal participation in decision making by all stakeholders. Also, development within CCD encompasses strategies that increase access to social services such as health care, education, clean energy for cooking, and improvement in standard of living (Mitchell & Maxwell, 2010). CCD is a development first approach that aims to deliver development by pursuing projects that minimize climate change vulnerabilities such as food insecurity, while maximizing opportunities such as emerging carbon markets and growth in RE technologies (Klein et al., 2005). Thus, its application is particularly relevant to developing countries in SSA, because of its development centeredness and the recognition of RE technologies as some of the strategies for its operationalization. Its core tenets align well with the most pressing needs of SSA countries – climate change and energy access – as highlighted earlier.

While CCD offers a clear framework of how RE exploitation could potentially address climate change and energy access concurrently in developing countries, its application in the real world is limited. In particular, the model has not been amply applied within the energy sector in SSA. In the energy sector, Suckall et al. (2015) used CCD's framework to review a study by Adkins et al. (2010) on the benefits of light emitting diode (LED) solar lanterns in rural southern Malawi. Suckall et al. (2015) concluded that though adaptation, mitigation, and development benefits were apparent from the study, these were not classified as such.

In the original study, Adkins et al. (2010) found that households that utilized the LED lanterns experienced reduced expenditure on kerosene, increased incomes, and extended hours of study for school children. While adaptation, mitigation, and development benefits were obvious, such benefits were not identified within a CCD framework. Relatedly, Burney et al. (2010) reported several benefits of solar-powered irrigation pumps including improved earnings, which enabled farmers to purchase television sets, mobile phones, motorcycles, as well as being able to send their children to school. Similar to Adkins et al's research, the Burney et al's study was not designed within a CCD's frame to specifically assess adaptation, mitigation, and development benefits. Furthermore, in Ghana Boateng (2016) examined the potential socio-economic and environmental impacts of solar mini grids and found benefits such as improvement in education, reduced environmental pollution, but these benefits were not identified through a CCD's lens. A study done through a CCD's frame can facilitate easy identification of RE benefits for rural populations and enhance better communication of results. Effective reporting of RE benefits can potentially shape the decisions of policy makers and development partners to prioritize allocation of resources to increase RE deployment in the developing countries.

Some critics have argued that it is difficult to distinguish CCD from other concepts such as “climate resilient pathways; green growth; and low carbon development (Ficklin et al., 2018).” Contrary to this criticism, CCD is clearly distinct from other climate change models on the basis of its cautious development first approach. In fact, CCD draws its strength from this very piece of criticism. First of all, CCD is more development centered and has been specifically designed for use in the developing world, because developing countries still face a lot of development challenges and need pro-development policies to achieve development. Furthermore, CCD recognizes RE technologies as some of its main implementing strategies, fundamental to solving climate change and lack of energy access in the developing countries without compromising on emissions reductions and building resilience. Additionally, CCD presents a comprehensive framework that addresses adaptation, mitigation, and development issues concurrently without dealing with these dimensions of climate change separately.

Despite these strengths, CCD major limitation is that it has not been adequately applied in an empirical sense. Its application in the scholarly literature and in the real world particularly in the energy sector as already highlighted above is limited. Against the lack of empirical application of CCD within the energy sector and given its importance to addressing climate change and energy access in rural SSA, the present study applies this relevant theoretical framework to assess adaptation, mitigation, and development benefits of solar mini grids in three Ghanaian rural island communities. The study seeks to answer the following questions:

1. What do island community’s members identify as adaptation, mitigation, and development benefits of solar mini grids within the context of climate change and development?

2. Which category of benefits do island community's members consider as having the greatest impact on their wellbeing?

The remainder of the paper is as follows. Section 2 describes the methods, Section 3 presents the results, Section 4 discusses the results, and Section 5 draws conclusion and speculates policy implications in the context of the findings.

Methods

The study utilizes the CCD framework to assess adaptation, mitigation, and development benefits of solar mini grids in Ghanaian rural island communities. The islands, numbering over 2000, were created in 1965 by the construction of the Akosombo Dam, which is Ghana's largest hydroelectric dam and also reported to be the largest man-made lake by total surface area in the world (Phillips, 2015). Since their creation, the islands remained unelectrified until 2015 when the World Bank Group funded the provision of solar mini-grid systems in five communities. The unelectrified households in Ghana are mainly those living in the rural islands where grid connection is difficult to execute and as such, the government of Ghana chose to deploy the solar min grids there in her quest to achieve universal access to electricity by 2030. The communities are located along the Volta Lake, which transcends six regional boundaries. I limited the study to only three communities namely Pediatorkope, Kudorkope, and Atigagome due to logistical constraints. Additionally, these communities share common socio-cultural, economic, and geographical features with other islands and as such, they are representative of the others. The Ghanaian rural islanders are mainly fishers and farmers (Nuru et al., 2020). While few of the islands have public schools and health centers, the majority lack these essential social amenities.

The study applied a survey to identify the benefits of solar mini grids to households in the Ghanaian rural island communities. The use of surveys for data collection in the energy access field has been documented. Wilson et al. (2017) used survey to assess the benefits and risks of smart homes technologies to users in the UK. Similarly, Butera et al. (2019) applied survey to study energy access in "slum" residential neighborhoods in Brazil. In the present study, a survey was administered to identify the benefits of solar mini grids to rural households. Questionnaires were designed based on common benefits of RE obtained from existing literature. Questions were formulated based on the following variables: demographic and socio-economic characteristics of respondents; households electricity tariffs; quality, affordability and importance of the mini-grid systems; uses of the mini-grid systems; electrical appliances use by households; households sources of energy for cooking; and benefits of the solar min-grid systems. These variables were arrived at consistent with the CCD framework regarding solar mini grids benefits , as well as the need to understand respondents' socio-economic and demographic features. Question patterns were mixed comprising yes and no, multiple choice answers with one option to choose, multiple choice answers requiring a respondent to check all that apply, a few open-ended questions, and Likert scale questions ranging from fully disagree to fully agree and strongly disagree to strongly agree statements. Prior to going to the field, the questions were pretested with an expert in survey research. The expert's guide led to replacement and rephrasing of inappropriate questions, as well as ensured validity and accuracy in the order of the questions (Berenda & Zottola, 2009). Questionnaires were also piloted to gauge the amount of time required to complete one questionnaire. Each questionnaire contained 28 questions and a respondent spent an average of 15 minutes to complete a questionnaire. The questionnaire is attached to the dissertation as Appendix A.

I had proposed to use simple random sampling technique to collect the data but changed the procedure upon reaching the communities and realizing that the houses were far apart and not enumerated. Thus, it was difficult attempting to assign numbers to the households for the purposes of the survey. Instead, the team approached and interviewed households that were users of the mini-grid systems until the target sample size of 35 was reached in each community. A similar sampling technique had been applied by Butera et al. (2019) to collect field data on energy utilization among “informal settlements” in Brazil, given that such neighborhoods are often unplanned and makes the assignment of random numbers tedious, if not impossible for a researcher. To ensure that only respondents utilizing the solar mini-grid energy were interviewed, question one, which read, “ Does your household use power from the solar mini grids?” with “Yes” and “No” answers, was strategically placed to screen out non-beneficiary households. Respondents from two households answered *No* and were excluded from the study. I excluded them because their responses would likely not reflect the actual benefits of the mini-grid systems as the study sought to identify.

Questionnaires were administered via face-to-face interviews, allowing the research team to have practical control of the process and actually interviewed households that the questions were intended for (Creswell & Creswell, 2018). One month was spent on data collection in each community between August 2019 and November 2019. I was assisted by four field officers to conduct the survey in each island community. The four officers who assisted me comprised one female and three males. All four come from communities closer to the island communities and could speak the native languages spoken in the study communities. Each of them holds at least a first degree and possesses field research experience.

The survey was conducted in line with the Ghana National Survey where one adult aged 18 years and above answered a questionnaire (Ghana Statistical Service, 2019). Interviews were held with persons of sound mind, who were knowledgeable in the household affairs. The interviews were held based on a respondent's choice of a venue either under a tree near the house or within the compound. Though one person was responsible for answering questions, some respondents chose to answer the questions in the presence of other household members. Incidentally, most of the interviewees turned out to be the household's heads. Respondents included both males and females and their ages ranged from 18 to 70+ years. Instructively, in traditional African societies, minors usually do not respond to formal queries from visitors and as such, their inclusion was not considered. A broader selection criterion was, however, maintained to increase eligibility and participation.

The data were represented and summarized using descriptive statistics to illustrate both common and unique patterns, as well as provide snapshot view of the findings. To ensure validity, reliability, and transparency, the raw data are attached as Appendix E. Processing of the data proceeded as follows. First, since much of the data were made up of categorical variables including age, gender, I created contingency tables via Microsoft Excel. Variables were then arranged in columns with individual respondents in the rows corresponding to a specified community. Second, variables were reduced to short codes to enable entering them in the columns of the excel sheet manageable. For example, "level of education" was shortened to "education". Third, the data were cleaned up by deleting non-response blank spaces and inconsistent and erroneous entries. Fourth, Microsoft Excel was used to create pivot tables and charts, summarizing the results. Some of the tables were converted into proportion tables. Comparison of some of the findings was made among the three communities. Again, since the variables were all categorical, a chi-square test of goodness of fit was performed on selected results to determine if there were significant differences in the results between some variables , as well as among the three communities. An alpha level of $\alpha = 0.05$ was used for the chi-square test. Finally, narratives from the open-ended questions were used to supplement the survey findings.

Results

The main findings from the survey conducted in the three Ghanaian rural island communities are thematically summarized and presented below.

Demographic and socio-economic characteristics of respondents

The survey covered a total of 105 households with 35 questionnaires administered in each community. The demographic and socio-economic characteristics of respondents covered in this study include gender, age, education, employment, and annual income as shown in Table 3.1. The gender distribution of the respondents consisting of males (49%) and females (51%) shows that the proportion of males is less than females in the surveyed island communities. This is consistent with the Ghana National Population gender distribution[1]. Whilst the gender representation of respondents in Pediatorkope and Kudorkope is the same for males (43%) and females (57%), the proportion of males (60%) is higher than the females (40%) in Atigagome. A P-value of 0.25, which is greater than $\alpha = 0.05$, however, suggests that the differences between males and females across the three island communities is not statistically significant.

The age range of respondents in the survey is from 18 to 70+ years. The age categories in Table 3.1 shows that majority (34%) of the respondents were aged between 30 and 39 years in all the three island communities. Within the same age bracket, Kudorkope has the highest (40%) followed by Atigagome (37%) and Pediatorkope (26%). The likelihood of older people aged 70+ years living in the islands is generally low (3%) across the three communities. Pediatorkope with

[1] The sex distribution of Ghana National Population is males (48.5%) and females (51.5%). Source: Ghana Statistical Services (2019).

(6%) of respondents aged 70+ being the highest proportion is still low . This suggests that the Ghanaian islands are inhabited by younger populations. It also affirms Pediatorkope as an older settlement and as such, has more older people than Kudorkope and Atigagome. None of the respondents interviewed fell within the age range of 18 – 19.

The educational attainment of respondents presented in Table 3.1 reveals that nearly half (46%) of the surveyed population have never attended school. More than one-third (38%) have

Table 3.1
Demographic and socio-economic characteristics of respondents (n = 35, 105)

Variable	Pediatorkope	Kudorkope	Atigagome	Overall
Gender				
Male	43%	43%	60%	49%
Female	57%	57%	40	51%
Age				
18 – 19	0%	0%	0%	0%
20 – 29	20%	14%	17%	17%
30 – 39	26%	40%	37%	34%
40 – 49	14%	20%	31%	22%
50 – 59	23%	17%	9%	16%
60 – 69	11%	6%	6%	8%
70+	6%	3%	0%	3%
Education				
Elementary	49%	40%	26%	38%
High school	23%	9%	6%	12%
Tertiary	6%	3%	3%	4%
Never attended school	23%	49%	66%	46%
Employment				
Employed	9%	3%	3%	5%
Self-employed	43%	66%	83%	64%
Trading	34%	26%	14%	25%
Unemployed	14%	6%	0%	7%
Annual Income				
Under $100	31%	6%	20%	19%
$100 - $200	20%	0%	14%	11%
$201 - $400	20%	9%	6%	11%
$401 – $500	9%	14%	14%	12%
$501 - $600	0%	9%	9%	6%
$601+	20%	63%	37%	40%

attained elementary education. Attainment of tertiary education (4%) is low across the three communities. The number of respondents who completed high school in Pediatorkope (23%) is, however, higher than Kudorkope (9%) and Atigagome (6%). This pattern is indicative of the presence of better public basic schools in Pediatorkope than Kudorkope and Atigagome. Whilst Kudorkope has a poorly structured public basic school, Atigagome has no basic public school at all. The differences in education among the three communities is statistically significant, given a P-value of 0.02, which is less than $\alpha = 0.05$.

Employment status in the present study refers to an engagement in an income generating activity and the ownership of that entity. Table 3.1 shows that a high proportion (64%) of the respondents were self-employed[2], which accounts for the low (7%) unemployment reported in the survey. If one were to consider formal sector engagement, which is being referred to as employment in this survey, then unemployment in the general sense of the term would be high, as only (5%) of respondents from the three island communities were engaged in formal sector work. Atigagome, which has the highest (83%) self-employment implies that the majority of inhabitants there were engaged in some form of income generating activity and were self-supporting rather than relying on family members.

Annual income in Table 3.1 shows the highest (40%) proportion of households in the survey earn $601+ annually. It is observed that the proportion of households earning $601+ in Kudorkope (63%) is higher than Atigagome (37%) and Pediatorkope (20%). Surprisingly, Pediatorkope with relatively better educational attainment among households surveyed has a higher proportion (31%) of households earning below $100 annually than Atigagome (20%) and

[2] Self-employment in this study is where a respondent does his/her own work to generate income and in some cases engages others. The employed are those who have been engaged in formal sector work either privately or publicly and earns a monthly salary. Respondents in trading basically buy merchandise from the mainland areas and resell within the islands. The unemployed are people who do no work and rely on family members for support.

Kudorkope (6%). Given a *P-value* of 0.002, which is less than $\alpha = 0.05$, the differences in households annual income is statistically significant.

Households electricity tariffs

The survey matched households' annual income with households' electricity tariffs[3]. Figure 3.2 shows that households' electricity tariffs are reflective of the households' annual income. Kudorkope (63%) and Atigagome (37%), which have greater proportions of households earning above $600 annually than Pediatorkope (20%), also have households paying higher electricity tariffs above $6. Whilst the proportion (14%) of households in Kudorkope and Atigagome each are paying tariffs above $8.01+ monthly, no household in Pediatorkope is at the same tariffs level. Furthermore, the proportions of households within the commonest tariff bracket $2.01 -$4 per month in Kudorkope (57%) and Atigagome (51%) are higher than Pediatorkope (40%). Overall, households in Kudorkope earn higher annual income and are able to afford higher electricity tariffs than both Atigagome and Pediatorkope. It is not surprising, because higher proportions of households in Pediatorkope (31%) and Atigagome (20%) record lower annual income below $100 than Kudorkope (6%). The results suggest a correlation between higher annual income and higher electricity tariffs.

[3] Households electricity tariffs used in this study are estimates of the equivalent of the actual solar mini-grid tariffs in the island communities.

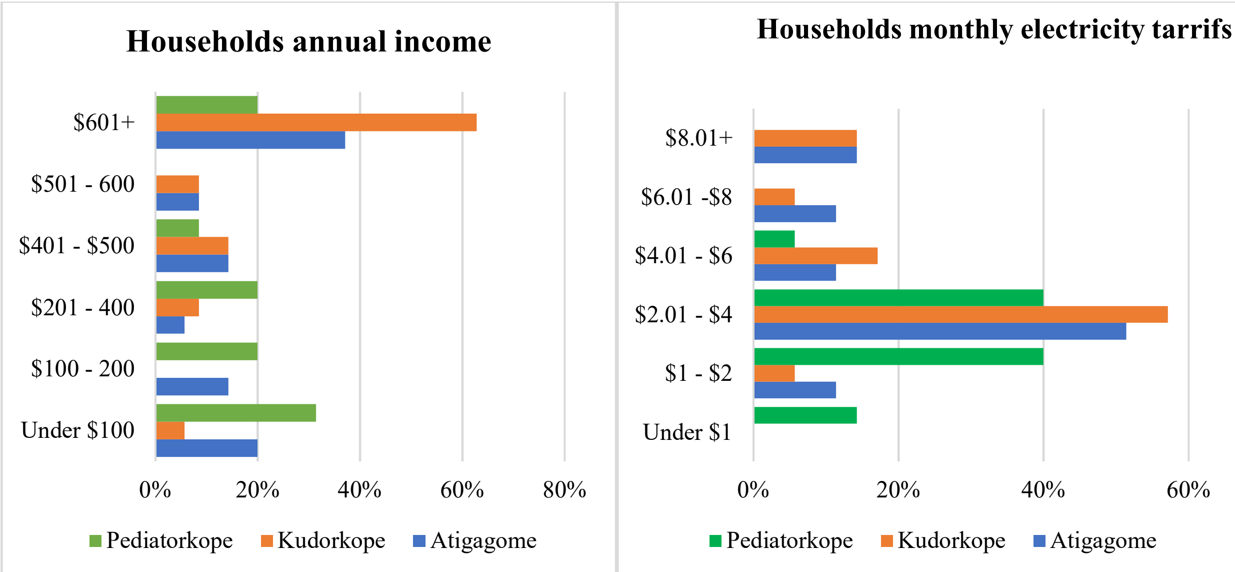

Figure 3.2. Households' annual come and households' electricity tariffs

Quality, affordability , and importance of the mini-grid systems

The survey assessed the quality, affordability, and importance of the mini-grid systems to households in the three island communities. The results show that (50%) rated the power quality as good, (38%) as satisfactory, (10%) as poor , and (2%) as very poor. This suggests that, on the average, the quality of power in the three island communities is generally good. Whilst no respondent in Kudorkope and Atigagome rated the power quality as very poor, (6%) in Pediatorkope indicated the quality as such.

Figure. 3.3 displays households' assessment of the affordability and importance of the mini grids. More than half (69%) rated the power as very affordable. Affordability, however, varies across the three communities. The highest proportion of households in Atigagome (83%) rated the power very affordable, and also (69%) in Kudorkope and (54%) in Pediatorkope. Surprisingly though, whilst Atigagome leads in the positive assessment of the power being affordable, it is also the community that has a slightly higher (11%) proportion of households than Kudorkope (9%) and Pediatorkope (3%) rating the power as not affordable. The rating of the mini-grid affordability is consistent with its importance to households. Overall, a higher proportion (97%) assessed the power as being important to households. As with the affordability, in Atigagome (100%) assessed the power as important, (97%) in Kudorkope, and (94%) in Pediatorkope. Whilst no respondent in Atigagome and Kudorkope assessed the power as unimportant, (3%) in Pediatorkope rated it as unimportant. Also (3%) of households each in Kudorkope and Pediatorkope are indifferent about the importance of the mini grids.

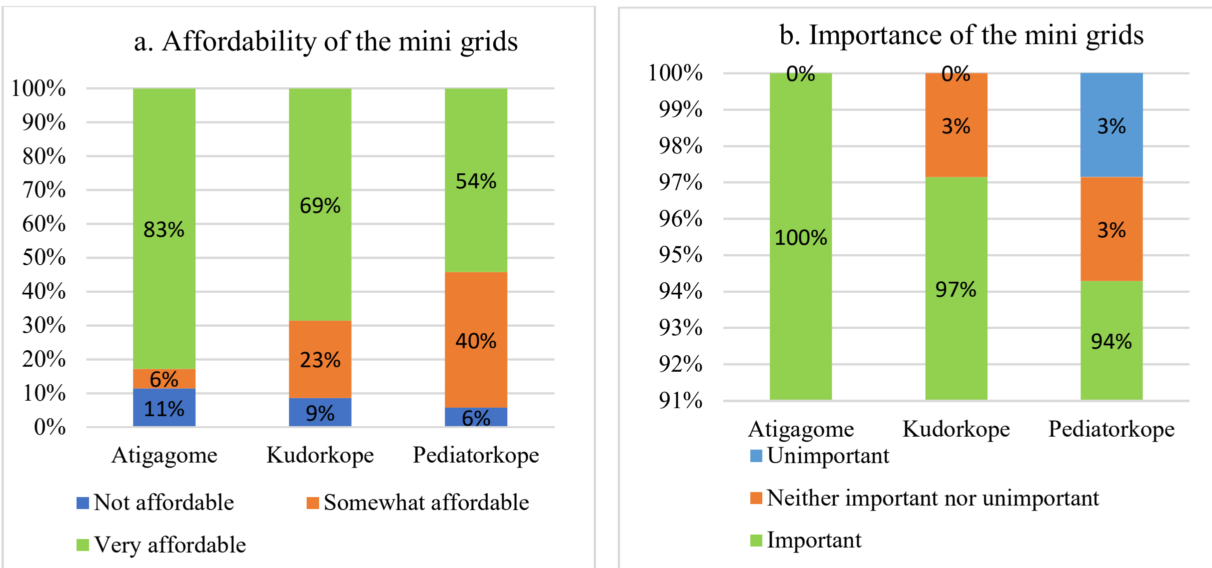

Figure.3.3. Affordability and importance of the mini grids to households

Uses of the mini grids by households

Figure.3.4 provides information on the major ways that households in the island communities use the power from the solar mini grids for.

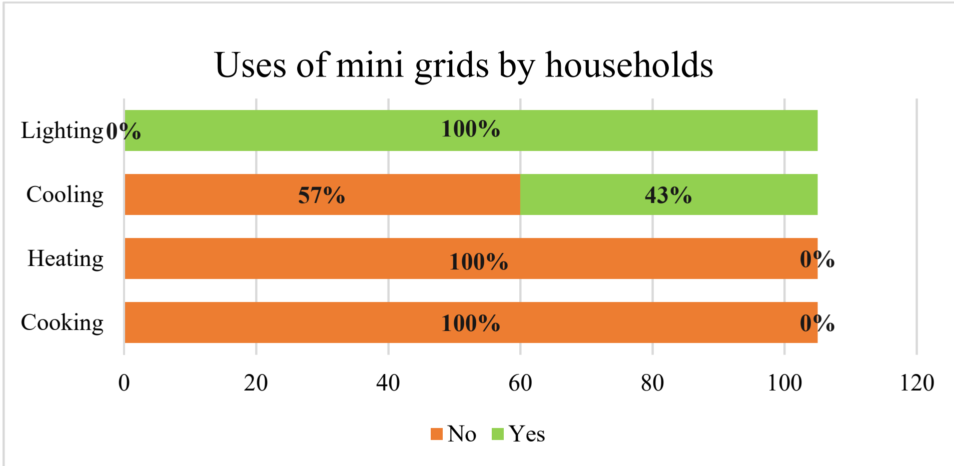

Figure. 3.4. Uses of the solar mini grids by households

The results from Figure. 3.3 indicate that all households in the survey use the power for lighting (100%) and (43%) use it for cooling[4]. In all the three island communities surveyed, no household uses the power for heating[5] or cooking.

Electrical appliances use by households

As seen in Figure.3.5, all of the surveyed households (100%) in the Ghanaian island communities use electrical bulb. This is consistent with the proportion of respondents who indicated that they use power from the solar mini grids for lighting. This is not surprising, because no one can enjoy light from the mini grids without the use of an electrical bulb. Besides lighting, a high proportion of households use the power to charge phone (96%) and also use it to watch television (67%). Thus, more than half of the households surveyed indicated that they use the power for lighting, charging phone, and watching television. Conversely, less than half of the respondents use appliances such as refrigerator and pressing iron. While a small percentage

[4] Cooling in the context of the Ghanaian rural island communities means the use of electric fan, as no one in the communities has an air conditioner.
[5] Heating in the present study is using the power for home heating. No household was found to be using the mini-grid power for home heating. Small proportion of households (7%), however, indicated that they occasionally use water heater to heat water for tea.

(7%) uses a water heater, (2%) a blender, no household in the three island communities surveyed uses an electrical stove.

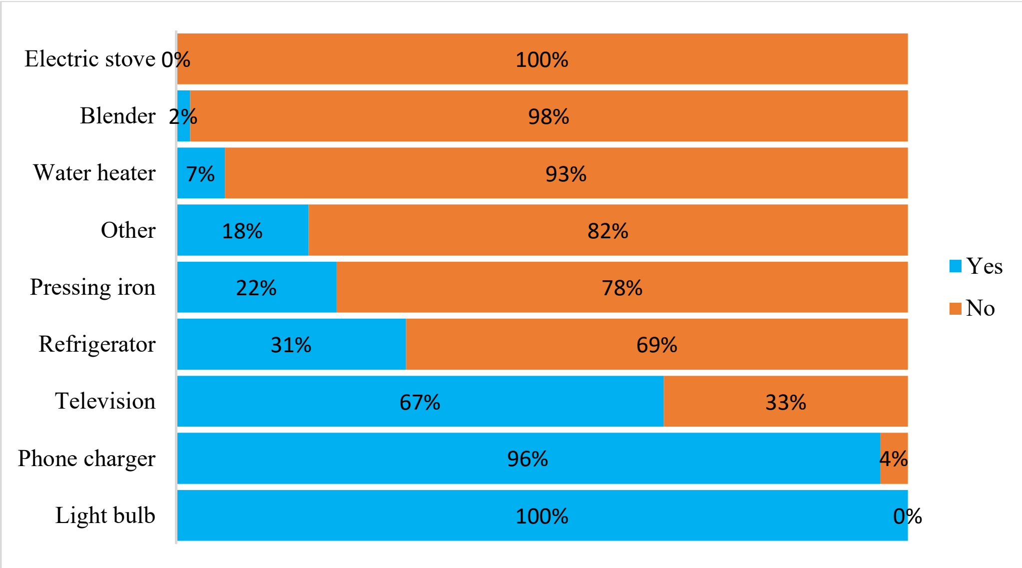

Figure. 3.5. Households electrical appliances

Households sources of energy for cooking

Figure. 3.6 displays the sources of energy for cooking by households. Charcoal, firewood, liquified petroleum gas (LPG), and crop residue are the main sources of energy households in the three island communities use for cooking. Charcoal is the widely used energy source for cooking accounting for (89%), firewood (79%), LPG (20%), and crop residue (2%). No respondent indicated using kerosene, electricity, and animal dung as sources of energy for cooking. The lack of electricity use for cooking confirms the results from Figure.3.4 where no household uses electric stove as an electrical appliance.

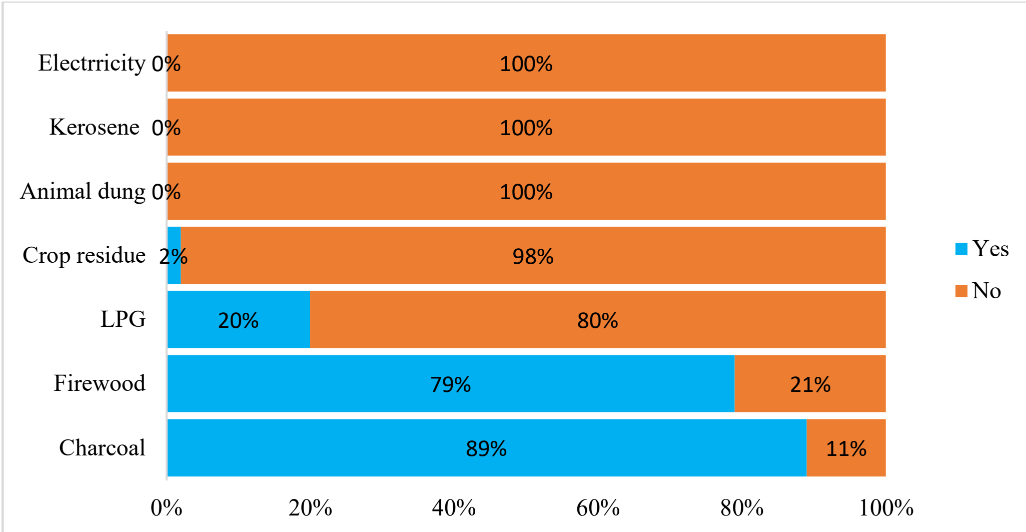

Figure.3.6. Household sources of energy for cooking

Benefits of the solar mini grids

To fully understand the multiple benefits of the solar mini-grid systems to the island communities, the survey used different questioning strategies. First respondents were asked to indicate how much they "agree" with statements about benefits being derived from the solar mini grids. Figure. 3.7 reveals that whilst half (50%) of the respondents "agree" that the mini-grid systems have created job and business opportunities, more than half "agree" that the systems have brought about better community life (53%), have been beneficial to households (56%), have improved entertainment (57%), and have increased information access (57%). Meanwhile, less than half of the respondents "agree" that the solar mini-grid systems have reduced environmental pollution (36%) and have increased households' income (31%).

With the "strongly agree" responses, whilst one-third of the surveyed households "strongly agree" that the mini grids have brought about better community life (35%), more than one-third indicted that the mini grids have been beneficial to households (37%) and have increased access to information (38%). Nearly a third of the respondents "strongly agree" that the solar mini grids have improved entertainment (34%) and have created jobs and business opportunities (29%). Furthermore, less than one-third of respondents "strongly agree" that the mini-grid systems have reduced environmental pollution (8%) and have increased households' income (13%). An outlier pattern is the replacement of kerosene use. There is no form of disagreement over the fact that kerosene use has been replaced by the solar mini-grid systems, as (43%) "agree" and (57%) "strongly agree." It goes to confirm the earlier result in Figure.3.6 where no household indicated kerosene as a source of energy for cooking. Another interesting pattern is that, whilst more than one-third of the respondents (36%) "agree" that the mini-grid systems have reduced environmental pollution, nearly a third (27%) are "neutral." Reduction in environmental pollution and increased household incomes are two statements that saw higher proportions of "disagree" and "strongly disagree" among respondents.

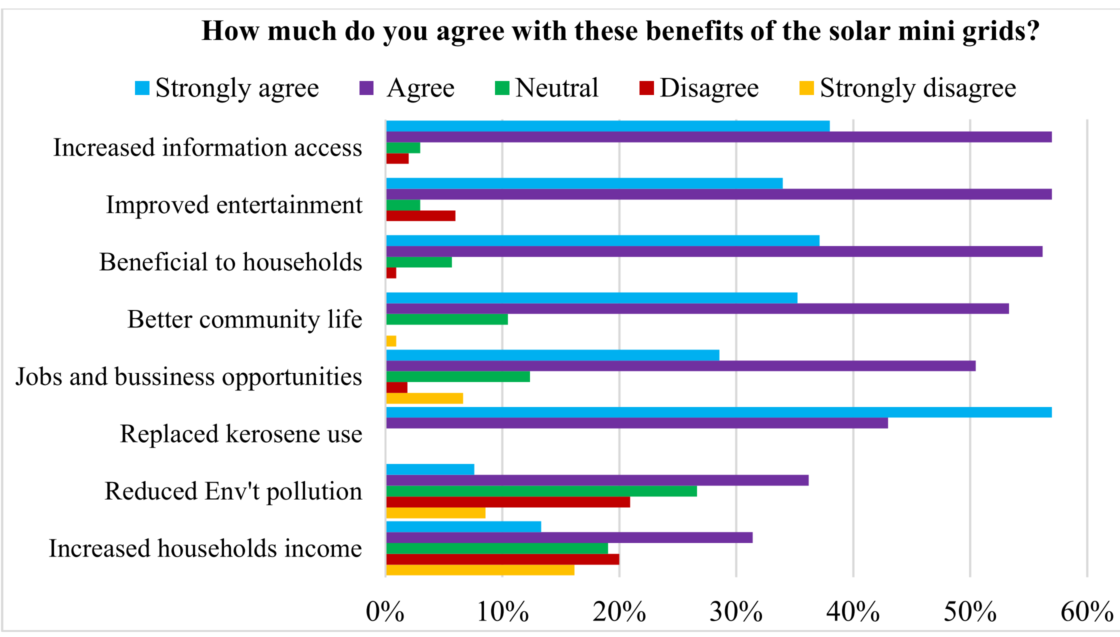

Figure.3.7. Benefits of the mini grids to households

The fact that more than half of the respondents "agree" that the mini-grid systems have been beneficial to households suggests that there are related benefits to the island communities as whole entities. As such, the survey further identified specific benefits of the solar mini grids to the island communities. Additional question provided a list of mini -grid benefits to the communities and asked the respondents to check all the options that apply to the communities. Figure.3.8 presents the major benefits being derived by the island communities from the solar mini grids. The survey found support for petty trading (85%) as the most common benefit being derived from the mini-grid systems with reduced pollution (24%) being the least frequently identified benefit. It is not surprising that reduction in pollution was found to be the least benefit from the solar mini grids, as the use of firewood, with significant air pollution, continues to be high in the island communities. As with creation of job and business opportunities as benefits to households in Figure. 3.7, creation of job opportunities is also high as a benefit to the communities. This suggests that job creation has been an enormous benefit from the solar mini grids to the island communities. Other benefits with higher proportions are prevention of snake bites (81%), reduced youth migration (70%), reduced women burden (67%), improved education (65%), reduced domestic accidents (56%). Whilst creation of business opportunities was high as a benefit at the household level, it, however, dropped slightly as a benefit at the community level. This disparity in response to creation of business opportunities was probably because it was combined with job creation as a benefit in the previous question and as such, respondents did not "agree" to it on its own merit. It also suggests that the mini grids created businesses for individual households but not the communities as collectives.

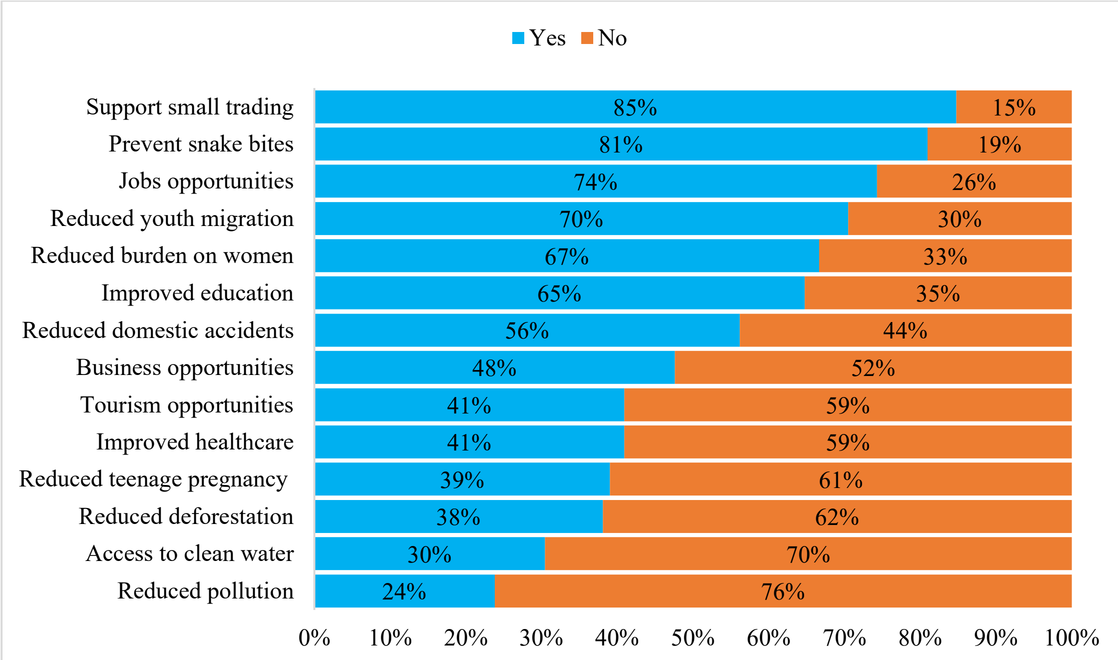

Figure.3.8. Major benefits of solar mini grids to the island communities

Other important benefits worth noting from Fig. 8 are: improved health care (41%), tourism opportunities (41%), reduced teenage pregnancy (39%), reduced deforestation (38%), and access to clean drinkable water (30%).

All the benefits identified from the survey can be classified under livelihood diversification (adaptation), environmental protection (mitigation) and social services (development) consistent with CCD's framework. To understand which of these categories of benefits the island communities consider as being most beneficial to them, the survey asked respondents to rank these three classifications of the solar mini-grid benefits. Figure.3.9 reveals that respondents considered livelihood diversification benefits (66%) as being first, with improvement in social services (55%) and environmental protection (52%) occupying the second and third positions. For the island community members, being able to tap the mini-grid power to engage in alternative income generating activities constitute the most fundamental benefits to them.

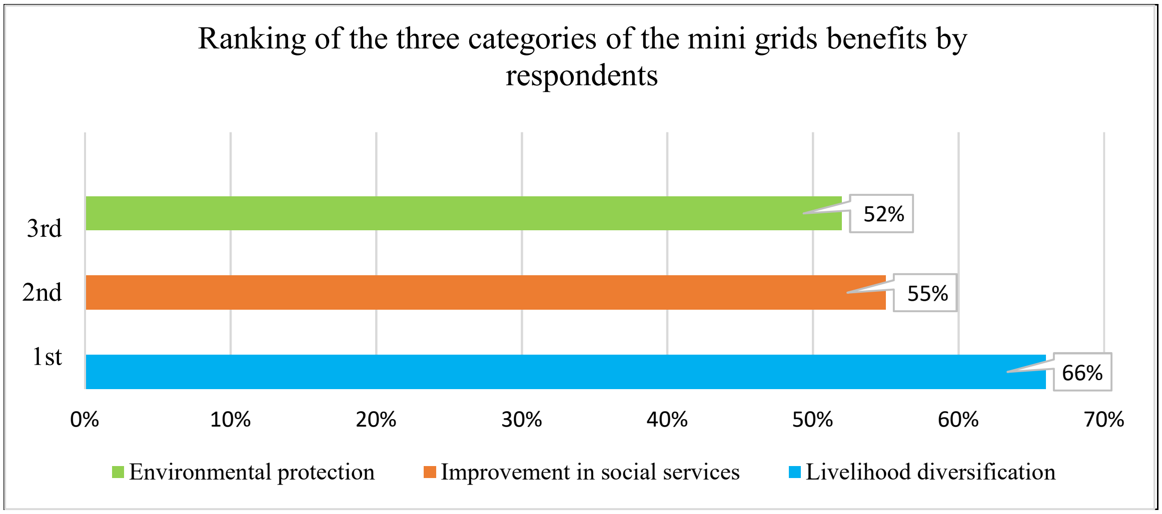

Figure. 3.9. Ranking of livelihood diversification, social services, and environmental protection

The ranking of livelihood diversification as first before social services and environmental benefits is consistent with the results in Figure. 3.8 where support for petty trading has the highest proportion (85%) among a list of benefits. It shows that through petty trading, households in the island communities are able to diversify their means of livelihood thereby building resilience against climate change impacts such as poor harvest from their fishing and farming activities. A P-value of 4.3, which is greater than $\alpha = 0.05$, however, suggests that the difference that lies between these ranked benefits is not statistically significant.

Discussion

The analysis of the survey data identified multiple benefits of the solar mini grids to the island communities. Consistent with CCD's focus, the main benefits identified can be classified under adaptation, mitigation, and development. While benefits falling into all three categories were apparent in each study community, respondents considered adaptation or what I term livelihood diversification benefits as having the most impact on their wellbeing. The other two categories are mitigation, which means emissions reduction benefits, and development, which refers to access to social services. This section further discusses the main and related benefits that emerged from the survey, supported by narratives gathered from a few open-ended questions that reinforced some of the benefits directly captured by the survey. The discussion follows a sequence beginning with adaptation, through mitigation to development benefits. Table 3.2 lists some of the major benefits in each category.

Table 3.2
Summary of the major benefits of the solar mini-grid systems to the island communities

Category	Benefits
Adaptation	Creation of jobs and business opportunities Acquisition of new livelihood skills Support for petty trading Creation of tourism opportunities Preservation of fresh fish Reduction in youth migration Extension of economic activities into the night Increased households' income
Mitigation	Replacement of diesel generators Replacement of kerosene use Reduction in deforestation Reduction in burning of wood Planting of trees
Development	Improvement in healthcare Improvement in educational performance Improvement in entertainment Reduction in social vices (e.g. rape and theft) Access to information Access to clean water Reduction in domestic accidents Reduced women burden.

Adaptation benefits

Adaptation benefits promote livelihood diversification, create opportunities for new skills, and limit reliance on natural resources (Mitchell & Maxwell, 2010). The survey revealed several adaptation benefits that were realized from the solar mini grids. The mini-grid systems created job and business opportunities for some inhabitants in the island communities. Some individuals have been employed and provided with basic technical skills to enable them to monitor the systems on behalf of the operators. There is a system administrator, who is being supported by other people serving on the mini-grid committee in each island community. The support staff are responsible for cleaning the panels and monitoring the meters. In terms of business opportunities, some inhabitants engaged in petty trading by selling cold drinks and other frozen foodstuffs. The deployment of the solar mini grids also created tourism opportunities in the islands (see Figure. 3.8), as the number of people including researchers, government officials, development partners visiting these communities has increased following the deployment of the mini-grid systems. The frequent visits to the island communities related to the mini grids has boosted the business of the motorized boat owners who now make several trips carrying people to and from the islands at attractive fees. Likewise, there has been a boost in demand for cold drinks and fish products by the visiting public.

With electricity, fishers are able to preserve their catch by refrigerating the fish to later sell for better prices in the mainland areas on market days. New livelihood skills have been acquired by the youth who operate hairdressing and barbering salons and other small-scale business enterprises. Opportunity to do business has been enhanced, enabling some of the youth to reside in the island communities without any intention to migrate to the mainland areas in search for jobs and social amenities. This development has witnessed reduction in youth migration (Figure. 3.8) from the island communities to the cities.

The lighting has made it possible for people to extend their economic activities late into the night, thereby increasing productivity. Basket weavers, tailors, and seamstresses continue to ply their trade in the night. Fishers and farmers use the lights at night to process some farm produce or the fish, especially if they return home late in the night. All of these livelihood diversification activities made possible by the mini-grid systems enable households within the islands to generate income. With increased household incomes, families are able to purchase television and radio, which enable them have access to information about climate change and other happenings around the world. All of these benefits enable the islanders to build resilience and become less vulnerable to climate change.

Mitigation benefits

Mitigation benefits are derived from strategies that lead to the elimination or reduction in carbon emissions (Mitchell & Maxwell, 2010). It implies generating energy from RE sources like the solar mini grids. It also concerns protecting carbon stores such as forest and vegetation covers. Mitigation benefits have been recognized in the study in various forms. Prior to the deployment of the solar mini grids, the island communities were utilizing fossil-fuel based generators and kerosene lanterns for lighting and for other purposes. The mini grids, however, came to replace these carbon laden sources of energy. The discontinued use of diesel generators and kerosene lanterns has contributed to reduction in carbon emissions and environmental pollution in the island communities and by extension, globally.

Another important mitigative benefit from the mini-grid systems has been reduction in deforestation. Fishing being the predominant occupation, a lot of firewood used to be harvested for smoking the fresh fish to prevent them from getting rotten. The mini grids have now made it possible for the fishers and fishmongers to freeze some of their catch without having to smoke all of it. This fish treatment method requires no firewood, hence reduction in the need to harvest wood in large quantities. It is particularly important that the deployment of the solar mini grids contributed to reduction in deforestation, considering that charcoal and firewood constitute the major sources of cooking for these island communities. It suggests that provision of an alternative sources of energy other than the charcoal and firewood widely used for cooking by rural populations in SSA could potentially eliminate or drastically reduce their use, thereby leading to conservation of the tropical forests.

Also, the model of mini-grid systems deployed had been insulated, making it possible to pass the wiring systems through trees without having to cut the trees. At night, the communities are illuminated by streetlights and the lighting from individual houses . The illumination of the communities has prevented unscrupulous people from taking cover in the dark to cut trees. Previously, some communities regarded their settlement in the islands as temporary. With the lights, however, some of them recognize the need to make permanent homes on the islands, using aluminum zinc and some have taken it upon themselves to plant trees in their backyards. Hence there is a sense of ownership and sustainability in these island communities than before. These are all mitigative strategies that contributed to reduction in depletion of forests resources in these island communities. Admittedly, the cutting of trees in the island communities has not stopped entirely, as charcoal and firewood constitute major energy sources for cooking in the islands and continue to cause air pollution. This calls for research into clean cooking strategies such as improved cookstoves to be considered alongside the deployment of RE projects in rural areas in the developing countries.

Development benefits

Development benefits essentially refer to access to basic social services such as lighting, health care, education, clean water, clean energy and improvement in quality of life (Mitchell & Maxwell, 2010). The island communities have been deprived of such important social services for many decades. The mini-grid systems, however, made it possible to access such services. Hitherto, health and educational professionals would not accept postings to the island communities, a situation that used to affect healthcare delivery and performance of school children. With lights in the island communities, some workers now accept assignments there. Besides, households are able to store certain medications and drugs that require cool temperatures in fridges. School children are able to study at night, thereby improving academic performance. In addition, social vices such as rape and theft that used to be rampant occurrence at night have been mitigated by the mini-grid lighting at night. Previously, thieves used to steal fish that were being smoked whilst their owners were asleep. The illumination at night tend to scare potential thieves away.

The communities are able to access information via television and radio, as well as entertain themselves through the mini-grid power. They tune into radio stations and listen to music. They have digital satellite television decoders which enable them to access foreign news and watch soccer and other forms of game. The mini grids also led to introduction of sachet water in the communities. Previously, the Volta Lake used to be the only source of drinking water for the island communities. The switch from the Lake water to sachet water has significant health benefits for the islanders.

These findings clearly demonstrate that the deployment of RE projects like the solar mini grids can offer adaptation, mitigation, and development benefits for rural communities in the developing countries. As such, it is imperative for policy makers and development partners to prioritize the deployment of such projects that can potentially address climate change and development challenges in the poorer regions concurrently. Practitioners in the climate change and energy access domain should plan and execute projects that have the potential to achieve livelihood diversification, social services , and environmental benefits for rural populations in developing countries. It further stresses the need for researchers working in the field of climate change and energy access to frame studies with a goal towards identifying projects that deliver tri-benefits to meet adaptation, mitigation, and development goals. Research into projects that can provide these tri-benefits at the same time would avoid the need to design separate projects to achieve each of them, leading to significant cost savings (Suckall et al., 2014).

This study agrees with Suckall et al. (2015) that there is a high potential to attract greater funding support for investments in projects that can address climate change and development in poorer countries if the tri-benefits of such projects are fully identified. Thus, the results of this study align with Suckall et al.'s (2015) desk study, which recognized the "triple-wins" of projects across different sectors including solar-based energy projects. The present study marks an important step to operationalize the CCD's framework, drawing from empirical data to identify the tri-benefits that can result from RE projects within the context of climate change and development.

This research slightly differs from other studies that were designed to identify the benefits of RE projects in rural areas in SSA, but which failed to overtly report the tri-benefits as such. While Adkins et al.'s (2010) study sought to identify the benefits of light emitting diode (LED) in rural Malawi, only development benefits were clearly recognized, though adaptation and mitigation benefits were also apparent from the study. In addition, Burney et al. (2010) and Burney and Naylor (2012) explicitly reported only adaptation benefits from their studies of solar-based irrigation systems in the Republic of Benin, while mitigation and development goals were equally achieved. As the present study and Suckall et al (2015) agreed, failing to recognize the tri-benefits of projects could lead policy makers to pursue different projects with additional costs aim at achieving the same benefits that could have been accomplished through a single project.

While this study was designed as a single country case study, similarities such as lack of access to electricity, use of traditional methods of cooking, scattered settlement patterns, lack of infrastructure, socio-cultural practices, and difficulty in grid extension that the study communities share with other rural areas and the broader SSA regional context, makes these findings transferable to other rural jurisdictions in the region, as well as other developing regions such as Asia and Latin America.

As with survey research, the approach used in the present study is subject to limitations. First, the approach only provides a quantitative data, excluding nuanced details such as emotional feelings about the respondents, which would have otherwise been covered by qualitative analysis through interviews. Second, it is difficult to measure if the questionnaire administered has been exhaustive and sufficiently captured all possible benefits being derived from the solar mini-grid systems by the respondents. Third, the use of only the survey method created no room for triangulation of the data. Fourth, though initially designed to follow a simple random sampling, the procedure was varied in the field due to the informal settlements in the study communities. This could affect the selection of respondents and sample size with a potential for bias and misrepresentation of data. Despite these potential limitations, the survey approach allowed gathering of useful data, representing a cross-section of the study communities. Also, comparison of the data from the three communities allowed rigorous analysis and brought robustness to the results.

Conclusion and policy implications

Policy makers and development partners have often not considered the tri-benefits from the deployment of RE projects to rural communities in the developing countries. In particular, academic discourses have also paid little attention to the potential of RE in providing adaptation, mitigation, and development benefits for rural populations in SSA within the context of climate change and development. While the discourse on climate change have often focused on adaptation and mitigation with little or no consideration for development, energy access literature also tends to dwell mainly on development only, caring less about climate change. The evidence from this study, however, points to a relationship among these three dimensions which can be pursued at the same time.

This paper argues that climate change and development can be addressed concurrently in developing countries through the deployment of RE projects, especially solar mini grids. The paper demonstrates that the deployment of solar mini grids can yield adaptation, mitigation, and development benefits for rural populations in SSA within the context of climate change and development.

By applying a CCD lens to the current study, I conclude that the deployment of solar mini grids can yield adaptation, mitigation, and development benefits concurrently. While these results were largely anticipated from a CCD perspective, a major surprise that emerged from the study is that respondents ranked livelihood diversification (adaptation) benefits ahead of access to social services (development). Given that CCD is a development first approach and the generally high expectations of development to result from the provision of electricity to developing countries by development partners, it was hoped that respondents would consider development as being of higher priority to them than both adaptation and mitigation. Instead, respondents indicated adaptation as the category of benefits from the solar mini grids with greater impact on their livelihood.

It is, however, understandable that adaptation benefits were considered as having higher priority among the surveyed households, because the solar mini-grid systems have not drastically translated into a lot of development for the islands yet, as the communities still lack access to basic social services. Generally, social infrastructure has not been built alongside the provision of the mini-grid systems. Majority of the Ghanaian rural islands are without schools, health centers, sanitation facilities, clean water, and means of transportation. Without these basic social amenities, the development benefits currently being derived from the mini-grid systems are limited. Nevertheless, the provision of the solar mini grid systems constitutes a fundamental initiative to achieving overall development for the islands, as the presence of the electricity will trigger different shades of development in later years. From the conclusion, I posit that the findings have relevant implications for policy.

First, the solar mini grids yielded tri-benefits for the Ghanaian island communities within the context of climate change and development consistent with the CCD's theoretical framework applied in this study. It does bring to the fore the need for governments, policy makers, donor agencies, and development partners in SSA to consider adopting the CCD's framework to addressing climate change and development challenges in the region and other developing regions in the world. Researchers also need to focus more attention on identifying the full range of RE benefits within the context of climate change and development.

Second, reaping the tri-benefits from RE projects implies that limited resources could be spent judiciously on such projects and still achieve the same climate change and development goals. It would save development partners substantial resources that would have otherwise been expended on pursuing separate projects to accomplish the same objectives. This can potentially result in significant cost savings and also attract investment from donors, who would be convinced by the tri-benefits likely to result from a single project investment.

Third, the multiple benefits being derived from the solar mini-grid systems to the island communities underscores the suitability of RE generally for such isolated rural communities in SSA. It affirms the suitability of these projects for rural communities in the developing countries, which calls for their increased deployment. The solar mini grids have proven to be viable solutions to electrifying rural areas in the developing countries. Increase deployment of such projects has the potential to simultaneously address the challenges of climate change and energy access confronting many developing countries including those in SSA and contribute towards the achievement of some of the sustainable development goals.

While this research was undertaken in a Ghanaian rural context, these islands share significant socio-economic and geo-demographic features with rural areas in SSA, as well as other developing regions such as Asia and Latin America. As such, the results are transferable to other rural contexts in SSA and by extension, other developing countries in the world. Thus, the study argues for policy makers and development partners concerned about the challenges of climate change and energy access to prioritize and increase allocation of resources towards the deployment of RE projects in SSA rural areas and other developing regions of the world. The study also argues for further studies using a CCD framework to identify the full range of RE benefits to rural people and highlight their importance and the need for increased deployment in the region and other developing countries to decisively address both climate change and energy access at the same time.

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Chapter 4

Identifying Barriers and Strategies for Overcoming the Barriers to Deployment of Solar Mini-Grids in Rural Ghanaian Island Communities

Abstract

Energy access remains a challenge for rural populations in sub-Saharan Africa. Ghana is no exception as 15% of her population lives in remote areas without access to electricity. In 2015 the World Bank Group provided funding for the Ghanaian government to extend electricity to some of her rural island communities. Despite technological advancement and increased financial support from development partners, the deployment of renewable energy technologies in sub-Saharan Africa continues to face significant barriers embedded in the socio-cultural contexts of rural communities. Designed through a broader socio-technical systems lens, this study uses a social construction of technology framework to explore the barriers and strategies to overcoming the barriers to solar mini grids deployment in rural Ghanaian island communities. Data were collected through semi-structured interviews, focus group discussions, and direct observations. Respondents included experts (government officials and development partners), key informants, and focus group discussants (community members where the projects were deployed). Barriers that emerged from the study include infrastructural, socio-cultural, technical, financial, regulatory, and research and development factors. Stakeholders' suggested strategies for overcoming the barriers include construction of access roads, community involvement in projects, transfer of technical expertise, deregulation of mini grid sector, effective research and development, and increased generation capacity. The study draws three main conclusions and outlines three policy implications on overcoming the barriers by addressing, for example, infrastructural and socio-cultural challenges.

Key words: Ghanaian island communities, social construction of technology, solar mini grids

Introduction

Access to energy by rural people is undoubtedly one of the biggest challenges facing developing countries (Cook, 2011; Doll & Pachauri, 2010) including those in sub-Saharan Africa (SSA). Close to half of the countries in SSA have their energy generation capacity below 200 megawatts [MW] (Khennas, 2012). A fundamental reason why energy poverty is so pervasive in SSA is because the vast majority of the region's population live in extremely remote areas some of which are island communities located far from grid connections and as such, remain unelectrified (Khennas, 2012). Extension of electricity to such stranded communities is not only difficult, but also expensive (SE4ALL, 2013). Moreover, the remoteness and low earnings of rural populations in the region tend to dissuade private investors from channeling resources there (Sovacool, 2014).

Given the poor state of energy access in SSA, governments and multilateral development partners such as the UN and the World Bank Group, have embarked on various energy projects to address the lack of energy access in the region. In 2012, the UN Secretary General launched the Sustainable Energy for All program (SE4ALL, 2012). The goal was to achieve universal energy access for all people by 2030. The World Bank Group over the years has also devoted about $10 billion for energy infrastructure development and energy efficiency management in SSA (Monari, 2011). All of these interventions are meant to improve energy access by rural populations in SSA.

While the overall objective is to increase energy access, consideration is being given to climate change and sustainability (United Nations [UN], 2017). With a sustainable energy goal, the most viable and cost-effective strategy to electrify the very isolated rural areas in SSA is via mini-grid and off-grid renewable energy (RE) solutions (IEA, 2011). Mini grids are typically stand-alone electricity generation plants limited to specific locations with capacity between 10 kilowatts (kW) and 10 MW (see Kaplan & Sissine, 2009; Sovacool, 2014). The IEA has predicted mini grid solutions to play strategic role in achieving the UN universal energy access goal by 2030. Currently, mini grids are rapidly springing up as additional energy options to utility scale grid connected and other off-grid solutions to electrify rural areas (Pedersen, 2016). At optimized levels, mini grids operationalization is comparatively cheaper than large utility scale power plants (Szabo et al., 2011; Casillas & Kammen, 2012). The geographical uniqueness of many SSA rural areas lend themselves easily to off-grid energy infrastructure (Sovacool, 2014). The provision of mini-grid systems can offer a multitude of benefits for SSA rural communities. Such benefits which can be categorized into adaptation, mitigation, and development benefits include, for example, selling cold drinks to generate additional income, refrigerating of fresh fish instead of smoking to reduce burning of wood, and teachers accepting postings to rural communities, thereby improving education (Nuru et al., 2020). While mini grid RE can yield enormous benefits to rural inhabitants in developing countries in SSA, deployment is not without barriers. Given the great potential of solar mini grids to accelerate energy access throughout rural SSA, additional research is needed to understand the range of social and technological barriers that can limit their deployment.

Studies focusing on the barriers to RE projects in the developing regions of the world are not uncommon. Prior to the UN's declaration of SE4ALL by 2030, there had been efforts to understand factors that could hinder the penetration of RE projects in some of the poorest and hardest to reach communities in the world (IPCC, 1995; Cabraal et al., 1996; Gutermuth, 1998; World Bank, 1999; Oliver & Jackson, 1999; Nobert & Painuly, 1999). These earlier studies were centered on a wide range of factors including technical, financial, market regulation, and institutional analysis. From the early 2000's, however, the focus has largely shifted to technology and economics as the main drivers of RE penetration in the developing countries (Miller & Hope, 2000; Martinot et al., 2002). In more recent times, research in the energy social science have emphasized transcending the rhetoric on technical and economic parameters to understand nuanced factors couched in the socio-political and cultural configurations of rural communities that often pose greater threats to RE deployment (Ulsrud et al., 2011, Sovacool et al., 2011; Sovacool, 2012; Kumar, 2018; Ockwell et al., 2018). We opine here that the need to pay greater attention to the socio-cultural contexts when deploying RE projects in poorer regions is probably informed by significant progress made in addressing the hitherto predominately technical and economic barriers. Advancement in technology and increasing financial support from multilateral organizations such as the World Bank Group and African Development Bank, have drastically mitigated the technological and financial hurdles that used to destruct the materialization of RE projects in poorer regions like Africa and Asia.

While the financial and technical constraints, to some extent, still remain barriers to grapple with, evaluative studies on the successes and failures of extant RE projects in developing countries are pointing to other more intricate issues usually embedded in the social structure of beneficiary rural communities (Sovacool, 2011; Kumar, 2018). An overarching argument has been that understanding the socio-cultural milieu to RE deployment is as important as the technical and financial barriers, because a variety of socio-cultural dynamics coalesce to make energy access a reality (Mceachern & Hanson, 2008). Recognition of the several socio-cultural determinants of energy access have, however, been neglected in favor of the technical factors (Ryan, 2014; Standal & Winther, 2016). Watson et al. (2011) advocated a deeper reflection on the link between technology and culture in relation to energy access in the poorer and isolated communities.

Despite the depth of literature that exists on energy access globally, there is less contribution in Africa, especially SSA (Ockwell et al., 2018). Particularly, the social science field, which is critical to understanding the core challenges of energy poverty, has seen limited scholarship in SSA. Prior works in the field of energy social science in the region have been concerned with technology and economics with little attention given to the broad socio-cultural and political factors, which characterize many SSA countries (Ockwell et al., 2018). Indeed, Ockwell et al. reported a paucity of African scholarship in the field of energy and sustainable development. In instances where works on energy and sustainable development in Africa exist, the use of a relevant theoretical framework that bridges social and technical considerations, as a lens to distill the real energy access problems endemic to the region is a rarity.

Furthermore, in SSA there is limited research on solar mini grids deployment (Pedersen, 2016). For example, Kirubi et al. (2009) evaluated the contribution of solar mini grids to development in Kenya. Using a technological diffusion approach, Eder et al. (2015) provided a description of a specified mini grid system in Uganda. While Ilskog et al. (2005) studied and analyzed organizational-led approach to rural electrification in Tanzania. None of these papers cited have sought to specifically understand the socio-technical barriers to solar mini grids in the region. Despite the increasing competitiveness of mini grids and the appropriateness of deploying them more easily in SSA rural areas than the utility scale grid connectivity, research into factors that could pose as barriers is limited in the region. Against this backdrop, this paper uses a broad socio-technical framing, specifically drawing on social construction of technology

(SCOT) theoretical framework to study the barriers to the deployment of solar mini grids in three Ghanaian rural island communities within SSA.

SCOT is rooted in socio-technical approach with an understanding of technological development as a co-evolution of technology and society (Geels, 2004). SCOT originates from Sociology of Scientific Knowledge and Sociology of Technology (Bijker et al., 2012). SCOT contends that the extent to which a given technology emerges and thrives is determined by social behaviors of various stakeholders (Pinch & Bijker, 1984). SCOT takes into consideration a wide range of socio-technical factors including but not limited to technical, social, financial, and political to understanding technology (Sovacool, 2006). Its ontological underpinnings greatly lean towards "social constructivist" theory which dictates that technological development is socially constructed (Bijker et al., 1987). SCOT opposes technological determinism in favor of socio-technical influences. Thus, in any technological development, understanding the social contexts is as critical as the technical milieu (Pinch & Bijker, 1984, Sovacool, 2009). Thus, the barriers to any piece of technology are not 'cut and dried' technical factors, but an interplay of social and technical dynamics.

The SCOT framework has been criticized for failing to address power relations among different social groups in terms of which group's views are included or excluded in the decision-making process (Klein & Kleinman, 2002). Despite this criticism, SCOT serves as a vital analytical framework for understanding the socio-technical factors that can either enhance or hinder technological development. Thus, SCOT is applied in the present study as a theoretical and an analytical framework to understand the socio-technical barriers to the deployment of solar mini grids in rural Ghanaian island communities from the perspectives of stakeholders. The study is designed to achieve the following goals:

1. To identify stakeholders' perspectives of the barriers to solar mini grids deployment in Ghanaian rural island communities.
2. To determine which barriers, pose the greatest threats.
3. To identify stakeholders' suggestions for overcoming the barriers.

The rest of the paper is organized around the following sections. Section 2 describes the methods employed for the study; Section 3 presents the results; Section 4 provides a discussion on the results in the context of socio-technical framing and in relation to similar studies; and finally, Section 5 draws conclusion and outlines implications for policy.

Methods

In this section I first provide justification for choosing Ghana for the case study and brief description of the island communities. I then describe the methodology used for the data collection and analysis.

A number of factors make Ghana an ideal country for our case study on solar mini grids. First, Ghana is one of five countries in SSA with a national electricity access of about 85%, with an urban access nearing 100% (Power Africa, 2018). A World Bank Representative on energy in Africa confirmed Ghana's high rating on electricity access in SSA during an interview with the author when he mentioned that, "the access rate in Ghana is one of the highest in Africa." (Expert, World Bank Group, personal communication, September 2019). Despite its high rating, Ghana still has about 15% of her population without access to electricity most of whom are residing in island communities. Thus, it is imperative to understand why in spite of the high relative accessibility to electricity, the island communities remain unelectrified. Second, the government of Ghana has a specific policy on mini grids deployment. The policy has so far seen solar mini grids deployed in five island communities. I posit that it is also essential to understand barriers that were encountered to inform policy in future projects deployment. Third, Ghana is one of the few countries that has deployed solar mini grids in SSA. The experiences from Ghana will provide useful policy guide for other countries considering similar projects in the region.

For the case selection, I focused on three out of the five island communities that were provided with the solar mini grids in 2015. I limited the scope to only three communities due to logistical constraints. The data collection took place in Pediatorkope, Atigagome, and Kudorkope.

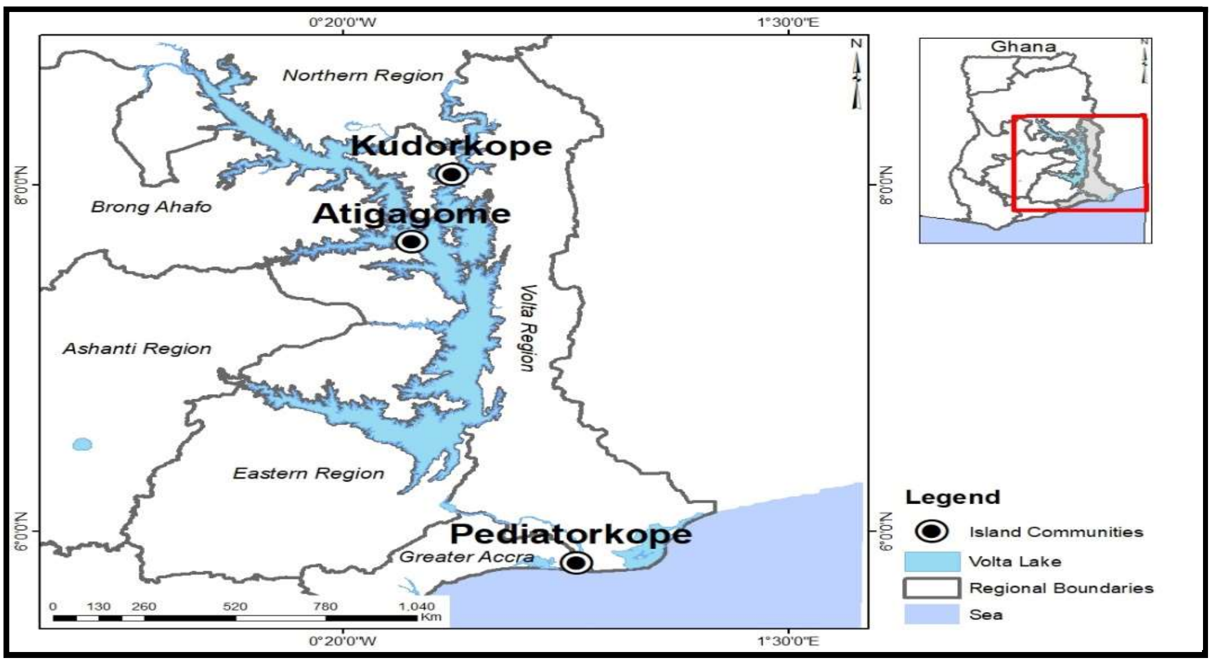

Figure.4.1. Map showing study communities. Source: By the research team.

These communities were chosen based on their strategic locations: Pediatorkope in the southern belt, Atigagome in the middle belt, and Kudorkope in the northern belt of the country. In addition, the three communities share significant socio-economic and geo-demographic characteristics with other island communities such as being isolated from the mainland areas by the Volta Lake, with primary livelihood activities being fishing, oyster mining, and farming. The construction of Ghana's largest hydroelectric dam (Akosombo Dam) in 1965 created over 2000 island communities. Also, the island communities were chosen over other rural communities on the basis that majority of Ghanaians without electricity live on the islands where grid connection is cumbersome (SE4ALL, 2012; World Bank Group, 2017). Approximately, 2.9 million of the 5 million Ghanaians without electricity reside in the island communities along the Volta Lake (Netherlands Development Organization, 2018).

With funding from the World Bank Group, the government of Ghana in 2015 chose to provide electricity for selected island communities with population of 500 and above. The most viable energy option was solar mini grid. Prior to deploying the mini grids, the communities depended on energy sources such as kerosene lamps, diesel generators, mini rechargeable solar lamps, candles, dry cells for flashlights, firewood, and charcoal. The communities are so deprived to the extent that some of them lack social amenities like public school, public toilets, pipe borne water, health centers, market centers and means of transportation. Apart from footpaths crisscrossing the communities, there are no access roads to facilitate vehicular movement. Community members usually resort to canoes and motorized boats at a fee in order to reach the mainland areas. A typical journey by the motorized boat to the mainland areas takes between 20 to 60 minutes. While the communities lack social amenities, there are however churches in each community, confirming Africans' religious inclination (Mbiti, 1990).

An estimated number of 1000 to 2300 people inhabit each community with an average household size of 8 persons. The main livelihood activities are fishing, oyster mining, and farming. Fishing is the predominant occupation in all the islands for the men, whilst women

Figure.4.2. A solar mini-grid plant with backup wind turbines in Pediatorkope (Photo credit: Jude Nuru).

engage in fish mongering and petty trading. A summary of the socio-economic and geo-demographic information of the three island communities is provided Table 1.

For the data collection, I adapted a three-stage framework proposed by Painuly (2001, p.76) consisting of "literature survey, site visits, and interaction with stakeholders." Consistent with Painuly's proposal to review case studies on RE at both local and global levels, a review on the barriers to RE in developing countries was done as shown in the introduction of the paper. Practical site visits to the communities were conducted and finally, there was an engagement with different stakeholders to elicit their perspectives on barriers that were encountered during the deployment of the solar mini grids. Qualitative data were collected using multiple strategies: semi-structured interviews, focus groups discussions, and direct observation.

Table 4. 1
Summary of the socio-economic and geo-demographic information of the three island communities

Community	Ethnic Group	Main Livelihood Activities	Population Estimate	Social Amenities	Vegetation	Housing Type
Pediatorkope	Adangbe	Oyster mining Fishing Farming	2300	Health center Basic school	Savanna	Thatch roof Aluminium zinc
Atigagome	Ewes Adangbe Fantes	Fishing Farming	1100	N/A	Savanna	Thatch roof Aluminium zinc
Kudorkope	Ewes Adangbe	Fishing Farming	2000	Basic school	Savanna	Thatch roof Aluminium zinc

Source: Field data from interviews with key informants and direct observation

A total of 121 stakeholders participated in the study. I was assisted by four research assistants comprising of three males and a female, who come from communities closer to the island communities and understand the native languages spoken in these island communities. Data collection took place between July 2019 and November 2019 with the research team spending a month in each community. For purposes of confidentiality and ethical considerations, individual participants are anonymized. I, however, present in Table 4.2 stakeholder groups and organizations that were interviewed, as well as the different sampling techniques used to collect the data. Two streams of semi-structured interviews were conducted. The first was with experts drawn from stakeholder organizations that have been involved with the mini grids' deployment and as such, were better placed to share the barriers that were

Table 4. 2
Summary of stakeholder groups/organizations and methods

Group/Organization	Number of Participants	Methods	Sampling technique
Experts Organizations [a] World Bank Group, Ministry of Energy, Energy Commission, Volta River Authority Netherlands Development Organization	5	Interviews	Purposeful sampling
Key Informants [b] Chief, Assemblyman, Headteacher, Pastor Head of Health Center, Queen mother Systems Administrator	18	Interviews	Purposeful sampling [d]
Community Stakeholder Groups [c] Fishers, Farmers, Women	98	Focus Group Discussions	Snowball sampling [e]
All Settings	N/A	Direct Observation	Auditory and Visual
Total	**121**		

[a] 1 expert from each organization was interviewed bringing the total number of expert interviewees to 5. Interviews with all the experts took place at their respective offices. The interviews lasted between 20 and 30 minutes.

[b] 3 Chiefs, one from each community; 3 Assembly wo/men, one from each community; 2 Headteachers, one each from Pediatorkope and Kudorkope, because Atigagome has no school; 1 Head of health center from only Pediatorkope, because the other two communities have no health centers; 3 Queen mothers, one from each community; 3 Pastors, one from each community and; 3 System Administrators, one from each community bringing the total number of key informant interviewees to 18 participants. Interviews last between 20 and 30 minutes. Interviews took place in the communities.

[c] 36 fishers' focus group discussants 12 from each community; 26 farmers' focus group discussants, 8 each from Pediatorkope and Atigagome, 10 from Kudorkope and; 36 women's focus group discussants 12 from each community bringing the total of focus group participants to 98. Discussions took place in the communities either at church premises, chief palace or mini-grid plant site. Discussions lasted between 40 and 60 minutes.

[d] Purposeful sampling in this context refers to the recruitment of informants with specific type of knowledge or information.

[e] Snowball sampling is used here to denote the recruitment of participants through referral by other participants.

encountered during the deployment. The second line of semi-structured interviews were held with key informants drawn from all three communities. These were leaders knowledgeable in the community affairs including demographics, livelihood activities, challenges facing the communities (Marshall, 1996), as well as useful information about the solar mini-grid projects. In line with SCOT theoretical framework, the key informants were stakeholders from the communities and as such, their perspectives would be crucial for the success of the mini grids. To further enrich the data, three focus group discussions (fishers, farmers, and women) were held in each community. These three groups constitute relevant social groups in the communities and understanding their perspectives was also important (Longhurst, 2003). Finally, throughout the study direct observations were recorded in diaries by all research team members and used to complement the findings from the other sources. The guides for expert interviews, key informant interviews, and focus group discussion are attached as Appendices B -D.

Participants' consent was sought to record all interviews using a tape recorder. Recordings were then transcribed. Data analysis was done qualitatively. The analysis was done through a SCOT's framework. In line with this framework, the barriers identified from the stakeholders ranged from technical to socio-cultural factors. The thematic barriers presented in the results section were inductively drawn from the literature according to Painnuly's (2001) framework. During the analysis, however, those barriers from the literature that did not reflect the situation on the ground were omitted from the final list, thus affirming a fact that barriers to deployment of RE projects vary from country to country and from locality to locality (Painuly, 2001). The transcripts were read repeatedly to understand responses clearly. As characteristic of qualitative research, themes can emerge from findings or a researcher can have a set of predetermined themes (Yin, 2014). Consistent with the SCOT theoretical framework, socio-technical themes were inductively predetermined. Codes were then generated from the transcripts and categorized based on the predetermined themes. A cross comparison of themes from all three communities and from the experts was done to arrive at common themes that reflected responses from all cases (Creswell & Creswell, 2018). For example, the term 'stakeholders' is used to refer to responses that reflect cross-cutting findings from all respondent groups. However, findings unique to particular respondent category have been clarified as such by stating for example 'expert' or 'key informant' or 'focus group discussant.'

Results

This section presents the findings from the field studies. The classification of barriers under the various categories was not rigidly done (Painuly, 2001). Whereas some barriers are explicit, others are implied within the study context and as such, readers may not find all barriers relevant in different scenarios. This flexibility in identification of barriers was introduced in order not to miss nuance barriers specific to the study communities. While past studies largely centered on systematic or operational barriers (Kumar, 2018; Ulsrud et al.,2011), the present study focused on barriers that were encountered during deployment of the mini-grid systems. The analysis sometimes dovetails into some operational barriers as well. Also, to give readers the benefit of knowing which barriers were greatest at a glance, and to fulfil objective two of the study, the barriers follow a rank order in Table 4.3. The ranking was achieved based on the frequency with which a barrier was identified from the transcripts. The following section provides further details on each barrier.

Infrastructural barriers

Stakeholders indicated that the lack of infrastructure in the island communities posed the most arduous barrier during deployment of the solar mini grids. Transportation was the most significant barrier to deploying energy projects in the Ghanaian rural island communities. It was a big hurdle transporting the heavy equipment (1 battery weighing about 450 see Figure.4.1) on the Lake, given the countless tree stumps along the way. Since the Lake was not easily navigable, it took the vessel carrying the equipment unusually long time to reach the communities, thereby delaying projects' execution. Stakeholders mentioned that when the vessel eventually berthed at the shores of the lake, transportation to the community was also a huge challenge due to non-existent road networks in the communities. Stakeholders affirmed the infrastructural hurdle as supported by the following statement from an expert, "logistical problem of transporting the equipment across the lake to the island communities was probably the biggest challenge." The lack of infrastructure as the greatest barrier was also confirmed by a key informant thus, “here, car transportation is not there, so you have to use small [wooden] trucks and be pushing”. The

Figure.4.3. Solar mini-grid batteries set (Photo credit: Jude Nuru).

lack of road networks in all the communities visited was also captured through direct observation by the research team:

> Apart from very tiny footpaths that meander through bushes from one section of the communities to other parts, there are no visible, motorable roads in the three communities visited. Except when they use the motorized boats or canoes to cross the lake to the mainland areas, inhabitants virtually walk to perform all daily activities within the communities.
>
> (Field notes from direct observation by researcher)

The stakeholders disclosed that the lack of road infrastructure leading to the communities and within the communities delayed execution of the projects.

Table 4.3
Barriers to solar mini grid deployment in Ghanaian rural island communities

Barriers	Description	Frequency [a]	Difficulty [b]	Impact [c]
Infrastructure	No navigable route on lake Tree stumps in the lake Lack of appropriate vessels Lack of access roads	24	AAA	High (Most impact)
Socio-cultural	Non-involvement of communities Poor understanding of systems Untruthfulness with estimates Land disputes Scattered settlement	18	AAA	High
Technical	Limited technical know-how Lack of technicians Inadequate technical training Low voltage Shortage of meters	15	AAA	High
Financial	Lack of funding by gov't Expensive mini-grid model Cost of transportation Distribution networks costs Maintenance costs	7	AA	Medium
Regulatory	Restriction on private sector Delay subsidies reimbursement Rigidity with high standards	6	AA	Medium
Res & Dev't [d]	Inadequate research & dev't	4	A	Low (Least impact)

[a] frequency represents the number of times a barrier was identified from the responses provided by stakeholders.

[b] the alphabet 'A' signifies the strength/weight/difficulty of each barrier.

[c] 'low/medium/high' depicts a barrier impact on the project. An impact is the effect a barrier has on the project and its level is determined by frequency and weight counts. Barriers are ranked in order of impact from most to least. Thus, barriers with a frequency x ≥10 are assigned AAA with impact level being High. Barriers with a frequency ≥5x<10 are assigned double AA with impact level being Medium.
Barriers with a frequency x<5 are assigned single A with impact level being Low.

[d] Res & Dev't (Research and Development)

Socio-cultural barriers

Table 4.3 shows that the socio-cultural barrier was the next greatest barrier that confronted project developers. It was pervasive during deployment phase and continues to manifest itself after the deployment. The socio-cultural issues that stakeholders identified fall into several strands. First, communities' members were not fully involved in the projects until the developers encountered the difficulty transporting the equipment and sought assistance of the community members to cut tree stumps beneath the water and to cart the equipment from the shores of the Lake to the construction sites. Leaders of the communities were merely informed about government's intention to provide them with electricity as part of the government's policy to electrify the rural areas, but their buy in was not considered.

Second, community members' lack of understanding about solar mini-grid systems, being a novelty in SSA, posed a socio-cultural challenge. As a focus group discussant pointed out, "lack of understanding of the mini-grid power caused us to give wrong answers which the people [developers] used to estimate the power for us and we are now having low voltage." A similar view was expressed by a key informant thus, "from the beginning, the people were not educated, let me say they did not have enough education on the projects as to how they were going to operate." The views shared by the stakeholders clearly show that the communities received less education about the systems, which caused some of them to use the power inappropriately, thereby resulting in occasional power outages. Third, the communities underestimated the kind of appliances they had intended to use as reflected in the following statement from an expert:

> I think they did an initial assessment of the energy requirements of the people, but some of them were not forthcoming with the actual things they were going to do with the electricity. So, they in a way underquoted their energy requirements, because of that it affected the sizing of the systems. So, some of the systems are sized the way they are because the people [communities] didn't tell them [developers] the entire truth about what equipment or devices they were going to use and some thought that it was going to be used to determine the price of electricity they were going to pay, but they turned out to use more equipment
>
> (Interview with an expert)

From the onset, people concealed information about the gadgets they would use the power for, but are now using more than they had indicated, thereby resulting in low voltage. Consequently, some even attempt illegal connection when they exhaust their monthly allowance.

Fourth, a cultural barrier that emerged relates to perceived loss of properties by community members. According to community respondents, culturally, sale of land is prohibited in the island communities. Consequently, the developers could not have purchased a piece of land for the power plants. In Kudorkope, a family opposed the construction of the power plant on their property. Another family mounted strong resistance when an electric pole was to be erected near their compound. Some community members, especially Pediatorkope, were unhappy when a coconut tree was fell to pave way for the construction of the power plant. Across all the three communities, there was general complaints about fishing gears that got damaged by the vessels carrying the equipment to the communities. The following statement from a headteacher lends further evidence:

> There was a problem with the acquisition of the land for the project. The land belongs to a community member and it was difficult convincing the owner to give up the land. Apparently land is not sold in the community, so it was difficult to acquire the land. Before the construction of the project, somebody was already farming on that piece of land
>
> (Interview with a key informant)

A chief of one of the communities also expressed similar sentiments about the acquisition of land in the following words:

> We had to cut a tree along the wiring route and there was this family that opposed cutting down a tree on their land. I had to ask for police assistance and those people were arrested and detained to pave way for the passage of the grid line.
>
> (Interview with a key informant)

Fifth, the scattered settlement pattern of the island communities was also a barrier. As with rural settlements in SSA, the houses in some parts of the communities are isolated which made it difficult to distribute the power networks. In SSA, rural settlements are so sparsely distributed to create room for backyard farming. A system administrator echoed thus, “distributing the networks was a challenge because the buildings in our community are far apart.”

Finally, an ensuing social development affecting the amount of power originally estimated for consumers is the sudden in-migration of people from neighboring communities to settle in communities connected to the mini grids. The development has seen abrupt upsurge in populations, thereby putting more demand on the systems. This trend is highlighted by an expert as follows:

> People are building new houses on these islands and they want services, you know. I had an interaction with the people, and they are telling me you know what, the people who left the communities because of electricity are now returning.
>
> (Interview with an expert).

All these perspectives shared by the various stakeholders expose the fact that the socio-cultural barrier to the deployment of mini grids projects in SSA can manifest in many shades.

Technical barriers

Stakeholders enumerated a number of technical barriers that can be classified as: limited technical know-how about solar mini grids in the country, lack of technicians to manage the systems in the communities, inadequate training for those engaged to manage and maintain the systems, ‘low voltage, and lack of dispensers (meters).

According to the stakeholders, the engineers commissioned to execute the projects had no prior experience with solar mini grids and had to subject themselves to a lot of modeling processes before a concept was found. An expert shared a view thus, “the technical barriers at the time, the know-how was not too much there, so we need to really think and rethink the entire process to ensure that the systems would run when we energize them.”

Eventually when this initial hurdle was cleared, lack of technicians to manage the systems in the communities proved yet another barrier. One expert commented that, “getting people from the communities to manage the systems was a problem. I mean lack of technicians to manage the mini grids in the islands." A key informant further elaborated the lack of technicians as follows:

> The people that they brought to do the installation some of them didn't know much about the mini grids. Some of them were not qualified electricians. So, the way that they did, some were very poor. You could imagine that we have three phases here, instead of them to share the customers we have equally on these lines, they didn't do that. Some of the lines have more, even double customers on it.
>
> (Interview with a key informant)

All these perspectives underscore the lack of expertise in mini grids in particular and RE solutions in general in SSA. This obstacle feeds into a related barrier of inadequate training offered to people who were recruited to manage and maintain the systems. The insufficient training received by the people recruited locally to manage the systems caused a failure of the systems at some point, which called for some retraining. Commenting on this barrier, an expert intimated that, "There was a time the systems went off and we checked and noticed operational deficiency on the part of the operators. So, we restored the systems and retrained the workers onsite." Not only were the site operators not given adequate training about the systems from the onset, but only one technician has been placed to provide technical services to more than one community. In some cases, the technicians do not reside in their assigned communities. Only the system administrator and committee members do. Teachers without basic technical acumen were recruited as system administrators.

The other technical barrier commonly shared by the stakeholders related to either lack of or faulty meters. A women's focused group participant commented that, "I am a hairdresser, but I am not able to use the power to run my hair dryer, because sometimes I experience frequent fault with my meter." When the research team sought clarification from a system administrator why the meters arbitrarily go off, he explained that "people meters go off when they attempt to use appliances that consume more power than their allowable limit." But commenting further on the unavailability of meters a key informant said that, "we have insufficient meters. Other people are not connected yet, because they don't have meters. Some of us don't have meters." Respondents were of the view that without a meter, a person cannot access the power and yet meters are not readily available. They indicated that some inhabitants have built new houses, but remain unconnected, because of lack of meters, as the meters have to be ordered from Volta River Authority (VRA), Ghana's public sector utility operator charged with the responsibility to manage the mini-grid systems in the island communities.

Financial barriers

On the financial front, stakeholders mentioned barriers such as the government's inability to fund the solar mini grid projects, the expensive model of the mini grids, the cost of transporting the equipment, the distribution networks costs, and the maintenance costs. The government of Ghana lacked the financial resources to undertake the projects and as such, funding was provided by the World Bank Group. The model of mini grid deployed were of high quality and were too expensive for the government. Respondents expressed concern over how the rest of the island communities would be funded. As submitted by an expert, "The World Bank Group provided funding through Ghana Energy Development Access Project (GEDAP) for the government to increase access in Ghana. I think there were options and mini grids were the best option. The government couldn't afford the cost."

Apart from government's inability to provide the required funds, the choice of the mini-grid model by the government turned out expensive. "The systems installed are gold plated, making them very costly, they did that because they didn't want to cut down trees, so it was for environmental purposes", an expert commented. The gold-plated model enabled the installers to pass them through trees without cutting down the trees. Further sharing the expensiveness of the systems installed, another expert respondent said:

> The issue we had is that we have installed gold plated mini grids and this cannot be replicated, they cannot be the standard for future deployment, because they are very expensive. But they were meant to be like that initially to ensure confidence with the technology and understand how it works. We needed a robust system that would not fail because of design but can fail because of social problems and other dynamics.
>
> (Interview with an expert).

The amount of money spent to transport the equipment to the communities and how much was expended to distribute the networks were two other financial barriers raised by the stakeholders. Throwing more light on this, a fisher group discussant added that, "renting and buying diesel to fuel the vessel that carried the equipment cost the developers a lot of money." Some of the stakeholders were concerned that the state-owned utility company tasked to manage the projects might not have the financial capability to operate and maintain the systems. At least the upfront costs have been absorbed by the World Bank Group for the five first projects, funding for future projects, however, remained undetermined. A respondent summed it up thus, "funding will be a challenge for the mini girds, because these are very expensive."

Regulatory barriers

Stakeholders pointed to three regulatory actions initiated by the government as barriers to the deployment of the solar mini grids, namely strict regulations that allow only public sector to deploy the solar mini-grid systems in the island communities, government not forthcoming with subsidies reimbursement, and unrealistic mini grid tariffs. The government has passed a policy allowing only the public sector to undertake mini grids in all the island communities. Private sector participation is strictly prohibited. Government's position is that once private sector actors are driven by profit motive, allowing them to deploy the mini grids will create unprohibited prices, which the island communities cannot pay. The sector has therefore become an exclusive reserve for the public sector. Stakeholders, however, see such a regulatory measure as anathema to speeding up the process. Respondents wish for the government to deregulate the sector by allowing private sector participation as evidenced by the following remark:

> One of our keys asks of government has been for them to reconsider their policy position of only having the public sector lead the process of deploying the systems. We think that the private sector has the capacity and resources to support in the process of speeding up universal access to electricity. So, we feel that opening up the space for their involvement would be useful and it would also save the public purse in terms of the level of investment that is required of government, you know!"
>
> (Interview with an expert)

Another regulatory barrier identified by respondents was delay subsidies reimbursement to the public utility company managing the mini grids. By an energy sector regulation, the island communities pay 30% of the monthly tariffs on electricity from the mini grids while the government pays the remainder. As a respondent noted, "by the model, government is to pay cost subsidies and we know that government is not prompt in paying its costs and this can result in accumulated arrears and complicate issues." The delay subsidies reimbursement is seen as a barrier to the smooth operation of the mini-grid systems in the country so long as government continues to regulate the sector.

Finally, and closely related to subsidies, respondents also considered the mini grid tariffs dictated by government as being unrealistic. An expert commented that, "knowing our electricity tariffs culture, prices are not reflective of costs." By state regulation, the cost of electricity everywhere should be flat be it mini grid or grid-connection. Ordinarily, consumers of the mini-grid power should pay higher tariffs, but the government's regulation allows the island communities to pay 30% of the monthly tariffs, a measure respondents thought is incommensurate with the cost of power from the mini-grid systems.

Research and Development barriers

Limited research and development conducted prior to the deployment of the mini grids emerged as a barrier in the study. Articulating this view, a stakeholder said that, “poor assessment of the potential power demand led to a mismatch between what communities demanded, and the generation capacity that had been installed.” All the island communities complained about what they called “low voltage.” Interviews with stakeholders revealed that a thorough research was not done to properly gauge the communities’ demand for power and match that with supply. The outcome of the limited research had been a disproportionate supply. Consequently, three months after deployment, the demand in Atigagome, for example, outstripped the supply, compelling the operators to double the initial capacity by increasing it from 20.66 kWh to 41.31 kWh. Contributing to this, a respondent remarked that, “they had to rapidly increase the capacity because consumption exceeded the capacity soon after installation, which exposes the fact that the energy demand assessment in the beginning was faulty.” Confirming the position of this respondent, a focus group discussant said that:

> Customers were asked how much they earn at the end of the month and tariffs were estimated not based on appliances they were to use rather on a supposed monthly earning quoted by customers. People were asked how much they were willing to pay and not how many appliances they were going to use
>
> (A focus group participant)

The stakeholders, however, believe that if researchers contracted to do the study had asked a lot of more relevant questions the demand and supply imbalances being experienced in all the communities would not have come to the fore. “They didn’t consider all things someone has mentioned but rather the amount the person mentioned he would pay", commented a key informant.

Suggested strategies to overcome the barriers

This section presents stakeholders' suggested strategies for overcoming the barriers. The suggested strategies are summarized in Table 4. 4.

Table 4.4
Summary of stakeholders' suggested strategies for overcoming the barriers

Strategy	Description
Construction of Roads	Construct overhead bridges across the Lake to the island communities Construct direct feeder roads via land to those island communities that are shorelands Create access roads within the island communities
Education & Community Engagement	Educate community members about the correct use of mini-grid systems Involve community members in projects deployment
Transfer of Technical Expertise	Build more local technical capacity through training and transfer of expertise Set up technical offices in the island communities Keep technicians in the island communities to resolve technical faults promptly
Deregulation of Mini Grid Sector	Liberalize mini grid sector for private sector participation Government to relax its hold on deploying the same standards of mini grids in all island communities Impose actual mini-grid tariffs Prompt subsidies reimbursement by the government
Effective Research & Dev't	Thorough research to fairly match communities' energy demand with supply
Increased Generation Capacity	Increased generation capacity to allow productive use of the systems

Construction of access roads

Stakeholders suggested increasing accessibility to the island communities by constructing access roads. Improving access to the islands has two dimensions. First, respondents proposed construction of overheard bridges linking the islands with the mainland areas, preferably at the narrow sections of the lake. "As some of the islands are shoreland communities, it is possible to construct direct roads from the mainland to the islands", suggested a respondent. There is a way to move from Kudorkope via land to the mainland without going through the Lake. The only reason why people use the Lake is because the footpath is not motorable, especially during rainy season and a journey takes more hours on land than via the Lake. Second, stakeholders suggested construction of access roads within the communities. Footpaths are the only viable means to commute from one section of a community to another. Stakeholders believe access roads will not only ease transportation challenges but enhance economic activities. The Chief of Kudorkope, a key informant appealed for roads when he said, “as a chief my suggestion is for the government to construct roads linking Kudorkope to Dambai [district capital] to resolve the transportation problem. So, my main suggestion is for us to have access roads in the community.”

Education and community engagement

A suggestion was made by stakeholders to educate community members about the correct uses of the mini-grid systems and also involve communities in projects deployment. A focus group discussant commented that, “next time there should be enough education among community members for them to understand the systems to enable them give correct estimates.” Stressing the importance of community engagement, a stakeholder remarked that, “first of all we have to advise them to involve the community that would help them do the work.” To highlight that community members were unaware of the deployment, a famers’ group discussant suggested that, “in future projects the community should be informed in advance so that members can arrange for materials to be used for the projects.” With regards to the lack of understanding of the mini grids which caused so many of the socio-cultural barriers, a respondent proposed that, “the community has to get deeper understanding, so it reduces shortage.” Another stakeholder gave a similar suggestion that, “they have to let the community members know that what they asked for is what they would get.”

Further on the need for education, an assemblyman suggested thus. “because the system is a new thing we are using in Africa now, that is solar, when they are bringing it, they should let the people understand it better by letting them know how the systems work”. A suggestion strongly put forward by the community respondents is to extend the power to their neighbors so that in their words, “they can live in peace with them”. According to stakeholders, neighboring communities without the power refuse to get involved in community labor, because they feel their kinsmen have been favored by the government. In a way, there is some degree of resentfulness.

Transfer of technical expertise through training

Stakeholders suggested training for local people. While some basic training was offered to the system administrators, the committee members received no such training. As an expert respondent suggested, “they need to build more local technical capacity there.” Another respondent also added that, “I will also suggest since the projects have been installed in the island communities, a technical office should be set up close by so technical problems can easily be solved.” One other stakeholder suggested that, “having technicians in the communities to solve our problems quick for us is my suggestion.” Currently each community has one system administrator and three committee members. The administrator is a liaison between community members and the operators at the head office. He coordinates the activities of the committee members and also reports any issue about the systems to operators at the head office in the city. The tasks of the committee members include controlling meters, cleaning the solar panels and the powerhouse. None of them has been provided adequate technical training to resolve even minor technical problems.

Deregulation of mini-grid sector

Stakeholders' suggestion for liberalizing the mini grid sector are in four categories. First, stakeholders want the government to open up the sector for private participation to speed up the process of electrifying the over 2000 island communities. An expert suggested that, "the private sector should be given more involving role to supplement government's efforts". Another respondent bluntly stated that, "the private sector would manage things more effectively than the public sector, because the private sector would put more competent people there." Second, stakeholders suggested that government should relax her insistence on maintaining the same standards for all solar mini-grid deployment throughout all islands, because the piloted mini grids are prohibitively expensive. Third, respondents want government to impose tariffs that reflect the actual tariffs of the mini-grid power to attract private investors. To highlight this, a respondent remarked that, "what the communities are paying is not reflective of the costs of the mini-grids." Finally, related to unrealistic pricing, a respondent suggested that if the government would keep subsidizing the mini grids, "then subsidies reimbursement must be prompt to enable the public utilities be financially sound and function more efficiently."

Effective research and development

Stakeholders believe that research prior to the deployment of the mini grids was poorly done. To overcome such barrier in future, a respondent commented that, "I think the greatest suggestion to ensure a thorough assessment of the potential demand is done to be able to fairly match demand with supply so as to avoid the need for rapid capacity increase." Another respondent corroborated the need for an in-depth research when he said, "we need to engage a consultant to do socio-economic studies that will let us get the information." All these views shared by stakeholders highlight the importance of effective research prior to deployment. Adequate research conducted at the beginning could have probably pre-empted some of the socio-technical barriers that surfaced during the deployment.

Increased generation capacity

Throughout the study, most stakeholders suggested an increase in the generation capacity of the mini grids, as the communities keep complaining about "low voltage." A chief, a key informant suggested that, "people are complaining about low voltage so they should come and increase the capacity. Now in the night the streetlights are down so we want them to increase the capacity." A women's focus group participant added that, "the power voltage should be increased for us to power appliances like deep freezers." Explaining why people are experiencing "low voltage" a respondent who is a member of the mini-grid systems committee remarked that, "some people are consuming above what they requested and that is why they are experiencing low voltage in their homes." The reason why stakeholders are calling for capacity increase is to enable community members to tap the power for productive use and ultimately overcome an economic barrier of low-income levels that characterized the island communities. Adding his voice to the call for increased generation capacity, an expert commented, "what actions have they taken to grant access to productive use equipment, refrigerators, corn mills etc. What would be the business development actions to impact entrepreneurship in these people? I haven't seen any!"

Discussion

The analysis done through a social construction of technology lens revealed a number of factors which stakeholders identified as barriers to the deployment of the solar mini-grid systems in the Ghanaian island communities. Barriers identified are consistent with the broad socio-technical framing. The barriers range from lack of infrastructure, socio-cultural, technical, financial, regulatory, to research and development. From these findings, it is obvious that the barriers to the deployment of solar mini grids in the Ghanaian islands are multifaceted. Strategies that stakeholders suggested for overcoming these barriers follow same multidimensionality. The strategies include construction of access roads, education and community engagement, transfer of technical expertise through training, deregulation of mini-grid sector, effective research and development, and increased generation capacity. Thus, the variation noticed in the barriers and suggested strategies defies the notion of technological determinism (Pinch & Bijker, 1984) and aligns with the basic tenets of our theoretical and analytical framework. These findings are consistent with Sovacool et al's. (2011) study that barriers to deploying RE projects in developing countries should be seen as a mixed basket of issues rather than being exclusively technical or social.

Contrary to existing energy access literature (Miller & Hope, 2000; Martinot et al., 2002; Norbert & Painuly, 2008) where emphasis on barriers to RE projects deployment in the developing countries rests with the technical and financial barriers, the present study has demonstrated that infrastructural and socio-cultural barriers manifested the most in the Ghanaian island communities. This study has therefore brought to the fore that even under relatively controlled technical and financial conditions, ignoring the infrastructural and socio-cultural factors could still pose significant challenges for RE developers in rural communities in the developing countries. It stresses the point that too much reliance on the economics and technology (Kumar, 2018) in SSA may cause developers to pay less attention to the underlying challenges peculiar to developing countries. It further reinforces an earlier opinion I shared that though the technical and financial issues are still relevant to contend with in SSA, advancement in technology and increasing donor support may have reduced their impact on energy projects development in the region. On that basis, I agree with Kumar's (2018) study in India where greater focus on the economics and technical contexts relating to off-grid energy projects to the neglect of the socio-cultural milieu of rural communities caused the failure of the projects.

Indeed, the influence of culture over RE deployment in the developing countries is not inconsequential (Ulsrud et al., 2011; Palit et al., 2013), as it can be both a 'blessing and a bane'. In this study, whereas few community members initially opposed giving up their lands for construction of the mini grid plants, the same communities offered land at no fee and provided free labor to support the construction of the plants. While similar studies found that community engagement during mini grid deployment garnered communities' support and resulted in successful systems (Sovacool, 2012; Marks & Davis, 2012; Katre et al., 2019), other studies reported that mini grids failed due to non-involvement of the communities (Ulsrud et al., 2011; Palit et al., 2013). The consistency of this study with other solar min- grid literature underscores the fact that whilst other commonly known barriers may exist, the unique social structure of a people carries greater weight over the extent to which successes are recorded with certain energy projects in developing countries (Sovacool, 2014; Sovacool & Drupady, 2012).

While the barriers seen in this study are undeniably multifarious, it is also revealing from the results that the infrastructural and the socio-cultural factors, as I have already highlighted, were the greatest of all the barriers encountered in the Ghanaian island communities. Thus, a significant contribution of our study is the element of ranking which we introduced. Whereas past studies (Painuly, 2001; Sovacool, 2009; Sovacool et al., 2011; Luthra, 2015) have identified similar range of barriers to RE penetration in developing countries, such rank ordering was not seen. This study has therefore added to the literature a novel angle of looking at the multiplicity and relative impact of barriers hindering smooth deployment of RE projects in the developing countries.

The findings in this study highlight the need to widen the scope to encompass a variety of socio-technical factors when assessing the barriers to the deployment of mini grids in rural island communities in developing countries while also placing more emphasis on the infrastructural needs and cultural contexts of the host communities. Admittedly, there could be variation in the barriers and strategies to overcoming the barriers to deploying RE projects in different countries and regions (Painuly, 2001). This calls for additional research into the social contexts of local communities whenever RE projects are to be deployed, as there is a strong correlation between society and technology (Geels, 2004; Watson et al., 2011). Nonetheless the barriers and solutions identified from the three Ghanaian rural island communities and the strategies suggested by the stakeholders may be transferable to other rural areas in developing countries given the similarities of socio-economic dynamics.

Conclusion and policy implications

The aim of this study was to understand barriers to solar mini grids deployment, which barriers were the greatest, and strategies to overcoming them in three Ghanaian rural island communities. To accomplish that, the study adapted a socio-technical approach, drawing specifically on aspects of social construction of technology (SCOT) framework. Contextualizing the analysis within this framework, a range of socio-technical barriers emerged that hindered deployment of the mini grids in the Ghanaian island communities. The study identified infrastructural, socio-cultural, technical, financial, regulatory, and research and development barriers. The infrastructural and socio-cultural barriers turned out the greatest. Strategies to overcome them include construction of access roads, adequate education and community engagement, transfer of technical expertise through training, deregulation of the mini grid sector, effective research and development, and increased generation capacity. Based on these findings the study draws three main conclusions and outlines three policy implications.

First, I conclude that the barriers to the deployment of solar mini grids in rural communities are socio-technical consisting of both technical and social forces. As such, understanding the socio-cultural barriers is as important as understanding the technical barriers. Second, while the barriers are undeniably multidimensional, infrastructural and socio-cultural were the topmost ones. These two barriers were commonly identified by stakeholders as the ones that had the greatest impact on deployment of the projects. The two barriers signify major structural challenges facing SSA rural communities. Third, I conclude that the socio-cultural barrier manifested itself in many ways and permeated other barriers. It shows the important place of culture in SSA and the need to seriously consider the social structure when designing energy projects for rural communities in the region.

This research represents one of the few studies using SCOT within the broader socio-technical framing to collect empirical data on the barriers and strategies to overcoming the barriers to deploying mini grids in SSA. Thus, its contribution to the energy access scholarship in the region has several policy implications. I outline below three policy implications for policy makers, development partners, donor agencies, researchers, and governments in the design and deployment of future projects.

First, while the appropriate technology and financial challenges may have been addressed through donor support and technological advancement, other socio-cultural barriers could still pose a huge threat. This implies that successful energy projects implementation in the region requires more than solving one barrier, because the barriers are multifarious. As such, equal attention ought to be given to both technical and social issues.

Second, the infrastructural barrier exposes a complete lack of infrastructure in some SSA rural communities. It further shows that development partners had not considered the impact the lack of infrastructure was going to have on execution of the projects. It means that in future deployment, greater consideration must be given to infrastructure, since energy projects deployment and infrastructure are 'bedfellows.'

Third, the socio-cultural barrier was so pervasive and to an extent, affected other barriers, especially the technical barrier. The study results suggest that enough education was not provided to let the communities understand the mini-grid systems. In subsequent projects, adequate education ought to be provided, as well as a complete involvement of the communities. To pre-empt many of the socio-cultural barriers, more thorough research to understand specific cultural dynamics is recommendable.

The Ghanaian case study has clearly demonstrated that, to fully understand the barriers to the deployment of solar mini-grid in SSA, it is important for governments, policy makers, and development partners to look beyond the technical and financial factors to pay equal attention to the socio-cultural contexts of rural communities in the region. Overcoming the technical and financial barriers will prove inadequate unless the socio-cultural barriers are equally addressed.

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Chapter 5

Conclusion

Policy makers and development partners are exploring strategies to address climate change and energy access in rural sub-Saharan Africa. Renewable energy exploitation is being considered an important strategy to overcome climate change vulnerabilities and energy poverty in the region. The goal of this dissertation was to understand the benefits and barriers, as well as strategies to overcoming the barriers to deployment of renewable energy in sub-Saharan Africa. It explored these topics in the context of the deployment of solar mini-grid systems in Ghanaian rural island communities from the perspectives of stakeholders drawn from government officials, development partners, and the island community members. To do this, the study synthesized Climate Compatible Development and Social Construction of Technology theoretical frameworks to create an integrated framework capable of holistically assessing renewable energy deployment in rural sub-Saharan Africa. The integrated framework was then applied to assess the benefits and barriers of solar mini grids in the Ghanaian rural island communities. While the Climate Compatible Development component of the integrated framework facilitated analysis of the benefits, the Social Construction of Technology dimension was applied to identify the barriers to the deployment of the solar mini grids.

The Climate Compatible Development framework underscored that the deployment of renewable energy projects can deliver co-benefits for adaptation, (for example enhancement in livelihood skills) mitigation benefits, (for example reduction in carbon emissions), and development benefits, (for example access to basic social amenities such as clean water and health care) all within the context of addressing climate change and development. The Social Construction of Technology framework also highlighted that a combination of social and technical factors tends to influence technological development, but not the technical component per se, as it shed light on a range of socio-technical factors to that effect. In this regard, factors that determine the success of a piece of technology can range from technical, financial, political, regulatory, research and development to socio-cultural. The two frameworks are complementary in that while the former underscores the co-benefits of renewable energy projects, the latter highlights that these benefits can only be realized when barriers like funding challenges are addressed and political commitment shown by political actors. While this integrated framework can be applied prior to deployment of renewable energy projects in developing countries, the present study focused on post-deployment of renewable energy projects. The operationalization of the Climate Compatible Development requires an enabling environment offered by the Social Construction of Technology framework. In other words, for the Climate Compatible Development framework to succeed, positive socio-technical factors ought to be in place. In the current study, the integrated framework was applied in the field to gather data on benefits and barriers at the same time. To ensure ease of data organization, however, the analysis and presentation of findings was done separately in Chapter 3 and Chapter 4.

Operationalizing the Climate Compatible Development framework, the study found that solar mini grids can deliver tri-benefits (adaptation, mitigation, development) for rural communities in sub-Saharan Africa within the context of climate change and development. Surveys were used to identify the different dimensions of benefits that the projects delivered to the island communities. The surveys revealed several adaptation benefits that were realized from the solar mini grids. The mini-grid systems created job and business opportunities for some inhabitants in the island communities. Some individuals have been employed and provided with basic technical skills to enable them to monitor the systems on behalf of the operators. A system administrator, and other support staff have been employed to manage the day-to-day functioning of the solar mini-grid systems. In terms of business opportunities, some inhabitants now engage in small trading by selling cold drinks and other frozen foodstuffs. In addition, tourism opportunities have been created, as different people including researchers, government officials, and development partners now visit these communities for different reasons. These frequent visits have boosted the business of the motorized boat owners who now make several trips carrying people to and from the islands at attractive fees. Likewise, there has been a boost in demand for cold drinks and fish products by the visitors.

In terms of mitigation benefits, the solar mini-grid systems replaced diesel generators and kerosene lamps, contributing to reductions in emissions and air pollution. Prior to the deployment of the solar mini grids, the island communities were utilizing fossil-fuel based generators and kerosene lanterns for lighting and for other purposes. The mini grids, however, came to replace these carbon-laden sources of energy. The mini-grid systems have also contributed to reduction in deforestation. Fishing being the predominant occupation, a lot of firewood used to be harvested for smoking the fresh fish to preserve them. Fishers and fishmongers are now able to freeze some of their catch without having to smoke all of it. This fish treatment method requires no firewood, hence reduction in the need to harvest wood in large quantities.

The development benefits realized from the solar mini-grid systems include access to improved healthcare, enhanced school performance, and reduction in social vices such as theft and rape due to illumination of the communities at night. Previously, thieves used to steal fish that were being smoked and other items whilst their owners were asleep. The illumination at night tends to scare potential thieves away. The practice whereby people used to take advantage of the darkness at night and rape young girls, resulting in teenage pregnancies has also been checked. Additionally, health and educational workers used to refuse postings to the island communities for lack of social amenities - a situation that affected healthcare delivery and performance of school children. With lights in the island communities, these workers now accept assignments there, since they have access to information and entertainment much like their counterparts in the urban areas. Moreover, households are able to store certain medications and drugs that require cool temperatures in fridges.

While multiple benefits were realized from the solar mini-grid systems for the island communities, barriers were also encountered. Contextualizing the Social Construction of Technology framework, the study employed qualitative strategies including semi-structured interviews, focus group discussions and direct observations to identify several socio-technical barriers that emerged during deployment of the solar mini-grid systems. The barriers encountered include infrastructural, socio-cultural, technical, financial, regulatory, and research and development. While a range of barriers was identified, infrastructural and socio-cultural barriers had the greatest impact on the solar mini grid deployment. Energy projects require infrastructure, but much of the needed infrastructure was unavailable in the communities. For example, there was no access route to facilitate transportation of the logistics to the island communities. The lack of favorable means of transportation across the Volta Lake and within the communities delayed execution of projects.

The socio-cultural barriers identified include land disputes, poor understanding of the solar mini-grid systems by community members and scattered rural settlement patterns. For example, some community members opposed the mounting of electric poles on their plots of land and near their compounds. There was also limited technical know-how about solar mini-grid systems among engineers in the country. In terms of financial impediments, the government of

Ghana lacked the needed funds to undertake such projects until the World Bank Group provided support. On the regulatory front, the government passed strict regulations baring private sector participation in the mini grid sector in Ghana, which some experts believe is a barrier to speeding up the extension of electricity to the isolated rural communities in the country. Also, prior to the deployment of the solar mini grids, adequate research was not done to properly match demand with supply. Consequently, there has been an insufficient supply of power resulting in occasional low voltages in some of the beneficiary communities

Following the identification of these barriers, strategies were identified that could address them. The strategies include construction of access roads, education and community involvement, transfer of technical expertise through training, deregulation of the mini-grid sector, effective research and development, and increased generation capacity. For example, the stakeholders suggested increasing accessibility to the island communities by constructing access routes both across the Volta Lake and in the communities to enable vehicular movement. Furthermore, community members should be sensitized to understand the functioning of the solar mini-grid systems to provide correct estimates to the developers. Community members involvement would enable them gain better understanding of the solar mini grids and avoid the tendency to misuse the systems. Also, local community members should be trained and equipped with technical expertise to fix minor technical problems without resorting to technicians from the city. The stakeholders further suggested that government should deregulate the mini-grid sector to allow private sector participation to accelerate provision of electricity to the rural areas. In addition, adequate research prior to project deployment has been recommended to properly match demand with supply to avoid potential low voltages.

Based on the realized co-benefits, the study posits that renewable energy can address both climate change and development concurrently in the developing countries. In this context, the study considers renewable energy projects suitable for rural communities in sub-Saharan Africa. The study thus argues that policy makers and development partners should prioritize and increase the deployment of solar mini grids in sub-Saharan Africa to address climate vulnerabilities and energy poverty. An increased deployment of solar mini grids would save policy makers and development partners substantial resources that would have otherwise been spent on pursuing adaptation, mitigation, and development goals separately. Also, based on the multiplicity of the barriers, the study concludes that the barriers to solar mini grids deployment in sub-Saharan Africa are socio-technical in nature, which are neither determined exclusively by technical nor socio-cultural factors. Thus, understanding the socio-cultural barriers to the deployment of renewable energy projects in rural communities of the developing countries is as important as the technical factors.

Drawing from the conclusions from the assessment of both benefits and barriers to the deployment of the solar mini-grid systems, a number of policy implications are discernable from the study in respect of the benefits and also for the barriers. Starting with the policy implications for the benefits, one implication is that the solar mini-grid systems delivered adaptation, mitigation, and development benefits consistent with the Climate Compatible Development analytical framework applied in the study. It does suggest the need for policy makers and development partners in sub-Saharan Africa to adopt the Climate Compatible Development framework for tackling climate change and development challenges. It also implies that limited resources could be spent on renewable energy projects and still be able to address both climate change and development challenges simultaneously without having to duplicate projects leading to significant costs savings. This has the added advantage of attracting investment support from donor agencies due to the promise of co-benefits likely to emerge from investment in renewable energy projects. In addition, the variety of benefits that accrued to the rural island communities have proven the suitability of solar mini-grid systems for the rural areas, which calls for their increased deployment. The study argues for policy makers and development partners to prioritize such projects in sub-Saharan Africa by channeling more resources into their deployment.

A further implication is that the barriers to renewable energy deployment in sub-Saharan Africa are multifarious, with some of them rooted in cultural considerations. It shows that the barriers go beyond technical and financial issues to encompass socio-cultural factors. It means that different strategies have to be put in place to address the multiplicity of barriers by paying equal attention to both technical and socio-cultural impediments when deploying renewable energy projects in rural sub-Saharan Africa. For example, while technicians are required to execute the projects, making land available for siting the power plants without opposition from landowners is equally important. Second, the high impact that the infrastructural barriers had on the solar mini-grid projects exposes a serious infrastructural gap in rural sub-Saharan Africa. It clearly shows that key infrastructure such as motorable road networks to support energy projects are woefully lacking in the rural areas within the region. Accordingly, in future project deployment, greater attention should be given to the infrastructure needed to transport the equipment to the rural communities. Third, the pervasiveness of the socio-cultural barriers found in this study suggests that insufficient education was provided for the communities to understand the solar mini-grid systems. It also underscores the important place of culture in sub-Saharan African rural societies. It implies that in the future, more consideration should be given to the socio-cultural contexts and adequate education needs to be provided. Awareness raising about the nature and importance of renewable energy projects through campaigns and community workshops should be organized for community members to help them better understand how the solar mini grids function and what to expect.

This study offers three key contributions. First, through these policy insights it contributes towards energy access and development policy in sub-Saharan Africa and by extension other developing regions of the world. It highlights that renewable energy can deliver multiple benefits for rural people within the context of climate change and development. It stresses the need for policy makers to redirect more resources towards renewable energy projects to tackle both climate change and lack of energy in the developing countries. Second, it contributes to the operationalization of Climate Compatible Development and Social Construction of Technology theoretical frameworks. Despite being important theories to shape development, their application is limited in sub-Saharan Africa, particularly in the energy sector. This dissertation is perhaps the first to have integrated these major theories in a single study and as such, its contribution to theoretical integration in the social sciences is significant. Third, the literature on solar mini-grid systems in sub-Saharan Africa is limited. This dissertation adds to the existing literature and extends information available on solar mini-grid systems in the region.

While this dissertation was conducted in the Ghanaian rural island context, the results are still applicable to other rural areas within sub-Saharan Africa and even other developing countries. The Ghanaian rural island communities share some common characteristics with other rural areas in the region. These include scattered rural settlement patterns, remote locations, poor road networks, lack of electricity, clean water, health posts and educational facilities, reliance on natural resources, and limited livelihood diversification skills *inter alia.* As such, the results from this study are transferable to, for example, rural areas in Malawi, Cameroon, Rwanda and

Nigeria. Moreover, the analytical frameworks applied in the study have broader application and the study itself has been contextualized within larger sub-Saharan Africa. Future research, however, needs to include a number of cases from across the region to understand the full range of renewable energy benefits to rural inhabitants in multiple contexts. Research is also needed in the area of improved cookstoves, which can further the gains derived from renewable energy deployment, by reducing dependence on firewood and improving women's health in the region. By informing policy makers, development partners and other stakeholders of the multiple benefits to be derived from renewable energy, they can be encouraged to implement strategies to remove potential barriers and pave the way for renewable energy projects deployment in the region.

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Appendix A: Survey Instrument

Households Questionnaire

Time interview begins: Time Interview ends:

Name of community: ___________________

1. Does your household use power from the mini-grid solar project?

☐ Yes ☐ No

2. If yes, how much does your household pay for electricity bill from the mini-grid project per month?

1☐ Under $1
2☐ $1 - $2
3☐ $2.01 - $4
4☐ $4.01 - $6
5☐ $6.01 - $8
6☐ $8.01+

3. If no, which of the following is the reason for your household not utilizing power from the mini-grid? (Check all that apply)

☐ Cannot afford to pay the bills
☐ Do not need the power
☐ Do not have appliances in my household
☐ Other (Specify_____________________________)

4. If your household uses the power from the min-grid project, how do you rate the affordability?

☐ Very affordable ☐ Somewhat affordable ☐ Not affordable at all

5. Please rate the mini-grid project importance to your household.

☐ Important ☐ Neither important nor unimportant ☐ Unimportant

6. How do you rate the power services from the mini-grid project to your household?

☐ Very poor
☐ Poor
☐ Satisfactory
☐ Good

7. How do you think the power supply to your household could be improved?
☐ High voltage
☐ Less intermittent
☐ Satisfactory

8. What other suggestions do you have for improving power supply?

____

9. Which of the following ways does your household use power from the mini-grid project for? (check all that apply)

☐ Cooking
☐ Lighting
☐ Heating
☐ Cooling
☐ Other (specify_______________________________________)

10. What electrical appliances do you use in your household? (check all that apply)

☐ Television
☐ Pressing iron
☐ Phone charger
☐ Refrigerator
☐ Light bulb
☐ Electric cookstove
☐ Blender
☐ Water heater
☐ None

☐ Other (Specify___________________________________)

11. What type of energy does your household currently use for cooking? (Check all that apply).

☐ Liquified petroleum gas (LPG)
☐ Electric stove
☐ Kerosene stove
☐ Charcoal
☐ Woody biomass
☐ Crop residue
☐ Animal dung
☐ Other (Specify___________________________________)

12. Please indicate how much you agree or disagree with the following statements:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The mini-grid project is beneficial to my household	1	2	3	4	5
The project has helped increase my household income	1	2	3	4	5
Life in the community is better with the project	1	2	3	4	5
There is reduction in environmental pollution	1	2	3	4	5
There are more jobs and business opportunities than before	1	2	3	4	5

13. Which of the following are the benefits of the mini-grid project to your community? (Check all that apply).

☐ Support petty trading
☐ Reduction in deforestation
☐ Reduction in youth migration
☐ Prevention of snake bites in the dark
☐ Reduction in burden of women
☐Job opportunities
☐ Improvement in business
☐ Prevention of domestic minor accidents
☐ Access to clean water
☐ Access to improved health care
☐ Improvement in education
☐ Tourism opportunities
☐ Reduction in air pollution from burning wood
☐ Reduction in teenage pregnancy

14. The mini-grid project in the community has brought about improvement in entertainment.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐Agree ☐ Strongly agree

15. The mini-grid project has reduced the use of kerosene lamps in the community.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

16. The mini-grid project in the community has increased accessed to information via electronic media.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐Agree ☐ Strongly agree

17. Apart from the ones listed above, what other benefits do you derive from the mini-grid project?

____

____

____

____

18. Please rank the following benefits of the mini-grid project to your community. (1 is the most important and 3 is the least. Choose only 1 item per number)

	1	2	3
Livelihood diversification	☐	☐	☐
Environmental protection	☐	☐	☐
Improvement in social services	☐	☐	☐

19. What challenges were encountered during deployment of the mini-grid project in your community?

____

____

____

____

20. Please suggest strategies that could be used to address the barriers you mention above.

____

____

____

____

21. Do you have any other comments about the mini-grid project?

____

____

22. How many people are in your household? ___________

23. What is your household annual income?

☐ Under $100
☐ $100 - $200
☐ $201 - $400
☐ $401 - $500
☐ $501 - $600
☐ $601+

24. What is your employment status? (Choose only 1 option: If people belong to two categories, they should indicate the source where they derive most income).

☐ Employed ☐ Unemployed ☐ Self-employed ☐ Trading

25. What is your current job?

☐ Government employee
☐ Non-government employee
☐ Self-employed
☐ Not applicable

26. What is your level of education?

☐ Elementary
☐ High school
☐ Tertiary
☐ Never attended school

27. Please choose the age range most appropriate to you.

☐ 18 - 19
☐ 20 - 29
☐ 30 - 39
☐ 40 - 49
☐ 50 – 59
☐ 60 - 69
☐ 70+

28. Please indicate your gender

☐ Man ☐ Woman ☐ Other

Thank you for your time. Your ideas are valuable.

Appendix B: Expert Interview Guide

Time interview begins: Time Interview ends:

1. What do you identify as the main challenges facing the island communities?

2. What do you think were the reasons for the deployment of the mini-grid solar projects?

3. What are the benefits of the mini-grid projects to the island communities

4. Which benefits do you think are most important to the communities?

5. What challenges do community members face with the projects?

6. What barriers were encountered during deployment of the projects?

7. Which barriers were the greatest?

8. How were these barriers overcome?

8. What other suggestions do you have for overcoming the barriers that were encountered?

9. Which suggestions do you consider the greatest?

10. What other questions should I have asked you and what would be your response?

Thank you for your time. Your ideas are valuable.

Appendix C: Key Informant Interview Guide

Time interview begins: Time Interview ends:

1. How many people live in your community?

2. What are the main livelihood activities in your community?

3. What are the biggest threats to your community members' livelihood?

4. What do community members generally use the power from the mini-grid project for?

7. What were the sources of power for the community members before the mini-grid solar project?

8. What are the benefits of the mini-grid projects to the island communities

9. Which benefits do you think are most important to the communities?

10. What challenges do community members face with the projects?

11. What barriers were encountered during deployment of the projects?

12.. Which barriers were the greatest?

13. How were these barriers overcome?

14. What other suggestions do you have for overcoming the barriers that were encountered?

15. Which suggestions do you consider the greatest?

16. What other questions should I have asked you and what would be your response?

Thank you for your time. Your ideas are valuable.

Appendix D: Focus Group Discussion Guide

Time Discussion begins: Time Discussion ends:

1. How many people live in your community?

2. What are the main livelihood activities in your community?

3. What are the biggest threats to your community members' livelihood?

4. What do community members generally use the power from the mini-grid project for?

7. What were the sources of power for the community members before the mini-grid solar project?

8. What are the benefits of the mini-grid projects to the island communities

9. Which benefits do you think are most important to the communities?

10. What challenges do community members face with the projects?

11. What barriers were encountered during deployment of the projects?

12.. Which barriers were the greatest?

13. How were these barriers overcome?

14. What other suggestions do you have for overcoming the barriers that were encountered?

15. Which suggestions do you consider the greatest?

16. What other questions should I have asked you and what would be your response?

Thank you all for your time.

Appendix E: Raw Survey Data

Does your household use power from the mini-grid solar project?

Row Labels	No	Yes	Grand Total
Atigagome	0	35	35
Kudorkope	0	35	35
Pediatorkope	0	35	35
Grand Total	0	105	105

If yes, how much does your household pay for electricity bill from the mini-grid project per month?

Row Labels	Atigagome	Kudorkope	Pediatorkope	Grand Total
Under $1	0	0	5	5
$1 - $2	4	2	14	15
$2.01 - $4	18	20	14	49
$4.01 - $6	4	6	2	12
$6.01 -$8	4	2	0	6
$8.01+	5	5	0	9
Grand Total	35	35	35	105

If your household uses the power from the min-grid project, how do you rate the affordability?

Row Labels	Atigagome	Kudorkope	Pediatorkope	Grand Total
Not affordable at all	4	3	2	7
Somewhat affordable	2	8	14	24
Very affordable	29	24	19	72
Grand Total	35	35	35	105

Please rate the mini-grid project importance to your household.

Row Labels	Atigagome	Kudorkope	Pediatorkope	Grand Total
Important	35	34	33	102
Neither important nor unimportant	0	1	1	2
Unimportant	0	0	1	1
Grand Total	35	35	35	105

How do you rate the power services from the mini-grid project to your household?

Row Labels	Atigagome	Kudorkope	Pediatorkope	Grand Total
Good	20	17	16	53
Poor	2	4	4	10
Satisfactory	13	14	13	40
Very poor	0	0	2	2
Grand Total	35	35	35	105

Which of the following ways does your household use power from the mini-grid project for? (check all that apply)

Row Labels	No	Yes	Grand Total
Cooking	105	0	105
Heating	105	0	105
Cooling	60	45	105
Lighting	0	105	105

What electrical appliances do you use in your household? (check all that apply)

Row Labels	No	Yes	Grand Total
Light bulb	0	105	105
Phone charger	4	101	105
Television	35	70	105
Refrigerator	72	33	105
Pressing iron	82	23	105
Other	86	19	105
Water heater	98	7	105
Blender	103	2	105
Electric stove	105	0	105

What type of energy does your household currently use for cooking? (Check all that apply

Row Labels	No	Yes	Grand Total
Charcoal	12	93	105
Firewood	22	83	105
LPG	84	21	105
Crop residue	103	2	105
Animal dung	105	0	105
Kerosene	105	0	105
Electricity	105	0	105
Other	105	0	105

Please indicate how much you agree or disagree with the following statements.

Row Labels	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Grand Total
Increased information access	0	2	3	60	40	015
Replaced Kerosene use	0	0	0	45	60	105
Improved entertainment	0	6	3	60	36	105
Beneficial to household	0	1	6	59	39	105
Increased household’s income	17	21	20	33	14	105
Better community life	1	0	11	56	37	105
Reduced Env't pollution	9	22	28	38	8	105
Jobs and business opportunities	7	2	13	53	30	105

Which of the following are the benefits of the mini-grid project to your community? (Check all that apply).

Row Labels	No	Yes	Grand Total
Support petty trading	16	89	105
Reduced deforestation	65	40	105
Reduced youth migration	31	74	105
Prevent snake bites	20	85	105
Reduced women burden	35	70	105
Jobs opportunities	27	78	105

Business opportunities	55	50	105
Reduced domestic accidents	46	59	105
Access to clean water	73	32	105
Improved healthcare	62	43	105
Improved education	37	68	105
Tourism opportunities	62	43	105
Reduced pollution	80	25	105
Reduced teenage pregnancy	64	41	105

Please rank the following benefits of the mini-grid project to your community. (1 is the most important and 3 is the least. Choose only 1 item per number)

Row Labels	1st	2nd	3rd	Grand Total
Livelihood diversification	69	19	17	105
Improvement in social services	28	58	19	105
Environmental protection	21	29	55	105

What is your household annual income?

Row Labels	Atigagome	Kudorkope	Pediatorkope	Grand Total
Under $100	7	2	11	20
$100 to 200	5	0	7	12
$201 to 400	2	3	7	12
$401 to $500	5	5	3	13
$501 to 600	3	3	0	6
$601+	13	22	7	42
Grand Total	35	35	35	105

What is your employment status? (Choose only 1 option: If people belong to two categories, they should indicate the source where they derive most income).

Row Labels	Atigagome	Kudorkope	Pediatorkope	Grand Total
Employed	1	1	3	5
Self-employed	29	23	15	67
Trading	5	9	12	26
Unemployed	0	2	5	7
Grand Total	35	35	35	105

What is your level of education?

Row Labels	Atigagome	Kudorkope	Pediatorkope	Grand Total
Elementary	9	14	17	40
High School	2	3	8	13
Tertiary	1	1	2	4
Never attended school	23	17	8	48
Grand Total	35	35	35	105

Please choose the age range most appropriate to you.

Row Labels	Atigagome	Kudorkope	Pediatorkope	Grand Total
18 – 19	0	0	0	0
20 – 29	6	5	7	18
30 – 39	13	14	9	36
40 – 49	11	7	5	23
50 – 59	3	6	8	17
60 – 69	2	2	4	8
70+	0	1	2	3
Grand Total	35	35	35	105

Please indicate your gender

Row Labels	Female	Male	Grand Total
Atigagome	14	21	35
Kudorkope	20	15	35
Pediatorkope	20	15	35
Grand Total	54	51	105

Appendix F: Copy Right Permission

Copy Right Clearance - Climate Compatible Development Framework

Jude Nuru [redacted] Feb 20, 2020, 10:41 AM (1 day ago)

to odi

Dear Sir/Madam

ATTN: Tom Mitchell and Simon Maxwell,

I am a final year doctoral student at Antioch University New England, USA. My research focuses on climate change and energy access in sub-Saharan Africa. Specifically, I am researching into adaptation, mitigation, and development benefits of renewable energy for rural populations in sub-Saharan Africa.

Through my literature search, I found Climate Compatible Development theoretical framework, which you developed in 2010 to be very suitable for my research. I have adapted the diagram for my doctoral dissertation, aspects of which I intend to publish in peer-reviewed academic journals.

I am therefore by this message asking for copyright clearance to allow me use an adapted version of the CCD theoretical framework diagram in my dissertation and other future scholarly publications. I have adopted CCD as my primary theoretical framework, which has shaped my doctoral dissertation and will have an impact on my future research as well.

I look forward to hearing from you.

Yours sincerely.

Jude Nuru

Elizabeth Tribone [redacted] 5:14 AM (6 hours ago)

to Elize, me

Dear Jude,

Thanks for your interest in this work and for reaching out about permissions.

We're happy to grant use rights for the CCD framework, but would require you to cite the 2010 CDKN policy brief in question, 'Defining climate compatible development' (https://cdkn.org/wp-content/uploads/2012/10/CDKN-CCD-Planning_english.pdf) as the source of the adapted framework, both in the dissertation and in future publications uses.

Kind regards,
Lizzie