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“Business Models for Renewable Energy in Emerging Markets: A Case Study of Off-Grid Solar Solutions in Kenya”

“Anastasia Pavlopoulou”

Supervisor: “Georgios Oikonomidis”

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“Business Models for Renewable Energy in Emerging Markets: A Case Study of Off-Grid Solar Solutions in Kenya”

“Pavlopoulou Anastasia”

Supervising Committee

Supervisor:
“Georgios Oikonomidis”

Co-Supervisor:
“Christopoulos Dimitris”

Patras, Greece, June 2026

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Dedication

This dissertation is dedicated to my family, whose love, encouragement and unwavering support have been a constant source of strength throughout my academic journey.

Their belief in me has inspired me to pursue my goals with determination and perseverance.

Anastasia Pavlopoulou

Abstract

The thesis discusses business models in the off-grid solar energy industry as an effective tool for promoting sustainable energy transitions in developing countries with a specific focus on Kenya. This research looks into the role decentralised renewable energy systems and digital financial technologies can play in relation to sustainable development, paying specific attention to Pay-As-You-Go (PAYG) solar systems.

Firstly, this dissertation analyses the current situation regarding energy transition processes on the global stage as well as the increasing significance of renewable energy technologies in tackling the problem of climate change, energy insecurity, and energy poverty. Specific emphasis is put on the emergence of alternative energy options in regions where expanding the grid network becomes too costly or technologically unfeasible.

Next, this dissertation focuses on the evolution of business models in the off-grid solar sector. Special attention is paid to Pay-As-You-Go solar technologies, which utilise renewable energy sources along with innovative mobile money technologies allowing poor families access to electricity in exchange for small payments made in instalments. Kenya is considered as one of the best-case scenarios for Pay-As-You-Go implementation owing to the country's advanced mobile money infrastructure and wide use of decentralised solar technologies.

Through the application of BMC and TBL approaches, the dissertation examines the sustainable dimensions (economic, social and environment) of the current Pay As You Go (PAYGO) business models. It concludes that although PAYGO technology has tremendously enhanced energy access and inclusivity, its impacts on economic development continue to be hampered due to the limited use of productive energy usage and scattered household-level infrastructure.

In an attempt to mitigate the above challenges, the dissertation introduces the Hybrid Community Energy Hubs (HCEH) approach as a conceptual business model. This model seeks to demonstrate how decentralized renewable energy solutions can be used not only for achieving electrification but also socio-economic development through energy access coupled with productive economic activities and infrastructure development.

Keywords

- Renewable Energy
- Off-Grid Solar Systems
- Pay-As-You-Go (PAYG)
- Decentralised Energy Systems
- Sustainable Business Models
- Energy Transition

“Επιχειρηματικά Μοντέλα για τις Ανανεώσιμες Πηγές Ενέργειας σε Αναδυόμενες Αγορές: Μελέτη Περίπτωσης των Αυτόνομων Λύσεων Ηλιακής Ενέργειας στην Κένυα”

“Παυλοπούλου Αναστασία”

Πάτρα, Ιούνιος 2026

Περίληψη

Η παρούσα διπλωματική εργασία διερευνά τον ρόλο των επιχειρηματικών μοντέλων ηλιακής ενέργειας εκτός δικτύου (off-grid solar business models) στη μετάβαση προς πιο βιώσιμα ενεργειακά συστήματα στις αναδυόμενες αγορές, με βασική μελέτη περίπτωσης την Κένυα. Η έρευνα εστιάζει στη σχέση μεταξύ αποκεντρωμένων συστημάτων ανανεώσιμης ενέργειας, ψηφιακών χρηματοοικονομικών τεχνολογιών και βιώσιμης οικονομικής ανάπτυξης, δίνοντας ιδιαίτερη έμφαση στα συστήματα Pay-As-You-Go (PAYG).

Αρχικά, παρουσιάζεται το θεωρητικό υπόβαθρο της παγκόσμιας ενεργειακής μετάβασης και αναλύεται η αυξανόμενη σημασία των ανανεώσιμων πηγών ενέργειας ως απάντηση στις προκλήσεις της κλιματικής αλλαγής και της ενεργειακής φτώχειας. Στη συνέχεια, εξετάζονται τα αποκεντρωμένα ενεργειακά συστήματα και οι τεχνολογίες εκτός δικτύου, οι οποίες αποτελούν μια ουσιαστική λύση για περιοχές με περιορισμένη πρόσβαση στις συμβατικές ενεργειακές υποδομές.

Η εργασία εστιάζει επίσης στα επιχειρηματικά μοντέλα που έχουν αναπτυχθεί στον τομέα της ηλιακής ενέργειας εκτός δικτύου, με ιδιαίτερη αναφορά στα συστήματα PAYG, τα οποία συνδυάζουν την ηλιακή τεχνολογία με ψηφιακές πληρωμές μέσω κινητής τηλεφωνίας. Η Κένυα παρουσιάζεται ως ένα από τα πιο επιτυχημένα παραδείγματα διεθνώς, χάρη στην ευρεία διάδοση των ψηφιακών χρηματοοικονομικών υπηρεσιών και στη ραγδαία ανάπτυξη της αποκεντρωμένης αγοράς ενέργειας. Η ανάλυση των επιχειρηματικών μοντέλων πραγματοποιείται με τη χρήση του Business Model Canvas (BMC), ενώ η αξιολόγηση της βιωσιμότητάς τους βασίζεται στο πλαίσιο Triple Bottom Line (TBL), το οποίο εξετάζει τις οικονομικές, κοινωνικές και περιβαλλοντικές διαστάσεις της βιωσιμότητας.

Παράλληλα, η μελέτη αναδεικνύει και τις αδυναμίες των υφιστάμενων μοντέλων, κυρίως σε ό,τι αφορά τη μακροπρόθεσμη οικονομική βιωσιμότητα και την περιορισμένη σύνδεση με παραγωγικές δραστηριότητες. Για τον λόγο αυτό προτείνεται το μοντέλο Hybrid Community Energy Hubs (HCEH), το οποίο συνδυάζει κοινόχρηστες ενεργειακές υποδομές, παραγωγικές χρήσεις ενέργειας και ψηφιακά χρηματοδοτικά εργαλεία σε επίπεδο κοινότητας.

Συνολικά, η εργασία υποστηρίζει ότι τα αποκεντρωμένα συστήματα ανανεώσιμης ενέργειας μπορούν να συμβάλουν όχι μόνο στη βελτίωση της ενεργειακής πρόσβασης, αλλά και στην ευρύτερη κοινωνικοοικονομική ανάπτυξη, όταν συνδυάζονται με κατάλληλα επιχειρηματικά μοντέλα, παραγωγικές χρήσεις ενέργειας και στρατηγικές βιωσιμότητας σε επίπεδο κοινότητας.

Λέξεις – Κλειδιά

- Ανανεώσιμες Πηγές Ενέργειας
- Ηλιακή Ενέργεια Εκτός Δικτύου
- Συστήματα Pay-As-You-Go (PAYG)
- Αποκεντρωμένα Ενεργειακά Συστήματα
- Βιώσιμα Επιχειρηματικά Μοντέλα
- Ενεργειακή Μετάβαση

List of Abbreviations

- BMC – Business Model Canvas
- ESMAP – Energy Sector Management Assistance Program
- GOGLA – Global Off-Grid Lighting Association
- GSMA – Global System for Mobile Communications Association
- HCEH – Hybrid Community Energy Hubs
- IEA – International Energy Agency
- IRENA – International Renewable Energy Agency
- KPI – Key Performance Indicator
- PAYG – Pay-As-You-Go
- PV – Photovoltaic
- SDGs – Sustainable Development Goals
- SHS – Solar Home System
- TBL – Triple Bottom Line
- UNDP – United Nations Development Programme

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1. Introduction

1.1 Background and Context

There have been a number of key events that have happened within the energy industry in recent times. There have been increased discussions surrounding the topic of climate change, energy security, and sustainable development since more and more countries and organizations are relying on renewable energy resources. The dependency on fossil fuels is tied to greenhouse gases emission and the environmental problems that humanity is facing right now (IEA, 2022; IPCC, 2021).

However, the lack of access to electricity has been another major issue. It has become particularly widespread among some developing countries and especially countries of Sub-Saharan Africa where the lack of electricity affects millions of individuals (World Bank, 2023). Therefore, this is why energy access is becoming a more pressing concern.

Another option is provided by off-grid solar installations. This type of solution is primarily used in locations where it is challenging and economically unfeasible to develop the national electricity grid network. Thanks to small solar systems functioning independently from the national grid system, many households can be supplied with energy needs (International Renewable Energy Agency [IRENA], 2022). Lowering the cost of solar technologies in recent decades contributed greatly to the increased application of such solutions.

Nevertheless, technology itself is not sufficient for the success of these innovations. Access of customers to such services also needs to be considered. For example, a Pay-as-you-go (PAYG) model became possible due to which millions of households gained access to solar energy through regular small payments, but not a single huge investment in equipment initially (GSMA, 2022; Rolffs et al., 2015). PAYG model proved itself well in combination with mobile payment methods in Kenya.

Indeed, today Kenya is recognized as one of the leading examples of off-grid solar development in Africa. Kenya has demonstrated remarkable progress not only in terms of renewable energy resources but also off-grid energy access. Mobile banking and mobile payment options have been instrumental in the creation of business models which can also

be tailored towards poorer people. This makes Kenya a unique example to study the interplay between energy access, business model, and sustainable development.

Nevertheless, despite off-grid solar having made a positive impact on increasing access to electricity, some questions remain open regarding its contributions to economic development. Indeed, in many instances, such technologies help to meet basic demands for lighting and mobile phone charging, yet are not instrumental in income-generating activities.

From this, the aim of this paper is the consideration of how business models play a role in the development of renewable energy systems in developing countries, with particular focus on the use of off-grid solar systems in Kenya. The paper will also evaluate the sustainability of existing business models through the Triple Bottom Line framework and explore whether alternative approaches that integrate productive uses of energy can generate greater developmental benefits for local communities.

1.2 Problem Statement

Although considerable advancements have already been made in renewable energy and provision of electricity to emerging markets, there are some concerns with regards to sustainability and efficiency of such solutions. Now off-grid solar technologies are quite popular due to their affordability and efficiency in terms of providing electricity to rural and remote communities. At the same time, the effectiveness of such an approach in stimulating further growth of local economies remains doubtful.

There is a whole list of questions related to current models, especially to Pay-As-You-Go (PAYG) Solar Home Systems. Such technologies have greatly facilitated access to electricity of a lot of low-income families in terms of small installments and payments done via digital services. In Kenya, for instance, PAYG Solar Home System greatly changed the existing model of energy provision in the country.

The major problem with this type of innovation is its primary focus on fulfilling basic needs (lighting, mobile phone charge). The amount of energy provided in such a case may be insufficient for income generating activities (for example, running small enterprises, agricultural processing). This implies that the process of economic development of the community as a whole may suffer from such an approach.

Moreover, this problem is relevant for sustainable business models as well. The PAYG model presupposes the payment process throughout a prolonged period of time by users of the services provided. Nevertheless, the situation arises when people are unable to make continuous payments due to the absence of additional sources of income despite the presence of energy. It poses a challenge for both the consumer and the service-providing company itself.

In addition, the currently applied solutions mainly address households' problems. Fewer efforts are made in the sphere of developing solutions for more complex and large-scale consumption of energy aimed at increasing economic activity within the community. Despite the emergence of alternative solutions such as mini-grids, limited attention has been given to integrating the flexibility of PAYG financing with community-based infrastructure capable of supporting productive uses of energy and broader local economic development.

In this regard, the aim of this study is to identify some of the possible ways for improving this situation by exploring alternative approaches to off-grid solar technology applications that could help increase both sustainability and positive developmental impacts of such systems. In particular, this study explores the idea of Hybrid Community Energy Hubs, in which the attention is focused on more productive uses of energy rather than mere consumption of electricity. With the help of renewable sources, common energy facilities, and different ways of financing, this approach allows for fostering more local development, while keeping access costs and ecological consequences low.

Given the above, the general thesis of this study may be presented as follows: off-grid solar energy business models have contributed greatly to increasing energy access and helping people get connected to power grids, yet these models alone may be insufficient to deliver the broader economic and developmental outcomes required for sustainable development.

1.3 Research Aim and Objectives

The objective of this research is to determine the part that business models play in the deployment of decentralised renewable energy systems, especially off-grid solar energy systems in the Kenyan market. In this regard, this research seeks to establish the extent to which current business models contribute towards sustainable development and to explore possible ways of improving the contribution of such business models.

For this objective to be achieved, the research aims at accomplishing the following objectives:

1. To review the shift worldwide from non-renewable sources of energy systems to renewable energy systems, especially decentralized and off-grid energy systems in the emerging markets.
2. To review the components and characteristics of off-grid solar business models, especially PAYG systems, with respect to their ability to increase energy access.
3. To measure the sustainability of current business models using the Triple Bottom Line approach.
4. To determine the weaknesses of current off-grid solar systems, especially with regard to productive uses of energy.
5. To develop and evaluate the Hybrid Community Energy Hubs (HCEH) concept as an alternative business model designed to enhance the developmental impact and sustainability of decentralised renewable energy systems.
6. To examine the implications of the proposed model in terms of strategy and practical considerations for the companies, policymakers, and investors active in the renewable energy industry.

In this way, the objectives of the research are meant to contribute to the body of knowledge and practice regarding renewable energy business models.

1.4 Research Questions

The following research questions will inform this investigation, and they are based on the identified problem, research objective, and purpose, namely:

Primary Research Question

1. To what extent do contemporary off-grid solar business models contribute to sustainable development in emerging economies, and how might alternative business models enhance this contribution?

Sub-Research Questions

1. How does the application of renewable energy resources such as off-grid solar power improve access to energy resources in emerging economies?

2. How can the PAYG business model be defined within the framework of the off-grid solar market?

3. How successful have contemporary business models been in meeting the objective of fostering sustainable development in economic, social, and environmental spheres?

4. What are the shortcomings of existing off-grid solar technology in terms of promoting productive use of energy resources and economic development?

5. How can these shortcomings be overcome by adopting alternative business models such as Hybrid Community Energy Hubs?

1.5 Structure of the Dissertation

The dissertation comprises five chapters, each covering various aspects of the research topic.

- The first chapter will contain the introduction part. This chapter will provide a background for the study along with the problem definition and objective. Furthermore, it will discuss the research questions addressed in the dissertation.
- The second chapter will cover literature review. It will highlight relevant literature on global energy transition, decentralised energy systems and business models for renewable energy. Sustainability theories like Triple Bottom Line approach will be discussed as well.
- The third chapter will describe the research methodology used in the dissertation. This will include research design, use of secondary data, case studies and analysis techniques applied

in the research. The validity and reliability along with the limitations of the research will be covered as well.

- The fourth chapter will discuss the findings of the dissertation. It will cover analysis of the present day business models and their sustainability. Furthermore, the proposed Hybrid Community Energy Hubs (HCEH) model will be developed and evaluated as an alternative approach to decentralised electrification.
- The fifth chapter will conclude the dissertation by highlighting the findings. It will include its theoretical and practical implications along with policy recommendations and future research recommendations.

2. Literature Review and Theoretical Framework

2.1 Introduction

Currently, there is a major shift taking place in the energy sector on account of environmental issues, technological changes, and the requirement of sustainable economic development. The use of renewable energy systems has received a lot of attention from government institutions, international organizations, and even private players due to their ability to lower carbon dioxide emissions, increase energy security, and also provide energy to people who do not have access to electricity, especially in developing and emerging nations. While global electrification has seen a lot of success, it must be noted that many people remain without access to electricity, particularly those living in rural parts of Sub-Saharan Africa.

In this chapter, an extensive review of the pertinent literature on the topic of study will be conducted, along with the presentation of the theoretical underpinning for the study. Firstly, the idea of the global energy transition and increasing importance of renewable energy technology will be considered. Secondly, the discussion will be centred around decentralised energy and the issue of off-grid electrification in the context of emerging markets. Thirdly, the chapter will focus on business models utilised in the off-grid solar industry, paying special attention to Pay-As-You-Go (PAYG) business models and sustainable innovation in this sphere. Fourthly, the Triple Bottom Line theory will be presented as the primary theoretical framework for the subsequent discussion.

2.2 Global Energy Transition and Renewable Energy

Today's global energy system is undergoing a radical transformation process for various reasons, some of which include environmental, economic, technological and geopolitical perspectives. The said radical transformation process that is currently taking place is referred to as global energy transition, and it entails the shift from traditional energy sources, such as fossil fuels, towards renewable energy sources (International Energy Agency [IEA], 2022). The global energy transition is predominantly shaped by global concerns on climate change, environmental degradation, energy security and sustainability issues.

Historically, during the industrialisation process, the world economy was fueled primarily by fossil fuels like coal, oil, and natural gas. Fossil fuels contributed immensely to

industrialisation and growth of national economies. However, as years progressed, the traditional energy sources started becoming major players in greenhouse gas emissions and therefore contributed immensely to climate change (Intergovernmental Panel on Climate Change [IPCC], 2021). It is for this reason that pressures increased for decarbonisation and energy transition.

Indeed, the agreement on climate reached at the end of 2015 in Paris became one of the key achievements of the entire planet concerning the development of the climate agenda, as it introduced an international framework for mitigating climate change and reducing carbon emissions. For instance, it required the parties to introduce their own approach aimed at reducing greenhouse gas emissions and usage of renewable energy sources. Moreover, the European Green Deal provided a highly ambitious goal related to climate neutrality in the EU countries by 2050, thus highlighting the role of renewable energy investments.

However, apart from the purely environmental aspect, energy transition on the global level is related to the issues of energy security and geopolitics, which became highly relevant due to recent geopolitical tensions and instability in the global energy market. As a result, renewables became considered not only as an environmental approach but also as a geopolitical and economic issue (IEA, 2022).

There have been impressive advancements in renewable energy technologies like solar, wind, hydropower, geothermal and biomass within the past two decades. Technology advances and economies of scale, alongside the appropriate policies, have resulted in great strides towards reducing the cost of producing renewable energy (IRENA, 2022). In many regions, solar photovoltaics have become one of the most cost-competitive sources of new electricity generation, often outperforming conventional fossil-fuel alternatives.

There is a strong association between an increase in renewable energy technology and an increasing concern about the sustainability of energy based on hydrocarbons. Oil, natural gas, and coal have been used for over a century to develop economies, offering energy that was dependable and affordable in terms of running industrial activities, transportation, and even household activities. Nonetheless, the adverse effects associated with the burning of fossil fuels have prompted the need for renewable energy systems.

Renewable energy has some environmental benefits as compared to hydrocarbons since they have fewer operational emissions, and they depend on natural energy rather than limited

natural resources. Renewable energy systems play a crucial role in mitigating climate change and contributing to efforts by the world to achieve its decarbonization goals. With the advancement of technology, it has become economically favorable to use renewable energy systems.

However, the shift from hydrocarbons to renewable energy does not come without its own difficulties. Energy generation systems based on renewable energy sources can encounter problems linked to intermittency, energy storage, and integration into existing infrastructure, whereas the use of hydrocarbon energy sources continues to be supported by an already functioning supply chain and infrastructure with higher energy density. Therefore, modern energy shifts tend to occur gradually and through diversification, rather than abrupt replacement, of the energy sources.

Improvements in energy efficiency of renewable energy technologies have shifted the focus of investments in the global energy industry. Renewable energy technology investments have gained momentum due to various climate finance initiatives, green bonds and ESG investment approaches. Renewable energy investments are increasingly preferred by development banks and institutional investors because of their positive contribution to the achievement of the sustainable development goals.

However, it is important to highlight that an energy transition is a much bigger process which involves significant shifts in economic and industrial structures related to energy. The term just energy transition refers to fair distribution of both positive outcomes and negative consequences associated with the transition from a carbon-based economy to a sustainable one (Sovacool, 2021).

The topic of energy and development becomes particularly pertinent when we speak about developing countries. While developed countries work on minimizing greenhouse gases and pursuing decarbonization strategies, there are problems concerning energy access and building infrastructure in some developing countries. According to the data gathered by the World Bank (2023), there is a huge population of people without access to electricity living in Sub-Saharan Africa.

Thus, the dual problem faced by developing economies – providing more people with access to energy sources and building sustainable energy systems – is what makes them critical players within energy policies discussions worldwide. Centralized electrification entails

massive expenditures and significant periods of implementation making it inefficient for isolated and impoverished regions. The importance of decentralized renewable energy projects becomes obvious in such cases (ESMAP, 2020).

Figure 1 shows the rapid growth in renewables capacities worldwide experienced throughout recent decades. Growth in renewables can be attributed to decreasing prices for the technologies and growing support from governmental and international investments.

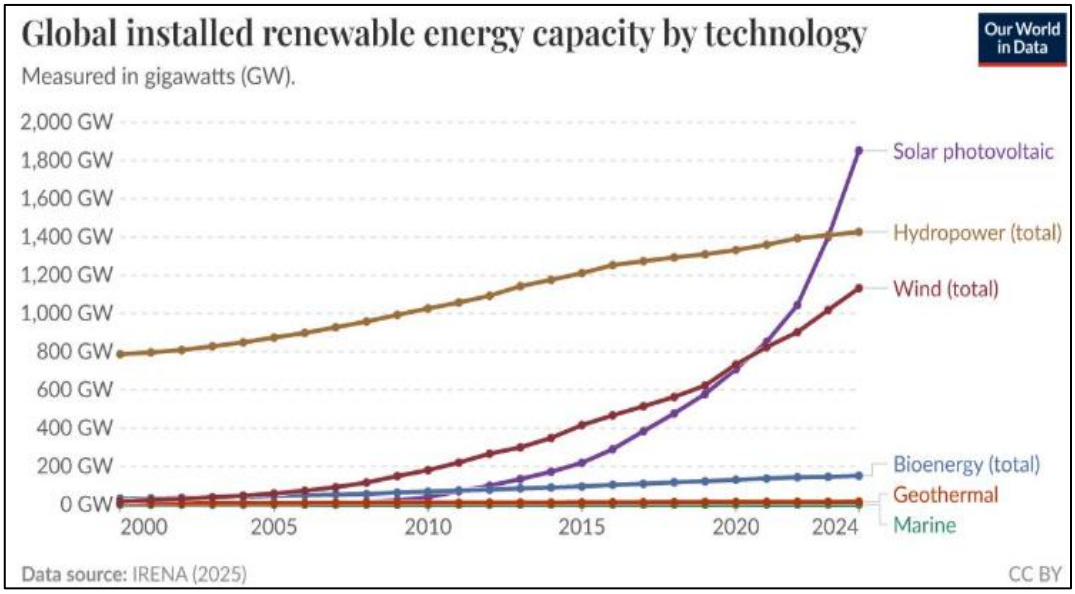

Figure 1: Global Growth of Renewable Energy Capacity (Source: IRENA 2025)

As depicted in the graph below (Figure 1), the capability of renewable energy in the world has witnessed a tremendous growth rate in recent years, especially solar and wind energy that is considered among the fastest-growing energy sources in the world. The rise in the use of renewable energy sources proves the significance of renewable energy sources in the process of decarbonization of the global economy.

In this respect, off-grid renewable energy systems have gained much popularity in the international community due to their scalability and flexibility that enable them to operate regardless of national electricity grids. The evolution of technology pertaining to solar energy, batteries, and digital services has rendered these energy systems efficient and affordable.

The topic of digitalisation should also be mentioned in the context of the energy transition. Modern technologies such as smart grids, mobile payments, digital solutions and many others have been used to develop energy sectors. The adoption of digital finance in

combination with renewable energy in emerging economies has created novel opportunities to deliver energy and engage clients within the decentralized energy market.

Nevertheless, even though much progress has been made in the field of renewable energy, there remain several issues that require solving. For example, the following issues may appear when working with renewable energy systems: problems associated with intermittency, storage, and integration and regulation of renewable energy systems in the infrastructure (IEA, 2022). Besides, the use of renewable energy systems on a global scale can result in some issues including sustainability throughout the lifetime cycle, proper waste management for electronic equipment, and access to minerals.

On balance, the energy transition is a complex process that entails changes in environmental, technological, economic and social spheres. Renewable energy systems play an important role in the context of the global energy transition because they help to decrease emissions, provide energy security and promote sustainable development. Nevertheless, the success of renewable energy systems is not only dependent on technological advancements but also on developing proper business models and institutional frameworks.

This factor is especially important in the case of emerging markets where renewable energy systems have to solve two equally important tasks – sustainability and energy access. The next section will analyse decentralised energy systems and off-grid electrification in more detail.

2.3 Decentralised Energy Systems and Off-Grid Electrification

Decentralized energy systems are now recognized as becoming a vital aspect of the electrification process at a global level, particularly for developing and emerging economies where conventional electricity networks are either non-existent or limited. Decentralized energy systems are distinct from centralized energy systems in that decentralization refers to electricity production and supply near the demand.

It is primarily energy access issues within rural areas and geographically remote locations that have made decentralized electrification more important than ever before. In almost all developing countries, extending the national grid into rural and remote regions has proven to be economically infeasible owing to factors such as low population density and the absence of supporting infrastructure (World Bank, 2023). This is why decentralized

renewable energy systems have been recognized as economically viable options towards solving rural electrification challenges.

Despite the progress that has been witnessed in the field of electrification in recent years, many African countries still face issues regarding access to electricity. Electricity access levels in various African countries are illustrated in Figure 2 below.

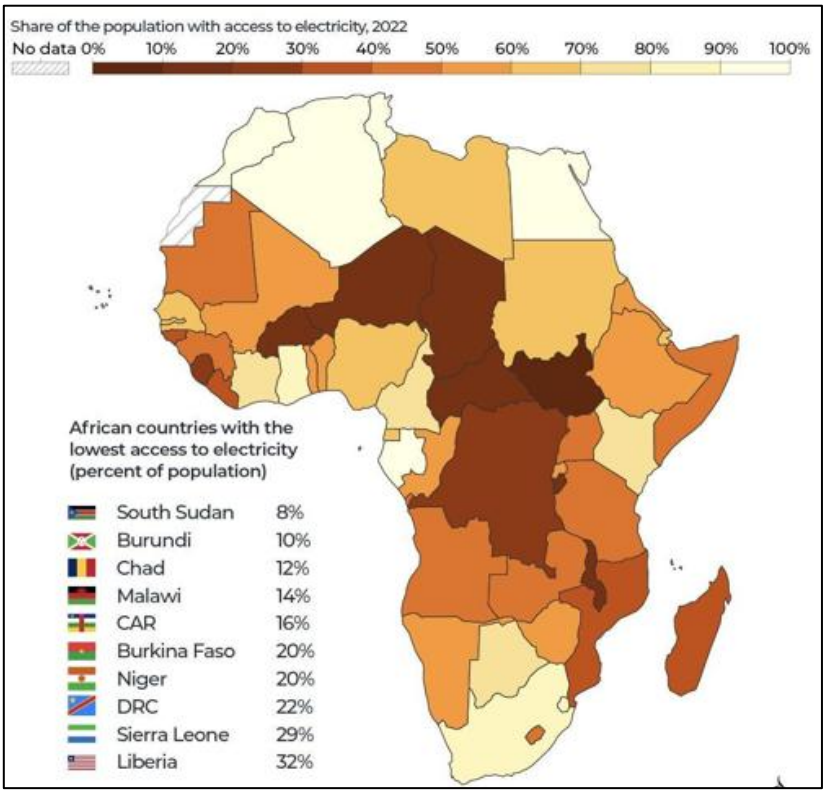

Figure 2 : Electricity Access Across Africa 2022 (Source: World Bank 2023)

As shown in Figure 2 , there are tremendous differences in electricity access percentages in the African continent, where some Sub-Saharan countries still show relatively low electrification percentages. These differences indicate the inefficiencies of grid-based electrification and hence make the use of off-grid renewable energy technologies justified.

Off-grid energy solutions include Solar Home Systems (SHS), mini-grids, and other off-grid renewable energy technologies, which can be utilized without being connected to centralized grids. There have been tremendous improvements in photovoltaic systems, battery storage systems, and energy management systems in the last ten years that have made off-grid systems much more effective and affordable (IEA, 2022).

Among the off-grid technologies, solar photovoltaic systems have become particularly important because of their reduced costs, modularity, and scalability. SHS is widely used for providing basic electricity needs such as lighting, charging cellphones, and powering up small electronics. These systems have increased the quality of life as well as reduced dependence on non-renewable electricity generation technologies such as kerosene.

Nevertheless, it would be wrong to attribute the advantages of decentralized energy supply only to electricity availability. The notion of productive use of energy (PUE) has gained increasing popularity recently, referring to the application of electricity in income generation through irrigation, cooling, processing food crops, and manufacturing products using small-scale machinery. As recent studies show, decentralized energy systems based on renewables may become key in addressing energy access issues in the Sub-Saharan region of Africa. According to Babayomi et al., (2023), renewables-based mini-grids appear to be a viable alternative for rural electrification in areas where conventional extension is financially unsustainable.

As mentioned above, productive use of energy can greatly increase the developmental power of electrification efforts. Indeed, according to ESMAP (2023), productive-use applications contribute to increased local production, entrepreneurship, and economic resilience. Likewise, the Efficiency for Access Coalition (2024) emphasizes that productive use of energy helps improve both rural livelihoods and financial viability of decentralized energy supply solutions.

The distinction between electrification and productive use of energy is particularly relevant in the context of developing markets where access to electricity allows enhancing living standards while economic growth requires more efficient systems capable of promoting entrepreneurial activity. As a result, the academic community emphasises the need to move beyond connection goals in favour of development goals.

Another distinctive feature of decentralised energy systems is their association with digitalisation. Innovations like mobile money services, smart metering devices, and digital payments have transformed the economics of off-grid electrification in an unprecedented way. Thanks to digital finance, renewable energy products and services are now available for customers in developing countries using various flexible payment models. Kenya has

become one of the most promising instances of how the dynamics of decentralized renewable energy systems and digital finance are intertwined. The popularity of mobile money services, such as M-Pesa, has led to favorable conditions for creating new funding approaches, including pay-as-you-go. Digital payment infrastructure has contributed to lowering transaction costs and improving repayments collection as well as allowing renewable energy companies to access underdeveloped areas. For this reason, Kenya can be considered a leader in off-grid solar power installation and is a good example of the impact of digital finance on renewable energy.

However, there are some limitations to decentralised renewable energy technologies. The technical issues relating to battery lifespan, their maintenance and ability to store energy are relevant. In addition, a system of individual household systems would lower the possibilities of gaining economies of scale in terms of renewable energy use.

Furthermore, the regulation policy relating to the use of decentralised renewable energy systems could be considered a limitation. For example, legislation in developing countries has not developed licensing or tariffs policies for incorporating such systems into electrification schemes in national energy programmes.

However, decentralised renewable energy systems are still very relevant for current energy transition processes. Thanks to their flexibility and scalability, they can be easily incorporated into the Internet-of-things framework, making them perfect tools to solve energy access issues in emerging economies. Moreover, thanks to productive uses and infrastructure initiatives, there is a growing possibility that decentralised energy systems might not only provide energy access but become tools of economic development of communities too.

That being said, there has been increasing interest in creating business models that would make it possible to deploy and finance off-grid renewable energy systems successfully. This question will be considered in the next chapter in relation to the evolution of business models in the off-grid solar industry and PAYG systems.

2.4 Business Models in Renewable Energy Systems

Rapid growth of decentralised renewable energy systems in developing economies has created a strong focus on the creation of innovative business models that will be able to promote sustainability and energy access simultaneously. In many economically underdeveloped countries, standard models of providing access to electricity services are not appropriate owing to a lack of infrastructure, financial restrictions and institutional barriers. Therefore, businesses engaged in renewables are increasingly using customer-focused business models to increase accessibility and scale of their operations.

Innovation of the business model concept has been critical for the off-grid solar industry in particular. Business models have been defined by Teece (2010) as means for the generation, delivery and capturing of value. Similarly, business models are viewed by Osterwalder & Pigneur (2010) as tools used for explaining how organizations create value to themselves and other participants by connecting different business activities. Business models are especially relevant for the renewable energy sector due to the importance of additional elements beyond technology.

Perhaps one of the most innovative business strategies developed in the off-grid solar industry has been the concept of Pay-as-you-go (PAYG). PAYG business models involve the integration of renewable energy solutions with financial digital tools, which allow consumers to pay for their electricity needs in flexible instalments as opposed to paying large sums at once (GOGLA, 2023). Such a solution helps overcome affordability challenges and allows the companies to work efficiently in areas of low income and dispersed population density.

PAYG systems have been developed due to the rise of mobile finance in developing countries, especially in East African countries. Digital payment tools like M-Pesa helped renewable energy companies implement an automated process of repayments, reducing costs of transaction as well as increasing access to customers (GSMA, 2022). Therefore, the use of mobile finance in renewable energy production is an example of convergence of digitalisation and sustainable energy solutions.The operational process of PAYG systems involves renewable energy solutions and remote monitoring and payment technologies. The

following diagram shows the simplified operation of a PAYG system in the solar energy market

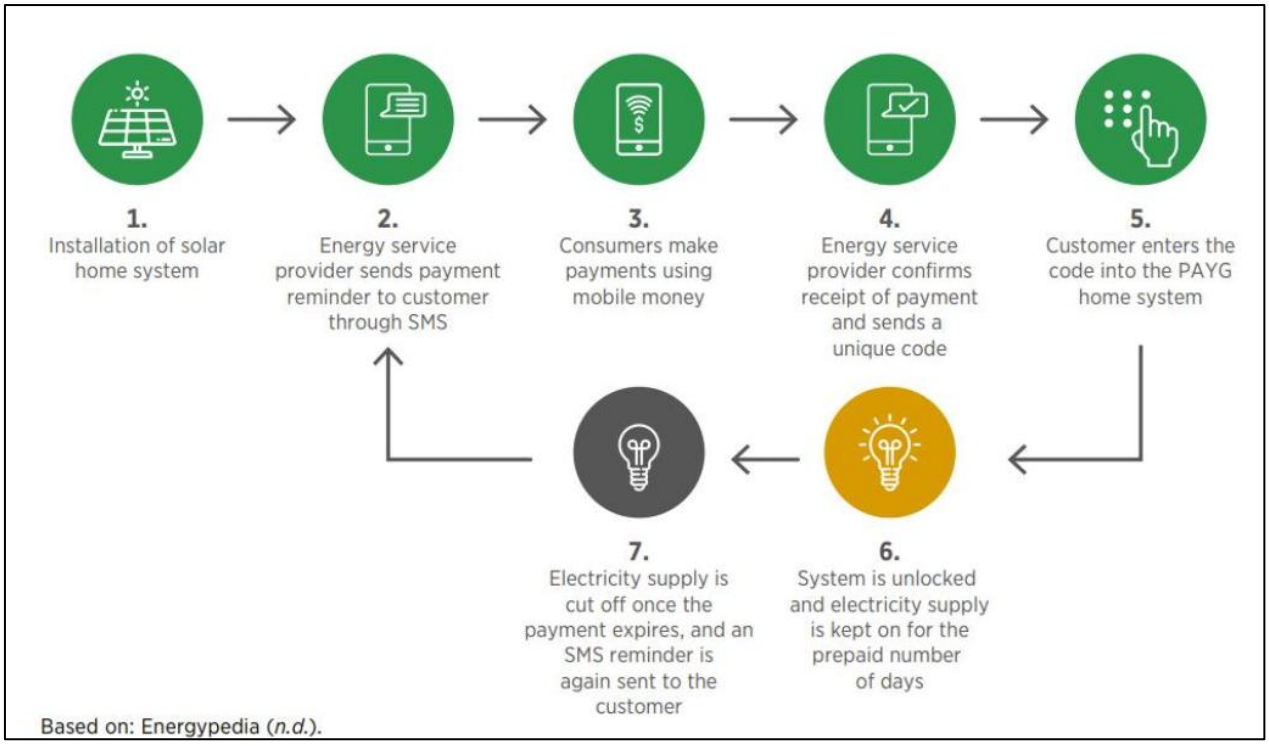

Figure 3: Operational Structure of the PAYG Solar Business Model (Source: GOGLA (2024) and Energypedia)

As seen from Figure 3: Operational Structure of the PAYG Solar Business Model PAYG financing solutions incorporate payment processing, identity verification and electricity provision under flexible financing arrangements. As a result, consumers can use the services of renewable energy providers without having to make large upfront investments in these services. Such a scheme greatly facilitated the adoption and spread of off-grid solar energy solutions in emerging economies.

The Kenyan market of off-grid solar energy products has become one of the best illustrations of PAYG financing solutions. Providers like M-KOPA, Sun King and d.light have been able to successfully combine the provision of solar technologies and finance management, developing highly scalable businesses which were able to impact the lives of millions of people. These companies showed that decentralised renewable energy technologies could be used not only to solve development problems but also to conduct profitable business operations.

Nonetheless, PAYG models come with their own limitations. Among these, the repayment risk and the ability of consumers to afford such payments stand out. In many cases, consumers live in unstable economic environment or engage in economic activity without formal registration. Thus, repayment capabilities could change depending on seasonality, agricultural productivity and other factors (GOGLA, 2023).

Another crucial issue is the problem of operating costs and managing the infrastructure. In this regard, off-grid renewable energy businesses normally operate in scattered rural areas in which transportation and maintenance costs will still be fairly high. Issues like battery replacements, technical assistance, and durability might be other aspects influencing the operational sustainability.

Moreover, there is an objection to the notion that some of these PAYG schemes are more consumption-oriented than development-oriented. In the case of Solar Home Systems, these schemes provide services such as lighting and charging of mobile phones, but do not provide sufficient services to enable productive activities. Consequently, although communities are able to access electricity, this does not contribute significantly to income generation and broader development in the respective communities.

As such, this has triggered significant academic and organizational interest regarding sustainable business model innovation in the renewable energy sector. As highlighted by Bocken et al. (2014), the objective of sustainable business models is the creation of value not just in terms of economy, but also socially and environmentally. Modern studies focus on how sustainable business model innovation is important in supporting sustainability transitions by ensuring that business models incorporate environmental, social inclusivity and economic sustainability (Bocken & Konietzko, 2022). Regarding off-grid solar technologies, this is accomplished through the integration of renewable energy, financial inclusion and digital technology innovations together with objectives in terms of community development. This multi-disciplinary approach to sustainability is similar to the Triple Bottom Line concept introduced by Elkington (1997).

Furthermore, recent developments in the market have shown that the solar power industry continues to grow in developing areas as a result of falling prices for solar panels, rising investor confidence, and increased usage of mobile payments (GOGLA, 2024). This shows

that just as technological advancements play a role in the success of decentralised energy projects, innovations in business models are crucial as well.

Regarding decentralised energy systems, sustainable business model innovation is increasingly focused on productive use integration, community involvement and infrastructure sharing strategies. The scholarly literature suggests that the future renewable energy systems might have to go beyond household electrification in order to ensure productive uses at the community level.

A further important issue in relation to decentralised energy systems is their potential role in local development. Unlike traditional electrification models, which typically concentrate only on ensuring higher connection rates, the emphasis is increasingly placed on development goals, such as entrepreneurship, job creation and social inclusion. These broader perspectives demonstrate the understanding that energy systems should serve not only as infrastructure projects but also as socio-economic transformation tools.

Another significant area to consider is that of financing of decentralised energy projects. Hybrid financing models that involve development banks, impact investing, climate finance schemes and private sector investments are increasingly seen as crucial for the scaling up of renewables in developing countries.

At the same time, digitalization continues to change the business models in the renewable energy industry. In this context, such digital tools like smart meters, among others, may prove useful to help optimize operations, manage debt collection, and better understand consumer behaviors. The interplay between digitalization and decentralization could create further opportunities in the off-grid space.

In conclusion, there is a growing body of evidence that business model innovation has played an important role in the success of decentralized renewable energy models. In particular, the Pay-as-you-go model has proven to be very efficient in increasing access to electricity in developing countries; at the same time, its potential developmental contribution will remain limited until electrification is accompanied by productive uses and development projects.

The above discussion highlights the growing importance of sustainable business model innovation in the renewable energy sector. The next section introduces the Triple Bottom Line framework, which provides the theoretical basis for evaluating the economic, social and environmental sustainability of off-grid solar business models.

2.5 Sustainability and the Triple Bottom Line Framework

Sustainability is one of the key principles applied by modern enterprises in order to create strategies that will combine economic growth and sustainable development on the one hand and environmental protection on the other hand. With renewable energy systems becoming a part of sustainable development, it is necessary to find appropriate ways of measuring the performance of such organizations. One of the most widely recognised frameworks for assessing sustainability is the Triple Bottom Line (TBL) approach introduced by Elkington (1997) and subsequently applied across numerous sustainability and business model studies (Schaltegger et al., 2016).

According to the principle of the Triple Bottom Line, the assessment of organizational performance should not only include economic achievements but also address social and environmental results. In such a way, the notion of value creation goes much further than just generating profits and includes such important components as economic, social and environmental sustainability.

On the economic level of sustainability in the TBL approach, financial sustainability, efficiency, and value generation become important. In the field of renewable energy, sustainability from an economic perspective relates to affordability, attractive investments, scalability, and financial sustainability of business models in the field. In terms of off-grid solar systems, financial sustainability needs to be combined with the need to make electricity affordable for customers while at the same time ensuring that energy companies can operate effectively. Among innovative business models in the renewable energy field, Pay-As-You-Go becomes relevant.

At the social level of sustainability in the TBL approach, the influence of business on people and society becomes critical. At the social level of sustainability in the realm of renewable energy, energy access improvements, poverty reduction, social inclusion, education improvement, and the overall enhancement of people's quality of life should be considered.

The implementation of decentralized power plants can yield considerable social gains in that electricity will be accessible to previously underprivileged communities.

Environmental considerations include conserving natural resources and the reduction of environmental impacts from the operations of businesses. Renewable energy systems are viewed as environmentally friendly in the sense that their carbon footprint is much less compared to the fossil fuel options. Solar energy serves as one of the examples where renewable energy helps to address the problem of climate change. Environmental sustainability means not only conservation but waste management and considering all kinds of life cycle effects that might emerge with regards to any energy technologies.

In recent times there have been significant shifts in sustainability research which contributed to the expansion of the use of business models to the area of sustainability. In particular, Geissdoerfer et al. (2023) note that sustainable business models serve as the drivers for transformation to ensure consistency between economic development and sustainability. Similarly, Bocken and Konietzko (2022) stress that business model innovations play an important role in solving problems related to sustainability by integrating value creation processes. It emphasizes the importance of using the TBL in assessing renewable energy projects in emerging countries. Consequently, the TBL framework provides an appropriate analytical lens for evaluating whether renewable energy business models create balanced economic, social and environmental value.

One of the key elements of the Triple Bottom Line theory is the understanding that these three components are mutually dependent. Excellent environmental performance without financial profitability or social benefit would not make a project sustainable. In addition, a project that is economically successful may still be viewed as unsustainable if its environmental performance is poor and/or it fails to generate positive outcomes for local communities. Thus, sustainable development should involve consideration of all three aspects at once.

Another reason why the Triple Bottom Line model is especially useful for the analysis of decentralized solar PV systems operating in developing countries is that although such systems are usually sold for their environmental benefits, their sustainability in the long run also involves financial viability and social performance. This way, the TBL concept enables comprehensive evaluation of the results produced by the solar power solutions.

For this reason, the Triple Bottom Line framework is particularly suitable for evaluating renewable energy business models operating in emerging markets, where economic development, social inclusion and environmental sustainability are closely interconnected. The framework provides a holistic perspective that allows researchers and policymakers to assess whether renewable energy initiatives generate balanced value across all three sustainability dimensions.

In this dissertation, the TBL approach is used as the main sustainability perspective under which the off-grid solar business models are assessed. The TBL framework is subsequently applied in the Kenyan case study presented in Chapter 4 in order to evaluate the sustainability performance of both existing PAYG business models and the proposed Hybrid Community Energy Hubs (HCEH) concept across economic, social and environmental dimensions.

3. Methodology

3.1 Introduction

This chapter presents the methodology used to prepare this thesis, as well as the way in which the key research issues are approached. More specifically, the research design, the research approach chosen, the data sources and the analysis tools used are described.

The work is interdisciplinary in nature, combining elements from the renewable energy sector, business strategy and economic development. For this reason, the methodology chosen emphasizes mainly on strategic evaluation and qualitative analysis of business models and not on technical or mechanical optimization parameters (Yin, 2018).

To this end, the research relies exclusively on secondary data, such as academic studies, reports of international organizations and available statistical sources. At the same time, the limitations arising from the use of this type of data are also mentioned.

3.2 Research Approach

This research is based primarily on a qualitative and exploratory approach, with the aim of understanding how off-grid solar business models develop and operate in emerging markets. The qualitative approach was chosen because the study focuses more on understanding strategies and business practices than on technical metrics or statistical models (Yin, 2018).

The off-grid solar energy industry is in constant evolution, as businesses constantly adapt to new technologies, market changes and consumer needs (GOGLA, 2023). For this reason, the research is also exploratory in nature, trying to better understand how these business models are shaped in practice.

At the same time, a comparative approach is used, since different companies are examined within the same national environment. Through this comparison, both common practices and differences in the strategies followed by companies in the sector can be seen (Osterwalder & Pigneur, 2010).

This specific methodological approach is often found in research related to renewable energy sources, especially developing economies, where understanding the local economic and institutional framework is considered important for market analysis (Pueyo, 2018).

3.3 Research Design

The research design is based on a single-country case study, with Kenya as the main case of analysis. The choice of this approach is considered appropriate, as it allows for the examination of real economic and social conditions that influence the development of off-grid solar energy business models (Yin, 2018).

Kenya was chosen because in recent years it has shown particularly strong growth in the field of off-grid solar systems, mainly through Pay-As-You-Go (PAYG) models (GOGLA, 2023). In many rural areas of the country, access to stable electricity supply remains limited. For many households, small autonomous solar systems have been a more practical and economical solution compared to connecting to the main grid.

Equally important was the widespread use of mobile money in Kenya. Services such as M-Pesa enabled consumers to pay for equipment in installments, through small digital payments (GSMA, 2022). This was particularly helpful for lower-income households, who would have difficulty covering the total initial purchase cost.

Another reason for choosing Kenya is that the country's off-grid energy market has been extensively studied by international organizations and research institutions. Thus, there is available evidence and secondary data that can support the research (World Bank, 2023).

The analysis focuses on companies such as M-KOPA, Sun King and d.light. These companies are used as examples of different business approaches in the off-grid solar energy sector and not as a statistically representative sample of the entire market. In this way, a more meaningful examination of how these specific business models operate within the same economic and institutional environment is made.

3.4 Data Sources

The research is based exclusively on secondary data, which were collected from academic studies, reports of international organizations and publications related to the energy sector. The sources used include scientific articles, policy reports, industry reports and corporate reports related to the development of off-grid solar energy. Among the main sources of the research are the International Energy Agency (IEA), the World Bank, the United Nations

Development Programme (UNDP), Sustainable Energy for All (SEforALL), GOGLA, GSMA, the Energy Sector Management Assistance Program (ESMAP), the International Renewable Energy Agency (IRENA), and the Efficiency for Access Coalition (IEA, 2022; World Bank, 2023; GOGLA, 2024; ESMAP, 2023).

The use of secondary data was considered appropriate for this work, as the off-grid solar energy sector has developed significantly in the last decade and there is already a lot of material available from international organizations, companies and previous research. This allows for the use of different sources of information and the comparison of data, which contributes to better reliability of the analysis (Yin, 2018).

At the same time, this choice is also linked to the objective of the work, which focuses more on the strategic and business dimension of the industry and less on technical or engineering analyses. For this reason, it was not deemed necessary to conduct primary research, such as interviews, field surveys or technical system measurements.

3.5 Analytical Framework

To structure the analysis and ensure consistency, the study employs a combination of established business and sustainability frameworks.

3.5.1 Business Model Analysis

The Business Model Canvas (BMC) by Osterwalder & Pigneur (2010) is used to analyze the business models of the research. This tool was chosen because it offers a relatively simple and organized way of presenting the way in which a business operates and creates value.

Within the BMC framework, elements such as the value proposition of each company, the customers it addresses, the distribution channels, the revenue sources, the cost structure, the basic resources and the partnerships that support the operation of the business are examined. In this way, it becomes easier to understand and compare different business models in the off-grid solar energy sector.

The Business Model Canvas is widely used in strategic management and business analysis, especially in markets characterized by innovation and rapid change. For this reason, it was

considered appropriate for this specific work, as it helps to better understand the way in which off-grid solar companies develop and adapt to the conditions of emerging markets.

In Chapter 4, the Business Model Canvas is applied comparatively to M-KOPA, Sun King and d.light in order to examine differences in value propositions, customer segments, revenue streams, cost structures and key partnerships. This comparative analysis provides a structured basis for evaluating how different firms create, deliver and capture value within the Kenyan off-grid solar market.

3.5.2 Triple Bottom Line (TBL)

The Triple Bottom Line (TBL) framework is also used to assess the sustainability of business models. This framework examines the operation of a business through three basic dimensions: social, environmental and economic (Elkington, 1997).

The use of TBL was deemed useful for this work because it allows for a more comprehensive approach to the sustainability of off-grid solar business models. Thus, the analysis is not limited only to the financial results or profitability of companies, but also takes into account issues such as access to energy, the potential reduction of emissions and the social impact that specific energy solutions may have on local communities.

The Triple Bottom Line is used quite often in studies related to renewable energy sources and sustainable development, as it helps to better understand the overall impact of a business model over time and not only its financial performance (Pueyo, 2018; UNDP, 2021).

In this thesis, the TBL approach will be used to evaluate the sustainability of not only the current PAYG energy business models but also the new Hybrid Community Energy Hub idea along economic, social, and environmental lines. Through this evaluation process, it will be possible to compare different business models for renewable energy projects.

3.5.3 Strategic and External Environment Analysis

For the purposes of the analysis, SWOT analysis elements are also used to examine the main advantages and disadvantages of the off-grid solar energy sector in Kenya, as well as the opportunities and difficulties that affect its development. This specific approach helps to

better understand both the internal characteristics of the sector and the external market conditions.

At the same time, elements of the PESTEL framework are also utilized to examine the broader environment in which businesses in the sector operate. The analysis takes into account political, economic, social, technological, environmental and legal factors that can influence the course and development of the market (OECD, 2021).

The use of these tools allows for a more organized approach to the analysis and helps to better capture the risks, constraints and potential opportunities that exist for off-grid solar businesses in Kenya.

3.6 Data Analysis Procedure

The data analysis follows a structured qualitative process consistent with established case study research methodologies (Yin, 2018). The procedure consists of six main stages:

- Systematic review of academic and institutional literature
- Identification and categorisation of dominant off-grid solar business models
- Comparative analysis of selected firms using the Business Model Canvas
- Evaluation of sustainability impacts using the Triple Bottom Line framework
- Identification of structural gaps and limitations in existing models
- Development of an original conceptual proposal, the Hybrid Community Energy Hubs (HCEH) model

This step-by-step process ensures that the analysis is transparent, replicable and grounded in existing literature.

3.7 Research Credibility and Limitations

Although the research is not based on primary data, an effort was made to ensure that the data used was as reliable as possible. For this reason, mainly scientific articles, reports of international organizations and publications related to energy access and renewable energy sources are used. The main sources of the work are organizations such as the International

Energy Agency (IEA), the World Bank and GOGLA, which are often used in the relevant literature (IEA, 2022; World Bank, 2023).

At the same time, the data does not come from only one source. Information and data are compared between different reports and studies, in order to have a more comprehensive picture of the off-grid solar energy sector and to reduce the possibility of a one-sided approach. In addition, tools such as the Business Model Canvas and the Triple Bottom Line are applied in the same way in all cases examined, so that there is greater consistency in the analysis (Yin, 2018).

The work does not include interviews or collection of personal data, as all the data used is publicly available. For this reason, no ethical approval process was required.

However, there are some limitations. The use of only secondary data means that the research is based on existing information rather than direct field research. Thus, some local conditions or practices may not be fully captured. Furthermore, the analysis focuses only on Kenya, which limits the generalizability of the results to other markets. Also, some corporate reports may mainly present positive results and less on the difficulties or weaknesses of the companies (GOGLA, 2023).

Despite these limitations, this methodological approach is considered appropriate for the objectives of the work, as it allows for a more strategic and comprehensive approach to the off-grid solar energy sector in emerging markets.

4.Off-Grid Energy in Kenya : Market analysis and business models

4.1 Introduction and Context

This chapter presents the case study of off-grid solar energy in Kenya, with the aim of examining how this market works, which business models dominate and whether they can be considered sustainable at an economic, social and environmental level. At the same time, the theoretical concepts and methodology presented in the previous chapters of the work are applied in practice.

Although access to electricity has improved significantly in recent years worldwide, in many emerging economies — and especially in rural areas — many people still do not have stable and affordable electricity. Within this environment, off-grid solar systems have begun to be used increasingly as a more flexible and relatively low-cost solution. The reduction in the cost of solar technologies and the possibility of gradual financing have significantly helped the development of this market.

Kenya is one of the most characteristic cases of off-grid solar energy development in Africa. The widespread use of mobile payments and platforms such as M-Pesa have enabled many companies to develop business models that enable households to access electricity through small and flexible payments. For this reason, the country is considered particularly interesting as a case study on the relationship between energy access, business models and sustainable development.

From a business and strategic perspective, the off-grid solar energy sector in Kenya is of particular interest, as it combines private investment, digital technologies and development objectives. Companies in the sector do not operate solely as traditional energy providers but more as service providers, which raises new issues regarding value creation, risk management and the long-term sustainability of business models.

Although PAYG Solar Home Systems have significantly improved access to electricity, several challenges remain regarding their overall development contribution. In many cases, these systems mainly cover basic consumption needs and not activities that can substantially

enhance local income or entrepreneurship. In addition, the instability of incomes of many users also affects the sustainability of the business models themselves.

For this reason, the chapter also presents an alternative business approach, Hybrid Community Energy Hubs (HCEH). This proposal attempts to shift the emphasis from individual energy consumption to more community and productive uses, with the aim of strengthening local economic activity and the overall sustainability of energy solutions.

The chapter then presents the Kenyan energy sector, the development of off-grid solar energy, the main business models currently used and an assessment of their sustainability. At the same time, the proposed HCEH model is analyzed as a possible alternative approach for decentralized electrification in emerging markets.

4.2 Kenya's Energy Sector and the Role of Off-Grid Solar

First, the state of the off-grid solar industry in Kenya can be considered quite advanced and progressive in the context of Sub-Saharan African countries. Indeed, over the last two decades, Kenya has achieved a considerable level of progress in the development of renewable energy, electricity access, and digital finance inclusion, which has positively affected the development of decentralised energy solutions. Therefore, the situation in the off-grid solar market in Kenya can be considered quite relevant for analysis from the perspective of renewable energy technologies and business models.

The history of the off-grid solar industry in Kenya cannot be discussed without mentioning the general picture of the energy industry in the country. Specifically, over time, there have been quite obvious differences in electricity access for urban and rural populations, where urban settlements had a much higher level of electricity access than the rural population because of the high cost of extending the grid and building the necessary infrastructure (World Bank, 2023). In addition, the low population density and the dispersed nature of the territory contributed significantly to the problem.

As a result of these issues, the government of Kenya increasingly started to develop policies in favour of renewable energy and decentralisation of power supply. Energy strategies of the state were increasingly directed at rural electrification, involvement of the private sector and promotion of renewable energy, understanding the inefficiency of purely centralized

approach. The above policy trends reflected the global trend towards achieving Sustainable Development Goal 7 (SDG7) related to universal access to affordable, reliable, sustainable and modern energy services (United Nations, 2015).

On the other hand, Kenya witnessed fast-growing development of its renewable energy production. The country is a leading producer of geothermal energy in the region and has been increasingly involved in investments in wind and solar energy (IRENA, 2021). Such broad process of energy transformation contributed to the institutional environment that was favourable to decentralized solar power systems and awareness about the importance of renewable energy for development.

One of the important enabling conditions for the growth of the off-grid solar market in Kenya has been the extensive use of mobile money services such as M-Pesa. Launched in 2007, M-Pesa revolutionized financial services in Kenya, introducing mobile payment services on a broad scale. Combining mobile money and renewable energy financing laid the groundwork for the swift development of PAYG business models (GSMA, 2022).

One of the most unique features of the Kenyan market is the link between digital finance and energy access. Using mobile payment solutions, customers can pay in small increments for solar energy products, which substantially alleviates the problem of purchasing equipment upfront. Financial flexibility has been crucial in extending energy access to low-income communities, especially those located in remote areas lacking access to traditional banking services.

The fast proliferation of PAYG systems in Kenya has drawn a lot of international interest from development agencies, investors and policy makers. Companies like M-KOPA, Sun King and d.light became important players in this market, using renewable energy sources, digital payment systems, and customer data management system in order to create sustainable businesses. Such companies have shown that decentralized renewable energy systems can be used not only for development purposes but also as commercial enterprises.

It is also interesting to note how important the private sector innovations become in the context of renewable energy transition. Unlike in case of conventional electrification which is mostly based on national utility companies and infrastructural projects, in the Kenyan

solar market the private sector plays the predominant role in providing the off-grid solar services.

Notwithstanding these achievements, however, the growth of the off-grid solar industry has been faced with several structural challenges. The first problem that needs to be addressed is related to affordability and repayment capacity. Although PAYG technology lowers initial expenditures, many people in rural areas belong to vulnerable social groups who rely on irregular incomes from agriculture or other informal means of earning money (GOGLA, 2023).

Another important challenge associated with the use of Solar Home Systems concerns the capacity of these devices. Most of these systems used in rural Kenya do not provide enough energy to meet demands associated with productive economic activities like refrigeration, irrigation, or agro-processing. On the contrary, the energy capacity of such systems is sufficient only for meeting basic household needs for lighting and electricity for phone charging and other electronic appliances (ESMAP, 2020).

The dispersed nature of solar energy systems in households may also constrain possibilities of achieving economies of scale and common productive infrastructure. In many societies, energy access is often individualized, not communal, thus limiting chances of having coordinated economic development activities and industries within the society. This problem acquires more significance in view of the wider developmental significance of energy systems in developing economies.

In terms of investments, Kenya has become one of the most promising renewable energy markets in Africa for impact investors and climate finance organizations. Development organizations and international bodies now recognize that decentralized renewable energy systems are key in promoting sustainable development, reducing greenhouse gas emissions, and enhancing social inclusion. Hence, significant amounts of capital have been invested in the Kenyan off-grid energy market within the last decade.

However, the long-term sustainability of investments in the sector is contingent upon a number of conditions such as repayment capacity, regulatory stability, and market maturity. While the market in Kenya shows great potential in terms of growth, there are issues

regarding profitability, client loyalty and operating expenses. In particular, companies working in rural areas incur considerable costs associated with logistics and servicing.

Regulation is another crucial factor that influences decentralised energy systems. Kenya demonstrates a relatively favourable regulation of renewable energy investments and the private sector involvement when compared to other countries in the region. However, some uncertainty remains regarding tariffs, licensing, and integration into future grid extensions. It poses certain risks for decision-making in the context of long-term planning.

Another aspect of sustainability is the issue of environmental sustainability beyond carbon reduction. Although decentralised solar energy systems play a positive role in clean energy transition, the growing use of batteries and photovoltaics generates the issue of e-waste management and recycling (IEA, 2022). As the market grows, the latter will become an increasingly relevant concern.

However, the Kenyan case study shows both the strengths and weaknesses of decentralized renewable energy systems in developing countries. First, Kenya shows how renewable energy technologies, innovative financial solutions and business models can help increase energy access and promote social inclusion. Second, the analysis highlights that despite its benefits, energy electrification alone will not be enough to transform economies if energy systems continue to be designed mainly for consumption.

These insights serve as a basis for the further discussion of off-grid solar business models and their sustainability through the TBL approach. In addition, they support the notion that alternative strategies taking into account productive use of energy and community infrastructure might be required to maximize the developmental impact of decentralized renewable energy systems.

4.3 Business Models in Kenya's Off-Grid Solar Market

The development of the off-grid solar energy market in Kenya over the last decade has become truly significant and can be considered as one of the best examples of decentralized energy production in Africa. It has happened due to the emergence of innovative business models focused on the combination of energy with payment systems and improved financial solutions.

Contrary to conventional approaches in the energy market, which are based mostly on grid networks and infrastructure built by the state authorities, the majority of off-grid energy solutions are provided by private companies attempting to satisfy needs in those regions that have difficulties with connection to the national grid (GOGLA, 2023; IEA, 2022; Tenenbaum et al., 2014).

The most common type used in Kenya is the Pay As You Go (PAYG) Solar Home System. By using this technology, users can get electricity without making big payments at once. Instead, they make small payments over time, making the solar systems cheaper for poor families (GSMA, 2022; World Bank, 2023; Lighting Global, 2020).

This model has worked quite well in rural areas of the country, where incomes are often unstable and many people work seasonally or in informal activities. Thus, the possibility of small and more flexible payments has made it easier to access electricity for many households that would otherwise have difficulty buying a solar system.

The development of PAYG models has also changed the way businesses themselves operate. Companies no longer rely solely on selling equipment but more on creating an ongoing relationship with the customer. Users pay small amounts over a long period of time, and thus businesses gradually gain more stable revenues (Rolffs et al., 2015; Lee et al., 2016; BNEF, 2019).

On the other hand, this means that the companies themselves also take on greater financial risk. They have to cover the initial cost of the equipment, while also having to manage cases of late or non-payment by customers. In many cases, the financial instability of households also affects the viability of the business models themselves.

Several large companies are active in the Kenyan market, following different strategies within the framework of PAYG models. One of the most well-known examples is M-KOPA. This company is not limited to providing solar systems but also uses its customers' payment data to offer other products, such as smartphones and electrical appliances (GSMA, 2022; Suri & Jack, 2016).

In this way, the company operates more as a digital services and financing platform than just an energy provider. This strategy allows it to diversify its revenue sources and maintain a longer-term relationship with its customers. However, it also increases its exposure to

financial risks, especially in times of economic instability or reduced repayment capacity by users.

Sun King focuses on last-mile distribution through extensive agent networks, prioritising accessibility and customer trust in rural communities. This approach improves market penetration and adoption rates but involves higher operational and logistical costs due to the need for local presence and ongoing servicing (GOGLA, 2023; Lighting Global, 2020). In contrast, d.light adopts a more standardised and multi-country expansion strategy, emphasising product reliability and scalability. While this supports international growth, it may limit responsiveness to local market conditions (BNEF, 2019).

While the discussion above highlights the strategic differences between the three leading firms operating in the Kenyan PAYG solar market, a more systematic comparison can be achieved through the Business Model Canvas (BMC) framework. As discussed in Chapter 3, the BMC provides a structured approach for analysing how organisations create, deliver and capture value. Applying the framework to M-KOPA, Sun King and d.light allows for a clearer understanding of the similarities and differences in their business models and provides a stronger analytical basis for evaluating their sustainability and competitive positioning. Table 1 summarises the key Business Model Canvas elements for the three companies and provides a structured comparison of how they create, deliver and capture value within the Kenyan off-grid solar market.

Table 1: Comparative Business Model Canvas Analysis of Leading PAYG Providers

BMC Element	M-KOPA	Sun King	d.light
Value Proposition	Affordable solar energy combined with digital financial services	Affordable solar products through extensive rural distribution	Reliable solar solutions combined with consumer financing
Customer Segments	Low-income rural and peri-urban households	Rural households and micro-enterprises	Underserved households and small businesses

Revenue Streams	PAYG repayments, financing services and product sales	Product sales and PAYG instalments	Product sales and financing repayments
Cost Structure	Technology deployment, customer acquisition and logistics	Manufacturing, distribution and maintenance	Distribution, financing and customer support
Key Partnerships	M-Pesa, investors and technology suppliers	NGOs, distributors and financial institutions	Development organisations, suppliers and financiers

The following strategic differences are notable through the analysis of the firms. First, M-KOPA pays more attention to the usage of technology and customer's credits in order to become an energy supplier and a platform for financial inclusion at the same time. The approach allows diversifying income and fostering stronger relationships with customers beyond providing energy.

Sun King is characterized by a more distribution-based strategy with a large coverage of rural areas through agents. The unique competitive advantage of Sun King comes from high accessibility and scale, which allows the firm to operate among rural people without access to conventional energy sources. Nevertheless, it should be noted that distribution networks are associated with higher operating costs.

Unlike Sun King and M-KOPA, the approach adopted by d.light includes multi-country development and standardization. Even though such a strategy is advantageous in promoting international operations, it can be less flexible than others because of its standardization.

Overall, the analysis demonstrates that competitive advantage within the Kenyan PAYG sector depends not only on solar technology but also on the strategic configuration of financing mechanisms, partnerships, customer relationships and revenue structures. Consequently, the Business Model Canvas framework provides a useful analytical lens for understanding the sustainability and growth potential of off-grid solar business models.

These variations reflect broader strategic trade-offs within the off-grid solar sector. Firms must balance affordability, scalability and financial sustainability, often under conditions of high uncertainty. Rapid expansion can increase market share but may also elevate credit risk and operational complexity. Conversely, more controlled growth strategies may improve financial stability but limit the speed of electrification impact (Tenenbaum et al., 2014; BNEF, 2019).

The economic sustainability of PAYG programs hinges on their underlying unit economics, which help determine if firms can make profits at affordable prices. Major cost factors for firms include initial capital investment in solar products, installation, and operating expenses like maintenance and customer services (ESMAP, 2020; World Bank, 2023). The source of income is the collection of payments from customers over long durations, which means that cash flows are sensitive to loan defaults and late payments.

Customer acquisition costs and efficient management of customer servicing are major contributors to the firm's profit-making capacity. The cost of acquiring customers through customer service is higher when companies have to operate in geographically distant regions, leading to reduced profits and higher risks (World Bank, 2023; Lighting Global, 2020). However, the increasing importance of data analysis means that firms use data to determine the creditworthiness of individuals and set appropriate prices (GSMA, 2022; Suri & Jack, 2016).

In addition to firm-level economics, PAYG relies on an ecosystem that includes other players, such as technology providers, mobile money operators, investors, and development agencies. The ecosystem-based approach facilitates innovation and scalability, but it also raises the complexity of interdependencies and systemic risks (IEA, 2022; GOGLA, 2023; Tenenbaum et al., 2014).

While successful in ensuring electricity access, the current models have inherent limitations. The energy capacity provided by individual SHS is generally limited, thus preventing their use for productive purposes, like processing agricultural produce, preserving food, and small-scale manufacturing (ESMAP, 2020; IRENA, 2021). Consequently, while improved living standards can be achieved, economic development does not always follow.

4.4 Sustainability, Risks and Structural Limitations

The proliferation of off-grid solar energy systems in Kenya has brought about various economic, environmental and social benefits that have made decentralized renewable energy solutions an integral part of any sustainable development approach in developing economies. Nevertheless, while current PAYG models have been successful in promoting electricity access, there still arise critical issues related to sustainability and developmental effectiveness, which should be considered when evaluating the performance of such systems. This analysis calls for adopting a multi-dimensional approach, accounting not only for the results achieved in terms of electrification, but also in terms of financial viability, environmental impact and social inclusiveness.

A good tool for measuring the sustainability of off-grid solar systems could be represented by the triple bottom line approach which evaluates business performance from economic, environmental and social standpoints at once (Elkington, 1997). An application of the TBL approach demonstrates both strong sides and potential vulnerabilities of PAYG systems.

Table 2: Triple Bottom Line Assessment of PAYG Systems in Kenya

Sustainability Dimension	Strengths	Limitations
Economic	Scalable PAYG model, improved financial inclusion, growing private-sector investment	Repayment risk, customer default, high operational and servicing costs
Social	Increased electricity access, improved quality of life, enhanced communication and education opportunities	Limited productive-use capacity, weak support for entrepreneurship and income generation
Environmental	Reduced reliance on kerosene and diesel, lower greenhouse gas emissions, contribution to clean energy transition	Battery disposal, e-waste management challenges, recycling concerns

In Table 2 the core strengths and weaknesses associated with PAYG solar power in relation to sustainability have been presented within the context of the Triple Bottom Line model. Even though this model is very effective when it comes to issues of environmental

sustainability and energy availability, there are still some concerns in relation to the sustainability of the systems economically and their potential impact beyond that of energy provision alone.

In terms of its economic value, PAYGO models have proven themselves economically scalable and attractive business models. The use of mobile money services, digital payment technologies, and service-based earning methods has allowed companies to quickly develop their operations in rural areas (GSMA, 2022; GOGLA, 2023). The examples of firms such as M-KOPA and Sun King prove that renewable energy generation can become profitable business operations under specific economic circumstances.

Nevertheless, economic sustainability in the area will be largely determined by the repayment ability and effectiveness of the process itself. Since businesses provide customers with the initial cost of equipment, they face credit risks in case payments from them turn out to be late and non-existent (Rolffs et al., 2015). The problem becomes more pronounced in poor and rural regions due to the volatility of household income in these regions, which is often associated with seasonal economic activity.

Operational costs also pose a significant problem. Geographically dispersed population increases operational costs in terms of transportation, installation, and maintenance. Although there is a chance for improved operational efficiency through application of new technology and data, long-run profitability of PAYG depends on scalability and ability to retain customers (World Bank, 2023).

In regard to environmental benefits, off-grid solar systems make a positive contribution to decreasing levels of greenhouse gas emissions by replacing conventional fossil fuel-based energy sources, like kerosene and diesel power generators (IRENA, 2021). Usage of solar power helps decrease environmental pollution in rural areas, improving air quality indoors. This contributes to the overall achievement of global decarbonization goals.

However, sustainability of the environment does not end in the operations stage of renewable energy technologies. Lifecycle problems regarding batteries disposal, electronics recycling, and photovoltaic panels recycling are still not sufficiently considered in most of today's business models (IEA, 2022). The rising deployment rates of off-grid solar will lead to greater significance of these sustainability issues.

The sustainability aspect that touches upon social problems is related to questions of inclusion and development, as well as living conditions. Indeed, off-grid solar systems were successfully applied in solving accessibility issues of basic energy services (lighting, communication, etc.). Furthermore, the creation of local networks resulted in employment chances for people.

Although there are multiple advantages, the development potential of many of the currently existing systems is hindered by their limited energy storage capacity. The vast majority of Solar Home Systems are tailored to meet individual consumption purposes, such as lighting and phone charging, and do not offer any productive-use options (ESMAP, 2020). As a result, although people have better access to energy, they may not be able to use it productively.

Limited productive-use capacity is the biggest structural flaw associated with existing off-grid solar systems. Lack of productive use makes it harder for the population to earn more money from having access to the energy system, thus hindering both economic development and repayment capacity. In practice, this translates into an ongoing cycle that prevents financial success.

Increasingly, literature highlights the importance of linking energy access to productive uses in order to optimise developmental gains (Bhattacharyya, 2013; Sovacool, 2012). In line with such observations, there have been other research findings showing that programs of electrification create much more economic impact when electricity is used for productive purposes like irrigation, refrigeration, agricultural processing, and light industrial activities (ESMAP, 2023; Efficiency for Access Coalition, 2024). Energy for productive uses would help foster local economic growth, enhance household earnings, and ensure the sustainability of decentralised energy systems. Nevertheless, such goals cannot be achieved without energy systems capable of handling higher loads and more integrated infrastructure than standard Solar Home Systems.

Another significant drawback involves the fragmented approach to electrification initiatives. Contemporary PAYG schemes have been tailored to meet household-level needs without much consideration of community-level energy supply options.

Current studies have shown that in assessing the success of energy access initiatives, there needs to be an evaluation of the broader developmental impact of these initiatives. According to ESMAP (2023), productive energy uses would greatly improve the efficiency of energy access initiatives by enhancing income generation and promoting entrepreneurship among the populace. Likewise, Efficiency for Access Coalition (2024) asserts that productive use of energy technology helps promote sustainable decentralized energy access because it adds to the economic value of the rural community. From the above findings, future off-grid energy initiatives need to place more emphasis on productivity among communities than simply increasing electricity access.

Overall, the conclusion from this analysis is that while the current PAYG systems make notable improvements in electricity access, they have significant limitations in supporting sustainable development. Although they score high in accessibility and environment, their economic robustness and developmental significance prove to be inconsistent. It becomes evident that there is a need for different ways of thinking, which would allow the incorporation of aspects such as affordability, productive use, and value generation on the community level.

Thus, in an attempt to respond to these concerns, the model of Hybrid Community Energy Hubs (HCEH), presented below, offers the solution by redirecting the attention from personal usage to infrastructure development and energy utilization.

4.5 Hybrid Community Energy Hubs (HCEH) – Proposed Business Model

An assessment of current off-grid solar power business models indicates that while there is a certain success in ensuring access to energy sources among poor households, their role in economic development is quite limited. Pay-As-You-Go Solar Home Systems represent a good example of successful expansion of access to energy among the poor but, nonetheless, fail to contribute to the development of economies or productive use of energy. Therefore, taking into account such shortcomings, this paper suggests adopting the Hybrid Community Energy Hubs (HCEH) business model.

Unlike the Solar Home System, the Hybrid Community Energy Hub approach is focused on establishing a decentralised renewable energy infrastructure for the use of communities for the purposes of economic development and productive energy use. More specifically, in contrast to Solar Home Systems that provide energy for single households, HCEHs involve decentralised energy hubs that are capable of providing energy to multiple users. The energy generation and provision system includes the use of solar photovoltaics, batteries, and energy distribution systems.

An important aspect of the HCEH model lies in productive utilization of energy (PUE). Prior research underscores the need for making sure that efforts for electrification are linked with activities that generate income in order to achieve optimal development impact (ESMAP, 2020; Bhattacharyya, 2013). In this sense, the design of HCEHs not only takes into account the need for lighting and general access to electricity but also the need for supporting activities such as refrigeration, irrigation, agricultural processing, battery recharging, internet access and light industrialization.

From an operational standpoint, the HCEH model stands out for its divergence from the existing household-based models. The former differs significantly by having centralized energy generation and storage capacity and distribution of this capacity among various users through localized micro-grids. While this strategy may be better in terms of efficiency, it may reduce redundancy in terms of equipment purchases and maintenance needs. Moreover, concentrating energy demand in community-based centers may prove to be more manageable from the standpoint of energy consumption and scheduling.

The physical components of an HCEH could include several interconnected elements. These may be a central solar PV array, battery storage facilities, intelligent metering systems, and

productive use areas. Productive use areas may involve agricultural co-operatives, food storage facilities, water pumps, e-learning facilities, or even micro-manufacturing units. In rural settings where productive economic activities are spread out, along with a lack of large-scale energy infrastructure, the clustering of economic activities around energy hubs might create economic ecosystems that provide job creation and entrepreneurial opportunities.

The Hybrid Community Energy Hub concept could become clearer when juxtaposed with other forms of decentralised energy electrification models. While Solar Home Systems and mini-grids constitute the current frontrunners in developing countries, HCEHs seek to incorporate the flexibility and scalability of PAYG systems into productive use and shared infrastructure features of community energy systems. Table 3 offers a comparison of all three models in terms of certain operational and strategic considerations.

Table 3: Comparative Assessment of Decentralised Energy Models

Criterion	Solar Home Systems (SHS)	Mini-Grids	Hybrid Community Energy Hubs (HCEH)
Primary scale	Individual household	Community/village	Community cluster
Typical energy capacity	Low	Medium–High	Medium–High
Main energy use	Basic household consumption	Household + productive use	Household + productive use
Productive-use support	Limited	Moderate	High
Infrastructure complexity	Low	High	Medium
Initial investment cost	Low	High	Medium–High
Scalability	High	Moderate	High
Operational flexibility	High	Moderate	High
Revenue structure	Household repayments	Tariffs/community payments	Diversified revenue streams
Dependence on customer repayment	High	Moderate	Lower
Community integration	Low	Moderate	High

Digital integration	High	Moderate	High
Potential for local economic development	Limited	Moderate	High
Regulatory complexity	Low	High	Moderate
Long-term sustainability potential	Moderate	High	High

According to Table 3 below, HCEH is strategically positioned in-between the Solar Home System and Mini-Grids as far as its use cases go. For example, HCEHs are capable of offering higher productivity uses, better community integration, and diversified revenues compared to Solar Home Systems. On the other hand, they may be cheaper to build and regulate compared to the mini-grids. This makes their position even more appealing for scaling and development purposes in semi-rural settings where there is need to cluster energy demands due to the lack of economic viability of central infrastructure.

The feasibility of this method is further backed up by practical examples from previous community-based renewable energy projects in developing countries. Mini-grids in Kenya, Tanzania and Rwanda designed for productive uses have shown that financial sustainability of renewable energy projects can be improved if the connection to productive economic activity such as irrigation, refrigeration and agricultural processing occurs (ESMAP, 2023). Moreover, the Efficiency for Access Coalition (2024) argues that productive energy technology usage can not only improve incomes but also result in better repayment and overall development outcomes in rural areas as a consequence of electrification programs. Even though the HCEH concept suggested by this dissertation is still at the conceptual stage, the above-mentioned examples are good support for the feasibility of the idea.

Table 4: Indicative HCEH Pilot Scenario

Parameter	Indicative Value
Households served	100
Solar PV capacity	50 kW
Battery storage	200 kWh
Productive-use facilities	Irrigation, refrigeration, agro-processing
Estimated beneficiaries	500–700 people

Management model	Community cooperative + private operator
Payment system	PAYG + community contribution

This hypothetical scenario in Table 4 serves merely to illustrate the practicality of the HCEH idea, which would be defined by various factors, including local demands, local solar conditions, and local financing schemes. However, the point is made about how a hub for renewable energy could fulfill both domestic and productive needs in a community context.

As far as business models go, HCEHs integrate characteristics of microgrids, PAYG financing, and platform service delivery. This means that customers can pay for energy services in much the same way as with the help of traditional PAYG services; thus making the use of HCEH electricity affordable and accessible for poor people. However, the main difference is that HCEH infrastructure costs are shared among several users.

This new approach is further strengthened by the introduction of diversified sources of revenues which constitute an essential strength regarding the robustness of finances. Apart from the payment of electricity within households, HCEHs could earn money through productive services provided by the HCEH, leasing of equipment and community-based commercial transactions. These could include refrigeration services for farm produce, rental of mobile power units, subscription for internet services or productive equipment leases. This would help reduce dependency on one particular source of income and mitigate risk associated with default or irregularity of incomes.

The financing approach for the establishment of HCEHs could be distinct from the traditional pay-as-you-go model. Where the financing of Solar Home Systems relies solely on the customers' ability to make repayments, community-based hub financing would allow more diversified and flexible financing schemes, involving both private and developmental finance sectors. Development banks, impact investors and climate-related financing institutions could provide essential support in meeting the greater financial needs for HCEH construction.

Another significant feature of the HCEH approach is its hybrid system of governance. The conventional off-grid solar systems are mostly characterised by a private sector arrangement based on the customer/provider relationship. Meanwhile, HCEHs are expected to be multi-stakeholder solutions where private companies, local communities, NGOs, and sometimes

governments cooperate with each other. This can lead to higher accountability, social acceptability, and access to funding.

Digital technologies remain important for the functioning of the HCEH system. Digital payment, monitoring systems and big data are useful tools that can help collect payments, manage energy usage, and engage with customers, just as PAYG models do (GSMA, 2022). In addition, the HCEH model relies on using digital solutions to optimise energy distribution and coordinate activities at the community level. Furthermore, smart metering systems will help to create more sophisticated pricing mechanisms based on energy consumption levels and productive uses, as well as peak hours of demand.

The Hybrid Community Energy Hubs proposal involves incorporating renewable energy systems, digital finance platforms, and productive use of energy in one common community-based system. This is different from the traditional household-based approach since the HCEH proposal aims to achieve economic development alongside providing energy access. Figure 4.3 shows the design of the proposed system.

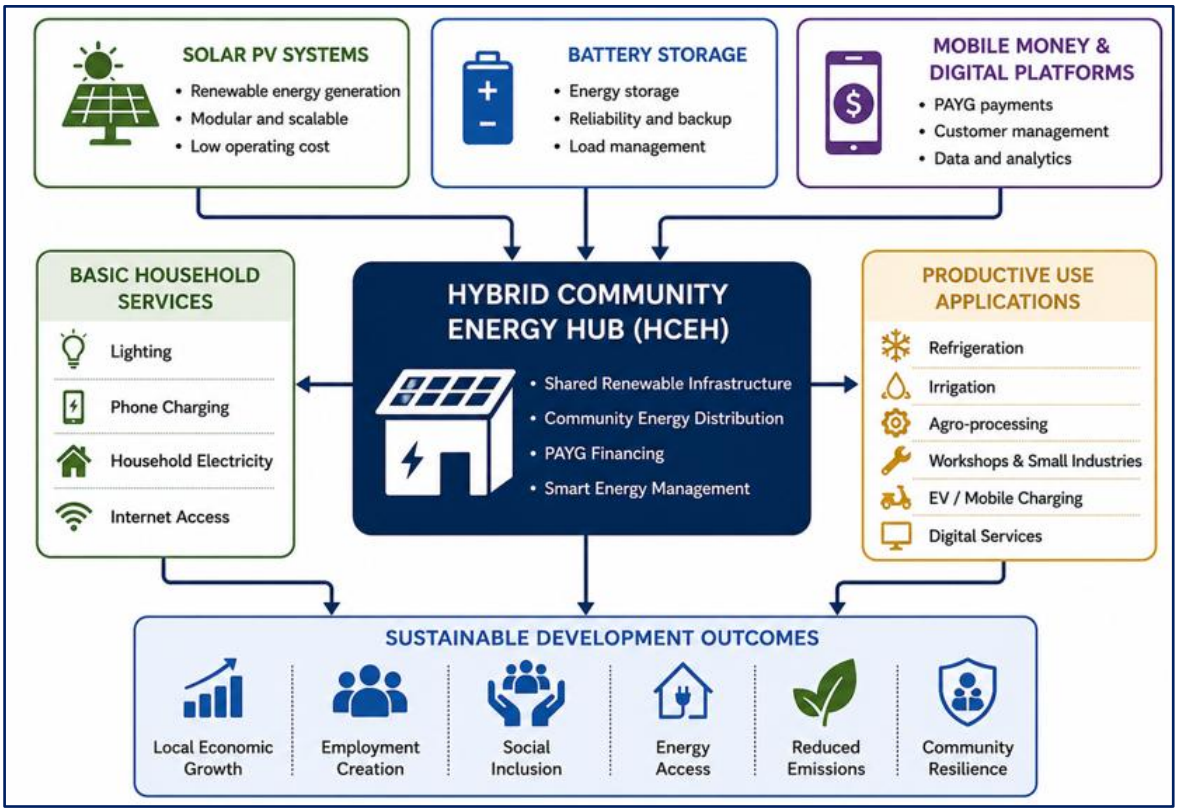

Figure 4: Conceptual Framework of the Hybrid Community Energy Hubs (HCEH) Model

As can be seen from Figure 4, the framework of HCEH integrates decentralized energy infrastructure with productive uses and digital finance solutions. In other words, this approach intends to take consumption-based electrification to a higher level by ensuring that energy generation is coupled with economic and infrastructural development in the locality. It is by virtue of this structure that HCEHs can achieve sustainability in both economic, social and environmental terms at once.

Table 5: Proposed Key Performance Indicators for HCEH Projects

Sustainability Dimension	KPI
Economic	PAYG repayment rate (%)
Economic	Revenue generated from productive-use activities
Economic	Number of jobs created
Social	Households electrified
Social	Schools and clinics connected
Social	Community participation rate
Environmental	CO_2 emissions avoided
Environmental	Diesel fuel displaced
Environmental	Share of renewable energy (%)

The proposed KPIs create a platform where any future pilots can measure the success of the HCEH approach. In line with the Triple Bottom Line concept, the indicators have been developed to consider economic, social, and environmental aspects and hence create a holistic measurement of sustainability impacts. Moreover, such indicators will enable stakeholders to judge the success of HCEH projects from a development and profitability perspective.

It must be pointed out here that HCEHs represent a middle ground between SHS systems and mini-grids. As compared to SHS, HCEHs have more capacity for energy generation as well as developmental potential, whereas when compared to mini-grids, HCEHs avoid some of the costly and complex aspects of mini-grid infrastructure (Tenenbaum et al., 2014).

Such an intermediary position could prove to be very beneficial in new energy markets. In light of the fact that rural economies will continue becoming more digital and networked, there is likely to be a high demand for reliable electricity and productive use applications. As such, HCEHs can act as models that facilitate future economic growth while retaining the benefits of being decentralized, such as off-grid power systems.

As far as sustainability is concerned, HCEH projects have been designed to overcome the shortcomings associated with the Triple Bottom Line approach. Financial sustainability can be improved by diversifying income and including productive use applications. Social sustainability will be fostered through promoting community involvement and infrastructure sharing. Lastly, environmental sustainability will retain the carbon-neutral features of renewable energy projects.

However, there are several challenges associated with the deployment of HCEHs as well. For instance, initial capital costs for setting up HCEHs are expected to be higher than SHS. It would require blending of financing instruments for investment into these facilities. Effective governance and community involvement will also be critical in implementing HCEHs.

Additionally, technical management skills may be among the potential bottlenecks in some cases. As opposed to the installation of SHS in households, community energy systems need better coordination of operations, especially in cases where infrastructure used for productive purposes needs to be established.

Lack of regulatory clarity might represent another challenge worth considering. In many developing countries, the regulatory framework concerning decentralised energy systems has not yet been fully established, especially when it comes to issues related to licenses, tariffs, and ownership models. Therefore, the future scalability potential of HCEHs might be contingent upon the institutional context and policy environment.

Nonetheless, the discussed model fits well into the paradigm of innovation in sustainable business models, according to which businesses should consider creating value in non-financial terms (Bocken et al., 2014). Unlike PAYG systems, whose focus is primarily on providing electricity access to communities, HCEHs strive to combine energy delivery with other development goals, such as economic viability and increased productivity.

To conclude, the HCEHs model can be viewed as one more attempt to transcend the prevailing consumption-oriented electrification trend toward a more holistic view of the development-oriented decentralised energy systems. In addition to the limitations that exist in current PAYG models, HCEHs can contribute to achieving sustainability in economic, environmental, and social spheres alike.

4.6 Discussion and Strategic Implications

The analysis conducted in this chapter underscores not only the revolutionary promise but also the structural constraints facing current business models for off-grid solar power provision in developing countries. Through the focus on the case of Kenya, the research identifies significant successes and shortcomings with regard to the contribution of decentralised renewables – notably the Pay-As-You-Go Solar Home Systems – to increased energy access for underprivileged communities. Notably, one of the major weaknesses of the current arrangements relates to long-term economic sustainability and productive uses of energy.

One of the key conclusions of this chapter can be stated as follows. The rapid adoption of off-grid solar power systems in Kenya cannot be attributed entirely to the development of innovative technologies. Rather, the proliferation of the sector has been facilitated through the combination of renewable technologies, digital finance solutions and adaptive business models. Mobile money platforms coupled with PAYG finance have increased access and affordability of technology for disadvantaged population groups who were traditionally excluded from regular financial and energy infrastructures (GSMA, 2022; GOGLA, 2023). Such results are in line with the discussion of the business models in Chapter 2 (Teece, 2010; Zott et al., 2011).

Therefore, the results support the hypothesis that energy transitions in developing countries are not only technological phenomena but rather socio-economic changes that include the process of financing, governance, entrepreneurship, and institution building. The interaction between innovation in the private sector, digital technologies and favourable market environment resulted in the creation of a suitable environment for large-scale introduction of renewable sources of energy in Kenya.

At the same time, the findings indicate that energy access does not necessarily result in economic development. The current Solar Home Systems provide their users with energy mostly for domestic purposes like lighting and communication. Although access to such energy can help to improve living conditions, it is incapable of ensuring sustainable economic activities from which households or communities can generate income (ESMAP, 2020). More recent studies similarly emphasise that electrification programmes achieve significantly greater developmental impact when electricity is linked to productive-use applications such as irrigation, refrigeration, agro-processing and small-scale enterprise development (ESMAP, 2023; Efficiency for Access Coalition, 2024). Therefore, the concept of energy access versus productive energy access has become one of the major issues highlighted by this research.

Based on the application of the TBL concept within the framework of sustainability, there exists an imbalance with respect to the economic, environmental, and social considerations. The existing PAYG approaches have proven to be effective concerning their contribution to environmental sustainability due to lower reliance on fossil fuel and higher accessibility to clean energy sources. In addition, they have been making positive contributions to social sustainability through higher electrification in areas without adequate infrastructure. Nonetheless, their contributions towards economic sustainability are less apparent, especially regarding the risks related to the cost of operation and production.

It can thus be concluded that the current approaches are focused mainly on consumption as opposed to development. This particular conclusion is significant for the case of developing countries, which need energy solutions that will help in achieving the development goals in addition to providing electricity (Pachauri & Rao, 2013; Sovacool, 2012).

Yet another problem is that of fragmented electrification efforts. The household-based Solar Home Systems have proven to be highly effective in boosting access quickly; nevertheless, its fragmented form may undermine possibilities of achieving economies of scale, sharing infrastructure, and coordinating productive efforts. In other words, although electrification rates can improve substantially, the process of local economic transformation will not necessarily follow unless the energy system itself is linked with productive-use infrastructure and development efforts.

As a solution to the problems discussed above, the hybrid Community Energy Hubs (HCEH) concept provides a potential alternative strategy for combining decentralized energy supply with productive economic activities. In contrast to traditional Solar Home Systems, which tend to emphasize household consumption, the HCEH approach seeks to address community-level infrastructure and productive uses of energy.

The proposed HCEH model has several strategic implications for the renewable energy industry. Firstly, it underscores the need for revenue diversification and productive uses to enhance financial viability. Renewable energy companies will be able to earn more money by engaging in commercial services and productive use applications rather than solely relying on revenue generated from repayment of household loans. Secondly, this business model underscores the significance of community-level infrastructures that could lead to better economies of scale and efficiency compared to household-level infrastructure. For example, shared storage facilities, productive use applications, and localized distribution networks would lead to higher energy utilization.

Thirdly, this model reflects the current trend of value creation in the context of sustainable development where organizations aim to achieve sustainable development in economic, environmental, and societal contexts concurrently (Bocken et al., 2014). In this case, renewable energy firms will not only engage in providing electricity but will offer development services including energy and digital services at the same time.

According to recent studies, the performance of decentralised renewable energy initiatives over the long term must not be judged on the basis of their rate of electrification but also on their contribution to local economic development. According to ESMAP (2023), productive energy uses have significant potential to raise the developmental gains from rural electrification through promoting entrepreneurship, generating incomes and creating local value. Likewise, as highlighted by Efficiency for Access (2024), productive energy use leads to enhanced financial viability of decentralised energy initiatives because of greater economic activity created in rural areas. This provides justification for the adoption of the HCEH approach, since it aims at linking energy access with economic development.

The results also raise a number of important considerations for policymakers and development agencies. Traditional electrification efforts frequently focus on achieving high

connection rates as an overriding policy goal. On the other hand, the results indicate that future energy policies will increasingly need to address the quality and development impact of energy access through its capacity to enable productive energy use. Such policy approaches will require enabling policy environments that stimulate productive energy applications and innovative funding instruments and partnerships.

Regulatory considerations suggest that governments will have to be able to design more flexible frameworks that can accommodate innovative hybrid forms of decentralised systems – combining aspects of solar home systems, mini-grids, and community-level infrastructures. In many developing countries, regulatory frameworks tend to be geared either towards national grid extension or individual household installations, offering little space for alternative systems like the HCEH system.

From an investment point of view, there are several implications related to the growth of sustainable finance and impact investments. With the growing popularity of environment and social governance (ESG)-oriented investment strategies in international development, projects with clear environmental and social benefits will gain more attention from impact investors and other types of finance institutions.

Meanwhile, the move towards an integrated system at the level of communities might need to be accompanied by new financing mechanisms that can account for long-term investments and high initial infrastructure costs. In this context, blended financing strategies that involve state funding, concessional lending, and private investments could become essential in scaling up such models.

The third implication relates to the potential impact of digitalization on the decentralized energy transition. As illustrated by the Kenyan case study, the use of digital finance infrastructure, especially mobile money networks, can completely transform the economics of renewable energy deployment. Decentralized energy systems in the future could be even more dependent on digital infrastructure, which includes smart meters, analytics tools, online platforms, and energy management systems enhanced by artificial intelligence.

The comparative success of Kenya compared to other emerging economies is another significant source of strategic lessons. In addition to having favorable conditions for solar power generation, the growth of decentralized solar systems in Kenya was made possible

by the high level of mobile money adoption, entrepreneurship, regulatory adaptability, and private sector involvement. This indicates that, apart from the feasibility of the systems, scalability would depend significantly on the broader ecosystem and readiness.

The suggested hybrid community energy hub model will have more strategic considerations for various stakeholder groups involved in the renewable energy ecosystem than traditional household-based power systems. In contrast to traditional household electricity supply systems, HCEH models combine energy delivery, productive infrastructure, information technology, and economic development at the community level. The strategic lessons derived from the suggested model are listed in Table 6 below.

Table 6: Strategic Implications of the HCEH Model

Stakeholder	Strategic Implications of HCEH
Renewable energy firms	Diversification of revenue streams and expansion toward productive-use energy services
Governments and policymakers	Support for rural development, decentralised electrification and energy inclusion
Local communities	Improved access to productive infrastructure and economic opportunities
Development organisations	Stronger alignment with sustainable development and poverty-reduction objectives
Investors and financial institutions	Opportunities for ESG-oriented and impact investment strategies
Agricultural and small-business sectors	Increased access to reliable electricity for productive activities
Digital service providers	Expansion of digital infrastructure and mobile-based service ecosystems
Energy sector regulators	Need for adaptive regulatory frameworks supporting hybrid decentralised systems

As illustrated in Table 6, the HCEH framework extends beyond traditional electrification objectives by creating linkages between renewable energy systems, economic productivity and community development. This multidimensional structure may increase the strategic relevance of decentralised energy systems for governments, investors and development institutions seeking integrated sustainability solutions.

The HCEH model also aligns closely with several Sustainable Development Goals (SDGs) established under the United Nations 2030 Agenda for Sustainable Development. Most directly, the model contributes to SDG7, which focuses on access to affordable, reliable and

sustainable energy. However, its emphasis on productive-use applications and community-level economic activity also supports SDG8 relating to decent work and economic growth, SDG9 concerning resilient infrastructure and innovation, and SDG13 associated with climate action and emissions reduction. This broader alignment demonstrates that decentralised renewable energy systems may contribute not only to electrification targets but also to wider socio-economic development objectives.

All things considered, it is evident that even though current off-grid solar business models have been quite successful in terms of providing greater access to energy, their effectiveness as tools of development is limited due to inherent structural flaws concerning productive uses and sustainability. HCEH is one example of how to mitigate some of the disadvantages through the application of a combination of shared infrastructure, financing and productive use of energy within a community context.

As such, the results obtained in this chapter further corroborate the need for an integrative approach to sustainable energy transition in developing countries, as both technological innovation and appropriate business models play a crucial role in facilitating the process. As stated earlier, renewable energy technology projects should not merely be viewed as infrastructure projects, but rather, as socio-economic transformation instruments as well. It is upon this that the concluding chapter of the thesis will be built.

5. Conclusions and Recommendations

5.1 Introduction

This chapter highlights the key conclusions that emerge from the study and discusses its implications at a more general level. The study has been conducted to analyse how business models based on off-grid solar technology help accelerate renewable energy transitions in emerging economies. In particular, there is a focus on the relation between decentralised renewable energy, digital finance, and innovations in sustainable business models. Furthermore, the proposed Hybrid Community Energy Hubs (HCEH) business model framework, which aims at addressing certain shortcomings of the existing PAYG solar business models, will be presented as an illustrative example.

The sections below discuss the main results of the study and highlight their implications both theoretically and practically. Additionally, the limitations of the study are presented along with suggestions for future research directions.

5.2 Summary of Main Findings

The results found in this dissertation show the increased importance of decentralised renewable energy systems in the energy transition processes globally, especially in places where the expansion of traditional power grids faces economic and geographical obstacles. The research showed that off-grid solar energy and alternative payment methods contribute greatly to increasing the accessibility of electricity to underprivileged people and helping achieve sustainability goals at the same time.

The example of Kenya reveals that the convergence of renewable energy systems and digital finance creates a high potential for scaling energy access solutions. Thanks to the development of mobile money systems like M-Pesa, energy companies could provide new PAYG financing mechanisms for low-income users, making it easier for them to buy energy devices and pay for them on a monthly basis.

On the other hand, this research was able to identify some of the limitations of the currently prevalent business models for PAYG systems. While the Solar Home System technology is proven successful in increasing access to electricity, their developmental effects are typically limited due to low productivity usage and household infrastructure fragmentation.

In many cases, access to electricity helps improve quality of life and social inclusion without contributing significantly to local economic development. Recent literature increasingly emphasises that electrification programmes generate greater developmental benefits when electricity is linked to productive-use applications such as irrigation, refrigeration, agro-processing and small-scale enterprise development (ESMAP, 2023; Efficiency for Access Coalition, 2024).

It has been noted that sustainability in decentralized renewable energy projects should not be solely assessed through an environmental lens. Utilizing the Triple Bottom Line approach revealed the necessity to consider the balance between the environmental benefits and the financial and social aspects of these ventures. Existing off-grid solar energy systems show outstanding performance regarding emissions and sustainable energy production; however, economic sustainability poses some challenges in many emerging markets.

Another key discovery regards the growing importance of business model innovation in renewable energy transitions. According to the research, the successful functioning of decentralised renewable energy systems depends not only on technological efficiency but also on the ability of businesses and organisations to develop adaptive models of operation, finance and governance. From this perspective, the development of PAYG is a good example of how digitalisation transforms the provision of energy and enhances market accessibility.

In this connection, the dissertation advanced the concept of Hybrid Community Energy Hubs (HCEH). This new model attempts to integrate decentralised renewable energy systems with productive uses and related economic activity. In contrast to conventional household-centric approaches to electrification, the suggested HCEH concept is primarily concerned with the combination of access to energy sources and economic opportunities for communities. Although the model remains conceptual, the analysis suggests that combining community-level infrastructure, productive-use energy applications and diversified revenue streams could address several of the structural limitations identified in existing PAYG systems. Furthermore, comparable productive-use energy initiatives implemented in East Africa provide indirect evidence supporting the potential feasibility of such an approach.

Furthermore, the proposed HCEH concept is in line with other recent developments in the sphere of sustainable business model innovation. In such a way, there is a growing trend towards creating business models that provide value not just from an economic perspective, but also through environmental and social aspects.

5.3 Theoretical and Practical Implications

This study's findings have contributed to the expanding body of literature on decentralized renewable energy systems and innovative sustainable business models. Theoretically, the dissertation supports the idea that renewable energy transitions should not only be considered from the technological perspective, but rather be understood as socio-economic transitions involving finance, governance, infrastructure and institution changes.

The dissertation makes contributions to debates around sustainable business models for emerging economies. While most of the literature focuses on the issue of electrification levels and technologies, this dissertation underscores the importance of productive use and local development implications. Against this backdrop, the developed HCEH framework provides an extension of the current PAYG models by considering a closer link between electrification and local economic growth as well as integrated infrastructure systems. This finding is consistent with recent research emphasising the importance of productive-use energy applications and community-based approaches in enhancing the developmental impact of decentralised renewable energy systems (ESMAP, 2023; Efficiency for Access Coalition, 2024).

Finally, the dissertation shows that digitalization is becoming an increasingly important element of renewable energy systems. As the Kenyan case suggests, the introduction of mobile money services enables greater affordability and scalability of renewable energy businesses and improved access for customers in poor communities. Digitalization can thus become one of the characteristics of the future decentralized energy systems.

In practice, there are several implications of the findings for renewable energy firms, policy makers, development organizations, and investors. Companies need to recognize that in order to achieve sustainability they have to think about applications of their product beyond household electricity generation. Using their solutions in combination with productive use and infrastructure development can prove more beneficial for development and economy.

Secondly, policies of national governments should be oriented not only on increasing the percentage of connections but on improving the quality of access to energy. It will enable productive uses of energy access, blended finance, and decentralized infrastructure to help in increasing sustainability of renewable energy.

Thirdly, organizations working in the sphere of development and finance should consider several aspects of sustainability during the evaluation of their projects. In the future, they cannot just look at the success of electrification processes but also at economic development, creation of jobs, and resilience.

Lastly, the concept of HCEH is relevant to development practice since renewable energy systems are more and more perceived as sustainable development tools. They do not only provide solutions for the environmental issues but also serve socio-economic needs defined by the UN organization.

5.4 Limitations of the Study

While the dissertation offers many strengths, there are also certain limitations to consider. Firstly, the research is predominantly qualitative, relying on secondary data sources as well. While secondary data allows for broad consideration of Kenya's off-grid solar industry, it does not allow for practical assessment of the actual processes and experiences within this industry.

Secondly, this research concentrates exclusively on Kenya as a one-country case study. Kenya stands among one of the most advanced off-grid solar markets worldwide thanks to a highly advanced system of mobile money and established systems of renewable energy. Thus, certain findings cannot necessarily be applied to any other emerging markets with differing institutional, economic, or legislative characteristics.

One additional limitation concerns the Hybrid Community Energy Hubs (HCEH) concept proposed in this dissertation. Although the model was developed through literature review, comparative analysis and theoretical reasoning, it remains conceptual in nature and has not been tested through pilot implementation or empirical evaluation. While indicative feasibility scenarios and performance indicators were proposed, future research will be

required to validate the operational, financial and developmental performance of the model in real-world conditions.

Furthermore, no techno-economic modelling and engineering studies related to decentralised renewable energy systems were carried out. Rather, the main emphasis of the dissertation was laid on the discussion of business models and their implications for sustainability.

Finally, due to the fast-paced changes and rapid development of renewable energy technologies, financing instruments and global energy policies, some results and conclusions drawn might need to be revised in the future, since market conditions can continue to evolve further.

5.5 Recommendations for Future Research

The research outcomes from this dissertation open up a number of possibilities for future academic investigation. One particularly promising avenue for future research involves the empirical testing of Hybrid Community Energy Hubs (HCEH) through pilot projects in developing-country settings. Future studies could evaluate the model using key performance indicators relating to economic viability, productive-use outcomes, social inclusion and environmental sustainability. Such research would provide valuable evidence regarding the practicality, scalability and long-term sustainability of community-based renewable energy systems.

The next possible avenue for further research pertains to the issue of viability and investment necessary for deploying community-based renewable energy in developing countries. By investigating various financing and organisational arrangements, scholars can derive useful information on ensuring sustained implementation at a large scale.

It is also important for scholars to investigate productive uses in decentralised energy systems. In turn, scholars may conduct further studies exploring the linkages between renewable energy deployment, entrepreneurship and development in the rural economy.

Another area where digitalization might be examined in relation to decentralization of energy markets is its significance in the operations of off-grid energy systems. In this sense, future research can be conducted in regard to how smart metering, digitalization, artificial

intelligence and data analysis affect operational efficiency, consumer behavior and economic sustainability of off-grid energy systems.

Cross-country comparative research will also help gain knowledge about the impact of institutional and regulatory environment as well as the level of digitalization of a country on the adoption of renewable energy sources. Although Kenya serves as a good example in this context, other studies involving emerging countries will enable greater generalization.

Lastly, quantitative research methodology and simulation modeling can be used to assess the operational feasibility and scalability of community-based energy systems.

5.6 Final Remarks

Sustainable energy transitions are amongst the most profound changes seen during the modern era in relation to economy, environment, and technology. In this regard, renewable energy systems have proven to be highly valuable tools used to improve energy access in developing economies and further contribute to sustainable development initiatives.

As shown by the experience in Kenya, new business models combined with digital finance and innovations in renewable energy technology are able to produce scalable solutions for electrification of underserved communities. At the same time, it is clear from the analysis conducted in this dissertation that the long-term effectiveness of decentralized renewable energy systems cannot be assessed without considering their contribution to productivity and development.

As can be observed from the design of the hybrid community energy hubs discussed here, it constitutes a shift away from consumption-driven electrification towards an approach which is much more holistic in nature and aims to promote sustainable development. Through the use of renewable energy technologies, productive uses of energy, and infrastructures for energy services, the approach attempts to address issues of sustainability on a multi-dimensional basis.

Overall, this dissertation highlights the importance of viewing renewable energy systems not merely as infrastructure projects, but as instruments capable of supporting broader socio-economic transformation.

Considering that the renewable energy transition is likely to accelerate globally in the coming years, factors such as sustainability, digitalization and development are expected to become increasingly important.

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