SOLAR ELECTRICITY CONSUMPTION, FINANCIAL INCLUSION, AND WELFARE IN SUB-SAHARAN AFRICA

By

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ABSTRACT

Solar electricity has continuously contributed towards alleviating energy poverty in sub-Saharan Africa. Moreover, the development of off-grid solar electricity technologies and business models that integrate mobile money into solar electricity transactions has improved access to electricity in the region. As a result, the demand and adoption of mobile money have also increased. However, existing literature has not exposed this positive development trend and other economic development opportunities inherent in solar electricity consumption. Most studies have focused on analysing the potential of solar electricity consumption in alleviating energy poverty. Although the analysis of solar electricity consumption and poverty alleviation is critical, studies have failed to extend the analysis to other economic development indicators such as financial inclusion, and money demand. This analysis is important because access to financial services and the development of financial systems in sub-Saharan Africa is low, yet economic theory postulates that renewable electricity demand induces the development of and access to financial services and increases capital stock. Therefore, it is critical to examine the broader economic opportunities inherent in solar electricity consumption to provide additional insight into development of prudent renewable energy and economic growth policies.

Additionally, the extant literature fails to expose the influence of the macro-economic environment, particularly human development indicators, on the demand for solar electricity. This is important because solar electricity consumption in sub-Saharan Africa is not consistent; it is characterised by rapid fluctuations and declines in some countries. Consumer welfare (education, health, and standard of living) may influence energy consumption patterns. Therefore, this thesis provides empirical evidence of additional economic indicators that influence the demand for solar electricity to contribute to the development of effective renewable electricity policies.

The thesis entails three essays that focus on the relationship between solar electricity consumption, financial inclusion, money demand and welfare. It employs a sample of 15 countries in sub-Saharan Africa for the period from 2010 to 2019 for all three essays. The first essay examines the linear and non-linear relationship between solar electricity consumption, and financial inclusion. A Financial Inclusion Index is constructed using the Principal Component Analysis. The effect of solar electricity consumption on financial inclusion is analysed using the Two-Step System Generalised Moments Method. The results show that solar electricity consumption positively influences financial inclusion, implying that solar electricity consumption is a determinant of financial inclusion in sub-Saharan Africa. Furthermore, a threshold point in the relationship between solar electricity consumption and financial inclusion is detected using the Dynamic Panel Threshold Model, and the positive effect of solar electricity consumption declines after the threshold point.

The second essay examines the short-run and long-run relationship between solar electricity consumption, mobile money, and money demand in sub-Saharan Africa. It employs the dynamic panel Autoregressive Distributed Lag with Dynamic Fixed Effects and Pooled Mean Group estimators and the Dynamic Ordinary Least Squares method to check the results' robustness. The empirical results reveal that solar electricity consumption has an insignificant effect on money demand (broad money balances) in the short and long run. However, if mobile money is introduced into the money demand function, solar electricity consumption positively impacts money demand. Subsequently, the interaction of solar electricity consumption and mobile money induces an upward effect on money demand. Therefore, the findings reveal that mobile money does not moderate the effects of solar electricity consumption on money demand; instead, it increases money demand leading to adverse effects on monetary policy. It is therefore recommended that monetary authorities should monitor solar electricity expenditure to control price fluctuation and maintain financial stability, particularly in countries where the dominant payment service is mobile money.

The third essay investigates the effects of welfare on solar electricity demand using the following proxies: the Human Development Index, inequality in income, government expenditure on education, infant mortality rate, and access to information and communication technology (mobile phone subscriptions and internet users). The study applied the panel quantile regression technique with nonadditive fixed effects, and the results confirmed that welfare has significant effects on solar electricity demand. It reveals that the Human Development Index, education, and infant mortality have an inverse effect on solar electricity demand. However, income inequality has a negative effect in countries with low solar electricity consumption and a positive effect in countries with median-to-high solar electricity consumption. Mobile phone subscriptions positively influence solar electricity demand in countries with low-to-median solar electricity consumption. In contrast, internet users positively affect solar electricity demand in countries with median-to-high solar electricity consumption.

The findings from the first essay endorse the proposition that solar electricity consumption induces the development of and access to financial products and services (energy-finance nexus). Whereas the findings from the second essay reveal the non-moderating effect of mobile money on the relationship between solar electricity consumption and money demand. Finally, the findings from the last essay reveal that human development factors drive solar electricity consumption. It is therefore recommended that policy makers should integrate renewable electricity goals and targets into economic development policies to enhance the transition to clean electricity sources and alleviate energy poverty in sub-Saharan Africa.

Keywords: energy; solar electricity; mobile money; financial innovation financial inclusion; money demand; welfare; education; health; mobile telephone.

DECLARATION

I, Andile Precious Dube, student identification number 1368891, declare that this PhD thesis titled "Solar electricity consumption, financial inclusion, and welfare in sub-Saharan Africa" is my own research work. Articles and materials, representing the works of others, used for this research have been duly referenced and acknowledged. This research work has not been presented before for examination leading to an award of any degree either to this university or any other.

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Andile Precious Dube (1368891)

May 26, 2023

DEDICATION

To my children

Fear God and treasure education,

"…*you shall inherit the nations and shall cause the cities that are deserted to be inhabited.*"

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I would like to thank my heavenly Father, Jehovah Yahweh for entrusting me with the momentous task of pursuing this qualification, and for providing every resource I needed to complete this qualification. To you oh God be the glory! I also would like to thank my parents for instilling in me the value of education. A special thank you to my mother who consistently believed in me and prayed for me, today I can say your prayers have been answered.

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LIST OF ACRONYMS AND ABBREVIATIONS

ADF	Augmented Dickey Fuller
AfDB	African Development Bank
AMG	Augmented Mean Group
ANOVA	Analysis of Variance
AFREC	African Energy Commission
ARDL	Autoregressive Distributed Lag
ASEAN	Association of Southeast Asian Nations
ATMs	Automated Teller Machines
AU	African Union
BRICS	Brazil, Russia, India, China and South Africa
CPI	Consumer Price Index
CSP	Consolidated Solar Power
CUP-BC	Continuously Updated Bias-Corrected
CUP-FM	Continuously Updated Fully Modified
DFE	Dynamic Fixed Effects
DNI	Direct Normal Irradiance
DOLS	Dynamic Panel Threshold Model
DPTM	Dynamic Ordinary Least Squares
EBED	Energy-Based Economic Development
ESP	Energy Service Provider
EU	European Union
FAS	Financial Access Surveys
FMOLS	Fully Modified Ordinary Least Squares method
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GMM	Generalised Moments Method
GOGLA	Global Association for the Off-grid Solar Energy Industry
GSMA	Groupe Speciale Mobile Association
GW	Gigawatt
GNI	Gross National Income
HDI	Human Development Index
ICT	Information Communication and Technology
IEA	International Energy Agency
IFC	International Finance Corporation
IMF	International Monetary Fund
IRENA	International Renewable Energy Agency
LED	Light-Emitting Diode
LSM	Living Standard Measurement
MCMC	Markov Chain Monte Carlo
MEDA	Mennonite Economic Development Associates
MG	Mean Group
MNO	Mobile Network Operator
MW	Megawatt
OECD	Organisation for Economic Co-operation and Development

PAYG	Pay-As-You-Go
PCA	Principal Component Analysis
PMG	Pooled Mean Group
POS	Point of Sale
PP	Phillips-Perron
PV	Photovoltaic
RCT	Randomised Control Trial
SDG	Sustainable Development Goal
SHS	Solar Home System
SMEs	Small Medium Enterprises
SSA	Sub-Saharan Africa
TW	Terrawatt
TWh	Terrawatt-hour
UN	United Nations
UNCDF	United Nations Capital Development Fund
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCC	United Nations Framework Convention on Climate Change
VEC	Vector Error Correction
WAEMU	West African Economic and Monetary Union
WHO	World Health Organisation

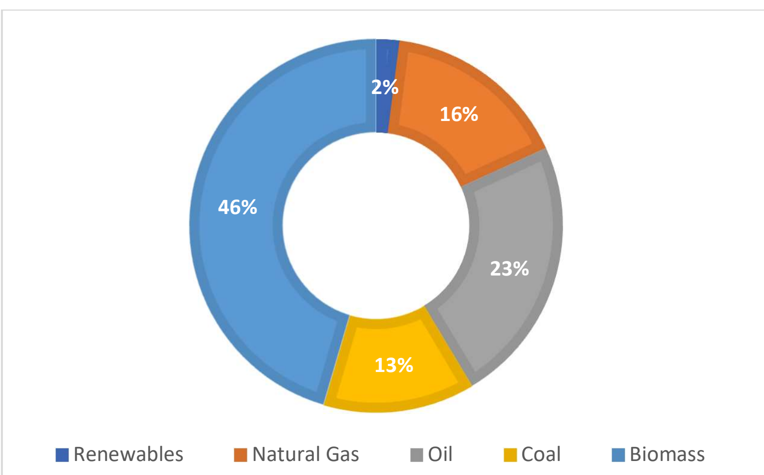
CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Africa is known for its vast energy resources, and these resources have to a certain extent, increased gross capital inflows into the continent in the last decade (The World Bank, 2018). Africa relies heavily on natural gas, coal, and oil for power generation. About 46% of the continent's energy demand is met by biomass and only 2% from renewables, as shown in Figure 1.1 below (International Renewable EnergyAgency [IRENA], 2021a). Electricity consumption in sub-Saharan Africa (SSA) is approximately 4% of total energy consumption, compared to 19% in North Africa. The dominant renewable electricity sources in SSA are wind, solar, hydro, and geothermal (United Nations [UN], 2020). A significant portion of electricity is consumed in the mining and oil refining sectors, leaving a smaller portion for other business services and households (Hafner, Tagliapietra, & Strasser, 2018).

Figure 1.1: Primary energy demand in Africa in 2018



Source: (IRENA, 2021a)

The transition to modern and clean electricity sources is growing steadily in Africa, although crude oil remains as dominant as it was over a decade ago (African Energy Commission

[AFREC], 2019). However, oil price volatility and increased electricity demand in most SSA countries are influencing the transition to renewable electricity sources (da Silva, Cerqueira, & Ogbe, 2018). In recent years, the electricity sector increased its focus on digitalisation, decarbonisation, and decentralisation as drivers of the transformation and transition to renewable electricity sources (Di Silvestre, Favuzza, Riva Sanseverino, & Zizzo, 2018).

Digitalisation in the energy sector refers to incorporating digital systems and Information and Communication Technology (ICT) into the energy system (Rhodes, 2020). As a result, the sector will benefit from new opportunities that include, but not limited to, a reduction of electricity production costs, breakdown of boundaries between electricity generation and consumption, increased flexibility and integration across systems (International Energy Agency [IEA], 2017), and improved access to alternative energy sources and innovative ways of energy production (Duch-Brown & Rossetti, 2020).

Decarbonisation has also taken centre stage in the development agenda of most countries in SSA. Countries have made a concerted effort towards controlling and stabilising Greenhouse Gases (GHG) in the atmosphere (Papadis & Tsatsaronis, 2020). In 1992, many countries became a party to the United Nations Framework Convention on Climate Change (UNFCC), which seeks to promote the reduction of greenhouse gases in the atmosphere to a level that will not pose a danger to the climate system (UN, 1992). In 1998, the *Kyoto Protocol* was introduced as an internationally binding agreement that set GHG emission targets for most countries (UN, 1998). After the Kyoto Protocol, another annual conference was held in 2015 in Paris, where the Conference of Parties of the UNFCC adopted the *Paris Agreement*, a key resolution that seeks to "limit the temperature increase to well below 2 Degree Celsius (°C) by mid-century compared to pre-industrial levels, with efforts to limit it to 1.5 °C" (UN, 2015a). The resolution came into force in November 2016.

In parallel to the Kyoto Protocol and the Paris Agreement, the UN developed the 17 Sustainable Development Goals (SDGs) agreed to by over 193 countries. Access to clean and modern energy sources is premised on SDG 7, which aims to ensure access to affordable and sustainable energy sources by 2030 (UN, 2015b). Africa also initiated the African Union (AU) Agenda 2063 that guides the attainment of economic development goals and targets, amongst which is access to clean and modern energy sources by all Africans by 2063 (AU, 2015). These frameworks reflect the collective effort of countries towards minimising carbon emissions, particularly in the power sector. However, the attainment of goals established in these frameworks is dependent on political will and the ability of countries to raise the investments required to support the decarbonisation initiatives (Hafner, Tagliapietra, & Strasser, 2018).

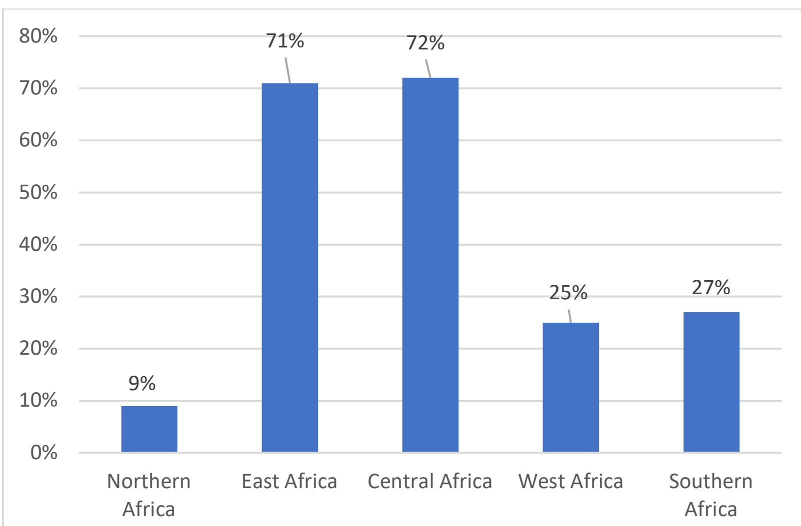
Lastly, decentralisation is also driving transformation in the energy sector following the persistent lack of reliability of centralised energy systems in most African countries (Zalengera et al., 2020). Decentralisation refers to the distribution of decision-making, production, consumption, and all related activities away from a central authority to the final consumer to improve energy access (Berka & Dreyfus, 2021). Decentralisation is creating important opportunities for greater energy access, improved efficiency, energy security, and greater affordability (Pascali, Santangelo, Perrone, & Bagaini, 2020; Zahedi, 2011).

The integration of these three transformation goals has yielded substantial reductions in economies of scale and the cost of renewable electricity technologies. As a result, there are growing opportunities for renewable electricity adoption, investment, policy coordination, resource allocation, and building relationships of the electricity sector with other sectors such as the financial services sector, transport sector, etc. (Mediavilla et al., 2013). These transformation goals, therefore, place electricity at the core of economic development in Africa to alleviate the effects of poor economic growth endured by most countries in the continent due to poor access to clean and reliable electricity (Dogan, Madaleno, & Taskin, 2021).

1.1.1 Renewable electricity consumption in sub-Saharan Africa

Renewable electricity (excluding hydro) continues to gain momentum steadily, although it is still marginal compared to other electricity sources. By 2018, renewable electricity capacity in SSA was 35.7GW, a majority was hydropower, and less than 13.8GW was geothermal, solar, and wind (IRENA, 2020b). Between 2014 and 2018, the procurement of utility-scale renewable energy projects increased following the introduction of the Renewable Energy Independent Power Producers Procurement Programme (REIPP) by South Africa in 2011 (Kruger, Stritzke, & Trotter, 2019). In 2019, renewable electricity accounted for slightly over 70% of the total generation mix in East Africa and Central Africa and slightly over 20% in West and Southern Africa, as shown in Figure 1.2 below (IRENA, 2021b).

Figure 1.2: Share of renewable energy in the generation mix by region in 2019



Source: (IRENA, 2021a)

The rate of adoption and integration of renewable electricity into the energy mix provide significant positive effects for development in Africa (Güney, 2019). These include improved economic development, new employment opportunities, improved human welfare, and reduction of climate change risks (IRENA, 2016a; Khellaf, 2018).

The deployment of renewable electricity may also improve energy security in countries without abundant domestic energy resources and reduce reliance on fossil fuels and fuel imports (Frondel, Ritter, Schmidt, & Vance, 2010; Nurunnabi, Roy, & Mahmud, 2018). It may also improve direct and indirect employment, disposable income, tax revenues, and Gross Domestic Product (GDP) however, this is highly dependent on the type of primary renewable energy source (Cansino, Cardenete, González-Limón, & Román, 2014; Mu, Cai, Evans, Wang, & Roland-Holst, 2018; Wassie & Adaramola, 2021). However, some scholars have criticised this argument for not considering the job losses in other industries due to increased investment in renewable electricity (Cai, Wang, Chen, & Wang, 2011; Hillebrand, Buttermann, Behringer, & Bleuel, 2006). They argue that if countries want to maximise the socio-economic effects of electricity technologies, a considerable share of the manufacturing of renewable energy technologies should take place in-country (Oliveira, Coelho, Pereira da Silva, and Antunes, (2013), and there should be a strong export-oriented industry (Lehr, Nitsch, Kratzat, Lutz, & Edler, 2008).

Although there are potential benefits to the deployment and integration of renewable electricity technologies into the grid, their full impact is not yet fully understood and it may present significant system challenges compared to conventional electricity sources (Stram, 2016). These challenges include intermittency challenges and a lack of dispatchable generation of both solar and wind energy (Phuangpornpitak & Tia, 2013; Sinsel, Riemke, & Hoffmann, 2020). The mitigation of these challenges requires that grid operators provide sufficient resources to accommodate the significant supply fluctuations inherent in renewable electricity technologies and maintain balance in the system (Bird, Milligan, & Lew, 2013). This includes providing resources for voltage control, effective forecasting, demand management, energy storage management, and power system ability (Eltigani & Masri, 2015). Nevertheless, renewable electricity sources still have the potential to improve access to electricity, contribute to social and economic development, and positively impact the delivery of outcomes across all SDGs (Nerini et al., 2018).

1.1.2 Solar electricity consumption in sub-Saharan Africa

SSA has the highest solar irradiation (31 countries) compared to other regions; hence it would be economically viable for the region to capitalise on this energy potential (Baurzhan & Jenkins, 2016). SSA uses two types of solar technologies for power generation: Solar Photovoltaic (PV) and CSP. Solar PV technologies have various applications that range from household systems to utility-scale, whilst the Concentrated Solar Power (CSP) operates optimally in utility-scale projects in desert regions (IRENA, 2015). Stand-alone solar PV systems and mini-grids are salient in SSA and are being embraced by most African countries. This is because they are a cheaper way of generating electricity and improving electrification in rural areas compared to utility-scale grid expansion (IEA, 2020). They also have the potential to operate independently or can be connected to the grid to supplement grid electricity (Ihirwe et al., 2021).

However, high installation costs are posing a threat to broader access to Solar PV in developing countries (Venkateswaran, Solanki, Werner, & Yadama, 2018). The quality performance of solar PV technologies, poor after-sales services by ESPs, and mistrust by communities of the technology have lowered consumers' confidence in other areas (Singh, 2016).

1.1.2.1 Utility-Scale – CSP and Solar PV

SSA has one of the highest Direct Normal Irradiance (DNI). It ranges between 6.7 to 7.2kWh/m^2 per day and countries that have the highest DNI are South Africa, western Sudan, Namibia, and eastern Ethiopia. The deployment of CSP in Africa is still in the nascent stages. There are few CSP projects in the continent, mainly concentrated in four countries: South Africa, Algeria, Egypt, and Morocco (IRENA, 2015). In 2016, South Africa and Egypt had

CSP plants with a total capacity of 140Megawatts (MW) and 600MW, respectively, with an additional 1 050MW in Egypt and 100 MW in South Africa expected in the future (IRENA, 2021b).

CSP systems are attractive in desert countries where solar irradiation is strong, and they store solar energy as heat to be used for electricity generation during periods of low or no sunshine. However, they are very capital-intensive; hence there is only one or a handful in each country. As a result, data on the installed capacity of CSP systems is limited, and, in most cases, these represent the bundling of smaller solar PV plants into a single CSP project (IRENA, 2016b). Overall, the market for CSP is still relatively thin and has yet to reach the same level of competitiveness as solar PV (IRENA, 2021b).

1.1.2.2 Solar PV in Africa

The technical potential of solar PV in Africa is very high compared to Europe and some parts of Asia. The continent has over 337 Terawatt (TW) (IRENA, 2021b), and this is concentrated in Namibia, Lesotho, Botswana, South Africa, and Sudan, to name a few (Energy Sector Management Programme [ESMAP], 2020). Solar PV is the most price competitive compared to CSP systems due to the fall in costs of PV panels and the shorter project lead times. Solar PV can be deployed much more rapidly compared to any other power generation option; hence their market has spread widely compared to CSP or other off-grid options (IRENA, 2016b).

Small-scale solar PV systems with storage can be used with or without connection to the grid. Solar PV systems provide power to houses and buildings for essential services such as lighting and charging electric appliances and provide a connection to existing power networks if an uninterrupted power supply is required, particularly in health facilities. They are also used for mini-grid services in communities to provide power for street lighting, pumping water, telecom towers, etc. These services were previously powered by diesel-based mini-grids but have been upgraded with solar PV systems. The deployment of solar PV systems has also expanded to industrial applications, particularly the mining sector. Mining companies are increasingly deploying hybrid solar PV and diesel systems to lower electricity costs, provide a backup supply during blackouts and increase access to electricity in remote areas without access to the grid (IRENA, 2015).

The market for solar PV is growing rapidly and is driven by falling costs, innovative new business models such as the PAYG schemes, and the growth of mobile money as a payment platform. Yet the market for CSP is tiny compared to solar PV (IRENA, 2016b). Solar PV capacity for 21 countries in eastern and southern Africa increased from 89MW to 4 828MW between 2012 and 2019. For the same period, electricity generated from solar PV increased significantly from 0.1 Terrawatt hours (TWh) to 6.0 TWh (IRENA, 2021b).

In Kenya, solar PV powers about 1.2% of households and is mainly used for lighting and charging television and cell phones (Takase, Kipkoech, & Essandoh, 2021). The actual installed capacity of solar PV in Kenya is not easy to estimate because a significant portion is small-scale off-grid household installations (Samoita, Nzila, Østergaard, & Remmen, 2020). However, Kenya has about 63 solar PV mini-grids; twenty-nine are operated by the national utility, 23 are operated by private developers, and 11 by communities. Towards the end of 2018, Kenya installed a 50.0MW grid connected-solar PV mini-grid, which is one of the largest in East and Central Africa to date (Ihirwe et al., 2021).

Solar PV in Tanzania is mainly off-grid, with no grid-connected solar PV plants. About 75% of the solar PV installed solar capacity is consumed through small-scale commercial systems and solar home systems, whilst the remaining 25% is consumed by public institutions such as schools, clinics, government offices, etc. (IRENA, 2017). Tanzania does not have solar CSPs; it only completed a feasibility study in 2018 for a first utility-scale solar plant to improve access to solar PV, particularly the rural and remote areas (Aly, Bernardos, Fernandez-Peruchena, Jensen, & Pedersen, 2019).

Uganda is endowed with high solar insolation ranging between 1,825 kWh/m² to 2,500 kWh/m² per year. The solar energy is primarily used for off-grid electrification of rural communities, and public buildings such as hospitals (Mokveld & Eije, 2018). The number of mini-grids in Uganda is not documented; however, about sixty-seven percent are privately owned, twenty-two percent are owned by communities, and six percent are owned and operated by a public-private partnership (Ihirwe et al., 2021).

In Zambia, solar PV is insignificant, the installed capacity in 2017 was estimated at 4MW, with only 1MW tied to the national grid. However, at the end of 2019, Zambia commissioned its first grid-connected solar PV plants, therefore, improving grid-connected solar PV (Mwanza & Ulgen, 2020). In Burundi, solar PV is not used at a utility-scale, and is mostly off-grid connections to residential households (Ihirwe et al., 2021). In 2018, Burundi was working on developing 7 solar PV mini-grids (Hafner et al., 2018). However, by the end of 2019, solar PV deployment in Burundi generated 5.103MW that was consumed off-grid (IRENA, 2020a).

Zimbabwe has substantial solar potential because it is one of the countries in SSA with high solar insolation an average of 5.7kWh/m^2 /day (Chahuruva & Dei, 2017). However, Zimbabwe only has 3MW of installed solar PV capacity, and most is used off-grid to supply power to rural households, schools, and hospitals (United Nations Environment Programme [UNEP], 2017).

Mozambique supplies electricity to rural villages through off-grid solutions such as solar, hydro, and biomass mini-grids. Solar PV is the most dominant technology and by the year 2019, Mozambique had installed 19 solar mini-grids with a total installed capacity of 3.3MW (Zebra, van der Windt, Nhumaio, & Faaij, 2021).

In summary, the installed capacity of solar PV in most countries in SSA is marginal but growing, and mainly consumed off-grid. However, other countries have launched projects that seek to develop grid-connected solar PV plants which will enhance access to electricity in the region.

1.1.2.3 The Pay-As-You-Go model in sub-Saharan Africa

Around the year 2012, Energy Service Providers (ESPs) in SSA introduced a PAYG model into the provisioning of solar electricity, to leverage the capabilities of mobile payment platforms that were available in the market (IRENA, 2020a). Mobile payment platforms such as mobile money transfers were introduced to the electricity sector to facilitate repayments for PAYG SHSs (Groupe Speciale Mobile Association [GSMA], 2020).

The PAYG business model is an innovative model that "provides electricity generated from renewable electricity sources at affordable prices, with payments facilitated by technologies available in these areas" (IRENA, 2020a). The PAYG model has been applied mostly in solar electricity consumption compared to other renewable sources of electricity, such as biomass (IRENA, 2020a). The GSMA (2020) reports that in 2020, about 31% of the total PAYG solar customers were new or had activated their mobile money accounts after not using them for over 90 days. Further, the average revenue per user of PAYG solar increased by about 9% in 2020. Lastly, solar PV exhibits greater potential to address the region's electricity needs compared to other renewable energy sources because of its high availability (Sampaio & González, 2017). Hence this study focuses on applying the PAYG financial instrument to solar electricity consumption.

The PAYG model allows ESPs to assemble and distribute their product, create a digital platform for operationalising the PAYG model and run an effective lending facility (International Finance Corporation [IFC], 2018). The physical components of the PAYG Solar

Home System (SHS) include solar PV modules, battery storage system, inverters, mobile payment system, information, and communications technology, and electrical appliances such as Light-Emitting Diode (LED) bulbs or mobile phones (IRENA, 2020a).

There are two basic variations of the PAYG model: a "lease-to-own model" and a "usage-based payment" model. The lease-to-own model requires that the customer pays for the entire SHS in instalments, usually between 12 and 36 months. This model is also known as the "consumer finance retail model". In this model, ownership of the asset only passes to the customer after the payment terms have been met. If the customer fails to make payments consistently according to the agreed terms, the ESP can repossess the system. In contrast, the usage-based payment system model also referred to as the "micro utility", requires that the customer pays for the electricity in advance, loads money onto a prepaid meter, and uses the amount of electricity that matches the amount of money paid. When the amount of electricity runs out, the system is automatically switched off by the ESP via a remotely managed control system until the customer loads money onto the system again. In this model, the customer will never own the solar PV system (IRENA, 2020a).

The usage of the PAYG model is facilitated by mobile money and can be adopted by households, businesses, and the community at large. For community usage, the end-user purchases prepaid cards from local vendors, and each card contains a code that when sent by text to the ESP via a payment server, will credit a smart meter located in the premises of the solar PV power plant which controls the electricity flow to individual end-users. When the credit is exhausted, the circuit is switched off until more credit is loaded (IRENA, 2020a).

The benefit of the PAYG model is that it provides small and flexible payments to customers (Conway et al., (2019), therefore allowing ESPs to establish stronger relationships with customers to enable the easy sale of appliances in the future (Adwek et al., 2020). The PAYG model also allows ESPs to bring new clients into the formal financial system and to allow them to build a credit history, collateral, and digital literacy for future credit for other assets, school fees, and liquidity (Waldron & Faz, 2016). As a result, PAYG SHSs have become popular over the years, particularly between 2010 and 2019 and they had an average annual growth rate of approximately 140% between 2013 and 2016 (IFC, 2018). SSA is the major market for PAYG SHSs, accounting for 70% of total global sales, while East Africa accounted for slightly less than 50% of global sales (Global Off-Grid Lighting Association [GOGLA], 2019).

The upscaling of the PAYG solar systems has also increased the uptake of mobile money in East Africa and West Africa, where these systems are prevalent (GSMA, 2020). ESPs drive mobile money penetration by assisting customers to register or reactivate their mobile money accounts and educating customers on using mobile money for solar payments. They also convert their agents to mobile money agents to enhance registrations and reactivations (GSMA, 2020). Recently, PAYG solar companies started partnering with insurance companies to offer hospitalisation insurance to customers to ensure that their repayments are not affected if the customer is hospitalised. In Uganda, some PAYG solar companies are providing education loans to customers. They use the customer's repayment history to assess creditworthiness (IRENA, 2020a).

The growth of the deployment of the PAYG model has also influenced the adoption of smartphones. Smartphone adoption in SSA has increased partly as digital financial services gain traction as well. Total connections to smartphones were about 50% in 2020 mainly due to the reduction in prices for devices and new devices entering the market. At the end of 2019, SSA had about 477 million people (45% of the total population) that had subscribed to mobile phone services (GSMA, 2020).

However, the growth of the PAYG model is threatened by customer default risk, information asymmetry, and high transaction costs for expanding to other locations (Abdul-Salam & Phimister, 2019). The affordability of PAYG solar systems is also a concern in countries where nearly half of the population lives below the international poverty line of $1.90 per day (Bensch, Grimm, Huppertz, Langbein, & Peters, 2018). Rolffs, Ockwell, and Byrne (2015) add that the potential success and future of the PAYG business model rely on the actual understanding of the electricity consumption patterns and repayment behaviour of the poor and marginalised people. Alstone, Gershenson, Turman-Bryant, Kammen, and Jacobson (2015) believe that the strength of the PAYG model will become clearer after the first wave of SHS age and undergo maintenance, expansion, and replacement.

1.2 Research Problem

Solar electricity consumption is on the rise in SSA, particularly in West and East African countries. This growth is primarily attributed to the increasing adoption of small-scale solar PV technologies, driven by the limited availability of Consolidated Solar Power (CSP) plants and the decreasing cost of renewable power generation technologies, particularly solar photovoltaic (PV) technologies (IRENA, 2020b; Victor, 2005).

The increased adoption of small-scale renewable electricity technologies is facilitated by financial innovation services that provide a payment platform to consumers who buy these technologies on a cash or credit basis. One of the financial innovation services is mobile money, which is integrated into solar PV technologies using a Pay-As-You-Go (PAYG) model for solar electricity supply (IRENA, 2020a). The PAYG business model facilitates the sale of small-scale solar PV technologies either through a "lease-to-own" model or a "usage-based payment" model, and customers make repayments using the mobile money payment platform (IRENA, 2020a). This model has become a blueprint for solar electricity consumption in most countries in SSA.

To attest to that, the GSMA (2020) conducted the first multi-country study to quantify the value of the synergy between PAYG solar sales and mobile money adoption. They used 12 months of data from five mobile operators from Uganda, Rwanda, Benin, Côte d'Ivoire, and Zambia. The results of the study reported that the value of solar transactions over 12 months increased by 28% in Benin, and 15% in Uganda. As the demand for solar technologies increased, the use of mobile money and telecommunication technologies to facilitate electricity access and payments in these countries increased. Some customers who had deactivated their mobile money accounts reactivated their accounts, and new registrations increased too. In Benin, there was about a 22% increase in mobile money accounts, 31% in Zambia, and 29% in Rwanda (GSMA, 2020). In Uganda and Zambia, there was a huge jump in the frequency of mobile money transactions during the first two months, and there was a decrease in subsequent months. However, in Côte d'Ivoire, the frequency of transactions increased over time (GSMA, 2020).

The study also reported that as payments of solar electricity increased, payments of other non-solar transactions (cash-in and cash-out transactions (remittances), airtime purchases, merchant payments, person-to-person payments, etc.) increased as well (GSMA, 2020). In Benin, there was about a 65% increase in mobile money transactions unrelated to solar electricity, while in Uganda, there was about a 60% increase in non-solar payments. Lastly, the study found that the frequency of PAYG solar transactions and the value of the transactions are not consistent over time in all countries. The total value of transactions tends to be smaller over time which makes the impact or value of the synergy inconsistent in the five countries. Therefore, the study recommended further research on the causality of the synergy and the factors that influence the frequency and total value of transactions (GSMA, 2020).

Following the findings of this study, a multi-dimensional problem statement is formulated, which underpins the undertaking of the study. The first aspect of the problem emanates from the use of financial innovation (mobile money) in the consumption of solar electricity. It is evident that solar electricity consumption is providing opportunities to include in the modern financial system (through mobile money) those consumers who have no access to grid-electricity and have been excluded from the modern financial system. These consumers are often excluded from the modern financial system due to various reasons that include geographic, socio-economic, and lack of opportunity limitations[1] (UN, 2020b). This implies that the availability and use of solar electricity technologies leads consumers to enrol for mobile money because it is a convenient payment platform. As a result, they gain access to financial products and services, and this could impact financial inclusion because mobile money is an indicator of financial inclusion.

However, it is also reported that after the initial purchase of solar electricity and the uptake of mobile money, the frequency of mobile money transactions changes. This synopsis presents a hypothesis of threshold levels of solar electricity consumption on mobile money, therefore prompting the analysis of the threshold levels on financial inclusion to determine the wider impact of solar electricity consumption. Identifying and analysing the threshold levels is necessary for policymaking because it will identify the turning point of solar electricity consumption that confers a favourable effect on financial inclusion. Therefore, a question arises that has not been answered in any study yet and that is whether there is a linear and non-linear relationship between solar electricity consumption and financial inclusion in SSA or not?

The second aspect of the problem is that the increase in solar electricity consumption and the adoption of mobile money has led to an increase in the broader usage of mobile money for other non-solar payments. Financial innovations, such as mobile money, have the potential to alleviate liquidity constraints in financial markets, and improve transaction efficiency, therefore enhancing consumption (Bayoumi, 1993, Liu, Pan, and Yin, 2020). When consumption increases, goods, and services sold in the economy also increase thereby increasing the demand for money since consumption is directly proportional to money demand

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[1] However, some consumers voluntarily elect not to use formal financial services because they have no need for them or because of religious or cultural reasons Beck, Demirguc-Kunt, and Honohan, (2009), or lack of trust in financial institutions (Dittus & Klein, 2011).

(Ziramba, 2007, Chrystal and Mizen, 2005). As the adoption of solar electricity and mobile money expands, the demand for money may experience significant shifts, necessitating a proactive approach from central banks in formulating monetary policies that align with the changing nature of money demand in the region.

Given the changing landscape of solar electricity consumption, mobile money adoption, and their impact on money demand, there is a need to more thoroughly investigate and understand these dynamics. This study intends to provide empirical evidence and insights to guide the design of appropriate monetary policy responses in SSA by analysing the links between solar electricity consumption, mobile money usage, and money demand. Understanding the implications of these linkages will enable policymakers and central banks to make informed decisions, ensuring effective monetary policy frameworks that support sustainable economic growth, financial stability, and inclusive development in the region (Folarin & Asongu, 2019).

The last aspect of the problem is that the frequency and value of solar transactions are not consistent over time in all countries. The increase in the total value of transactions is lower than the increase in the frequency of transactions, which shows a tendency for frequent transactions of a smaller value. Numerous factors could lead to this, but they have not been explored in literature. This study, therefore, selected welfare as a variable to measure and assess the extent to which it contributes to the variability in solar electricity consumption across countries. Welfare, in this context, refers to the socio-economic wellbeing of households and communities, encompassing factors such as income levels, access to basic services, and quality of life. Theory suggests that welfare influences energy demand in a way that if the welfare of households increases, they will demand cleaner sources of electricity. However, if their welfare decreases or the electricity price increases, they will demand less sophisticated energy sources such as biomass fuels (Leach, 1992). In other words, the relevance of welfare lies in its ability to influence energy demand, particularly in terms of shift towards cleaner sources of electricity as welfare improves.

While extant literature acknowledges the welfare effect on energy demand, there is lack of evidence regarding the specific factors contributing to the variability in solar electricity consumption across countries in SSA. It is crucial to investigate how welfare, as a variable, affects this variability and how it affects the energy transition toward solar power. By addressing this gap, policymakers can gain valuable insights into the drivers of solar electricity consumption and would be able to develop targeted measures to promote the transition to sustainable energy in various socio-economic circumstances.

By conducting a thorough analysis of the relationship between welfare and solar electricity consumption, this study intends to evaluate the precise role of welfare as a variable in measuring and understanding the extent of its contribution to the variability in solar electricity consumption. By examining the influence of welfare indicators, such as HDI, inequality in income, infant mortality rate, government spending on education, mobile phone subscriptions and internet users, on the adoption and utilization of solar PV technologies, this research aims to provide nuanced insights into the socio-economic factors shaping the energy landscape in SSA.

The results of this study will advance knowledge by illuminating the nuanced connections between welfare, solar electricity consumption, and the SSA energy transition. Additionally, the insights gained will guide policymakers and stakeholders in formulating effective strategies to promote sustainable energy transitions, enhance welfare, and foster inclusive socio-economic development in the region.

1.2.1 Research questions

1. What are the linear and non-linear relationships between solar electricity consumption and financial inclusion in sub-Saharan Africa?
2. To what extent do solar electricity consumption and mobile money influence money demand in sub-Saharan Africa?
3. To what extent does welfare influence solar electricity demand in sub-Saharan Africa?

1.2.2 Research objectives

1. To determine the linear and non-linear relationships between solar electricity consumption and financial inclusion in sub-Saharan Africa.
2. To determine the extent to which solar electricity consumption and mobile money influence money demand in sub-Saharan Africa.
3. To determine the extent to which welfare influences solar electricity demand in sub-Saharan Africa.

1.3 Significance of the study

The significance of the study manifests in the contribution it makes to energy literature and policy formulation. The findings of the study contribute to the formulation of energy policies that promote financial innovation to address both access to electricity and access to finance. This is important because individuals' and firms' access to formal financial services is still lower in most African countries compared to developed countries (Demirgüç-Kunt & Klapper, 2012). In 2017, only 63% of adults in developing countries had an account at a financial institution compared to 94% of adults in high-income economies (Demirgüç-Kunt, Klapper, Singer, Ansar, & Hess, 2018). Therefore addressing financial inclusion challenges is critical to creating opportunities for the integration of households into the economy and easing external financing constraints on firms (Arora, 2014; Lee, Sameen, & Cowling, 2015).

Additionally, the findings of the study provide an impetus for policy makers to encourage and promote the introduction of other financial innovation products, other than mobile money, into the solar electricity market to improve both financial and electricity access and economic growth. The study also contributes towards providing evidence that the positive effect of solar electricity on financial inclusion has a turning point after which the effect declines, implying that the deployment of solar electricity technologies on their own cannot make a country maintain financial inclusion indefinitely. But integrating solar electricity deployment with other economic growth-enhancing programs will ensure the continuity of the positive effects on financial inclusion.

Secondly, the findings of the study are critical to the formulation of financial regulatory frameworks that support the transition to clean and modern energy fuels because. These findings expose the disaggregated effects of solar electricity consumption and mobile money on money demand. Therefore, they are important to ensuring financial stability because an increase in the consumption of goods and services may influence the stability of the money demand function. The results also contribute towards informing policy makers, ESPS, MNOs, and mobile money operators about the factors influencing solar electricity demand in SSA, to enhance their due diligence and market entry and expansion strategies in SSA.

Also, this study is significant because it highlights the factors driving solar electricity consumption in SSA. This is important given the pressing need to address the region's poor rates of electricity access. Also, because SSA has a different political and economic landscape compared to other regions, a targeted approach to driving the adoption of solar technologies is required to attain the electrification targets outlined in the AU 2063 Agenda and the UN 2030 Agenda for Sustainable Development. Policy makers have forecasted that SSA requires a minimum total investment of $50 billion and a maximum total investment of US Dollar ($)1.3 trillion to achieve universal energy access by 2030. This translates to an investment of $70 billion per annum up to 2030 compared to the current spending on energy of $8 billion on average per year (Hafner et al., 2018). Therefore, this study offers insights into factors that can facilitate or impede the realisation of these investment goals.

1.4 Contribution to knowledge

The contribution of this study to knowledge is broad. While there is growing literature that analysed the link between energy and finance (energy-finance nexus), the focus of scholars was unidirectional, running from finance to energy consumption. Existing literature portrayed the importance of financial development in promoting energy consumption, with limited or no attention to the role of energy consumption on financial development. Despite the argument by several studies (Guryay *et al*., 2007; Ndlovu, 2013) about the "demand-following" hypothesis that holds that the financial needs of the real sector induce financial system development, extant literature has not explored this phenomenon in the energy sector. Therefore, this study contributes to the body of knowledge by firstly exposing the significant role of energy consumption on financial inclusion. This is an important contribution because it promotes energy consumption to improve access to both energy and finance.

Secondly, this study introduces financial inclusion as a proxy for finance instead of financial development in the energy-finance nexus. A few studies have used financial inclusion as an indicator of financial access when analysing the energy-finance nexus. While these two concepts are underpinned by the same finance theories advanced by Levine (2004), they have different policy implications. Financial development relates to the provision of financial services, whilst financial inclusion relates to access to and ownership of financial services. Therefore, this study is one of the few studies in the energy-finance nexus literature that separates financial inclusion from financial development.

Thirdly, most of the existing literature has not used the disaggregated components of real income as determinants of money demand in a money demand function. Many scholars have supported the idea that interest rates and real income are the traditional determinants of money demand. As a result, scholars that investigated the determinants of money demand function in SSA also used real income and interest rates. This study, however, presents a novel way of specifying the money demand function for SSA by adopting components of real income, particularly consumption, and employing energy consumption and financial innovation as one of the key determinants. Energy consumption is denoted by solar electricity consumption, whilst financial innovation is denoted by mobile money; therefore, the interaction between these two concepts influences money demand. This contribution to the literature is important because household expenditure is a significant portion of GDP in SSA, and energy expenditure holds a significant share of household expenditure in developing countries. This contribution is also important because of the growing demand for solar electricity and mobile money in SSA and the resultant impact on other non-solar transactions.

Fourthly, this study also fosters a different way of analysing the conservation hypothesis of the energy-growth nexus. While most scholars analysed the relationship between energy consumption and economic growth, this study analyses the relationship between energy consumption and human development indicators as a proxy for welfare. Through this approach, the study reveals the importance of human development factors in accounting for renewable electricity consumption and in driving the transition to clean and modern renewable electricity sources. Finally, this study provides thought-provoking insights into how the rapid deployment of solar electricity technologies is impacting other spheres of the economy, an area that had been less explored prior to this study.

1.5 Structure of the thesis

The thesis is structured into six chapters. Chapter one introduces the research agenda and highlights the research problem and objectives of the study. Chapter two reviews the conceptual and theoretical literature between energy consumption and economic growth. The next three chapters, Chapter three, Chapter four, and Chapter five, address the study's objectives. Chapter three provides an empirical analysis of the linear and non-linear relationships between solar electricity consumption and financial inclusion in SSA. Chapter three also determines threshold levels of solar electricity consumption on financial inclusion. Chapter four provides an empirical analysis of the relationship between solar electricity consumption, mobile money, and money demand in SSA. Chapter five provides an empirical analysis of the effects of welfare on solar electricity consumption in SSA. Lastly, Chapter six presents the conclusion, policy implications, and recommendations for future studies.

CHAPTER TWO

LITERATURE AND CONCEPT REVIEWS

2.1 Introduction

This Chapter reviews literature and concepts that link energy consumption to economic growth. It builds a foundation for the discussion of the direct effects of solar electricity on financial inclusion and money demand and how welfare influences the consumption of solar electricity, which is discussed in subsequent chapters, i.e., chapters 3, 4, and 5. This is important because financial inclusion, money demand, and welfare contribute significantly to economic growth; therefore, their link with solar electricity consumption may have significant and direct effects on economic growth (Folarin & Asongu, 2019; Sethi & Acharya, 2018; Wang, Danish, Zhang, & Wang, 2018). The first part of this Chapter reviews the evolution of solar photovoltaics and the concept of solar electricity. The latter part reviews the theoretical and empirical literature that underpins the role of energy in the production function and, ultimately, its impact on economic growth.

2.1.1 The evolution of solar photovoltaic energy

The earliest introduction of solar PV dates to 1839, and by 1877, the first solid plate PV cells were already made and developed as light meters for photography (Lynn, 2010). However, the practical application of PV cells had to await the discovery of semiconductor electronics in the 1950s, hence history records the beginning of modern PV solar to be 1954. However, during that time, the price of solar cells was expensive, making it impossible to produce electricity at a greater scale (Lynn, 2010). Additionally, solar PV cells were highly inefficient, with a high risk of obsolescence and difficulty to maintain them (Naudet, 2000). The possibility of using solar for commercial energy heavily relied on reducing the price of solar cells.

However, two important developments occurred in the PV solar market that saw the pessimistic view towards PV technologies change and create new opportunities. Firstly, in 1973, the first oil price shock occurred when oil-producing countries increased the price of oil significantly and exerted more control over oil supply (Fthenakis & Lynn, 2018). As a result, oil-importing African countries faced difficulties as most oil electricity sources became two to three times more expensive than in the previous two decades (Nygaard, 2009b). Secondly, research efforts towards increasing the efficiency of solar PV intensified (Szabo, 2017). Governments like the US, Japan, and Germany increased funding for PV solar research programmes (Lynn, 2010). Consequently, the efficiency of solar cells improved, new PV materials and solar cells were discovered, and solar plants with megawatt capacity emerged, leading to a significant fall in the price of solar PV (Lynn, 2010).

In the 1980s, the uptake of solar PV as a source of electricity increased as more developing countries with abundant sunshine but no access to an electricity grid continued to use solar PV (Fthenakis & Lynn, 2018). However, the upfront costs of installing solar PV were still not affordable for most households in developing countries; therefore, donor funding supported installations across most developing countries (Nygaard, 2009). It then became evident that SHSs by themselves will not boost global solar PV production to the level of impact desired by the PV protagonists due to unaffordability by households in developing countries and maintenance problems that reduced the reliability of SHSs (Lynn, 2010). Subsequently, other types of standalone systems and PV power stations were commissioned by developed countries that wanted to assess the commercial viability and reliability of solar PV technology (Fthenakis & Lynn, 2018).

Thereafter, a global shift towards grid-connected solar PV systems occurred in the 1990s as developed countries' citizens paid for upfront solar PV installation costs. Governments also began to acknowledge the importance of solar PV and encouraged companies and individuals to invest in solar PV (Lynn, 2010). Electricity utilities also started allowing customers to be providers as well as consumers of solar PV electricity and introduced tariffs to encourage feeding electricity back to the grid through feed-in tariffs. As a result, the price of solar PV fell (Fthenakis & Lynn, 2018). In the decade of the year 2000, solar PV production experienced a boom that was driven, amongst other factors, by the renewed interest of governments in solar energy due to mounting environmental and climate change risks (Jones & Bouamane, 2012). The boom stimulated entrepreneurial activity in the manufacture of solar PV and this attracted large financial backing from venture capitalists (Jones & Bouamane, 2012).

After the boom in solar PV production, Chinese-owned firms started entering the solar PV manufacturing market, leveraging off the low-interest rate loans, and selling their PV technologies widely (Jones & Bouamane, 2012). European firms exited the solar PV manufacturing market, inducing a geographic consolidation of solar PV manufacturing in China (Jones & Bouamane, 2012). Chinese solar PV products dominated the market and exerted downward pressure on prices, which led to an 80% price decrease between 2008 and 2015 (Carvalho, Dechezleprêtre, & Glachant, 2017). As a result, by the year 2017, China was the world's leading supplier of solar PV cells, accounting for 70% of global PV production (Wang & Kryszak, 2020). Intense research and development (R&D) of solar cells, modules, and inverters continued to drive solar PV market penetration as the efficiency of solar cells continued to improve, leading to a further significant fall in prices (Fthenakis & Lynn, 2018). In the developed world, grid-connected solar PV continued to expand, and the market for power plants grew rapidly, while in developing countries, SHSs remained the solution for access to electricity to rural dwellers (Fthenakis & Lynn, 2018).

However, the adoption of SHSs was still slow due to the lack of access to finance by off-grid consumers and the price of SHSs, which was still unaffordable to most households in developing countries. Unfortunately, modern financial services did not fit the requirements of

SHSs and the demographics of rural dwellers (Nygaard, 2009). (Martinot, Chaurey, Lew, Moreira, & Wamukonya, 2002) state that finance for SHSs must satisfy several factors: small and short-term-based credit, group-based, and with a focus on women. Therefore, for these households to own SHSs, they needed a financial system that will accommodate low-cost, personalised, asset-linked, and collateral-free financial products (Bapat & Bhattacharyay, 2016). This led to the introduction of commercially led SHS delivery models aimed at making access to electricity affordable, thereby reducing reliance on donor funding and government subsidies (Nygaard, 2009). The commercially led delivery models provided fully developed SHSs technology that can be sold off the shelf to consumers or technicians either cash or via credit from the retailer.

2.1.2 The concept of solar electricity

Solar electricity is generated by harvesting and utilising light or heat from the sun (Baker, Fowlie, Lemoine, & Reynolds, 2013). Solar electricity technologies can be grouped into two main categories: passive and active solar technologies. Passive solar technologies entail the harvesting of solar energy for power generation, without transforming it into any other form. For example, solar energy is collected, stored, and distributed in form of heat for homes. However, active solar technologies collect solar radiation and convert it to heat and electric power using mechanical and electrical equipment. An example includes a solar water heating system (Lamnatou, Chemisana, Mateus, Almeida, & Silva, 2015).

Active solar technologies can further be grouped into solar photovoltaic technology (solar PV) and solar thermal technology (Dixit, 2020). Solar PV harvests energy from sunlight and converts it to electricity which can be used in electrical appliances or stored in batteries for later use (Ahmad, Khordehgah, Malinauskaite, & Jouhara, 2020; Shubbak, 2019). They are used in solar home systems, water pumps, satellites, and power plants amongst others (Parida, Iniyan, & Goic, 2011). Whilst solar thermal technology harnesses solar energy into thermal energy for commercial and domestic use such as heating, cooling, drying, cooking to name a few. Thermal technologies use concentrated solar thermal (CST) technologies on an industrial scale for heating and they use concentrated solar power (CSP) technologies for electricity (Kabir, Kumar, Kumar, Adelodun, & Kim, 2018).

Solar electricity presents several economic benefits to countries in SSA because it is free and abundant, therefore any costs associated with generating solar electricity are minimal. However, the storage systems or batteries are costly, and most developing countries have little technical expertise in these systems (Baker et al., 2013). Another benefit of solar electricity to countries in SSA is that it is widely available, and can be installed at any point of use with minimal labour requirement (Atsu, Agyemang, & Tsike, 2016). Also, as the level of deployment of solar electricity increases, either off-grid or grid-connected, the generation of fossil fuels is displaced therefore reducing carbon emissions (Bayrak, Abu-Hamdeh, Alnefaie, & Öztop, 2017). Therefore, most countries in SSA can leverage the abundant sunlight in the region in alleviating the energy poverty faced by most of their populations.

2.2 Theoretical literature

The link between energy and economic growth cannot be fully captured without first outlining energy as a critical factor of production in the production function. This is the foundation upon which the energy-growth nexus and other theories that advance the role of energy in economic growth are premised. Therefore, the approach adopted in this literature review will first outline the build-up of production functions chronologically from those that excluded energy to those that recognised energy as a factor of production and further reviews the energy-growth nexus and other emerging theories.

2.2.1 The role of energy in production

The inclusion of energy in the production function was scarce and not widely accepted in most literature (Pablo-Romero & Sánchez-Braza, 2015). Mainstream economic growth models (Marxist, Neoclassical, and Post-Keynesians models) regarded energy as an economic intermediate, not as a critical factor of production (Warr & Ayres, 2012). This violated the First and Second Laws of Thermodynamics which state that there is nothing that occurs in the world without the conversion of energy and production of entropy (Daly, 1997). This oversight continued until recently when new theories challenged the critical role of energy such as LINEX production functions, Constant-Elasticity-of-Substitution (CES) production functions, augmented Cobb-Douglas production functions, etc.

2.2.1.1 The Marxist theory of production

Marxist economists were among the scholars that overlooked the role of energy in production. They advanced the labour theory of value that states that economic output is only derived from; and is proportional to the labour input in the production function (Cockshott, Cottrell, & Valle Baeza, 2014; Cohen, 1979; Slack, 2021). They argued that labour is the only factor of production, and the value of a commodity is directly and significantly dependent upon the labour time during production and inversely related to the labour time required for the production of other commodities (Cohen, 1979). Therefore, if labour is the only fundamental cost in the production of a good, it means the cost of a good can only be linked to human labour (Murphy, 2006).

This theory was criticised for its neglect of other factors of production, such as capital, energy, etc. It was also criticised for not incorporating the contribution made by past and actual labour time spent in producing a commodity (Garegnani, 2018; Mohun, 1994). Hence, the

Neoclassicals developed a theory to counter the weaknesses of the Marxists' labour theory of value.

2.2.1.2 Neoclassical theory of production

Neoclassical theorists criticised the Marxist labour theory of value for its assertion that labour is the only factor of production. Instead, they argued that output is produced by substitutable factors of production, i.e. labour and capital (Ayres & Voudouris, 2014). Therefore each factor of production should receive income that is proportionate to its marginal productivity, and the income shares should be constant over time (Fix, 2015).

This is represented in a traditional production function as:

$$Y = f(K, L) \tag{2.1}$$

where Y (economic output) is a f (function) of K (capital) and L (labour). This means output is dependent on capital and labour, and these two factors are substitutable. Land and natural resources (energy) are not considered among the factors of production (Siddique & Majeed, 2015).

This theory is also supported by the Solow (1956) growth model which states that economic growth is explained by two factors of production: capital and labour. Therefore, Equation (2.1) can be expressed in a Cobb-Douglas production function as:

$$Y_t = A_t K_t^{\alpha} L_t^{\beta} \tag{2.2}$$

where Y is economic output, A is the technical change or total factor productivity (TFP), which explains the economic output not inherent to capital and labour (Solow, 1957), and t is the period of reference. If TFP increases, the functional relationship between capital and labour, and output changes. K denotes the stock of capital, α and β are constants or partial output elasticities of capital and labour and L is the stock of labour. Therefore, if $\alpha + \beta = 1$, it confirms constant returns to scale implying that changes in capital and labour have a linear relationship to changes in output (Ayres & Voudouris, 2014). The Neoclassicals also assume that a production function is continuous and differentiable and the income output generated is distributed entirely amongst the capital and wage earners (Brancaccio & Fontana, 2013).

The Neoclassicals' growth models regard energy as an intermediate good or raw material, not as a factor of production. This view has been criticised because it undermines the distinct function of energy and materials in an economy. Energy facilitates the conversion of raw materials to final products; therefore its function in production cannot be regarded as similar to raw materials (Alam, 2009). To support their argument, Neoclassicals argued that reporting payments to energy are not provided for or seldom reported in national accounts. They advanced that national accounts only account for GDP as the sum of payments to capital (interest) and labour (salaries and wages), there is no provision for payments to energy (Ayres, van den Bergh, Lindenberger, & Warr, 2013; Santos, Domingos, Sousa, & St. Aubyn, 2018). The Neoclassicals also advanced their argument by stating that the average cost shares of capital and labour across countries are stable. Labour receives about 70% of payments, whilst capital receives the balance of 30%, therefore there is no cost share allocation for energy. Further, each production factor's output elasticity equates to the respective cost share. Therefore, since there is no cost share for energy, it cannot be included in their models (Santos et al., 2018).

However, this two-factor economic model does not hold in a realistic economy (Brancaccio & Fontana, 2013; Daly, 1997; Germain, 2019). The substitutability of capital and labour means that output can be generated by capital with very little labour or vice versa. However, in real life, the range of short-term substitutability between these factors is narrow and has an optimal point as well. Therefore, too much capital or too much labour would result in under-utilisation of labour or capital respectively (Ayres et al., 2013; Fontana & Sawyer, 2016). Further, the dominant role of technological progress in the neoclassical model was criticised as the theory of growth that does not explain the main factor in economic growth, instead, it leaves the main factor unexplained (Kümmel & Lindenberger, 2020). Therefore, the Neoclassical theory is regarded as less suitable for identifying and resolving fundamental social events that could adversely impact the environment (Rezai, Taylor, & Mechler, 2013). Hence, post-Keynesian production theories were developed to counter the limitations of the Neoclassicals.

2.2.1.3 Post-Keynesian theory of production

The post-Keynesian theorists argue that production is a transformation of fixed proportions of inputs (capital and labour) into outputs (Fontana & Sawyer, 2013; Kronenberg, 2010; Skott & Zipperer, 2012), and these production factors have no direct substitutability (Fontana & Sawyer, 2016). The minimum levels of capital and labour at which output can be generated are determined by the capital-output ratio or the labour productivity function. The post-Keynesians advance that labour and capital stock must not be at optimal levels to allow the economy the flexibility to adjust in the event of short-term and long-term fluctuations (Naqvi & Stockhammer, 2018).

Therefore, the proportional relationship of capital to output can be written as:

$$Y_c = \frac{K}{v} \qquad (2.3)$$

In equation (3), K (capital stock) is linked to capacity output Y_c by this production function, where v is the capital capacity ratio as determined by relative prices. Actual output Y is then denoted by:

$$Y = u * \frac{K}{v} \qquad (2.4)$$

where u denotes the measure of capacity utilisation calculated as *Y/Yc* (Fontana & Sawyer, 2016).

Regarding labour, actual output is assumed to be proportionally linked to the people's capacity to work, denoted by *N*. Therefore, *N* is a multiple of labour productivity denoted by *q,* and person-hours denoted by *L*. *L* (person-hours) is determined by the average hours worked per year *h* and the number of people employed *E*, therefore *L=h*E.*

Therefore, the function of actual output to the people's capacity to work is shown as:

$$Y = a * N = a * q * h * E \qquad (2.5)$$

where a is a constant, and q is labour productivity which rises over time due to technological change and other factors. However, some technological progress may displace labour without increasing output (Fontana & Sawyer, 2016; Guarini & Porcile, 2016; Naqvi & Stockhammer, 2018).

Then the employment rate *e* will be denoted by the following function, where *F* is the labour force:

$$e = \frac{E}{F} = \frac{Y}{a * q * h * F} \qquad (2.6)$$

Alternatively, the proportional link of capital and labour to output can be written as:

$$Y = min\left(\frac{K}{v}, A * L\right) \qquad (2.7)$$

where *Y* (output) is a proportion of capital stock *K* to capital-output ratio *v*, and *A* is technical change and *L* labour time.

Criticism has also been levelled at the post-Keynesian theory for completely ignoring the critical role of energy but inadvertently focusing on full employment and capital accumulation (Spash & Ryan, 2012). As a result, other scholars such as Ayres and Warr (2005), Ayres and

Warr (2009), Ayres and Voudouris (2014), Fix (2015), Kümmel, Henn, and Lindenberger (2002), Warr and Ayres (2012) explored the inclusion of energy in the production function, and their arguments have attracted scholarly attention in recent years.

2.2.1.4 Capital-labour-energy production functions

Economists such as Kümmel, Henn & Lindenberger (2002), and Ayres & Warr (2005) advanced the critical role of energy in production. They argued that capital would be completely unproductive without a flow of energy to power machines, or heat and cool buildings (Warr & Ayres, 2012). Therefore, an increasing supply of useful energy is a condition for continued economic growth (Ayres, Voudouris, 2014).

Unlike other production functions, energy production functions do not assume equality of output elasticities and cost shares between energy, capital, and labour. However, they assume that there is substitutability between energy, labour, and capital at the margin, and the range of substitutability is limited (Ayres, Voudouris, 2014). Some of the production functions include the Linear-Exponential (LINEX) production functions which allow the introduction of variable output elasticities (Kümmel et al., 2002; Warr & Ayres, 2012). The LINEX production functions reflect economic output as a function of energy, labour, and capital (Ayres & Warr, 2005; Fix, 2015; Kümmel et al., 2002). They also denote energy as the sum of all energy inputs into the economy plus energy available for use in the economy, which is known as "useful work" (Lindenberger & Kümmel, 2011). Whilst the Marxists, Neoclassicals, and Post-Keynesians denote energy as total energy flows into an economy (Warr & Ayres, 2012).

Useful work refers to all energy inputs and useful energy (also known as exergy) in the economy. Energy inputs include nuclear electric power generation, hydroelectric power production, wind, oil, gas, and solar heat. On the other hand, useful energy refers to the net energy available for use in the economy (Ayres & Warr, 2005; Warr & Ayres, 2012). The argument for advancing the use of useful work instead of energy flows is that energy comprises both useful and non-useful energy components, but only the useful components are productive (Ayres et al., 2013). Also, economic output tends to grow faster than any of the three production factors (energy, capital, and labour) or even faster than any homogenous first-order combination of the three factors (Ayres & Warr, 2005). Therefore, using useful work or useful energy is a better approach than using energy flows in the production function.

A variation of the LINEX production functions is shown below as adopted from Ayres and Warr (2005); Warr and Ayres (2012):

$$Y = AUexp\left(\frac{aL}{U} - \frac{b(U+L}{K}\right) \tag{2.8}$$

where *Y* measures economic output, *A* denotes technological progress or multiplier, *U* denotes useful work, *a* and *b* are constants, *L* denotes Labour and *K* denotes capital (Ayres & Warr, 2005). Contrary to other mainstream models, *a* and *b* do not represent the proportion of income for labour and capital (Fix, 2015). Technological progress is also presumed to be time-independent in LINEX production functions (Ayres & Warr, 2005).

LINEX production functions have been used widely to explain the critical role of useful energy in the production function; they explain the substitutability component very well by not implying that these three factors are strict substitutes for each other but imply that there is also a complementary relationship amongst the variables (Ayres & Warr, 2005). García-Olivares and Ballabrera-Poy (2015) used the LINEX production function to forecast economic output growth in the US amid energy shortages. They found that an indefinite production of exergy can be the way to guarantee indefinite economic output growth.

Stresing, Lindenberger, and Kümmel (2008) applied cointegration analysis to output, capital, labour, and energy in Germany, Japan, and the US to confirm the theory underpinning the LINEX production functions. They found that the output elasticities which give economic weights of the factors of production are much smaller for labour and higher for energy. This means energy is a powerful factor of production in Germany, Japan, and the US compared to labour. (Kumhof & Muir, 2014; Kümmel, Lindenberger, & Weiser, 2015) also concluded that the output elasticity for energy is higher than its cost share, which confirms the theory of LINEX production functions.

As the focus on energy as a factor of production increased, other production functions such as Constant-Elasticity-of-Substitution (CES) production functions (Temple, 2012; Zha, Kavuri, & Si, 2018) and augmented Cobb-Douglas production functions are increasingly being used. CES production functions were developed from the Cobb-Douglas production function by Arrow, Chenery, Minhas, & Solow (1961); Uzawa (1962). They allow several factors of production and their elasticities of substitution to determine economic output (Brockway, Heun, Santos, & Barrett, 2017; Zha & Zhou, 2014).

The augmented Cobb-Douglas production function includes energy as the third factor of production, and it is depicted as:

$$Y = A(t)K^{\propto}L^{\beta}E^{\gamma} \tag{2.9}$$

where *A(t)* denotes technology, and *K, L, E* denotes capital, labour, and energy respectively. This production function still retains the condition of constant returns, therefore, $\alpha+\beta+\Upsilon=1$ (Ayres and Warr, (2009). The augmented Cobb-Douglas is widely used in energy studies Bhattacharya, Paramati, Ozturk, and Bhattacharya (2016), Shahbaz, Raghutla, Chittedi, Jiao, & Vo, 2020). Ayres & Voudouris (2014) applied the augmented Cobb-Douglas production function to explain economic growth in the US, United Kingdom, and Japan. They found a non-linear relationship between capital, labour, and energy and extreme variability of the output elasticities over time. The augmented Cobb-Douglas production function will inform the theoretical model for this thesis.

In summary, scholars have made significant progress in building production functions that capture the key factors of production in an economy, particularly the inclusion of energy which had received less attention from other scholars. This evolution in the literature on the role of energy in production has paved a way for the development of theories analysing the contribution of energy to economic growth. One of these theories is the energy-growth nexus advanced by Kraft and Kraft (1978) and discussed extensively in the ensuing section.

2.2.2 The role of energy in economic growth

Energy plays a critical role in economic development, and its relationship with economic growth is premised on the energy-growth nexus theory that emerged in the 1970s. Kraft and Kraft (1978) advanced the argument that the level of economic activity may influence energy consumption and the relationship flows unidirectionally from economic development to energy consumption. The argument by Kraft and Kraft (1978) was, however, disputed by Akarca and Long (1980); Yu and Hwang (1984), who found no causal relationship between energy consumption and economic development. They argued that the conclusion reached by Kraft and Kraft (1978) was a result of the inclusion of two more years into the data sample and therefore declared that the causal relationship was spurious. Hamilton (1983) also introduced an argument that contradicts the views of Kraft and Kraft (1978). Hamilton (1983) argued that the causal relationship is not unidirectional but bidirectional. He argued that a change in energy consumption because of a change in energy prices can also cause changes in economic growth and unemployment, therefore, confirming that the relationship is bidirectional.

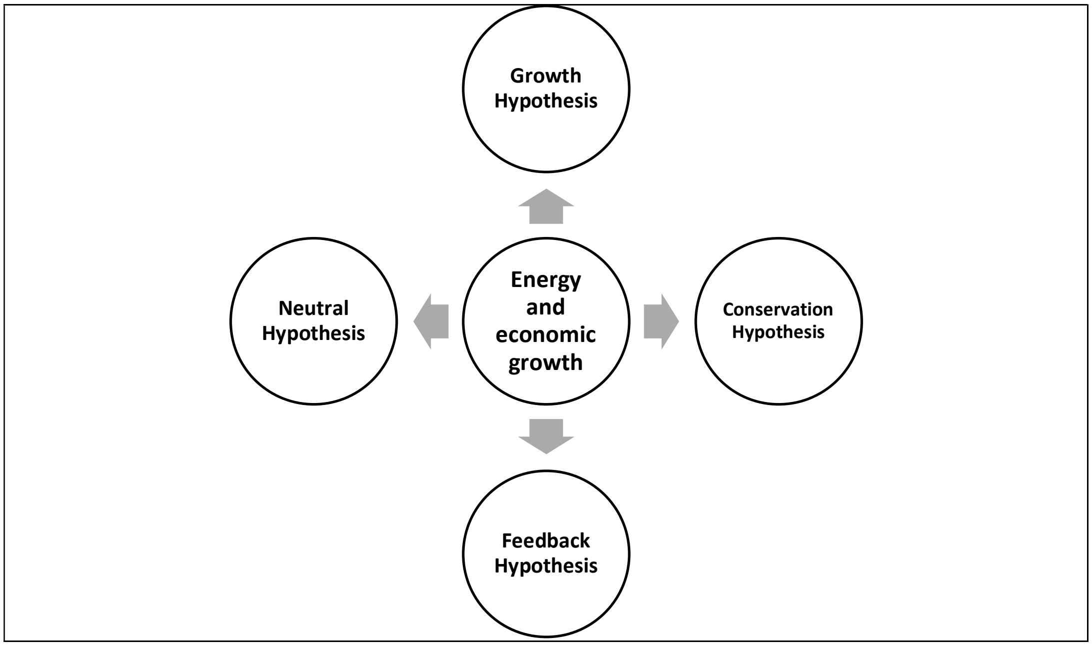
Building on the theoretical work of Kraft & Kraft (1978), Akarca and Long (1980), and Hamilton (1983) among other scholars, Apergis and Payne (2011) introduced the disaggregated theory on the role of energy on economic growth. They established four hypotheses to explain the link between energy and economic growth and these hypotheses are growth, conservation, feedback, and neutrality. This study is premised on the “growth hypothesis” of the energy-growth nexus.

The “growth hypothesis” states that energy consumption has a significant effect on economic growth, and this effect can be direct or complementary to labour and capital in the production function. This hypothesis asserts that there is a unidirectional causality running from energy consumption to economic growth; therefore, energy policies that restrict energy consumption would have adverse effects on economic growth. The “conservation hypothesis” asserts that energy consumption is driven by economic growth; therefore, a unidirectional causality from economic growth to energy consumption exists. The policy implications of the conservation hypothesis are that energy conservation policies designed to reduce energy consumption may not have adverse effects on economic growth (Apergis & Payne, 2011).

The “feedback hypothesis” asserts that there is an interdependent relationship between energy consumption and economic growth, meaning that there is bidirectional causality. Therefore, energy policies aimed at reducing energy consumption may impact economic growth. Likewise, any fluctuation in economic growth may impact energy consumption. Whilst the “neutrality hypothesis” stipulates that energy consumption has a relatively minor effect on economic growth. Therefore, a reduction in energy consumption through energy consumption policies will not impact economic growth (Apergis & Payne, 2011). To capture the four-dimensional effect of energy on economic growth is graphically presented in the theoretical framework in Figure 2.1 below.

In summary, the theoretical review establishes that the link between electricity consumption and economic growth is premised on the energy-growth nexus which attests that energy and economic growth can be unidirectional or bidirectional with causality. Energy consumption can induce economic growth and vice versa. In certain instances, energy consumption can have minimal effects on economic growth.

Figure 2.1: Theoretical framework for the role of energy on economic growth



This conclusion, therefore, prompts a need to ascertain whether the views of these theorists have been tested empirically on renewable electricity and what conclusions can be drawn from these empirical studies. To achieve that, the study reviews empirical literature that focuses on renewable electricity, to align the review with the type of electricity that forms the core of the study, which is solar electricity.

2.2.2.1 Empirical literature review of the energy-growth nexus

This section reviews the seminal work that has been published on the energy-growth nexus with a specific focus on the importance of renewable electricity to economic growth which is the focus of this study. The review is segmented according to the four-dimensional hypotheses.

The importance of renewable electricity in economic growth has been widely researched over the years (Li, Q. et al., 2021; Ohler & Fetters, 2014; Yang & Kim, 2020). However, the nature and direction of the causal relationship remain inconclusive, as some studies attest to a bidirectional relationship whilst others confirm that it is unidirectional. The direction of causality has significant economic implications, particularly for low-income countries

(Abdoli, Farahani, & Dastan, 2015). A unidirectional causality that runs from economic growth to electricity consumption implies that electricity conservation policies have minimal or no adverse effects on economic growth.

On the other hand, a unidirectional causality that moves from electricity consumption to economic growth implies that a reduction in electricity consumption could lead to a decline in economic growth (Abdoli et al., 2015). If the causality is bidirectional, policy implications will entail the development of policies that will smooth the effects of both electricity consumption and economic growth on each other. While if there is no evidence of causality, policymakers may place less emphasis on electricity consumption as an indicator of economic growth.

This review of the empirical literature is structured according to the four hypotheses discussed in the theoretical framework. Empirical studies that support the growth hypothesis found that renewable electricity consumption positively impacts economic growth (Ahmad & Majeed, 2021; Haseeb, Abidin, Hye, & Hartani, 2019a; Shahbaz, Raghutla, Chittedi, Jiao, & Vo, 2020). Alper and Oguz (2016) analysed the direction of causality between renewable electricity consumption and economic growth in new European Union (EU) member countries using the Autoregressive Distributed Lag (ARDL) approach, held that renewable electricity consumption positively impacts economic growth in all the countries investigated. Bhattacharya et al. (2016), also examined the causal relationship between renewable electricity consumption and economic output in the top 38 renewable energy-consuming countries using the Fully Modified Ordinary Least Squares method (FMOLS), found unidirectional causality that confirms a positive and significant effect of renewable electricity consumption on economic output.

Kouton (2021) applied the System Generalized Method of Moments (System GMM) method to explore the causal relationship between renewable electricity consumption and inclusive growth in 44 African countries and found a unidirectional relationship that runs from renewable electricity consumption to economic growth. This means, according to Kouton (2021), if

African countries succeed in transitioning to renewable electricity, they will capture additional and significant inclusive economic growth benefits. Ozcan and Ozturk (2019), while examining the causal relationship between renewable electricity consumption and economic development in Poland using the bootstrap panel causality test, found one-way causality running from renewable electricity consumption to economic development. These studies, therefore, imply that if countries develop renewable electricity policies that promote renewable electricity consumption, the quality of economic growth will improve therefore ensuring sustainable economic development. This means economic growth will be inclusive, with sustained poverty reduction, energy security, reduced environmental problems amongst other benefits which are not evident from the economic growth that spurs from the use of fossil fuels.

Contrary to the studies that support the growth hypothesis, several studies contend that economic growth influences renewable electricity consumption (conservation hypothesis) (Kula, 2014; Odhiambo, 2021). Furuoka (2017), while examining the causal relationship between renewable electricity consumption and economic development in Estonia, Latvia, and Lithuania using the Granger Causality test and found unidirectional causality running from economic development to renewable electricity consumption. Rahman and Velayutham (2020), while examining the relationship between renewable and non-renewable electricity consumption and economic growth in five South Asian countries using panel Fully Modified Ordinary Least Squares (FMOLS) and panel Dynamic Ordinary Least Squares (DOLS), found unidirectional causality running from economic growth to renewable electricity consumption.

(Odhiambo, 2021) applied the ARDL to ascertain whether economic growth in Botswana is energy-dependent and found that economic growth in Botswana leads to increased energy consumption but the relationship also depends on the type of energy. Wadström, Wittberg, Uddin, and Jayasekera (2019) analysed the role of renewable energy on industrial output in Canada using quantile regression and found that economic output influences renewable energy production in Canada. These studies reveal the linear relationship between renewable electricity and economic growth and the importance of aggregate output growth in attaining increased renewable electricity consumption.

Despite the studies referred to above, other studies have found bidirectional causality between renewable electricity and economic growth (feedback hypothesis) (Attiaoui, Toumi, Ammouri, & Gargouri, 2017; Ibrahiem, 2015; Kahia, Ben Aïssa, & Charfeddine, 2016; Mohsin, Kamran, Atif Nawaz, Sajjad Hussain, & Dahri, 2021; Ohler & Fetters, 2014).

Attiaoui et al. (2017) applied the ARDL technique to examine the causality relationship between renewable energy consumption and economic growth in 22 African countries over the period between 1990 and 2011. They concluded that a bidirectional long-run causal relationship between renewable energy consumption and economic growth exists. Another multi-country study applied the fully modified OLS to investigate the feedback hypothesis in high, middle, and low-income countries. The results showed evidence of the feedback hypothesis in about 79% of the countries (Al-mulali, Fereidouni, Lee, & Sab, Che Normee Binti Che, 2013).

Ibrahiem (2015) also examined the causality between renewable electricity consumption and economic growth in Egypt between 1980 and 2011. Their results also confirmed the evidence of the feedback hypothesis between renewable electricity consumption and economic growth in Egypt. Another single-country study was undertaken in Germany using a panel error correction model to examine whether renewable electricity consumption improved economic growth. The results showed that renewable electricity consolidated Germany's economic growth prospects (Rafindadi & Ozturk, 2017). The results of the studies imply that in countries where the feedback hypothesis holds, their economic growth policies should also promote and drive the growth of the renewable energy sector as this will have positive impacts on the economy and the environment because as renewable electricity increases, GDP will also grow (Kahia et al., 2016).

Although several studies found a causal relationship between renewable electricity consumption and economic growth, some studies show no evidence of a causal relationship (Ozcan & Ozturk, 2019). Kazar and Kazar (2014), applied the Granger causality test to analyse the causal relationship between renewable electricity net generation and economic development in 154 countries and found that in developed countries, there is no causal relationship between economic development and renewable energy production both in the short term and long term. This is because their level of development is high, and they are capital intense compared to developing countries.

Bah and Azam (2017) explored the causal relationship between electricity consumption and economic growth using the ARDL and Toda and Yamamoto Granger causality test in South Africa and found that there is no causality between electricity consumption and economic growth. The results of these studies, therefore, imply that policies and programmes that promote renewable electricity consumption will have marginal or no effect on economic growth (Chang et al., 2015). Further, the neutrality hypothesis seems to hold when countries are analysed individually not as a collective, therefore implying the importance of accommodating the heterogeneity characteristics of countries when analysing the energy-growth nexus (Destek, 2016).

There is also a strand of literature that disputes the positive effects of renewable energy on economic growth (Sharma, Tiwari, Erkut, & Mundi, 2021). Venkatraja (2020), while examining the relationship between the share of renewable electricity to the total electricity mix and economic growth in Brazil, Russia, India, and China (BRIC) found evidence of a decline in economic growth if BRIC countries increase their share of renewable electricity to the total electricity mix.

In summary, these studies show that the relationship between renewable electricity consumption and economic growth is mixed and inconclusive, also illustrated in Table 2.1 below. In-country policies and social and economic development factors seem to influence the conclusion drawn by these studies (Katırcıoğlu, Fethi, Kalmaz, & Çağlar, 2016; Kazar & Kazar, 2014). Further, the type of energy, methodology, and period of the study also influences the results of these studies (Inglesi-Lotz & Pouris, 2016). Most of the available studies use aggregate energy data to measure the impact of energy on economic growth and generalise the results to represent all types of energy. However, using aggregate energy data may not yield robust and reliable results because each type of energy influences the nexus differently. For example, Alper and Oguz (2016) found a neutral hypothesis between renewable electricity consumption and economic growth in new EU member countries because these countries had a lesser renewable electricity portfolio compared to developed EU member countries that had a sizeable renewable electricity portfolio. It is therefore evident that it is not possible to limit the impact of energy on economic growth to these four hypotheses.

Further, estimation methods employed by the studies in analysing the energy-growth nexus contribute to the inconclusiveness of the nature of the nexus (Wadström et al., 2019). Most of the studies employ the Granger-causality method using conditional mean regression models that have linear causal relations and cannot assess non-linear causal relationships (Troster, Shahbaz, & Uddin, 2018). In some instances, linear estimation methods are employed even when the results indicate a non-linear relationship (Wadström et al., 2019). This approach can have huge effects on the results of studies analysing the energy-growth nexus because emerging literature shows that the relationship between energy and economic growth can be asymmetric and non-linear over different economic sectors. Therefore studies that test causality within the nexus should employ asymmetric causality methods to provide robust and more reliable results

(Destek, 2016). Considering the above, the study employs both linear and non-linear estimation methods to analyse the nexus between solar electricity consumption and financial inclusion.

Lastly, most of the studies use GDP as a collective measure of economic growth. There are a few studies that measure the impact of energy on other indicators of economic development such as sectoral growth (financial inclusion, stability of money demand); HDI, inequality, etc. This literature gap can be narrowed by studies that provide empirical evidence of the disaggregated impact of energy on other economic growth indicators, hence the need to conduct this study.

2.2.3 Emerging energy-growth theories

Another emerging theory on the impact of energy on economic development stems from a new discipline known as "Energy-Based Economic Development (EBED)." EBED refers to the integration of all activities related to pursuing energy policy planning and economic development and growth, taking advantage of the economic development opportunities inherent in clean energy sources to create new and innovative economic growth (Carley & Lawrence, 2014). This discipline is an integration of two disciplines: energy policy and planning, and economic development. Energy policy and planning seek to improve energy efficiency which results in growth spurts in various sectors of the economy. Whilst economic development policies seek to improve growth through innovation which can lead to energy efficiency and opportunities for the development of new energy technologies. These two disciplines complement each other, hence it is becoming common to see economic development goals that include energy policy and planning initiatives, and further see energy policy and planning initiatives that have an economic development and growth agenda (Carley & Lawrence, 2014).

Recent developments in theory also advance that energy is crucial to economic development; it is an essential factor of production, necessary to satisfy basic human needs (Bhattacharyya, 2019); (Zweifel, Praktiknjo, & Erdmann, 2017). However, the opponents of this view argued that the importance of energy in the production function depends on the scarcity of energy in an economy. In economies where energy is abundant, the level of economic output is determined by other factors of production, not energy. However, if energy is relatively scarce, the level of economic output depends on the level of energy supply and energy-augmenting technologies (Stern & Kander, 2012).

Since most developing countries face energy scarcity; energy is an important factor of production. Whilst in developed economies where energy is abundant, energy is not a critical factor of production, all other factors of production influence economic output in the same way (Stern, Burke, & Bruns, 2017). Therefore, any efforts aimed at reducing energy scarcity will yield greater benefits of economic growth in developing countries than in developed countries.

In summary, the emergence of these energy-growth theories and the diverse views of economists on the energy-growth nexus reflects a need to review the theories that link the different types of energy to economic growth. Therefore, since the focus of this study is solar electricity, the study delves into electricity as a sub-set of energy and reviews the theories that link electricity to economic growth and ascertain whether they are aligned with the energy-growth nexus. This is important because electricity holds a critical role in the production and consumption of goods within an economy (Apergis & Payne, 2011). It also enhances industrialisation, technological and scientific advancements, and employment creation (Lawal, Ozturk, Olanipekun, & Asaleye, 2020).

2.3 Conclusion

The literature reviewed in this chapter provides significant evidence of the critical role of energy in production and economic growth. Despite the arguments advanced by earlier economists when excluding energy from their production models, the evidence of the pro-energy theorists overwhelms the former, hence the growing body of literature on single-country and cross-country studies. The subsequent chapters in this thesis are premised on this theoretical and empirical literature. However, an additional literature review has been undertaken in each chapter to supplement the theory reviewed in this chapter. Therefore, readers can use this literature as a foundation for the theoretical frameworks discussed in each chapter and obtain an understanding of the significance of this study to economic growth.

CHAPTER THREE

SOLAR ELECTRICITY CONSUMPTION AND FINANCIAL INCLUSION IN SUB-SAHARAN AFRICA

3.1 Introduction

This chapter examines the linear and non-linear relationship between solar electricity consumption and financial inclusion in SSA. Access to electricity and access to finance are top of the economic development agenda in Africa, due to their critical role in economic growth. Off-grid solar electricity technologies are making an impact in addressing energy poverty in some parts of the continent. The adoption of these technologies has also impacted the adoption of mobile money as a payment system for these technologies and the actual electricity consumption. A study conducted by the GSMA (2020) in five African countries (Uganda, Rwanda, Benin, Côte d'Ivoire, and Zambia) revealed that the growing demand for solar electricity consumption in these countries has led to an increased usage of mobile money accounts. A significant number of customers reactivated their mobile money accounts and new account registrations increased as well during the period of the study. As such, mobile money accounts in Benin increased by 22%, 31% in Zambia, and 29% in Rwanda.

However, this study had several methodological limitations that constrain the applicability of its results across the continent. First, these findings were not tested empirically, and there is no evidence of the methodology adopted in the study. Secondly, the study covered a shorter period i.e., 12 months and the sample size were too small and not representative of the African continent. Lastly, the study adopted a micro-economic indicator – mobile money as a dependent variable instead of a macro-economic indicator – financial inclusion whose results could have an impact on policy formulation at an aggregate level. These shortcomings exposed the narrow focus of the study and the literature gap in the energy-finance nexus.

It is therefore against this background that this study seeks to–narrow this literature gap, by using financial inclusion as a dependent variable, instead of mobile money to analyse the relationship between solar electricity consumption and financial inclusion. The use of financial inclusion instead of mobile money is motivated by the Maya Declaration of 2011, signed by G20 countries endorsing digital approaches as indicators of financial inclusion (Aron, 2018). Consequently, all indicators of financial inclusion encompass mobile money statistics. It is, therefore, prudent to adopt the composite measure of access to finance in this analysis than a single indicator (mobile money), to ensure that the results contribute to policy formulation. Further, this study covers a larger sample of countries (15 countries), a longer period from 2010 to 2019, and applies a robust methodology to ensure the reliability and validity of the results. In this way, the results of this study may contribute to the body of knowledge within the energy-finance nexus.

It is also noted that the GSMA (2020) reports that after the initial purchase of solar electricity and the uptake of mobile money, the frequency of mobile money transactions changes. This implies that the positive effects of solar electricity consumption on mobile money decrease after a certain period, insinuating threshold effects in the relationship. This study, therefore, determines whether there are threshold effects discernible in the relationship between solar electricity consumption and financial inclusion. There are currently no studies, according to the researcher's knowledge, that has pioneered this non-linear relationship between solar electricity consumption and financial inclusion. This study, therefore, contributes to narrowing this literature and improving energy and finance policy formulation in developing countries.

This chapter is structured into the following sections: Section two discusses the theoretical framework underpinning the finance-growth nexus and energy-finance nexus. Section three discusses the research methodology adopted in the study. Sections four and five entail the interpretation and discussion of the linear and non-linear regression results, respectively.

Section six provides a conclusion and Section seven discusses recommendations, limitations, and future studies.

3.2 Theoretical framework

This study lies at the intersection of two strands of theory: the finance-growth nexus, and the energy-finance nexus. Therefore, the approach adopted in this literature review is to first outline theories (nexuses) that underpin the importance of finance to economic growth, followed by the theories that link energy to finance, which is the core theory that underpins this study.

3.2.1 Finance and economic growth nexus

The theory underpinning the importance of financial services to economic growth has a two-pronged approach: the supply-side approach, denoted by financial development, and the demand-side approach, denoted by financial inclusion. The supply-side approach: financial development, has always been the key indicator of finance in the finance-growth nexus. It is only in recent times that financial inclusion has emerged as an additional or alternate indicator in this nexus. Therefore, this theoretical review also follows this trend in discussing this nexus.

The importance of financial services to economic growth dates back to 1911 when Joseph Schumpeter argued that financial services are important for technological innovation and economic development (Aghion, Howitt, & Levine, 2018). However, some economists, such as Joan Robinson in 1952 argued to the contrary when he stated that finance is not a crucial factor in economic development, instead, financial development is endogenously determined by the needs of the real economy (Hartmann, Herwartz, & Walle, 2012). Patrick (1966) concurred. He developed two phenomena that describe the link between real sector growth (production, purchase, and flow of goods) and financial development. These two phenomena are the demand-following and supply-leading phenomena. The demand-following phenomenon exists when the creation of financial services occurs as a response to the demand for these services from the real sector (Eschenbach, 2004; Tita & Aziakpono, 2017). On the other hand, the supply-leading phenomenon advances the development of financial services in advance of the demand for these services by the real sector (Patrick, 1966).

However, the argument advanced by Patrick (1966) argument was criticised for being incomplete and sequential, not acknowledging a two-way relationship between financial development and economic growth (Hermes & Lensink, 1997; Levine, 1992). Lucas (1988) put forward a view that financial and economic development are independent of each other and are not causally related. Blum, Federmair, Fink, and Haiss (2002) also argued that the "demand-following" phenomenon occurs temporarily under special circumstances, such as a transition to a market economy.

Levine (2004) re-introduced the argument advocating the importance of the financial system when he stated that there is a need for the development of financial systems that will coordinate and promote the pooling of savings and the exchange of goods and services in an economy. Recent scholars corroborated the argument that a developed and inclusive financial system has the potential to reduce information and transaction costs, improve saving rates, and influence investment decisions, technological innovation, and long-term economic growth (Beck, Demirguc-Kunt, & Martinez Peria, 2005; Bist, 2018; Inoue & Hamori, 2016; Walle, 2014).

In summary, most theorists support the argument that finance plays a critical role in economic growth. Even though there are dissenting views on the direction of causality between finance and economic growth, most theorists nevertheless support the view that finance is one of the economic growth catalysts. However, to fully dissect the role of finance in economic growth, it is critical to analyse the role of the demand side of the provisioning of finance, that is, financial inclusion, in economic growth.

3.2.2 The concept of financial inclusion

The concept of financial inclusion is defined differently by various authors (Nguyen, 2021). Demirgüç-Kunt and Klapper (2012) define financial inclusion as the access and use of formal financial services by both households and firms. However, Han and Melecky (2013) define financial inclusion as access to and the use of appropriate, affordable, and accessible financial services, while Ozili (2018) defines financial inclusion as the provision of and access to financial services by all population groups, particularly the poor and other excluded population groups.

A common theme amongst these definitions is the emphasis on access to affordable financial services by all population groups. This study makes use of the definition advanced by Han and Melecky (2013). This definition is more appropriate for this study as it emphasises both access to financial services and the utilisation thereof, elements that do not feature in other definitions.

The growing appreciation of the importance of access to financial services has made financial inclusion a priority in developing countries (Beck, Demirguc-Kunt, & Honohan, 2009; Lahaye, Dashi, Dolke, & Soursourian, 2015). Access to financial services can be viewed as an essential public good that enables the participation of all population groups in the benefits of a modern economy (Peachey & Roe, 2004).

At the household level, access to financial services leads to the creation of equal opportunities for all population groups, ensuring their smooth integration into the economy (Arora, 2014; Beck et al., 2009). Whilst at the firm level, access to finance eases external financing constraints and enables firms to increase their investment and expand operations (Claessens, 2006; Lee et al., 2015).

Financial inclusion also promotes savings accumulation, and mobilisation to finance economic activities that improve the productivity of households and firms and increase aggregate output (Dabla-Norris, Ji, Townsend, & Unsal, 2015). It is also associated with lower transaction costs, proximity to financial intermediaries, stronger consumer rights, political stability, and strong economic development indicators (Allen, Demirguc-Kunt, Klapper, and Martinez Peria, 2016; Gwama, 2014; Sarma & Pais, 2011).

It also provides benefits of financial stability by reducing procyclicality risk and increasing both the size and stability of the depositors' base for banks, thus improving the stability of the banking system (Han & Melecky, 2013; Mehrotra & Yetman, 2015). Therefore, lack of access to finance leads to persistent income inequality and declining economic growth by restraining the accumulation of human capital and occupational choices (Banerjee & Newman, 1990; Beck et al., 2009; Galor & Zeira, 1993).

Karlan and Morduch (2010) also expand the argument by stating that access to finance is essential, but on its own, it will not alleviate poverty on a massive scale. Instead, financial access coupled with other interventions can be a powerful tool for poverty reduction. In contrast, Frank, Levine, and Dijk (2014); Moav and Neeman (2012) advance an argument that financial inclusion leads to a poverty trap. It interferes with the wealth accumulation of the poor by triggering irrational consumption and spending which leads to a race for social status. The poor devote a significant portion of their resources to consumption to "keep up with the Joneses" and continuously rely on credit, which narrows further wealth accumulation and extends the poverty cycle (Alvarez-Curdrado & Japaridze, 2017; Kumhof, Rancière, & Winant, 2015). However, that being said, the benefits of access to finance by the poor still outweighs the negative effects because access to finance can allow poor people to escape poverty (Li, 2018).

3.2.2.1 Measurement of financial inclusion

Several arguments are made regarding the measurement of financial inclusion. According to Sarma (2012), financial inclusion is a composite of three factors: availability of financial services, market penetration by customers, and usage of financial services by customers. On the other hand, Sahay et al. (2015) argue that the measurement of financial inclusion should include a combination of measures that relate to market depth, efficiency, and individuals' ability to access financial services. Hannig and Jansen (2010) suggest that financial inclusion measurement must include the usage, quality, impact of, and access to financial services.

The World Bank measures financial inclusion using account ownership at a financial institution and mobile money account ownership. The World Bank's Global Findex 2017 report provides insight into the level of financial inclusion worldwide using account ownership at a financial institution and mobile money account ownership as indicators of financial inclusion (Demirgüç-Kunt et al., 2018). Their report reveals that about 63% of adults in developing economies own an account at a financial institution, compared to 94% of adults in high-income countries.

In SSA, ownership of an account at a financial institution increased by 4% per annum from 2014 to 2017, whereas mobile money account ownership increased by 9% per annum over the same period. The increase in mobile money accounts was evident in Tanzania, Uganda, Gabon, Ghana, and Senegal. However, Kenya, Zambia, and Zimbabwe had an increase in the share of both accounts at financial institutions and mobile money accounts. Their report also revealed that SSA had more than 10% of adults as mobile money account holders in 2017 and is the only region in the world with a large share of mobile money accounts even though this technology is also advancing in other parts of the world.

The table below shows the adoption of mobile money across different regions including SSA (Demirgüç-Kunt et al., 2018).

Table 3.1: Regional growth of mobile money in Africa in 2020

Region	**Active Agents**	**Registered Accounts**	**Active Accounts**	**Transaction Volume**	**Transaction Volume (US$)**
Sub-Saharan Africa	157	548million	159million	27.4billion	490billion
East Asia and the Pacific	49	243million	52million	5.4billion	111billion
South Asia	36	305million	66million	7.5billion	131billion
Latin America and the Caribbean	30	39million	16million	701million	19.8billion
The Middle East and North Africa	29	56million	3million	146million	10.5billion
Europe and Central Asia	9	21million	4million	234million	4.0billion
Global	310	1.2billion	300million	41.4billion	767billion

Source: (GSMA, 2020)

However, although the increase in account ownership has benefited society, a gender gap still exists in account ownership in most countries (Demirgüç-Kunt et al., 2018). The number of men that owned an account at a financial institution was roughly double the number of women in 2017. This increase was seen in countries such as Algeria, Burkina Faso, Jordan, Mozambique, Nigeria, and Peru (Demirgüç-Kunt et al., 2018). However, the economic impact of financial inclusion is more evident in women than men as revealed in a study by Swamy (2014) that examined the impact of financial inclusion programs on poor households. This study will adopt the financial inclusion indicators published by the International Monetary Fund (IMF) Financial Access Surveys (FAS) because they are published annually and capture a wide variety of indicators and countries compared to the World Bank's Global Findex. These indicators are discussed widely in the succeeding sections of this Chapter.

3.2.3 Financial innovation and financial inclusion

The increase in the level of financial inclusion in developing countries is partly driven by financial innovation. Financial innovation entails the development and introduction of new financial products and services and, new forms of organisation in developed financial markets (Ajide, 2016). Financial innovation causes changes in the prices of financial products and services and attracts other market players into financial markets (Calvet, Gonzalez-Eiras, & Sodini, 2003).

The most common financial innovations in Africa are Automatic Teller Machines (ATMs) and Point of Sale (POS) systems (Nguena, 2019). However, recently mobile financial innovation has taken centre stage in the provisioning of financial services and products to millions of people in Africa (Demirgüç-Kunt & Klapper, 2012). Mobile financial innovation involves the use of a mobile phone to access financial services. Some of the mobile financial services are mobile money transfer, mobile payment, mobile banking, and mobile international remittance services (Kim, Zoo, Lee, & Kang, 2018). The most prevalent mobile financial innovation in Africa is mobile money.

The International Monetary Fund [IMF] (2019, p.1) defines mobile money as " a pay-as-you-go digital medium of exchange and store of value using mobile money accounts which are typically offered by a mobile network operator (MNO) or another entity in partnership with an MNO." The M-PESA in Kenya is one example of a mobile money transfer service launched in 2007 by Safaricom, a leading mobile network operator in Kenya. It allows users to withdraw money from or deposit money into their mobile money account using mobile devices (van Hove & Dubus, 2019). The adoption of M-PESA has significantly increased due to advances in mobile communication and wireless technologies (Nguena, 2019; Ouma, Odongo, & Were, 2017). The table below shows the regional growth of mobile money in Africa.

Table 3.2: Mobile money growth in Africa in 2020

Region	Active Agents	Registered Accounts	Active Accounts	Transaction Volume	Transaction Volume (US$)
West Africa	70	198m	47m	6.4bn	178bn
East Africa	57	293m	94m	18.6bn	273bn
Central Africa	16	46m	16m	2.2bn	35.7bn
Southern Africa	14	11m	3m	284m	3.0bn
North Africa	14	14m	1m	77m	5.4bn
Africa	171	562m	161m	27.5bn	495bn

Source: (GSMA, 2020)

Recent research suggests that mobile money transfer services are at the core of financial inclusion in developing countries (Demirgüç-Kunt & Klapper, 2012; Chauvet & Jacolin, 2017). G20 countries signed the Maya Declaration of 2011 which endorsed digital approaches to financial inclusion as indicators for financial inclusion (Aron, 2018). They reasoned that a large proportion of the population excluded from the mainstream financial system owns a mobile phone, therefore the provisioning of financial services via mobile phones and related devices can extend financial services to that excluded population (Ozili, 2018). This led to debate among scholars about the need to revise the definition of financial inclusion to include semi-formal inclusion instead of focusing only on formal sector banking inclusion (Aron, 2017).

Mobile financial services contribute to the financial inclusion objectives of developing countries by extending financial services to the poor which in turn improves productivity, lowers transaction costs, improves security, and creates a platform for other businesses to grow (Donovan, 2012). Mobile financial services improve financial inclusion by reducing dependence on traditional finance and physical outlets, therefore, improving the availability of credit and geographic coverage of financial services for small enterprises (Yang & Zhang, 2020). Digital financial services also expand methods of financial inclusion of population groups profiled as poor and disadvantaged in mainstream financial activities (Gabor & Brooks, 2017).

3.2.3.1 Empirical literature review of the link between financial innovation and financial inclusion

Studies examining the link between financial innovation and financial inclusion confirm that a positive association exists (Coffie, Zhao, & Adjei Mensah, 2020). Qamruzzaman and Wei (2019), in their study, revealed that financial innovation improves financial inclusion by introducing innovativeness in the financial system, therefore, enhancing financial efficiency, ease of access to financial services, and integration of the unbanked population into the modern financial system.

Kabir (2021) also affirms that financial innovation is accelerating financial inclusion in South Asian countries because of the rapid growth of the mobile ecosystem in South Asia due to the ease of access to mobile phones. Another strand of literature sought to examine the impact of digital financial services, particularly mobile money impact financial inclusion in Africa.

Senou, Ouattara, and Houensou (2019), while assessing the impact of financial services enabled by digital technologies on financial inclusion in the West African Economic Monetary Union (WAEMU) concluded that the advent of digital technology and the availability of the internet on mobile phones promotes greater financial inclusion because of the ease with which people can access their accounts online via the phones. Wellalage, Hunjra, Manita, and Locke (2021), while exploring entrepreneurs' assessments of the role and effect of digital technologies on their financial inclusion found that the average financial inclusion of entrepreneurs who use mobile money in their business is 8% higher than their counterparts who do not use mobile money.

In-country studies on the impact of mobile money on financial inclusion include a study by N'dri and Kakinaka (2020) that assessed the effects of mobile money on financial inclusion in Burkina Faso. Their results showed evidence of the positive effects of mobile money on financial inclusion because it enables financial institutions to provide swift financial services for people anywhere. In Mozambique, Fernandes, Borges, and Caiado (2021), while analysing the contribution of digital financial services to financial inclusion found that digital financial services play a crucial role in improving financial inclusion because they improve access to and use of financial services by the poor and under-served population.

In Kenya, Kim (2021), while assessing the extent to which mobile money affected the financial inclusion of women found that mobile money improved women's access to various financial services that they were previously excluded. Through mobile money, women in Kenya benefit from instant remittance and payment services, and safe storage of money which is a benefit most valued by young women with low levels of education and income.

3.2.4 Energy-Finance Nexus

The theory that links renewable electricity consumption and financial inclusion is premised on the energy-finance nexus. The energy-finance nexus theory suggests that energy consumption, particularly renewable energy, induces the development of and access to financial products and services (Haseeb, Abidin, Hye, and Hartani, 2019; Lee and Chien, 2010). On the other hand, Mahi, Phoong, Ismail, & Isa (2020) and Sadorsky (2010) argue that a well-developed and prudentially managed financial system facilitates adequate allocation of financial resources to the energy sector, to maintain a healthy balance between energy production and consumption. In essence, the energy-finance nexus theory postulates that the relationship between energy and finance is bi-directional with causality (Rafindadi & Ozturk, 2017; Shahbaz, Loganathan, Zeshan, & Zaman, 2015).

The argument that advances the importance of finance to energy identifies three channels through which access to financial services impacts the energy sector (Sadorsky, 2011). The first channel is the "level effect" channel which holds that access to financial services impacts the energy sector firstly by facilitating the allocation of financial resources to high-return energy projects instead of low-return projects. Secondly, access to financial services increases risk diversification for both consumers and energy firms and improves reporting standards of energy firms to enhance investor confidence, which in turn increases electricity consumption (Sadorsky, 2011).

The second channel is termed the "efficiency effect" which implies that access to financial services benefits energy firms by improving liquidity and facilitating asset allocation to projects that enhance electricity consumption (Sadorsky, 2011). Also, improved access to finance can improve businesses' capital expenditure, business expansion through equity and debt financing, and risk diversification (Mahi, Phoong, Ismail, & Isa, 2020).

The third channel is the "consumer effect" which advances that access to a developed financial sector provides consumers with affordable financial products and services for investing in energy products and purchasing appliances that contribute to electricity use (Roubaud, David and Shahbaz, Muhammad, 2018; Sadorsky, 2011). These include houses, refrigerators, washing machines, and air conditioners which consume a lot of electricity, therefore, increasing electricity demand within an economy (Mahi et al., 2020). Access to financial services also alleviates energy poverty through its positive effects on household income, and reduction effects on poverty, and inequality (Koomson and Danquah 2021). It can also bridge the gap between financing and marketing clean energy products by educating customers about the benefits of clean energy products (Levaï, Rippey, & Rhyne, 2011).

However, most of the scholars that have analysed the energy-finance nexus have focused on the importance of finance in improving energy consumption, neglecting the importance of energy to finance, even though theory indicates evidence of this direction of causality in the nexus. The theory underpinning the importance of energy to finance is still at an infant stage as only a handful of scholars have developed a theory in this regard. One of those scholars, Haseeb et al., (2019) argues that renewable energy consumption increases the mobilisation of deposits and enhances the domestic investment market. Therefore policy makers must know the level of energy consumption within an economy to efficiently forecast capital stock (Lee & Chien, 2010).

Recently, literature has introduced the feedback hypothesis in the nexus between energy and finance. The feedback hypothesis holds that renewable energy consumption improves the financial well-being of an economy and this is exhibited through a feedback causal effect within the nexus (Shahbaz et al., 2015). Therefore, policymakers must develop effective policies that will support renewable electricity markets within and across borders (Rafindadi & Ozturk, 2017).

3.2.4.1 Empirical literature review of the energy-finance nexus

Only a few studies address the effect of energy on finance. Most studies analyse the effect of finance on energy consumption. Therefore, this section reviews both strands of literature to show scholarly advancement in analysing the energy-finance nexus.

Scholars that have analysed the effect of finance on energy include Boutabba, Diaw, Laré, and Lessoua (2020). They examined the relationship between access to finance and access to energy using univariate analyses and Propensity Score Matching (PSM) analysis in the districts of Lomé in Togo. Their results showed that access to financial services reduces energy vulnerability by providing credit to consumers to purchase clean energy technologies for cooking and lighting.

Koomson and Danquah (2021), applied the Pooled Ordinary Least Squared (POLS) to examine the effects of financial inclusion through mobile money adoption on energy poverty in Ghana. The results showed that an increase in financial inclusion is associated with a decrease in energy poverty in Ghanaian households. This implies that financial inclusion provides households with the necessary financial resources to access modern and safe energy sources. Dogan *et al.,* (2021), also applied the Two-Stage Least Squares (2SLS) method to examine the effects of financial inclusion on energy poverty in Turkey in 2018. They confirmed that financial inclusion significantly improves energy access, and this effect is channelled through the positive effects of financial inclusion on the health and income of households in Turkey.

Another strand of literature introduces mobile money as a measure of financial inclusion to analyse the effects of finance on energy consumption. In countries where financial innovation adoption is low, access to solar electricity is low too. This is evident in Peru, where mobile money is still in the nascent stages and has not penetrated beyond urban areas. Access to solar electricity is low because it is costly for ESPs to set up the mobile money infrastructure and the threat of default is very high if customers have to make cash payments towards their PAYG solar systems (Mennonite Economic Development Associates [MEDA], 2020).

The UNCDF (2020a) also conducted a study that explored the impact of the use of digital financial services for energy access, on financial inclusion in Uganda. The findings of the study reveal that most of the respondents were using digital finance for energy access for the first time and they activated their mobile money accounts 45 days before making their first PAYG payments. Therefore, access to digital finance increased access to energy.

On the other hand, in countries where the adoption of financial innovation is evident, some studies conclude that solar electricity consumption increases financial innovation and drives financial inclusion. The GSMA (2020) conducted a study in five African countries: Benin, Uganda, Rwanda, Zambia, and Côte d'Ivoire on the value of the synergy between PAYG solar and mobile money. The findings revealed that the PAYG model has facilitated the adoption and success of mobile money in Africa. About 31% of new mobile money customers in 2020 were PAYG solar customers (GSMA, 2020). Furthermore, a majority of PAYG solar customers started using other mobile services such as SMS, voice, and data more than other customers, especially in Uganda and Côte d'Ivoire (GSMA, 2020).

Empirical studies that analyse the importance of energy to finance include Fang (2011), who examined the contribution of renewable electricity to the per capita annual income of rural and urban households in China. Their study applied the multivariate ordinary least square method for the period between 1978 and 2008. The results of the study showed a positive and significant relationship between renewable electricity and the financial well-being of both rural and urban households. A 1% increase in renewable electricity consumption increases per capita annual income of urban and rural households by 0.368% and 0.444% respectively. This implies that in China, the development and implementation of sound and robust renewable electricity policies and institutions will not only promote access to electricity but the financial well-being of the population as well.

Lee and Chien (2010) applied the Toda and Yamamoto Granger causality test to model the relationship between energy consumption and capital stock in G-7 countries for the period of 1960 to 2001. Their results showed that in the UK and Italy, energy consumption has a causal effect on capital stock. Therefore, policymakers in these countries may use energy consumption levels to improve capital stock in the economy. However, considering the environmental impact of some of the energy sources, shifting to renewable energy sources and increasing energy efficiency should be used to drive capital stock.

Rafindadi & Ozturk (2017) also applied the ARDL bounds testing approach to cointegration and the VECM Granger causality test to investigate the relationship between renewable electricity and capital in Germany for the period of 1971 to 2013. They found a feedback effect between renewable electricity and capital, implying that renewable electricity induces growth of capital stock in an economy, whilst capital stock growth also induces increased renewable electricity consumption. Therefore, policymakers in Germany must establish policies that will promote the renewable electricity markets both locally and internationally to grow their capital stock.

In summary, there is evidence of a positive impact of energy on financial development. However, there is a gap in the literature that analyses the impact of energy on financial inclusion, particularly in developing countries. The available studies present evidence from single-country studies or a few groups of countries, which makes the results unrepresentative of any economic region. Also, the scope of these studies did not extend to the impact of the different types of energy sources on financial inclusion. Therefore, this study narrows the literature gap by analysing the role of solar electricity consumption on access to financial services in SSA. The contribution of this study is significant to energy-finance studies because it provides empirical evidence using a robust methodology on whether developing countries can leverage the business models adopted in the consumption of solar electricity to improve financial inclusion.

3.2.4.2 Non-linear relationship between energy and finance

The study of the non-linear relationship of the energy finance nexus is still in the nascent stages. Previous empirical studies have focused on the linearity of the relationship, therefore leaving a gap in the analysis concerning the non-linearity of the relationship and creating an estimation bias. Knowledge about the non-linearity of the nexus can be obtained from other studies. From an econometric perspective, the panel threshold analysis is preferable compared to the linear models because of the heterogeneity across countries, and ignoring such heterogeneity can lead to inconsistent results in the energy finance nexus (Chang, 2015).

Several empirical studies have confirmed a positive and significant non-linear relationship between energy and finance, and this is denoted by an inverted U-shaped curve (Agbanike, Nwani, Uwazie, Anochiwa, & Enyoghasim, 2019; Mahalik, Babu, Loganathan, & Shahbaz, 2017; Qamruzzaman & Jianguo, 2020). These studies used financial development as a proxy for finance and they include Chang (2015) that applied a panel threshold regression to test the presence of non-linearity in the relationship between financial development and energy consumption in 53 countries in the period from 1998 to 2008. The results showed that threshold effects exist, and energy consumption increases with the improvement in financial development indicators, particularly in low-income countries.

Wang and Dong (2021) applied a non-linear panel threshold regression method to estimate the effects of financial development on renewable energy consumption in G20 countries from 2005 to 2018. They found that the linear relationship between financial development and renewable energy consumption is not significant. However, the non-linear impact is positive and statistically significant especially when technology, population, and affluence are above a certain threshold level, beyond which the effect turns negative. Wang and Gong (2020) also tested the non-linearity of the energy finance nexus in 30 provinces in China during 1997-2017 using the threshold regression model. Their results showed evidence of a significant threshold effect using a threshold regression model to measure the non-linear impact of financial development on energy consumption.

Baloch, Danish, and Meng (2019) applied a Driscoll–Kraay standard errors panel regression model when analysing the nexus in OECD countries from 1980 to 2016. Their results confirmed the presence of a negative and statistically significant non-linear relationship, implying that initially, the impact of finance increases energy consumption up to a threshold point after which energy use starts decreasing. Baloch et al. (2019) explain that this relationship may be because in the initial stages the financial sector may invest more in energy-efficient projects and offer finance to households and firms to purchase energy-efficient appliances, therefore increasing energy consumption. Further, after a threshold level, energy consumption will decrease as more households and firms use energy-efficient technologies.

The study by Raza et al. (2020) also confirms the negative and significant non-linear relationship in the energy finance nexus. They also confirm that at the initial stages, banks do not promote electricity consumption. They allocate financial resources to the most productive economic sectors which then increases electricity demand and consumption. However, after reaching a threshold point, they will start monitoring the allocation of resources and encourage firms to adopt energy-efficient technologies, which then reduce energy consumption.

In summary, the body of literature advancing the non-linearity of the energy finance nexus only focuses on the threshold effect of finance on energy consumption. There is no study, according to the author's knowledge, that has analysed the threshold effect of energy on finance using financial inclusion as a proxy for finance. This literature gap has led to a one-sided view of the role of energy in economic development, which impedes the formulation of energy and growth-enhancing policies in developing countries. This study contributes towards narrowing the literature gap by analysing the threshold effects of energy on access to finance.

3.3 Research Methodology

This thesis employs a dynamic panel regression model - Two-Step System Generalised Method of Moments (SYS-GMM) to execute the objectives of the study. The data and methodology are discussed in detail in the following section.

3.3.1 Data

To assess the relationship between solar electricity consumption, and financial inclusion, the study selected a sample of 15 countries in SSA. These countries are Burkina Faso, Cameroon, Côte d'Ivoire, Kenya, Malawi, Mali, Mozambique, Niger, Rwanda, Senegal, Tanzania, Uganda, Togo, Zambia, and Zimbabwe. The sample has been selected because these countries have a significant portion of the population without access to financial services, have populations with low levels of access to electricity, and rely on off-grid and small-scale solar PV electricity for power.

The availability of data was also another key consideration in selecting the sample. The available data covers a period of 10 years, from 2010 to 2019, because mobile money was launched around 2007 by Safaricom in Kenya before it spread to other countries (GSMA, 2020). Since then, more mobile money operators have entered the market even in countries where Safaricom has a presence and in other countries too. It was also around 2012 when small-scale solar electricity distribution was commercialised in most countries. Further, it was approximately the year 2012 when mobile money was officially introduced as an additional indicator of financial inclusion Demirgüç-Kunt and Klapper (2012), following the Maya Declaration of 2011 (Aron, 2018).

3.3.1.1 Dependent variable

Financial inclusion is the dependent variable and it is measured by a composite of indicators, not a single indicator (Amidžić, Massara, & Mialou, 2014; Park & Mercado, 2018). Several scholars have used different indicators as proxies for financial inclusion, however, their approach to measuring financial inclusion is the same. Demirgüç-Kunt and Klapper (2012) used the level of "savings, borrowing, payments and risk management" as indicators of financial inclusion, whilst Sarma (2012) used "banking penetration, availability of banking services and usage." Nguyen (2021) used "penetration, availability, and usage" as proxies for financial inclusion.

Similarly, this study does not use a single measure but uses the three basic dimensions of financial inclusion: accessibility, availability, and usage, as adopted by Adedokun and Ağa (2021); Anarfo, Abor, and Osei (2020). Accessibility is measured by the penetration of the banking system and mobile money payment system. This is proxied by the number of depositors with commercial banks per 1,000 adults, and the number of registered mobile money accounts per 1,000 adults. Availability is measured by the number of commercial bank branches per 100,000 adults, the number of ATMs per 100,000 adults, and the number of registered mobile money agent outlets per 100,000 adults.

Usage is measured by outstanding deposits with commercial banks (% of GDP), outstanding loans from commercial banks (% of GDP), the value of mobile money transactions (during the reference year) (% of GDP), and the number of mobile money transactions (during the reference year) per 1,000 adults and data was sourced from the Financial Access Surveys (FAS) database published by the IMF. Some studies use the Findex database however, the Findex data is only published every three years whilst the FAS data is published yearly. Therefore, the Findex database does not support the requirements of the study.

3.3.1.2 Independent variable

Solar electricity consumption is the independent variable and is proxied by solar electricity consumption per capita. Data is sourced from the Our World in Data database published by the Oxford Martin School at the University of Oxford. The database contains data on solar energy consumption for about 20 African countries. The database covers the period between 1965 and 2019. This database was chosen because it is the only database with up-to-date data on solar energy consumption for African countries, however, it does not cover all countries in SSA.

3.3.1.3 Control variables

Financial inclusion in SSA is influenced by several factors, both observable and unobservable. Some of the observable factors include a level of education, income, and the use of banking services, whilst the unobservable factors include risk aversion, community learning spill-over effects, and changes in technology preference. Age and gender have not been found to influence mobile money adoption and solar electricity consumption (Munyegera & Matsumoto, 2016).

Institutional quality is one of the control variables. Institutions refer to the rules of the game in society that shape how humans interact within political, economic, and social structures (North, 2010). The effective enforcement of institutions is referred to as institutional quality and is critical for economic stability (North, 2010). Institutional quality and regime changes influence mobile money adoption. For example, the cessation of conflict in Côte d'Ivoire and the onset of economic growth and stability in 2012 were key drivers of the uptake of mobile money (Pénicaud & Katakam, 2014).

Institutional quality is proxied by the Economic Freedom Index which measures the quality of institutions that promote open markets or trade. The Economic Freedom Index is measured by four indicators: rule of law, government size, regulatory efficiency, and open markets. Data for this variable is sourced from the Heritage Foundation database (Miller, Kim, Roberts, & Tyrrell, 2021).

Other control variables include GDP per capita, labour productivity, CPI, and interest rates. GDP per capita can cause households and firms to demand and utilise financial services, thereby impacting financial inclusion (Evans & Osi, 2017; Kodan & Chhikara, 2013). Labour productivity refers to the increase in labour output in an economy (Chunyu, Zain-ul-Abidin, Majeed, Raza, & Ahmad, 2021). It enhances economic growth, therefore, impacts financial inclusion (Fowowe, 2020).

CPI and interest rates also influence the degree of financial inclusion (Park and Mercado, 2015; Oshora et al., 2021). The study, therefore, attempts to include most of the observable control variables. Data on the control variables are sourced from the World Development Indicators (WDI) published by the World Bank, whilst data on labour productivity is sourced from the

International Labour Organisation (ILO). The table below shows the description of the variables.

Table 3.3: Summary of variables

Variables	**Notation**	**Description**	**Source**
Financial Inclusion Index	FII	Financial Inclusion Index	FAS
Depositors with commercial banks	DCB	Number of depositors with commercial banks per 1,000 adults	FAS
Registered mobile money accounts	RMMA	Number of registered mobile money accounts per 1,000 adults	FAS
Bank branches	CBB	Number of commercial bank branches per 100,000 adults	FAS
ATMs	ATM	Number of ATMs per 100,000 adults	FAS
Registered mobile money outlets	RMMO	Number of registered mobile money agent outlets per 100,000 adults	FAS
Outstanding bank deposits	ODCB	Outstanding deposits with commercial banks (% of GDP)	FAS
Outstanding bank loans	OLCB	Outstanding loans from commercial banks (% of GDP)	FAS
Value of mobile money transactions	VMMT	Value of mobile money transactions (during the reference year) (% of GDP)	FAS
Number of mobile money transactions	NMMT	Number of mobile money transactions (during the reference year) per 1,000 adults	FAS
Solar PV	SPV	Solar electricity consumption per capita	Oxford Martin School, University of Oxford
GDP	GDP	Gross domestic product divided by midyear population	World Bank
Interest rates	IR	Lending rate	IFS, WDI
Labour Productivity	LP	Output per worker	ILO
Consumer Price Index	CPI	Annual percentage change in the cost to the average consumer of acquiring a basket of goods and services	WDI
Institutional quality	IQ	Rule of Law, Government Size, Regulatory Efficiency, and Market Openness	Heritage Foundation

3.3.2 Theoretical model

This section of the paper discusses the theoretical model of the energy-finance nexus which exposes the importance of renewable energy to access to finance. Economic theory postulates renewable energy positively impacts access to financial services by increasing the mobilisation of deposits and the size of domestic investment (Haseeb et al., 2019). Therefore, the baseline function is shown below as adapted from Rafindadi & Ozturk (2017):

$$FII = f(SPV, LP, Y) \quad (3.1)$$

where *FII* is financial inclusion which measures the access and use of appropriate, affordable, and accessible financial services (Han and Melecky, (2013). SPV denotes solar electricity consumption per capita measured in kilowatt-hours (kWh). LP denotes labour productivity whilst *Y* denotes economic output, measured by GDP.

Equation (3.1) can be written as below to reflect a panel regression approach:

$$FII_{it} = \beta_1 + \beta_2 SPV_{it} + \beta_3 LP_{it} + \beta_4 Y_{it} + \mu_{it} \quad (3.2)$$

Solar electricity consumption is expected to be positively correlated with financial inclusion.

3.3.3 Estimation strategy

This study used two estimation models. The first model is the Two-Step System-GMM which was used to estimate the effect of solar electricity on financial inclusion. The second model is the Dynamic Panel Threshold Method (DPTM) to estimate the threshold level of solar electricity consumption on financial inclusion.

Prior to undertaking the estimation, the Principal Component Analysis (PCA) method was used to create the financial inclusion index. The PCA is an econometric technique that extracts the most important information from a data table, compresses the size of the data, simplifies the description of the data set, and analyses the observations and variables. Unlike the Common Factor Analysis (CFA), the PCA only reduces the observed variables without interpretation, which is required for this study (Widaman, 1993). The PCA starts with narrowing the indicators to a few indicators, followed by an estimation of parameters or weights of the narrow indicators, an estimation of dimension weights, and construction of the overall index. The composites with an eigenvalue above 1 were selected to create the financial inclusion index.

The estimation was carried out using the Two-Step System Generalised Method of Moments (SYS-GMM) estimation method developed by (Arellano & Bover, 1995). This is a dynamic panel data model that combines the standard set of moment conditions in first-difference with lagged levels as instruments, with an additional set of moment conditions employed to link solar electricity to financial inclusion. It provides several advantages compared to OLS and Difference GMM methods. It controls for time-invariant country-specific effects and deals with the endogeneity problem of the lagged dependent variable. Further, it also allows a certain level of endogeneity in regressor variables and optimally combines information on cross-country variation or within-country variation (Arellano & Bover, 1995).

Following the hypothesis that there is a certain threshold level of solar electricity that an economy needs to attain before positive effects of financial inclusion can be witnessed, a panel threshold regression model was employed. A panel threshold regression model was first developed by Hansen (1999) as a static model that largely depends on the value of an exogenous stationary variable. This means the coefficients fluctuate between two extreme regimes. However, the validity of the static models became weaker as dynamic panels emerged since they relied on the exogeneity of the regressors and threshold variables.

Therefore the Dynamic Panel Threshold Model (DPTM) was developed by Kremer, Bick, and Nautz (2013) and later modified by Seo et al. (2019); Seo and Shin (2016). The DPTM was introduced to first determine the effect of the initial level of the dependent variable on its present level and secondly to show the actual pattern of the relationship among the variables in the model especially when the threshold level is reached, that is whether the relationship is kinked or discontinued. Unlike other threshold regression models that assume discontinuity at the threshold level, the DPTM assumes that continuity or a kink may be present (Seo et al., 2019; Seo & Shin, 2016).

3.3.4 Model specification

Hypothesis 1: Solar electricity consumption increases financial inclusion in SSA

This hypothesis subscribes to the energy-finance nexus that advances that energy consumption increases capital stock and promotes access to financial services by increasing the mobilisation of deposits and the size of the domestic investment in an economy (Lee & Chien, 2010; Haseeb et al., 2019).

The estimation of the relationship between solar electricity consumption and financial inclusion started with creating a Financial Inclusion Index because financial inclusion is measured by several indicators as shown in Table 3 above. The construction of the index is critical to minimise the potential of multicollinearity, capture the direction of maximum variation among the variables, and minimise the loss of degrees of freedom (Anarfo et al., 2020; Odugbesan, Ike, Olowu, & Adeleye, 2020).

The financial inclusion index is shown in the equation below:

$$FII_i = \beta_1 DCB_i + \beta_2 RMMA_i + \beta_3 CBB_i + \beta_4 ATM_i + \beta_5 RMMO_i + \beta_6 ODCB_i + \beta_7 OLCB_i + \beta_8 VMMT_i + \beta_9 NMMT_i + u_i \quad (3.3)$$

Where *FII* is the Financial Inclusion Index is constituted by the variables namely the number of depositors with commercial banks per 1,000 adults (*DCB)*, number of registered mobile money accounts per 1,000 adults *(RMMA)*, number of commercial bank branches per 100,000 adults *(CBB)*, number of ATMs per 100,000 adults *(ATM)*, number of registered mobile money agent outlets per 100,000 adults *(RMAO)*, outstanding deposits with commercial banks% of GDP *(ODCB)*, outstanding loans from commercial banks % of GDP (*OLCB)*, the value of mobile money transactions (during the reference year) % of GDP *(VMMT)* and number of mobile money transactions per 1,000 adults *(NMMT)*. The relative weight of each variable is denoted by β and μ is the variation due to error.

Following the empirical literature, the baseline equation for estimating the effect of solar electricity consumption on financial inclusion is expressed as:

$$lnFII_{it} = \beta_0 lnFII_{it-1} + \beta_1 SPV_{it} + \beta_2 lnLP_{it} + \beta_3 lnGDP_{it} + \beta_4 IR_{it} + \beta_5 CPI_{it} + \beta_6 IQ_{it} + \mu_{it} \quad (3.4)$$

i = 1, …, N; t =1,..., T

where *lnFII* denotes the logarithm of the dependent variable: Financial Inclusion Index; $lnFII_{it-1}$ is the lag of the dependent variable; *SPV* denotes the independent variable: solar electricity consumption per capita. *lnLP* and *lnGDP* denote the logarithms of labour productivity and GDP per capita respectively*, IR, CPI, and IQ* represent Interest rate, CPI, and Institutional quality, and μ is the error term.

Hypothesis 2: There is a threshold level of solar electricity consumption on financial inclusion

A threshold effect denotes that the effect of a variable on another reaches a turning point, after which the trend of the effect of the variable changes (Wang & Wang, 2021). The threshold effect of solar electricity on financial inclusion is given in the equation below as adopted by Seo, Kim, and Kim (2019):

$$y_{it} = x_{it}'\beta + (1, x_{it}')\delta\, 1\,\{q_{it} > \gamma\} + \mu_{it} + \varepsilon_{it} \quad (3.5)$$

where I = 1, …, n; t =1,..., T; x_{it} may include a lagged dependent variable, $q_{it,}$ denotes the threshold variable. T is assumed to be fixed, whereas n (sample size) is assumed to grow to infinity. The incidental parameter μ_{it} is removed and the unknown parameters $\theta = (\beta', \delta', \gamma)'$ are estimated using the first-difference GMM (Seo and Shin 2016). The first-difference GMM is ideal because it uses first differences to eliminate unobserved country-specific effects and lagged instruments to correct for simultaneity in the first-differenced equations. Whereas OLS would have failed to control for unobserved heterogeneity and simultaneity, therefore yielding unsatisfactory results (Arellano & Bover, 1995).Therefore, the first-difference GMM will eliminate the endogeneity problem that arises from the correlation between solar electricity consumption, financial inclusion, and other unobserved factors that explain financial inclusion.

To ascertain the presence of a kink or continued relationship, not a jump or discontinued relationship after the threshold level, the model is expressed as:

$$y_{it} = x_{it}'\beta + \kappa(q_{it} - \gamma)\, 1\, \{q_{it} > \gamma\} + \alpha_i + \varepsilon_{it} \tag{3.6}$$

where *i=1,…,n; t=1,…,T.* The kink, not a jump may be present if $(1, x_{it}')\boldsymbol{\delta} = \kappa(q_{it} - \gamma)$ for some κ when one element of x_{it} is q_{it} with the coefficient **κ** and the first element δ equals -γκ. The bootstrap algorithm was also to test the presence of the threshold effect used because the asymptotic distribution was not pivotal.

3.4 Empirical Results

3.4.1 Results of the Principal Component Analysis

To determine the level of financial inclusion in the selected countries in SSA over the period 2010 to 2019, a Financial Inclusion Index using the PCA method was created. The index comprised eight indicators of financial inclusion which are: the number of depositors with commercial banks per 1,000 adults, the number of registered mobile money accounts per 1,000 adults, the number of commercial bank branches per 100,000 adults, number of ATMs per 100,000 adults, the number of registered mobile money agent outlets per 100,000 adults, outstanding deposits with commercial banks (% of GDP), outstanding loans from commercial banks (% of GDP), the value of mobile money transactions (during the reference year) (% of GDP), and the number of mobile money transactions (during the reference year) per 1,000 adults. The PCA calculated the eigenvalues for the nine indicators as shown in Table 5. The composite with an eigenvalue that is greater than 1 was considered for the analysis (Abdi & Williams, 2010).

The results in Table 3.4 show that only the first three components out of the nine have an eigenvalue greater than 1. The first three components have eigenvalues of 3.8, 1.6, and 1.3 respectively, and variations of 43%, 18%, and 15% respectively. The rest of the components have eigenvalues less than 1. However, the first component in the analysis was used because it has the highest eigenvalue of 3.8 and explains 43% of the variation in the data. Hence it is regarded as the best measure of financial inclusion.

Table 3.4: Principal Component Analysis results

Component	Eigenvalue	Difference	Proportion	Cumulative
Component 1	3.87708	2.23383	0.4308	0.4308
Component 2	1.64325	.265196	0.1826	0.6134
Component 3	1.37806	.596241	0.1531	0.7665
Component 4	.781815	.167249	0.0869	0.8534
Component 5	.614566	.175969	0.0683	0.9216
Component 6	.438597	.302846	0.0487	0.9704
Component 7	.135751	.0342956	0.0151	0.9855
Component 8	.101455	.0720268	0.0113	0.9967
Component 9	.0294284	.	0.0033	1.0000

Following the selection of the highest eigenvalues, the Financial Inclusion Index for each country for 2010 and 2019 was developed and shown in Table 3.5 below. In the table, Kenya ranked first in the overall Financial Inclusion Index followed by Zimbabwe, Tanzania, Togo and Mozambique, Senegal, and Côte d’Ivoire. Whereas, Uganda, Zambia, Rwanda, Mali, Burkina Faso, Malawi, Cameroon, and Niger have negative Financial Inclusion Index which indicates extreme levels of financial exclusion. At the beginning of the period of the study, most of the countries had extremely low levels of financial inclusion denoted by a negative index, however, within five years, a majority had improved their financial inclusion levels to positive levels. This is evident mainly in Burkina Faso and Uganda.

However, in countries such as Cameroon, Malawi, and Niger, even though the index is still negative, the trend over the years shows improvement, which when maintained can lead to a positive and high level of financial inclusion in coming years. These results are consistent with the findings of Demirgüç-Kunt et al. (2018) which show that the level of financial inclusion in Africa is still low compared to developed countries but improving at a slow pace. Therefore, there is a need for the development of policies that will accelerate financial inclusion, particularly in those countries that still have a negative overall index.

3.4.2 Descriptive Statistics

This study begins with a preliminary investigation of the descriptive statistics to provide insight into the selected variables for the period between 2010 and 2019. The statistics in Table 3.6 show that the Financial Inclusion Index has a mean of 0, a minimum of -2.783, a maximum of 13.071, and a moderate level of variability. This implies that financial inclusion in SSA is still very low to almost non-existent, except for a few countries that have improved financial inclusion over the 10 year-period. The independent variable: solar consumption per capita has a mean of 0.893, a standard deviation of 1.717 which exhibits a low level of variability, and a minimum and maximum range of 0.004 and 10.841 respectively. The statistics imply that solar electricity consumption is still low in most countries in SSA and has not changed significantly over the years.

An additional test of multicollinearity was undertaken using the variance inflation factor (VIF). The VIF results in the last column of Table 3.6 show that all the variables have a VIF value less than 5, which indicates moderate correlation without further corrective action required. Therefore, the VIF statistics also support that the variables are fit to be used in the regression.

Table 3.5: Financial Inclusion Index for sample countries from 2010 to 2019

Year	Burkina Faso	Came roon	Côte d'Ivoire	Kenya	Malawi	Mali	Mozam bique	Niger	Rwanda	Senegal	Tanzania	Togo	Uganda	Zambia	Zimba bwe
2010	-2.10	-2.47	-1.49	0.82	-1.96	-1.72	-1.00	-2.78	-1.98	-1.35	-1.39	-1.17	-2.03	-1.66	-1.62
2011	-1.89	-2.34	-1.09	1.30	-1.75	-1.58	-0.93	-2.71	-1.88	-1.12	-0.69	-0.78	-1.87	-1.49	-1.59
2012	-1.78	-2.31	-1.10	1.64	-1.46	-1.45	-0.69	-2.61	-1.39	-0.97	-0.09	-0.39	-1.21	-1.06	-0.95
2013	-1.45	-2.08	-0.65	2.41	-1.33	-1.15	-0.35	-2.44	-1.06	-0.70	0.54	-0.19	-0.67	-0.65	-0.56
2014	-1.05	-1.91	-0.10	3.16	-1.28	-0.72	0.24	-2.22	-0.32	-0.34	1.23	0.26	-0.34	-0.29	0.32
2015	-0.57	-1.56	-0.06	3.67	-1.34	-0.04	0.53	-2.03	0.05	-0.02	1.76	0.51	0.05	0.01	0.29
2016	-0.17	-1.36	0.24	3.98	-1.10	0.39	0.78	-2.05	0.48	0.33	2.09	0.96	0.36	-0.04	0.89
2017	0.85	-0.67	1.17	3.98	-1.03	0.46	0.88	-2.10	0.65	0.95	2.35	1.03	0.65	0.35	2.86
2018	1.38	-0.37	1.88	4.38	-0.72	0.56	0.81	-2.08	1.13	1.90	2.58	1.64	1.12	1.08	5.51
2019	2.15	-0.68	2.57	4.24	-0.46	1.45	1.37	-2.05	0.93	2.84	2.81	2.06	1.73	1.61	13.07

Table 3.6: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max	VIF
FII	150	0	1.969	-2.783	13.071	
SPV	150	0.893	1.717	.004	10.841	1.23
LP	150	2620.68	1338.114	1088.85	6492.12	3.58
Log GDP	150	6.801	0.456	5.755	7.747	3.17
IR	150	12.13	9.177	2.45	46.011	3.20
CPI	150	4.529	5.431	-3.233	27.283	2.76
IQ	150	55.004	7.338	21.4	71.1	1.08

3.4.3 Mean of selected variables

The study also conducted a preliminary investigation by drawing average statistics of the variables of interest across all the countries under study from 2010 to 2019. The average statistics in Table 3.7 are presented in such a way that countries with the highest Financial Inclusion Index are listed first until the country with the least index. The statistics show that among the 15 countries in SSA, only seven countries have positive mean scores in the overall Financial Inclusion Index - Kenya, Zimbabwe, Tanzania, Togo, Mozambique, Senegal, and Côte d'Ivoire. Out of all the countries, Niger has the lowest Financial Inclusion Index.

Likewise, the estimates show that Kenya, Mozambique, Zimbabwe, Tanzania, and Zambia have the highest deposits in commercial banks (DCB) and number of ATMs. Registered mobile money accounts (RMMA) are dominant in Tanzania, Kenya, Rwanda, Côte d'Ivoire, and Zimbabwe, whereas Togo, Mozambique, Cameroon, Malawi, and Niger have the lowest registered mobile money accounts (RMMA). The number of commercial bank branches (CBB) was higher in Zimbabwe, Rwanda, Kenya, Mali, and Senegal. However, Malawi, Burkina Faso, Tanzania, Cameroon, and Niger have the lowest average number of commercial bank branches (CBB). The average number of registered mobile money outlets (RMMO) was mostly dominant in Tanzania, Rwanda, Senegal, Kenya, and Uganda, whilst Burkina Faso, Malawi, Niger, Mozambique, and Togo have the lowest average number of registered mobile money outlets (RMMO). Countries that had the highest average outstanding deposits in commercial banks (ODCB) and outstanding loans with commercial banks (OLCB) include Togo, Mozambique, Zimbabwe, Kenya, Senegal, and Burkina Faso.

The average value of mobile money transactions (VMMT) and the number of mobile money transactions (NMMT) were higher in Zimbabwe, Kenya, Tanzania, and Uganda. Solar electricity consumption per capita solar was higher in Senegal, Rwanda, Kenya, Malawi, and Uganda, whereas lower consumption is observed in Zambia, Mali, Niger, Côte d'Ivoire, and Mozambique.

Labour productivity was higher in Senegal and lowest in Malawi, whereas GDP per capita was higher in Côte d'Ivoire and lower in Malawi. Interest rates and CPI were higher in Malawi, and institutional quality was higher in Rwanda and lower in Zimbabwe. Overall, these average statistics imply that there is considerable heterogeneity in the selected countries and variables of the study.

This study investigated the presence of multicollinearity amongst the selected variables using the pairwise correlation matrix to determine the fitness of the variables to be used in the regression.

The results in Table 3.8 show that the Financial Inclusion Index is positively correlated with all the variables except for CPI, and institutional quality. It is also noted that the Financial Inclusion Index is not highly correlated with solar PV. Solar PV is positively correlated with all the variables except for CPI. These results imply that there is no severe multicollinearity amongst the variables, and they are considered fit to be used in the regression.

Table 3.7: Mean of variables on selected SSA countries, 2010-2019

Country	FII	DCB	RMMA	CBB	ATM	RMMO	ODCB	OLCB	VMMT	NMMT	SPV	LP	GDP	IR	CPI	IQ
Kenya	2.96	1089	1119	5.147	9.14	462	35.4	31.56	40.1	37263	1.31	2594	1343.1	15.48	7.077	56.18
Zimbabwe	1.82	260	824	7.918	5.97	339	36.9	19.14	88.3	62838	0.45	2626	1381.7	9.589	2.251	33.81
Tanzania	1.12	252	1514	2.45	6.05	789	21.2	16.37	38.6	39312	0.28	1835	949.56	16.14	7.193	58.27
Togo	0.39	202	311	4.981	4.85	113	51.4	38.15	7.74	4876	0.3	1853	610.9	5.144	1.411	50.11
Mozambique	0.16	261	303	4.015	9.02	120	37.6	25.54	6.69	7151	0.04	1306	554.93	18.81	7.579	53.27
Senegal	0.15	167	374	5.041	5.23	550	33.2	28.74	7.66	11636	3.9	5735	1352	5.144	1.018	56.04
Côte d'Ivoire	0.14	209	848	4.746	5.82	409	25.7	19.84	14.1	16797	0.18	4634	1733	5.144	1.239	58.15
Uganda	-0.2	238	791	2.75	4.26	457	13.5	11.24	32.7	40300	0.99	2481	801.01	22.23	6.175	60.84
Zambia	-0.2	251	660	4.326	9.81	282	21.1	11.44	2.38	8521	0.25	4458	1554.2	13.42	8.749	57.63
Rwanda	-0.3	212	863	5.805	4.7	596	17.8	14.61	12.4	361.5	2.67	1516	734.44	17.02	4.24	65.12
Mali	-0.4	146	377	5.073	4.16	356	28	22.72	16.4	11580	0.25	2137	811.58	5.144	0.972	56.68
Burkina Faso	-0.5	135	347	2.591	3.12	251	32.3	26.45	21.7	15558	0.89	2104	741.39	5.144	0.746	59.61
Malawi	-1.2	184	234	2.72	4.59	208	21.8	12.76	7.31	7876	1.28	1257	397.08	35.61	16.43	53.92
Cameroon	-1.6	77	251	1.942	3.54	252	16.8	14.75	7.05	6209	0.38	3377	1421.3	2.781	1.857	52.3
Niger	-2.3	45.4	164	1.565	1.29	164	12.8	11.89	2.06	1612	0.22	1395	526.3	5.144	0.992	53.13
Average	0.0026	248.56	598	4.071	5.43	356	27.0	20.34	20.34	18126	0.89	2620	994.16	12,129	4,528	55,004

Note: FII=Financial Inclusion Index, DCB=Depositors in commercial banks, RMMA= Registered mobile money accounts, CBB=Commercial bank branches, ATM=Automatic Teller Machines, RMMO=Registered mobile money outlets, ODCB=Outstanding deposits at commercial banks, OLCB=Outstanding loans at commercial banks, VMMT=Value of mobile money transactions, NMMT=Number of mobile money transactions, SPV=Solar PV per capita, LP=Labour Productivity, GDP=Gross Domestic Product, IR=Interest rate, CPI=Consumer Price Index, IQ=Institutional quality Correlation matrix

Table 3.8: Pairwise correlations matrix

Variables	FII	SPV	LP	Log GDP	IR	CPI	IQ
FII	1.000						
SPV	0.251	1.000					
LP	0.158	0.278	1.000				
Log GDP	0.349	0.085	0.794	1.000			
IR	0.052	0.054	-0.388	-0.457	1.000		
CPI	-0.022	-0.012	-0.236	-0.324	0.790	1.000	
IQ	-0.024	0.197	0.056	-0.045	0.137	0.090	1.000

Note: FII=Financial Inclusion Index, SPV=Solar electricity consumption, LP=Labour productivity, GDP=Gross Domestic Product, IR=Interest rate, CPI=Consumer Price Index, IQ=Institutional quality

3.4.4 Linear regression results for the relationship between solar electricity consumption and financial inclusion in SSA

To investigate the impact of solar electricity consumption on financial inclusion, the study employed the Two-Step System GMM method developed by (Arellano & Bover, 1995). This approach can solve problems of heteroscedasticity, the autocorrelation of errors, and bias in the estimation (Woodbridge, 2010). The results are presented in Table 3.9 below from models 1-10. The results show that the lag of the dependent variable, financial inclusion, has a significant effect on the present financial inclusion at 1% significance level. The relationship is significant and positive across all the constructs of the financial inclusion index. This implies that the past financial inclusion level is likely to affect the present level. Therefore, policies directed at increasing financial inclusion for countries in the region are critical.

Further, in Model (1) the results reveal that solar electricity consumption has a positive and significant impact on financial inclusion, at a 5% significance level. Therefore, the study rejects the null hypothesis of no linear relationship between solar electricity consumption and financial inclusion is rejected. The results imply that increasing consumption of solar electricity would increase the degree of financial inclusion, insinuating that solar electricity plays a critical role in improving access to finance by firms and households. Therefore, countries should increase the deployment of solar electricity, particularly off-grid, to enhance the level of access to financial services in their economies.

Regarding the indicators of financial inclusion, a positive and significant impact of solar electricity on the number of depositors in commercial banks (DCB) was observed as shown in Model (2). This implies that households and firms that have access to solar electricity have a high likelihood of depositing funds with commercial banks. Similarly, Model (6) shows that the number of registered mobile money outlets (RMMO) is positively and significantly impacted by solar electricity consumption, implying that solar electricity consumption increases the number of Mobile Network Operators (MNOs) in an economy, therefore ensuring wider availability of mobile money services. It will therefore be prudent for countries to increase the deployment of solar electricity technologies and remove barriers to the roll-out of mobile payment systems to enhance financial inclusion.

Conversely, Model (3) shows no evidence of a statistically significant association between solar electricity consumption and the number of registered mobile money accounts (RMMA). The results suggest that a change in the consumption per capita of solar electricity will not affect the opening or closure of mobile money accounts. Therefore, policymakers may not use the consumption of solar electricity as a tool for promoting the opening of mobile money accounts. Similarly, outstanding deposits in commercial banks (ODCB), outstanding loans in commercial banks (OLCB), the value of mobile money transactions (VMMT), and the number of mobile money transactions (NMMT) are not significantly impacted by solar electricity consumption. These results corroborate the results in Model (3) and confirm that a percentage change in per capita solar electricity consumption will not impact the outstanding balances on deposit accounts, loan accounts, and mobile money accounts which represent the usage dimensions of financial inclusion.

However, solar electricity consumption has a negative and statistically significant association with the number of commercial bank branches (CBB) and ATMs as shown in Models (4) and (5). This implies that the consumption of solar electricity leads to lower usage of bank branches and ATMs. This is partly because most consumers primarily use mobile money payment services instead of formal banking for solar electricity transactions because of its low-cost and accessibility benefits. As a result, the demand for formal banking services declines significantly, leading to the non-profitability of the banks and the ultimate closure of bank branches. Therefore, countries should promote affordable, simple, and innovative banking services to enhance the use of formal banking services in solar electricity consumption.

Among the control variables, CPI has a negative and statistically significant association with the Financial Inclusion Index, registered mobile money accounts (RMMA), outstanding deposits in commercial banks (ODCB), and outstanding loans in commercial banks (OLCB). Interest rates have a positive and significant relationship with the Financial Inclusion Index, number of registered mobile money accounts (RMMA), and outstanding deposits in commercial banks (ODCB).

GDP has a positive and significant association with the Financial Inclusion Index, number of depositors in commercial banks (DCB), number of registered mobile money accounts (RMMA), number of ATMs (ATM), and outstanding deposits in commercial banks (ODCB). However, GDP has a negative and statistically significant association with the number of registered mobile money outlets (RMMO).

Labour productivity has a positive and significant association with the number of commercial bank branches (CBB) and the number of registered mobile money outlets (RMMO). However, a negative association with the Financial Inclusion Index, number of depositors in commercial banks (DCB), number of registered mobile money accounts (RMMA), and outstanding deposits in commercial banks (ODCB) is evident.

Table 3.9: GMM estimation results 2010-2019

Variables	(1) FII	(2) DCB	(3) RMMA	(4) CBB	(5) ATM	(6) RMMO	(7) ODCB	(8) OLCB	(9) VMMT	(10) NMMT
Lag of FII	0.977***	0.921***	0.965***	1.033***	0.882***	0.614***	0.954***	0.633***	1.625***	1.463***
	(0.089)	(0.051)	(0.026)	(0.065)	(0.022)	(0.057)	(0.176)	(0.169)	(0.244)	(0.041)
SPV	0.086**	7.183**	14.439	-0.098**	-0.202**	49.550***	0.260	0.379	0.032	-175.292
	(0.033)	(3.146)	(9.511)	(0.033)	(0.070)	(10.592)	(0.482)	(0.229)	(1.146)	(815.633)
CPI	-0.026**	0.572	-5.778*	-0.003	0.024	-3.113	-0.397***	-0.489**	0.265	230.902
	(0.010)	(1.813)	(3.199)	(0.016)	(0.015)	(4.229)	(0.130)	(0.165)	(0.386)	(179.628)
IR	0.019*	1.317	5.751**	0.006	0.004	-1.719	0.232***	0.083	-0.080	-257.204
	(0.009)	(1.434)	(2.315)	(0.013)	(0.012)	(3.835)	(0.048)	(0.124)	(0.318)	(155.897)
Log GDP	0.714**	114.899***	205.949***	-0.162	0.355*	-239.640**	6.425***	-1.312	5.774	-8.161.998
	(0.248)	(28.385)	(62.086)	(0.214)	(0.176)	(108.672)	(1.470)	(2.785)	(12.929)	(5.799.288)
LP	-0.403**	-81.334***	-110.693*	0.378*	0.085	193.915**	-4.831***	0.353	-4.686	5.160.941
	(0.170)	(22.501)	(54.172)	(0.196)	(0.166)	(87.561)	(1.521)	(1.906)	(12.072)	(4.687.024)
IQ	-0.017***	0.126	1.618*	-0.039***	0.021***	0.163	-0.293***	-0.188***	-0.795***	-19.962
	(0.003)	(0.427)	(0.877)	(0.006)	(0.003)	(1.660)	(0.030)	(0.054)	(0.168)	(74.012)
Constant	-0.606	-146.365*	-568.289**	0.291	-3.392**	139.738	12.084	25.810	39.598	18.782.668
	(0.996)	(72.905)	(254.768)	(0.766)	(1.567)	(330.490)	(13.834)	(20.881)	(34.308)	(12.264.398)
Observations	120	120	120	120	120	120	120	120	120	120
Number of ids	15	15	15	15	15	15	15	15	15	15
ar1p	0.658	0.0627	0.0603	0.268	0.203	0.452	0.0807	0.169	0.838	0.0963
ar2p	0.363	0.531	0.775	0.326	0.504	0.0995	0.285	0.414	0.246	0.279
Hansenp	0.438	0.576	0.537	0.139	0.339	0.494	0.575	0.130	0.278	0.258

Note: Standard errors in parentheses. *** significant at 1%, ** significant at 5%, * significant at 10%

FII=Financial Inclusion Index, DCB=Depositors in commercial banks, RMMA= Registered mobile money accounts, CBB=Commercial bank branches, ATM=Automatic Teller Machines, RMMO=Registered mobile money outlets, ODCB=Outstanding deposits at commercial banks, OLCB=Outstanding loans at commercial banks, VMMT=Value of mobile money transactions, NMMT=Number of mobile money transactions, SPV=Solar PV per capita, CPI=Consumer Price Index, IR=Interest rate, GDP=Gross Domestic Product, LP=Labour productivity, IQ=Institutional quality

Institutional quality has a statistically significant and positive relationship with the number of registered mobile money accounts (RMMA) and the number of ATMs. However, it has a negative and statistically significant relationship with the Financial Inclusion Index, the number of commercial bank branches (CBB), outstanding deposits in commercial banks (ODCB), outstanding loans in commercial banks (OLCB), and the value of mobile money transactions (VMMT). This implies that the effectiveness of institutions or regulatory frameworks may negatively impact financial inclusion. This may be due to that the regulatory requirements may be unattainable by most poor households and small firms.

3.4.5 Non-linear regression results for the relationship between solar electricity consumption and financial inclusion

To estimate the threshold effect of solar electricity consumption on financial inclusion in the 15 countries in SSA, the dynamic panel threshold with a kink technique was applied as proposed by Seo and Shin (2016). The results are reported in two sets: the dynamic threshold results and the kink regression results, and they are presented in Table 3.10 below. Model (1) reports the threshold results for the composite index, whereas Model (2 – 10) reports the threshold results when individual measures of financial inclusion are adopted for threshold estimation. The non-linearity test was evaluated at 300 bootstrap replications.

The results show that there is a non-linear relationship between solar electricity consumption and financial inclusion. Solar electricity consumption has a positive and significant effect on financial inclusion at a 5% significance level. Similarly, solar electricity also has a positive and significant effect on the number of registered mobile money accounts (RMMA) at 5% significance level. This implies that an increase in solar electricity consumption will lead to an increase in financial inclusion and RMMA specifically. However, solar electricity consumption has an inverse and significant effect on the outstanding deposits at commercial banks (ODCB) and the number of mobile money transactions (NMMT). Therefore, this implies that an increase in solar electricity consumption will lead to a decrease in deposits at commercial banks and the number of mobile money transactions. The remainder of the constructs of financial inclusion is not significantly impacted by an increase in solar electricity consumption. This implies that solar electricity consumption has a non-linear relationship with financial inclusion, RMMA, ODCB, and NMMT.

Further, the results present evidence of a threshold effect of solar electricity consumption on financial inclusion at a 1% significance level, therefore rejecting the null hypothesis that there is no threshold level. The study finds a threshold level of 5.02% for solar electricity consumption on financial inclusion as denoted by the Financial Inclusion Index. This implies that the positive effects of solar electricity reach a threshold point of 5.02% on financial inclusion, after which the trend of the effect becomes negative or declines. Therefore, there is evidence of a non-linear relationship between solar electricity consumption and financial inclusion.

When the individual measures of financial inclusion are adopted (Model 2-8 and 10), the results show that the threshold level on all, but one indicator (VMMT) is statistically significant and positive, but slightly less than the composite index. The threshold level of solar electricity on the number of mobile money transactions (NMMT) is the highest across all the models at 5.79%, even higher than the threshold level on the composite index as shown in model (10). However, Model (10) shows that VMMT fails to establish a threshold level with solar electricity, therefore the null hypothesis of no threshold levels for Model (9) is accepted.

Additional estimation was conducted to confirm whether the slope after the threshold point is identified as continuous (a kink) or discontinuous. The existence of a kink in the models was investigated following the theoretical argument by Hidalgo, Lee, and Seo (2019). The results indicate the existence of kinks in Models (1), (3), (7), and (10), which confirm the continuity of the slope after the threshold point.

Table 3.10: Dynamic Panel Threshold Method estimation results, 2010-2019

Variables	(1) FII	(2) DCB	(3) RMMA	(4) CBB	(5) ATM	(6) RMMO	(7) ODCB	(8) OLCB	(9) VMMT	(10) NMMT
Lag of FII	1.381***	0.701***	-0.225	0.569***	0.293	0.770	0.731	-0.738	1.999***	1.105***
	(0.178)	(0.175)	(0.222)	(0.160)	(0.455)	(0.782)	(0.777)	(0.520)	(0.613)	(0.219)
SPV	5.319**	1.320	5.642**	3.864	12.75	12.172	-92.62*	82.79	-24.72	-231.064**
	(2.480)	(1.044)	(2.411)	(6.700)	(12.48)	(8.675)	(48.83)	(59.51)	(66.70)	(117.320)
CPI	0.0493**	12.58***	-35.95***	-0.0267	-0.0119	-60.87***	-0.650*	-0.246	-2.429	4.911***
	(0.0227)	(4.515)	(12.21)	(0.0168)	(0.0356)	(18.51)	(0.357)	(0.204)	(2.326)	(1.040)
IR	-0.0547	-10.880	-5.670	0.0148	0.0270	-109.0	0.147	-0.0843	1.848	-7.057***
	(0.0753)	(7.331)	(28.56)	(0.0687)	(0.0256)	(127.1)	(0.454)	(1.003)	(2.643)	(1.824)
IQ	-0.110**	-2.127	-56.31**	0.0456	-0.0417	85.76	-0.303	-0.653**	4.545***	3.915***
	(0.0553)	(7.939)	(27.45)	(0.0346)	(0.122)	(56.55)	(1.018)	(0.331)	(1.501)	(1.167)
LP	-9.084**	-358.0	7.348***	0.313	3.411	-3.615	72.04	17.74	-80.55	209.832*
	(3.533)	(641.1)	(794.8)	(1.982)	(3.961)	(5.562)	(48.92)	(44.35)	(125.6)	(124.971)
GDP	1.846	78.99	-1.352***	-1.927***	-2.021	-576.4	-8.980	-14.14*	-34.12	-51.965*
	(1.886)	(236.5)	(501.3)	(0.736)	(1.772)	(1.126)	(9.854)	(8.513)	(25.24)	(28.498)
Post-estimation tests										
Kink slope	-5.506**	-1.298	-5.644**	-4.046	-12.98	-12.076	91.90*	-84.23	25.58	228.666**
	(2.385)	(1.039)	(2.411)	(6.659)	(12.45)	(8.680)	(48.92)	(58.58)	(68.25)	(115.149)
Threshold Level	0.502***	0.286**	0.311***	0.197**	0.265***	0.200***	0.224***	0.302***	0.586	0.579***
	(0.189)	(0.113)	(0.0831)	(0.0960)	(0.0665)	(0.0681)	(0.0578)	(0.0937)	(1.263)	(0.0966)
Linearity Test (*p*-value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
No. of countries	15	15	15	15	15	15	15	15	15	15

Note: Standard errors in parentheses. *** significant at 1%, ** significant at 5%, * significant at 10%
FII=Financial Inclusion Index, DCB=Depositors in commercial banks, RMMA= Registered mobile money accounts, CBB=Commercial bank branches, ATM=Automatic Teller Machines, RMMO=Registered mobile money outlets, ODCB=Outstanding deposits at commercial banks, OLCB=Outstanding loans at commercial banks, VMMT=Value of mobile money transactions, NMMT=Number of mobile money transactions, SPV=Solar electricity consumption, CPI=Consumer Price Index, IR=Interest rate, IQ=Institutional quality, LP =Labour productivity, GDP=Gross Domestic Product

Whereas, in the remainder of the models, there is evidence of jumps or discontinuity after the threshold point. The coefficient of the kink slope for Model (1) and Model (3) is negative and statistically significant at 5%, whereas for model (7) and Model (10), the coefficient of the kink slope is positive and statistically significant at 10% and 5% respectively. Therefore, the negative coefficient on the kink slope for Models (1) and (3) indicates a deterioration in the trend of financial inclusion and the number of registered mobile money accounts (RMMA) after the threshold point, implying that the countries that attained the threshold level were not able to sustain it over time.

On the contrary, the positive kink slope in Models (7) and (10) indicates a growth trend in outstanding deposits in commercial banks (ODCB) and the number of mobile money transactions (NMMT) after the threshold point, implying that the countries that attained the threshold level of solar electricity consumption on outstanding deposits in commercial banks (ODCB) and the number of mobile money transactions (NMMT) were able to sustain it over time. The results imply that the non-linearity in the relationship between solar electricity consumption and financial inclusion exists among countries in SSA. Therefore, the non-linear association must be taken into consideration when formulating policies on solar electricity consumption and financial inclusion in SSA.

3.4.6 Diagnostic and robustness checks

The study performed several diagnostic and robustness checks to ensure consistency, reliability, and efficiency of the models. The first test was to detect outliers among the variables by examining the descriptive statistics. The results showed that there were no outliers that were detected, and these results are presented in Table 3.6.

The second test was the test for multicollinearity among the variables using the VIF. The multicollinearity test shows a mean VIF value of 2.50 for all variables which confirms the eligibility of all the variables to be used in the model. The VIF statistics as presented in Table 3.8 are in line with the rule of thumb that suggests that the VIF value may not exceed 10 or even 5 in some instances. However, O'brien (2007) posits that the context within which the multicollinearity test is undertaken must be considered before inferring evidence of multicollinearity or even before removing certain variables from the model.

The third test verified the consistency of the estimations which is shown by the value of statistics AR1 and AR2 in Table 3.9. In all the models, the statistic value of AR1 is significant, whereas the statistic value of AR2 is insignificant, therefore implying evidence of consistency in the estimators. The fourth test was the verification of validity instrument which is derived from the Hansen test. The test statistic value of the Hansen test is insignificant, implying that there is no correlation between residue and over-identifying restrictions. Therefore, there is no problem with the validity instrument. Overall, these tests confirm the fitness of the variables for the models and the robustness, consistency, validity, and efficiency of the models.

3.5 Discussion of results

3.5.1 Linear relationship between solar electricity consumption and financial inclusion in SSA

This section discusses the findings presented in the sections above on the linear relationship between solar electricity consumption and financial inclusion in the selected countries in SSA for the period of 2010 to 2019. The descriptive statistics indicate that countries such as Kenya, Zimbabwe, and Tanzania enjoy high levels of financial inclusion compared to other countries within the sample. Whereas countries such as Cameroon, Malawi, and Niger have a significant proportion of their population excluded from the modern financial system. Several reasons such as lack of proper identification, religion, lack of trust in the financial institutions, poor financial literacy, etc may be contributing to the persistent low levels of financial inclusion in these countries (Ulwodi & Muriu, 2017). Further, the development of the formal banking system in these countries is still nascent, therefore negatively impacting access to finance by firms and households (Ibrahim & Alagidede, 2018). However, N'dri and Kakinaka (2020) posit that mobile money payments are making a significant contribution towards improving financial inclusion in those countries that have adopted mobile money.

On the other hand, solar electricity consumption is also gaining momentum in most countries in SSA, particularly Senegal, Kenya, Rwanda, and Malawi. It is also impressive to note that countries that generally have low access to electricity have a growing average solar electricity consumption per capita. For example, Malawi had an electrification rate of about 10% in 2010 Taulo, Gondwe, and Sebitosi (2015), but has improved its electrification rate using solar electricity over the 10 years. This is partly explained by the IEA (2020) to mean that solar electricity is a cheaper electricity source that can be used to improve rural electrification in most countries in SSA. Also, unlike other energy sources, solar electricity can operate independently or integrated into the grid and this makes it favourable for countries that have high solar irradiation (Ihirwe et al., 2021).

However, when a within-sample overview is undertaken to compare the trend of solar electricity consumption against financial inclusion, the results show that some countries such as Senegal, Kenya, and Zimbabwe have the highest solar electricity consumption and the highest Financial Inclusion Index. On the contrary, some countries such as Rwanda, Malawi, Uganda, and Burkina Faso also have the highest solar electricity consumption per capita but the lowest Financial Inclusion Index. Further, Cameroon, Zambia, Mali, and Niger have the lowest solar electricity consumption per capita and the lowest Financial Inclusion Index. However, Tanzania, Togo, Côte d’Ivoire, and Mozambique have the lowest solar electricity consumption per capita but the highest level of financial inclusion. These results reflect the heterogeneity in the sample when these two variables are compared against each other.

The study sought to analyse the linear and non-linear relationship between solar electricity consumption and financial inclusion in 15 countries in SSA from 2010 to 2019. The results of the linear relationship show that solar electricity consumption positively impacts financial inclusion in SSA. It indicates that increasing consumption of solar electricity in SSA may increase access to financial services significantly. This implies that when households and firms have access to solar electricity, they are highly likely to demand and utilise financial services. These results are consistent with the results of the GSMA (2020) that state that solar electricity consumption in SSA increases mobile money uptake. The demand for financial services emerges when consumers must make repayments for SHS systems purchased via the "lease-to-own model" and when they buy electricity in advance to load on prepaid metres also known as the "usage-based payment model" of the PAYG business model.

The results are also consistent with the findings of Fang (2011); Haseeb et al. (2019); Lee and Chien (2010); Rafindadi & Ozturk (2017); Shahbaz et al. (2015) that found that renewable electricity consumption improves the financial well-being of an economy, facilitates the mobilisation of deposits, improves the domestic investment market and increases capital stock in an economy. Therefore, this paper argues that efforts to increase access to modern and clean renewable electricity by all Africans should be accelerated because they will not only improve access to electricity but will also ensure the integration of households and firms into the modern financial system. This implies that solar electricity consumption is an important determinant of financial inclusion, therefore its role should be acknowledged when formulating financial inclusion policies.

Among the measures of financial inclusion, the consumption of solar electricity positively impacts only the number of depositors in commercial banks (DCB) and the number of registered mobile money outlets (RMMO). The positive effect on DCB is also in line with the findings of Haseeb et al. (2019) who found that access to renewable electricity increases the mobilisation of deposits and enhances the domestic investment market. This means when households and firms have access to solar electricity, they engage in productive activities that induce the demand for formal financial services such as bank deposit facilities. Therefore, as the consumption of solar electricity increases, the likelihood of using bank deposit facilities for transactions increases too. These results are also corroborated by Lee and Chien (2010) who held that renewable electricity consumption increases capital stock in an economy.

This finding has policy implications for central banks because an increase in the depositors' base for commercial banks can influence monetary policy. If the depositors' base is broad and diversified, the economy may experience financial stability therefore positively impacting monetary policy. This may be evident for example in the event of a financial crisis, where large depositors exit the banking system, low-income depositors may maintain their deposits, thereby retaining the stability of the financial system. Further, an increased depositors' base means a significant portion of the broad money stock is made up of interest-bearing bank deposits, instead of being accounted for by currency in circulation, therefore making interest rates a primary monetary policy tool in supporting the central banks' function of ensuring financial stability (Mehrotra & Yetman, 2015).

However, if the depositors' base is large and not diversified, financial stability may be impaired. An increase in the share of bank deposits may alter consumer spending, therefore inducing inflationary pressures in the economy. Also, the increase in bank deposits may lead to greater declines in the share of currency in base money and the velocity of money (ratio of GDP to money), which would influence monetary policy (Mehrotra & Yetman, 2015).

Similarly, the number of registered mobile money outlets (RMMO) is also positively influenced by solar electricity consumption. This indicates that as the consumption of solar electricity increases, it attracts more mobile money providers into the economy. The increased number of mobile money outlets is important to enhancing financial inclusion because it will broaden the availability of financial services and lead to lower information and transaction costs, improved technological innovation, and influence investment decisions as corroborated by (Beck et al., 2005; Bist, 2018; Inoue & Hamori, 2016; Walle, 2014). Further, the positive influence of solar electricity consumption on the number of registered mobile money outlets (RMMO) may enhance investment in the domestic market. As households and firms invest in solar electricity technologies, and financial institutions invest in ESPs and MNOs, the number of registered mobile money outlets (RMMO) will increase, thereby growing the domestic investment market. This effect is in line with the results of Haseeb et al. (2019).

However, the increase in registered mobile money outlets may introduce intense competition among mobile money operators in an economy. Intense competition may yield positive and negative effects in the sense that consumers may benefit from reduced transaction costs and improved technological innovation and efficiency if competition is intense because service providers may lower transactions and offer a broader service offering to attract customers. However, the opposite may also be true where increased competition may lead to competitive strategies that violate the regulatory frameworks set by regulatory authorities, thereby prompting regulators to impose additional restrictions on operators, which will impede financial inclusion. This has been recorded in countries such as Nigeria that have been accused of over-regulation of mobile money operators, therefore, constraining the growth of the number of registered mobile money outlets (Lepoutre & Oguntoye, 2018). These results, therefore, imply that the positive effect of solar electricity on mobile money outlets needs to be monitored and evaluated regularly to root out any emerging negative multiplier effects in an economy.

However, the number of registered mobile money accounts (RMMA) is not significantly impacted by solar electricity consumption. This implies that any change in the number of mobile money accounts will be influenced significantly by other factors, but not solar electricity. These results are in direct contrast to the findings of the GSMA (2020) that state that the growing demand for solar electricity, increases new registrations for mobile money accounts significantly. This implies that consumers' registration for new mobile money accounts is influenced by factors other than solar electricity consumption. Therefore, policymakers need to encapsulate this non-significant impact of solar electricity on the number of mobile money accounts when promoting financial inclusion through increased deployment of solar electricity technologies.

On the other hand, solar electricity consumption reduces the number of commercial bank branches (CBB) and ATMs. This is consistent with the findings of GSMA (2020) which found that solar electricity consumption in Africa is primarily facilitated by mobile money payments, instead of formal banking payment platforms. Therefore, if the payment for solar electricity is facilitated by mobile money, financial innovations such as ATMs that are linked to the formal banking system will be negatively affected. This could be due to the inaccessibility and unaffordability of the modern banking system to and by most consumers in these countries. Therefore, households and firms prefer to use easily accessible and low-cost financial innovations such as mobile money as payment platforms for essential services such as electricity instead of banking payment platforms. Consequently, this will lead to poor profitability of banks and ultimately closure of bank branches. This implies that financial services must be made simple and less formal for countries to leverage the positive effects of solar electricity consumption on financial inclusion. This is corroborated by (Sarma & Pais, 2011; Zins & Weill, 2016).

Contrary to the findings of GSMA (2020) that found that the growing demand for solar electricity increased the usage of mobile money significantly, this study found an insignificant impact of solar electricity consumption on the usage of mobile money measured by the value of mobile money transactions (VMMT), and the number of mobile money transactions (NMMT). The GSMA (2020) further supported their argument by stating that some consumers that had deactivated their mobile money accounts, reactivated their accounts to pay for solar electricity. However, this study disputes that the reactivation of the accounts was significantly influenced by the demand for solar electricity. A possible explanation of this insignificant impact is also found in the GSMA (2020) results that show that even though consumers enrol for mobile money to facilitate payment for solar electricity, they end up using mobile money for other non-solar payments as cash-in and cash-out transactions, merchant payments, person-to-person payments, and airtime purchases. Therefore, the demand for the broader usage of mobile money for these non-solar services, instead of solar electricity payments, may influence the usage of mobile money measured by the value of mobile money transactions (VMMT), and the number of mobile money transactions (NMMT).

Another possible explanation linked to the insignificant impact of solar electricity on the usage indicators of financial inclusion may be that the total value of mobile money transactions tends to be smaller and less frequent in some countries, particularly after the initial purchase of solar electricity (GSMA, 2020). Several reasons may contribute to this change and these include a change in electricity prices, resistance to change from the use of traditional technologies, and change in household income Briguglio and Formosa (2017) to name a few. Therefore, the impact of solar electricity on them may be too marginal to be considered for policy formulation. To address this usage challenge, policymakers should identify the barriers that lead to inconsistent and smaller transactions and develop policies and programs that will promote the frequent use of mobile money for solar payments to enhance financial inclusion.

Further, the results showed that solar electricity consumption has an insignificant impact on outstanding deposits in commercial banks (ODCB) and outstanding loans in commercial banks (OLCB), both indicators of the usage of financial services by households and firms. Even though this study and Haseeb et al. (2019) found that access to renewable electricity increases the mobilisation of deposits, the results show that the positive influence does not extend to the total value of the deposits measured by the outstanding deposits in commercial banks (ODCB). This means that a change in the outstanding deposits in commercial banks is influenced by other factors, not solar electricity consumption. Further, Haseeb et al. (2019) also found that access to renewable electricity enhances the domestic investment market, however, the findings of this study found an insignificant impact of solar electricity on outstanding loan balances at commercial banks (OLCB). This implies that solar electricity consumption may not contribute significantly towards the growth of the domestic investment market if the growth of the domestic investment market is measured by outstanding loan balances at commercial banks (OLCB).

Among the control variables, the positive and significant impact of GDP on financial inclusion is in line with the findings of Demirgüç-Kunt and Klapper (2012); Evans and Osi (2017) that found that GDP per capita growth, increases financial inclusion in Africa. Contrary to the findings by Sarma & Pais, (2011), an increase in labour productivity reduces financial inclusion but positively impacts the number of registered mobile money outlets. Regarding CPI, contrary to the findings of Park and Mercado (2015) that inflation is positively and significantly linked to financial inclusion, the results show that CPI is negatively and significantly linked to financial inclusion.

Regarding interest rates, contrary to the findings of Oshora, Desalegn, Gorgenyi-Hegyes, Fekete-Farkas, and Zeman (2021) that state that increases in the cost of borrowing reduces access to finance, this study found a positive and significant effect. This may be explained in part by the inclusion of mobile money in the Financial Inclusion Index, which would mean that when interest rates increase, the usage of mobile money will also increase significantly as people move away from the formal banking system towards the mobile-based payment system and this effect will overwhelmingly offset the negative effects that increased interest rates have on the use of bank branches and ATMs. Similar to the findings of Ajide (2017), institutional quality has a negative and significant impact on financial inclusion. When the aggregate index is used, the effect on financial inclusion is negative, however, if the composite variables are used, the effect varies widely. Oshora et al. (2021) partly explain this by stating that as financial institutions increase their regulatory frameworks, access to finance by SMEs will reduce.

Overall, the results imply that solar electricity consumption only impacts positively and significantly the accessibility and availability dimensions of financial inclusion. The effect of solar electricity consumption on the usage indicators of financial inclusion is not significant. Further, the results imply that the positive effect of solar electricity consumption is not strong enough to impact formal banking services. Since the focus of ESPs has been on the poor who are also financially excluded, they also designed business models that will mostly reach the poor therefore restraining the enjoyment of the potential benefits of solar electricity consumption by the wider population. It is therefore critical that efforts are made by policymakers to ensure that the positive impact of solar electricity consumption transcends to the formal banking sector to deepen the level of financial inclusion.

3.5.2 Non-linear relationship between solar electricity consumption and financial inclusion

The study investigated the non-linearity of the relationship between solar electricity consumption and financial inclusion and found that solar electricity consumption has a non-linear relationship with financial inclusion. These results corroborate the findings of Agbanike, Nwani, Uwazie, Anochiwa, and Enyoghasim (2019); Mahalik, Babu, Loganathan, and Shahbaz (2017); and Qamruzzaman and Jianguo (2020). Further, a non-linear relationship is evident with the constructs of financial inclusion namely the number of registered mobile money accounts (RMMA), outstanding deposits at commercial banks (ODCB) and number of mobile money transactions (NMMT). An increase in solar electricity consumption will lead to an increase in mobile money accounts but lead to a decrease in outstanding deposits at commercial banks and the number of mobile money transactions. Therefore, solar electricity consumption has a non-linear relationship with the accessibility and usage dimensions of financial inclusion.

The study also investigated the threshold level of solar electricity consumption that is necessary to stimulate financial inclusion for the selected 15 countries in SSA from 2010 to 2019. The findings showed that a threshold level exists in the relationship between solar electricity consumption and financial inclusion. Therefore, the relationship is deemed non-linear. This means, solar electricity consumption initially has a positive and significant effect on financial inclusion. However, after a threshold level of solar electricity is reached, financial inclusion declines, implying that the stimulatory effect of solar electricity consumption on financial inclusion decreases after a certain threshold is reached. This is consistent with the findings by Chang (2015), Wang and Dong (2021) and Wang and Gong (2020). Countries such as Senegal, Rwanda, Kenya, Malawi, and Uganda that have high solar electricity consumption are likely to be most affected by this result.

Further, when a kink constraint is imposed in the threshold estimation, the effect of solar electricity consumption after the threshold point reduces in a kink slope trend rather than a sudden jump. This implies that the threshold effect is not discontinuous but continuous after the threshold point is reached but in a declining kink pattern. This means countries that attain the threshold level are not able to maintain it over time, as denoted by the negative and significant coefficient of the kink-slope.

The results can be explained to be a consequence of the solar electricity consumption behaviour depicted in some of the countries studied by the GSMA (2020). The GSMA study revealed that in some countries, the frequency and uptake of solar-related mobile money transactions decline after the initial purchase. This was evident in Uganda and Zambia where a huge jump in the first two months of the uptake of solar electricity and mobile money, however a decline in transactions was observed in the subsequent months. However, Côte d'Ivoire witnessed an increase in the frequency of transactions even after the initial purchase (GSMA, 2020).

Therefore, countries should develop and implement policies that will maintain the positive effects of solar electricity consumption on financial inclusion after the threshold level. In summary, the set of regressions presented above show that solar electricity holds a critical role in improving financial inclusion in SSA through its linear and non-linear effects.

3.6 Conclusion

The role of solar electricity in economic development has attracted interest in both academia and policy discussions. Several studies have examined the role of solar electricity consumption in enhancing access to modern and clean electricity by all Africans. However, interesting information has emerged from development practitioners stating that solar electricity drove financial inclusion. Financial inclusion is still at lower levels in SSA which retards economic growth. It is therefore imperative to find ways to improve financial inclusion and ensure the integration of both households and firms into the modern financial system.

This study examined the role of solar electricity in improving financial inclusion in SSA in a sample of 15 countries in SSA. Financial inclusion was measured using nine indicators:

1. Number of depositors with commercial banks per 1,000 adults,
2. Number of registered mobile money accounts per 1,000 adults,
3. Number of commercial bank branches per 100,000 adults,
4. Number of ATMs per 100,000 adults,
5. Number of registered mobile money agent outlets per 100,000 adults,
6. Outstanding deposits with commercial banks (% of GDP),
7. Outstanding loans from commercial banks (% of GDP),
8. Value of mobile money transactions (during the reference year) (% of GDP), and
9. Number of mobile money transactions (during the reference year) per 1,000 adults.

The indicators were integrated to create a Financial Inclusion Index to minimise the potential of multicollinearity, capture the direction of maximum variation amongst the variables, and minimise the loss of degrees of freedom. Solar electricity consumption was measured by solar electricity consumption per capita, and the study controlled for various factors such as GDP, interest rates, labour productivity, CPI, and Institutional Quality using data from 2010 to 2019. The results showed that solar electricity has a significant and positive role in promoting financial inclusion in SSA. This implies that an increase in solar electricity consumption leads to an increase in the demand for financial services to facilitate the purchase or and/or payment for solar electricity technologies. Further, solar electricity consumption positively impacts the number of depositors in commercial banks and the number of mobile money outlets and negatively impacts the number of bank branches and ATMs. Overall, among the three dimensions of financial inclusion (accessibility, availability, and usage), solar electricity consumption significantly impacts accessibility and availability of financial services and has no significant impact on the usage of both banking and mobile money products and services. It increases accessibility of financial services by deepening the penetration of the banking system through increasing the number of depositors in commercial banks, and increasing the availability of financial services, particularly mobile money products and services. Lastly, the results further reveal that there is a threshold effect of solar electricity on financial inclusion, suggesting that the positive effects of solar electricity on financial inclusion reach a particular threshold, after which financial inclusion declines in a continuous or kink pattern.

3.7 Recommendations

The results offer multiple policy implications for countries in SSA. Firstly, policymakers in SSA need to strengthen policies that promote increased deployment of solar electricity technologies, particularly off-grid solutions, to the rural poor. These policies will not only increase access to electricity but improve access to financial services as well. Secondly, it is recommended that policymakers develop policies that promote huge investments in mobile financial innovation and mobile network coverage infrastructure. Mobile financial innovation does not only relate to mobile money payment as it is noted that mobile money has not been a success in some countries in SSA due to various reasons. It is for that reason that the focus should not only be on mobile money but other mobile financial innovations that will accommodate the intrinsic factors inherent in each economy across SSA.

Thirdly, policymakers need to include financial inclusion targets when designing renewable energy policies. Ignoring financial inclusion targets may lead to gross underestimation of the impact of the business models (PAYG model) adopted by ESPs to increase access to electricity, particularly in rural and poor households. Whereas, incorporating financial inclusion targets into renewable energy policies may not only lead to improved electrification and financial inclusion, but will also lead to improved economic growth.

Fourthly, it is also recommended that policymakers should establish or strengthen regulatory frameworks that promote the growth of ESPs, MNOs, and mobile money operators, particularly in the countries reviewed in this study. These regulatory frameworks should address issues of funding, cyber security, quality of technologies, and operating and licensing requirements to name a few. This is critical because the pursuit of regulation and compliance must not constrain the development impact of the services and products offered by ESPs, MNOs, and mobile money operators.

Lastly, it is also recommended that monetary policy authorities (central banks) should monitor the effects of the increase of the depositors' base on monetary policies. They also must monitor the diversity of the depositors' base, because a large and undiversified depositors' base may negatively impact financial stability, especially during a financial crisis.

The limitations of this study were mainly centred around data availability, due to the novelty of the study. Firstly, financial innovation data, particularly mobile money data is not readily available in most countries. In some instances, even when it is available, some data pockets make the data difficult to use. Secondly, the integration of financial innovation into solar electricity consumption in SSA started about a decade ago, making it difficult to examine the long-run relationship between solar electricity consumption and financial inclusion. This limitation of data availability has imposed constraints on the depth of empirical analysis that could be undertaken using the available data.

Nonetheless, this study made a significant contribution to new knowledge and policy discussions within the energy-finance nexus. It is the first to examine the impact of solar electricity consumption on financial inclusion in SSA. It is, therefore, recommended that other studies may consider examining the causality relationship between solar electricity consumption and financial inclusion. Further, it is recommended that future studies evaluate the threshold effects on a larger sample size in SSA.

CHAPTER FOUR

THE EFFECTS OF SOLAR ELECTRICITY CONSUMPTION AND MOBILE MONEY ON MONEY DEMAND IN SUB-SAHARAN AFRICA

4.1 Introduction

This chapter examines whether solar electricity consumption and mobile money impact money demand in SSA. This objective stems from the findings of the study by GSMA (2020) that reports that an increase in solar electricity consumption via mobile money in 5 African countries (Uganda, Rwanda, Benin, Côte d'Ivoire, and Zambia) led to an increase in the broader usage of mobile money for solar and non-solar electricity transactions. These non-solar transactions include cash-in and cash-out transactions[2], merchant payments, person-to-person payments, and airtime purchases. According to Ziramba (2007), an increase in consumption or real income increases goods and services sold in an economy. Hence, the real value of transactions will increase as well, inducing an increase in money demand. This implies that the increase in solar electricity consumption may influence money demand, a phenomenon that has not been explored in the existing literature.

For years, money demand has been specified as a function of income (scale variable[3]), price levels, opportunity costs, and other control variables (Mazher and Dahlan, (2020); Nchor and Adamec, (2016); Omar and Hussein, (2020). Consumption is rarely used as a scale variable when specifying a money demand function. However, emerging literature questions the appropriateness of real income (GDP) as a scale variable in traditional money demand functions (Algaeed, (2016); Ben-Salha and Jaidi, (2014); Mahanty, Rout, and Mishra, (2021);

[2] Cash-in transactions refer to the deposit of cash into a mobile money wallet, whereas cash-out transactions entail converting mobile money balances into hard cash. Mobile money agents facilitate cash-in and cash-out transactions by crediting and deducting a customer's mobile money account with the respective transaction.
[3] A scale variable is a measure that outperforms other aggregates in explaining money demand (Mankiw and Summers, (1986).

Ruxanda and Muraru, (2011). There is a renewed call to employ the disaggregated components of real income and ascertain the impact of each component on money demand (Ben-Salha and Jaidi, (2014)). This approach seeks to ensure that scholars do not fall into the trap of generalising the factors that influence money demand, as they can be country or region-specific and may vary according to the monetary aggregate being measured (Adhikari, 2019; Elyasiani and Zadeh, 1999; Tang, 2007). Also, the propensities for money demand across sectors in the GDP composition vary widely in developing countries. Therefore, the macro-approach to money demand specification ignores these differences and structural changes within the different sectors and creates a bias in monetary policy formulation (Subrahmanyam & Padma, 2011).

It is, therefore, against this background that this chapter analyses the consumption and money demand nexus with a specific focus on solar electricity consumption and money demand in SSA. This analysis is important because, with the increased uptake of solar electricity in developing countries and the view that solar electricity transactions have an upward effect on other non-solar transactions, monetary authorities require knowledge of its impact on money demand to control the stock of money, influence future macroeconomic variables and ensure financial stability. Also, the proper specification of the determinants for money demand is a fundamental building block for developing economies and critical to the formulation of monetary policy (Djebbouri, Mansouri, & Tahi, 2019; Goldfeld & Sichel, 1990). Therefore, the disaggregated approach provides more accurate empirical evidence that can be directly linked to policy development.

Subsequently, since solar electricity consumption is facilitated through a mobile money payments system, the chapter also models the effect of the interaction of mobile money and solar electricity consumption on money demand. This analysis links financial innovation and consumption with money demand, a concept that has not been explored in its tripartite form in the existing literature. It has been tested empirically that financial innovation has a strong influence on money demand (Dunne & Kasekende, 2018; Thompson, 2016); however, no work has been done to assess its role in the consumption and energy nexus. Therefore, this chapter seeks to ascertain whether mobile money moderates the relationship between solar electricity consumption and money demand. This analysis is of significance to the body of energy literature because there is a growing trend of business models that integrate financial innovation into the solar electricity supply. These models are hailed as having a positive impact on various macro-economic factors. Without a doubt, these financial innovations will introduce changes to the financial sector and potentially alter consumer behaviour. Therefore, this tripartite link can no longer be ignored and requires empirical analysis to ascertain its effects on monetary policy.

4.1.1 Money demand in sub-Saharan Africa

This background then leads to the need to understand the factors that influence money demand in SSA. This is important because a stable money demand function forms the core of the conduct of monetary policy and improves economic growth (Simorangkir, 2002). However, the stability of money demand may be affected by financial sector reforms because they could bring imbalance to the demand for money and change the velocity of money (Dagher & Kovanen, 2011).

In recent decades, most countries in SSA have implemented financial reforms that seek to improve financial deepening and competition (Fowowe, 2011). When such reforms are implemented, they expose monetary aggregates to unexpected shifts. When this happens, monetary aggregates lose their transparency and become less able to accurately determine monetary policy. This is one of the justifications of some countries in SSA using inflation targeting[4] as a monetary policy instrument instead of monetary aggregates. This is because the inflation targeting policy does not depend on the stability of money demand but the level of prices (Dagher & Kovanen, 2011). However, Heintz and Ndikumana (2011) argued that inflation targeting might not be desirable for countries in SSA because of the inflation dynamics and structural realities that might undermine economic development. Therefore, selecting the appropriate scale variable for the money demand function in SSA is important to ensure the effective formulation, implementation, and monitoring of monetary and fiscal policy (Elyasiani & Zadeh, 1999).

Several studies have investigated the determinants of the money demand function in SSA. Nchor and Adamec (2016) applied the Error Correction Model (ECM) to determine the money demand function in Ghana. Money demand was proxied by M1 and M2, real income was measured with real GDP, whilst the opportunity cost measure was measured by the 91-Day Treasury bill rate. The findings also confirmed a positive and strong association between GDP and M1 and M2 both in the short and long run. However, interest rate has a negative and statistically significant relationship with M1and M2 both in the short run and long run.

Omar and Hussein (2020) also assessed the money demand function stability for South Africa using M3 as broad money, the industrial production index as a scale variable instead of real income, government bond rates as opportunity cost, stock price index, real exchange to capture the opportunity cost of holding domestic money against foreign money. They applied the Vector Error Correction Model (VECM) and found that the money demand function is unstable in South Africa. Broad money has a significant relationship with all the other variables except for interest rate.

[4] Inflation targeting means the central bank sets inflation targets as the primary goal for monetary policy and remains accountable for meeting the inflation targets (Bernanke and Mishkin (1997).

In Zambia, Mumba and Ziramba (2021) investigated the money demand function by employing the Gregory Hansen cointegration technique using broad money, exchange rate, and interest rate. The results show that interest rate and inflation are significant determinants of money demand in Zambia. Although positive, GDP has an insignificant effect on money demand, whilst exchange rate has a negative and insignificant effect. This implies that the monetary authorities in Zambia can use money supply for monetary policy implementation and can target interest rates using monetary policy.

Epaphra (2017) investigated the stability and determinants of money demand in Tanzania by employing the Vector Autoregressive – Vector Error Correction Model (VAR-VECM) using real money balances and GDP, inflation, exchange rate, and deposit interest rate. The results showed that GDP and exchange rate are positively associated with money demand, whereas inflation and deposit interest rate are inversely related to money demand. This confirms the validity of these variables as determinants for money demand and that money demand is stable in Tanzania.

Panel empirical studies that also investigated the determinants of money demand function in SSA include Asiedu, Opoku, AbdElghaffar, Bimpong, and Yeboah (2020) that investigated the stability of money demand in 16 West African countries by employing the ARDL technique on M2, exchange rate, Libor, and real income. The results showed significant divergence in the stability of the money demand function in the 16 countries. This divergence amongst the countries implies that it is important to consider the significant divergence when designing monetary policies in West Africa. Asongu, Folarin and Biekpe (2019) examined the stability of money demand in the proposed West African Monetary Union (WAMU) by applying the ARDL bounds test using real income, domestic interest rate, and inflation rate. The results showed that all these variables significantly influence money demand in the WAMU.

The emphasis on real income as a key determinant of money demand is also seen in other parts of the world. Nepal and Paija (2020) applied the panel ARDL model and analysed the money demand function for South Asian economies using M2 as a proxy for money demand, real GDP as a measure of income and CPI, and real interest as a measure of the opportunity cost of holding money. Their findings showed a strong and positive long-run relationship between real income and broad money. Whereas CPI and interest rate are negatively associated with broad money. Mazher and Dahlan (2020) investigated the factors that influence money demand in Malaysia using real GDP, real interest rate, CPI, and financial innovation. They applied the ARDL Bound test for short and long-run estimates and found that GDP has a negative and significant relationship with money demand. Whereas financial innovation and real exchange rate have a positive and significant relationship with money demand.

Mahmood and Asif (2016) applied the ARDL cointegration technique to investigate the long-run relationship in the Gulf Cooperation Council (GCC). They employed M2, real gross domestic product (GDP), real interest rate, real effective exchange rate, and inflation rate and found that in the long-run interest rate has a negative and significant relationship whilst exchange and inflation rate have a positive and significant relationship. In the short-run, interest and exchange rates remained with a negative impact, whilst inflation remained with a positive impact. Umaru and Muhammad-Bashir (2018) investigate the determinants of the money demand function for ASEAN-5 countries by applying Pooled Ordinary Least Square, Random Effects Model, and Fixed Effects Model using these variables: M2, GDP, interest rate, exchange rate, inflation rate, and stock price. The results show that the variables are all significant. GDP and inflation rate have a positive and strong association with money demand whilst interest rate and stock price have a negative and significant association. However, the exchange rate has a minor impact on money demand.

In summary, the literature survey of the determinants of the money demand function in SSA and worldwide, reveals that most scholars emphasise the appropriateness of real income as a scale variable. These studies imply that monetary authorities can monitor real income and interest rates in ensuring financial stability. However, it can also be of significance to policy makers to identify the components of real income that strongly impact money demand. A direct assessment of the impact of these components would provide policy makers with accurate policy recommendations to ensure effective monetary policy formulation and implementation. It will also ensure that sectoral consumption is monitored against money demand to ascertain its effects on monetary policy. It is for that reason that this study adopts the disaggregated approach to analysing the determinants of money demand in SSA.

This chapter is structured into the following sections: Section two discusses the theoretical framework underpinning consumption, financial innovation, and money demand. Section three discusses the research methodology adopted in the study. Sections four and five entail the interpretation and discussion of the regression results respectively. Section six provides a conclusion, and Section seven discusses the policy recommendations, limitations of the study, and recommendations for future studies.

4.2 Theoretical Review

This section discusses the theoretical linkage between energy consumption, financial innovation, and money demand. It starts with a discussion of the functions of money, the theoretical views of early economists on the role of monetary policy, and the specification of the money demand function. Secondly, it introduces the theoretical views on the role of consumption in a money demand function and links this theory with energy consumption. Lastly, the study introduces financial innovation into the consumption-led money demand function, therefore creating a tripartite relationship between consumption, financial innovation, and money demand.

4.2.1 Functions of money

Money is a medium of exchange and the standard unit used to express prices and debts (Sriram, 1999). Money serves four primary functions: medium of exchange, store of value, unit of account, and source of deferred payment (Ingham, 2005). Many money demand theories have been developed based on these functions of money. These include a theory developed by classical and neo-classical economists that argue that the role of money is to express prices and values and to facilitate the sale of goods as a medium of exchange (Serletis, 2007).

However, Keynesian economists analysed money in terms of its store value, the motives for which people hold money, and the money demand arising from the motives. Keynesians argue that individuals hold money for three different motives: transactions, precautionary and speculative (Serletis, 2007). The transactions and precautionary motives emphasise the role of money as a medium of exchange, and they have a significant impact on money demand in the short run. Whereas, the speculative motive emphasises the role of money as a store of value (Serletis, 2007). Therefore, if individuals want to hold money for speculative motives, the price the individuals are willing to pay for holding money will depend on the rate of interest as depicted in the money demand function below (Sriram, 1999):

$$m^d = f(y, i) \tag{4.1}$$

where demand for real money balances m^d is a function of real income y and interest rate i.

4.2.2.1 Transactionary demand for money

The transactionary demand for money arises from the notion that the reasons for the inflow and outflow of money in households and firms are diverse. Therefore, households and firms must hold money until the next cash inflow to meet their personal and business expenditures. This means their demand for money is influenced by transactions and precautionary motives (Bitrus, 2011).

One of the earliest transaction theories is the inventory-theoretic approach which emanates from the seminal work of Baumol (1952) and Tobin (1956). The inventory-theoretic approach holds that money is an inventory held for transaction purposes. It further postulates that even though other liquid financial assets offer better returns than money, the transaction costs of going between money and these assets justify holding money for transaction purposes. Also, if the average cost of holding money is higher, transaction costs may be minimised, however, earnings of interest may be forgone (Thompson, 2016). Therefore, the inventory-theoretic approach is formulated as follows (Sriram, 1999):

$$M^* = \sqrt{\frac{a_0 y}{2r}} \qquad (4.2)$$

where M^* denotes the optimal demand for real money balances and is directly proportional to transaction costs (a_0) and real income (y) and inversely proportional to interest rate (i).

Thorn (1974) identified three main costs of holding money for transaction purposes: opportunity costs, stockout costs, and conversion costs. Opportunity costs are the costs of holding money that does not yield monetary return instead of an income-yielding asset. This implies that to hold money, an economic unit may forgo the income it could have earned if a portion of the wealth that is held as money was invested in assets that yield income.

Therefore, the opportunity cost function can be written as the equation below:

$$C = f(M, i) \qquad (4.3)$$

where C denotes total opportunity cost, as a function of M which is money balances held at a period, and i which is the rate of return on alternative assets yielding income. The opportunity cost is expected to increase with the money balances held.

The second type of costs related to holding transaction money balances is the stockout cost. These costs relate to the cost of running out of money and not being able to meet planned and unplanned expenditures. Therefore, the economic unit will incur costs as they wait for additional money or arrange a loan to meet the planned or unplanned expenditures. Lenders may charge a high interest rate due to the cash position of the economic unit and this may aggravate the original situation (Thorn, (1974).

Lastly, another type of the cost of holding transaction money balances is the conversion cost. The conversion cost relates to the costs of converting unwanted money balances into assets that will yield money or converting non-monetary assets into money. These costs are discreet, only occur when the conversion happens, and are independent of the value of assets being converted (Thorn, (1974) .

Although these costs of holding money are important and are generally incurred by both households and firms, money demand literature focuses on the opportunity cost of holding money. Therefore, this study will also adopt this type of cost in analysing the money demand function in SSA.

4.2.2.2 Precautionary demand for money

Money demand due to precautionary motives is the demand for holding additional money balances as a reserve in the event of uncertainty resulting from unplanned expenditures (Pietrucha & Maciejewski, 2020). The occurrence of uncertainty can increase the demand for holding money for precautionary motives (Gan, 2019). This is because the possession of money can offer a blanket of protection from future economic uncertainties (Cardim de Carvalho, 2010).

Whalen (1966) outlines three factors that affect the optimal size of precautionary cash balances: the cost of illiquidity, the opportunity cost of holding precautionary balances, and the average volume and variability of receipts and disbursements. According to Whalen (1966), the cost of illiquidity relates to the extent of the consequences faced by an economic unit for failure to hold the required money balances for necessary expenditures for a given period. These costs may be high and lead to insolvency and bankruptcy. Secondly, the opportunity cost of holding precautionary money balances occurs when a firm holds cash as a precautionary motive instead of an income-yielding asset because cash has no monetary return. Therefore, as precautionary cash balances increase, opportunity costs increase as well.

Lastly, the average volume and variability of receipts and disbursements also affect the size of precautionary balances held. Any uncertainty and discrepancy in the expected receipts and disbursements will increase the level of precautionary money balances to offset the inadequacy of cash held by the economic unit. In general, the demand for precautionary money balances exceeds the demand for money for transactionary purposes and is more sensitive to fluctuation in interest rates (Plessner & Reid, 1980).

4.2.2.3 Speculative demand for money

The speculative theory of money demand states that interest rates determine the demand for speculative money balances. This is more evident with investors in bonds that buy bonds when the actual rate of interest is perceived to be high relative to the normal rate of interest. Investors sell when the actual rate of interest is perceived to be low, relative to the normal rate of interest (Dow & Ghosh, 2009; Motley, 1979). This implies that the speculative demand for money does not only depend on income and the market rate but also investor opinions regarding the normal rate (Fisher, 1973).

Therefore, the speculative demand for money is volatile because it depends on investor opinions and the degree to which investors are willing to invest. Within the speculative theory of money demand, investors will tend to hold more speculative money balances when they face relatively large risks in expected future asset prices compared to those facing low asset price risks. High dividend payments on assets will also entice investors to hold assets longer, therefore, increasing speculative activity.

4.2.2 The role of monetary policy

The importance of monetary policy cannot be over-emphasised in developing countries, particularly with new factors that might influence monetary policy, such as electricity consumption. Several scholars have discussed the importance of monetary policy with varying approaches but reached the same conclusion. Monetarists such as Friedman advanced the importance of money supply growth and regulation of inflation. They argue that monetary authorities must focus on regulating the amount of money in the economy instead of directing nominal short-term interest rates as a tool for attaining long-term inflation (Lothian & Tavlas, 2018; Meltzer, 1995).

However, Keynesian economists disputed the emphasis on the direct association between money supply growth and inflation. They advanced that monetary policy effectiveness is not critical, but fiscal policy effectiveness is important and may have a direct impact on real output (Bibow, 2002; Moggridge & Howson, 1974). This led to the development of the Post Keynesian view on monetary policy, which advanced that the effectiveness of monetary policy depends on attaining full employment and economic growth. Post-Keynesian economists argued that monetary authorities could use interest rates and regulations to achieve financial stability. They can consider debt management as an instrument to control interest rates, such as reducing the cost of debt and promoting other lending activities. They also argued that the needs of the real economy drive the existence of money in an economy, and the decisions of commercial banks determine the supply of credit (Nayan, Kadir, Abdullah, & Ahmad, 2013; Pollin, 1991).

However, Classical economists posited that the economy will always be at full employment, therefore easing monetary policy can adjust levels of unemployment that occur due to declining levels of the wage rate. They argued that an increase in the level of prices causes a decline in real wages, which then enables employers to increase employment levels and output, therefore moving the economy back to full employment. They further state that easing monetary policy is critical to returning the economy to full employment (Dowd, 1990; Dutton & Gramm, 1973).

These theorists, in their differing opinions, confirm the role of monetary policy in economic growth. Some promote fiscal policy above monetary policy, whereas some emphasise the importance of ensuring financial stability and increasing economic growth. It is upon this theoretical foundation that this study pursues the analysis of the effect of solar electricity consumption on money demand to ensure financial stability and output growth in SSA.

4.2.3 Money demand and consumption nexus

For the longest time, a large body of literature supported the theory that interest rate and real income are the traditional determinants of money demand (Nchor & Adamec, 2016). However, other theories have not supported the use of real income as a scale variable; instead, they advocate for consumption as a scale variable (Tang, 2002). Adhikari (2018) argues that using a single scale variable in the aggregate money demand function may lead to aggregation bias. Therefore, using other scale variables such as consumption to empirically estimate money demand can minimise the bias and enhance monetary policy formulation and implementation. Subrahmanyam and Padma (2011) also argue that the aggregate money demand function creates a bias in the income elasticity of money demand, because it ignores the sector composition of GDP which can lead to monetary policy prescription for developing economies undergoing structural changes.

Earlier theorists such as Goldfeld (1976) argued that real output excludes transactions in financial assets such as equity stock, sale of intermediate goods, and purchase of existing goods such as houses. Therefore, it may not be a good measure of transactions. Saving (1971) introduced the shopping time model of money demand to explain the role of consumption in the money demand function. The shopping time model states that consumption determines the level of monetary balances because consumption is a time-consuming activity. As a result, consumers hold money balances to minimise the time required for consumption. Holmes and Smyth (1972) argued against income as an appropriate scale variable because it includes taxed income that households never receive.

Mankiw and Summers (1986) also advocate for consumption as a scale variable based on two arguments. Firstly, they argue that the use of income as a scale variable validates consumption as an ideal proxy because consumption is proportional to income. Secondly, they argue that even though all components of real income generate transactions, consumer transactions generate more money demand and hold a very large share of M1 and M2 than other economic agents such as government and businesses[5]. Therefore, consumption and money demand cannot be inseparable in a well-defined money demand function (Dutkowsky & Foote, 1992). Chrystal and Mizen (2005) argue that consumption is directly proportional to money demand. This means when money demand decreases because of unemployment or high inflation, consumption declines. This argument on the role of consumption is also supported by the transaction theory of money demand (Dahalan, Sharma, and Sylwester (2007).

Therefore, when real income or consumption increases, goods, and services sold in the economy increase as well. This leads to an increase in the real value of transactions which will increase the demand for money, given the price level (Ziramba, 2007). (Kharroubi & Kohlscheen, 2017) also, posit that consumption drives economic growth, it holds a significant share of aggregate demand and in some advanced economies, consumption grows faster than GDP. This implies that consumption can be a scale variable instead of GDP in a money demand function. Rua (2018) also raises another argument in favour of consumption expenditure by stating that cash intensity varies according to the type of consumer expenditure therefore it is

[5] Government transactions generate less money demand because their transactions are not included in M1 or M2. In the same way, business transactions also generate less money demand because of the sophisticated financial management tools that businesses employ to hold less money.

advisable to disaggregate consumer expenditure to manage changes across different types of spending and address the potential composition effects of each type of expenditure on money demand.

Elyasiani and Zadeh (1999) also argued that a scale variable is country-specific, therefore studies that advance an identical scale variable for money demand functions for all countries may be misleading. This was evident in their study to determine the appropriate scale variable for the money demand function for Germany, Italy, France, Canada, and Japan. Their results showed that only Italy favoured consumption as a scale variable, the other countries also favoured different scale variables. This implies that for each country to achieve its monetary target, it must be knowledgeable about the proper scale variable of its money demand function. If a particular country has consumption as a scale variable but denies its policy based on other variables other than consumption, it can miss its monetary target. The consequences of such are far-reaching as they can negatively impact the forecasting and modelling of exchange rate and interest rate because the equilibrium variables of these two depend on the level of monetary balances amongst other variables (Elyasiani & Zadeh, 2006).

Another strand of theory advances that the motive of holding money influences the choice of the scale variable in a money demand function. Chen (2006) argues that the asset-motive theories of holding money advance the consumption-based variables as scale variables and long-term interest rates as opportunity cost variables. Whereas the transaction-based theories approve the income-based scale variables and short-term interest rates.

4.2.4.1 Empirical literature on consumption and money demand

Empirical literature that postulates the relationship between consumption expenditure and money demand is scanty. This is a developing strand of research such that even the existing literature has methodological shortcomings because it does not attempt to estimate the impact of the various final expenditure components on money demand. Following arguments by Holmes and Smyth (1972) and Mankiw and Summers (1986), it is important to analyse the impact of each component of final consumption expenditure and determine how it affects money demand. Hence this study pioneered that strand of literature and estimated the impact of energy consumption, particularly solar electricity on money demand and further ascertained if the infusion of mobile money on renewables moderates the relationship.

Empirical studies that have examined the link between consumption and money demand include Tang (2004), who applied the ARDL framework to investigate the long-run relationship between broad money demand (M2) in Japan and its determinants namely: final consumption expenditure, expenditure on investment goods, expenditure on exports, deposit rate, and the government bond yield rate. They found that final consumption expenditure, expenditure on investment goods, and expenditure on exports have the most significant effect on the Japanese broad money demand in the long run. However, in the short- run, all the macro expenditure components and interest rates are significant.

Tlelima and Turner (2004) also used the error correction models to estimate money demand in the South African economy using real GDP and consumption as scale variables. They found that both equations perform reasonably well from a statistical point of view in that none of the diagnostic statistics indicate significant misspecification. However, there were some indications that the equation using GDP as the scale variable performs better from the point of view of its economic interpretation. Therefore, the test is inconclusive in that neither model can reject the other.

Tang (2007) further applied the ARDL estimation technique to investigate the money demand function for five South East Asian countries namely: Malaysia, Thailand, Singapore, the Philippines, and Indonesia. Tang used broad money (M2) as the monetary aggregate variable and consumption as a scale variable proxied by final consumption expenditure, expenditure on investment goods, and expenditure on exports. Tang's results showed that in Malaysia, the Philippines, and Singapore, M2 is cointegrated with final consumption expenditure, expenditure on investment goods, and expenditure on exports. However, there was no evidence of cointegration in Indonesia and Thailand, therefore supporting the view that the choice of the appropriate scale variable varies across countries.

Ruxanda and Muraru (2011) also introduced consumption in the analysis of household money demand in Romania. They applied the cointegrated VAR estimation method, and the consumption deflator was added as an opportunity cost and M2 was also deflated by the consumption deflator. They found that a shock in consumption has an upward effect on money demand. Further, the inclusion of consumption in the money demand function particularly when the monetary aggregate is broad money reveals the shifts inside M2 that occur when an increase in precautionary money is accompanied by a decrease in transaction holdings, which would have been invisible if consumption was not included in the money demand function.

Ben-Salha and Jaidi (2014) also applied the ARDL bounds testing approach to estimate the effects of real income components (final consumption expenditure, expenditure on investment goods, expenditure on total exports of goods and services, and the interest rate) on money demand (M2) in Tunisia for the period between 1979 and 2011. They found that final consumption and interest rates are the only variables that explain long-run money demand in Tunisia, with positive and negative coefficients respectively. Expenditure on investment goods and expenditure on exports have no impact on money demand in the long run. In the short run, expenditure on investment goods has a significant influence on money demand. Algaeed (2016) investigated the short and long-run relationship between broad money supply and private consumption in Saudi Arabia using the Error-Correction Methodology (ECM). The results showed a significant negative relationship between broad money and consumption, therefore, asserting the appropriateness of consumption as a scale variable in a money demand function.

In Nepal, Adhikari (2018) examined the short and long-run relationship between broad money balances, consumption expenditure, capital stock, and interest rate. They applied the ARDL estimation technique, and the results showed that only final consumption expenditure and interest have a positive and significant long-run relationship with broad money balances. This implied that monetary authorities could ensure financial stability through the control of expenditure components such as final consumption in the long run.

Another strand of the literature reveals that the form of monetary aggregate applied in the money demand function also influences the appropriateness of the scale variable. Dahalan et al. (2007) investigated the appropriate scale variable for money demand in Malaysia using income, consumption, disposable income, domestic absorption, and private spending as scale variables. The cointegration results showed that income, as opposed to consumption and other variables, is the appropriate scale for Malaysia. However, if the monetary aggregate is M1, consumption outperforms income as a scale variable. Whereas if the monetary aggregate is M2, the results were less conclusive. They also implied that the inconclusive results of consumption as a scale variable could be because of the smaller share of consumption in Malaysia's economic output, suggesting that the Malaysian economy is not driven by household consumption.

Ziramba (2007) also used the three disaggregated consumption variables: final consumption expenditure, expenditure on investment goods, and expenditure on exports to determine the long-run money demand function of South Africa. They applied the unrestricted error-correction model (UECM) and their results showed that only final consumption expenditure explains the narrow money demand (M1) in South Africa. The demand for M2 and M3 is mainly explained by final consumption expenditure and investment expenditure. This implies that different components of real income have different impacts on the demand for narrow money and broad money in South Africa. Mahanty et al. (2021) employed the ARDL panel methodology on panel data for 10 emerging Asian economies to investigate the short and long-run relationship between household consumption expenditure and money demand. The results showed a strong positive relationship between money and household consumption in the short-run and long run and this relationship continued to hold steady for narrow money (M1) and broad money (M3).

In summary, the literature reviewed shows that scholarly authors have attempted to empirically assess the impact of consumption on money demand in various countries and regions. However, the results are inconclusive. Some studies conclude that the effect of consumption on money demand is country-specific, implying that consumption cannot influence money demand across all countries. Other studies conclude that the impact of consumption on money demand is linked to the form of monetary aggregate employed in the study i.e., M1 or M2 or M3. Further, the estimation methods adopted in these studies vary widely, therefore not providing consistent results across the studies. Also, the number of studies that have explored the impact of consumption on money demand is limited, particularly in SSA.

Lastly, none of these studies have tested the influence of sectoral consumption on money demand, particularly energy consumption. The growing consumption of solar electricity combined with the increasing adoption of mobile money necessitates the analysis of the impact on monetary policy. Therefore, this study contributes to narrowing the literature gap by using a robust estimation technique to examine the impact of solar electricity consumption on money demand in SSA. The results provide monetary policy makers with the impetus to monitor the effects of the growing uptake of solar electricity on financial stability in their economies.

4.2.4 Energy and money demand nexus

The disaggregated approach to determining the factors that influence money demand provides an opportunity to link various components of final consumption expenditure to money demand.

Some of the components that have been used in money demand studies include final consumption expenditure, expenditure on investment goods, and expenditure on exports (Ziramba, 2007); Ben-Salha and Jaidi, 2014). Final consumption expenditure (GDP) is mainly explained by household final consumption expenditure and covers all purchases and payments made by households for food, clothing, energy, transport, durable goods, health, leisure, and other miscellaneous services (OECD, 2013). Energy expenditure forms the core of households spending in developing countries, especially in un-electrified households (Aitken, 2007; Bacon, Bhattacharya, & Kojima, 2010). Therefore, it can explain the demand for real balances in developing countries.

The nexus between energy and money demand is a developing phenomenon, particularly in SSA. The nexus is underpinned by the energy-growth nexus that endorses energy as a factor of production. Theory suggests that any change in energy consumption due to a change in energy prices can lead to changes in economic growth and unemployment (Bhattacharyya, 2019; Hamilton, 1983). Therefore, energy prices and energy consumption have an inverse relationship implying that an increase in energy prices will lead to a decrease in energy consumption, therefore negatively impacting economic growth. On the other hand, another economic theory links energy prices and money demand (Lardic & Mignon, 2008; Tang, Wu, & Zhang, 2010). They argue that an increase in energy prices would have an adverse effect on output growth and productivity because energy is a factor of production. As a result, real wages would decline, thereby increasing unemployment and inflation. Also, when consumers anticipate an increase in energy prices, they will borrow more than save to smoothen their energy consumption. However, that will increase interest rates. Therefore, with an increase in interest rates and slow economic growth, the demand for real cash balances will fall and inflation will increase (Arshad, Zakaria, & Junyang, 2016; Brown & Yücel, 2002).

Energy prices may influence the stability of the money demand function, particularly in countries where the particular type of energy contributes significantly to GDP growth (Alsamara, Mrabet, Dombrecht, & Barkat, 2017). For example, in Saudi Arabia, oil price shocks were found to have an impact on the stability of the money demand function. The results showed evidence of the long-run positive and significant impact of oil price shocks on money demand, whilst no significant effects emanated from oil prices in the short run. The results also highlighted that the positive effects of oil shocks are more important than the negative effects. Also, the effect of the change in oil prices on money demand is a long-run phenomenon, rather than a short-term phenomenon. Lastly, money demand appears to respond more to an increase compared to a decrease in oil prices.

Lizardo and Mollick (2010) also reveal that high energy prices may explain significant depreciation in the value of the local currency. This view was tested empirically by Arshad et al. (2016) while examining the impact of energy prices on economic growth using several indicators such as the real value of the local currency in Pakistan. They applied the GMM estimation technique, and the results showed that a percentage increase in energy prices will significantly reduce the real value of the local currency. This implies that the government of Pakistan should formulate policies that will control energy prices and increase energy consumption to improve economic growth.

From this literature survey, it is evident that the missing link then becomes the relationship between energy consumption and money demand. Energy consumption has not been used widely in money demand studies as part of the disaggregated components of final consumption expenditure. Given the rapid growth of energy consumption in developing countries, particularly solar electricity, it is key to understand the direct influence of energy consumption on money demand, particularly solar electricity which is being rolled out rapidly in most developing countries in SSA. It is for this reason that this study analysed the effects of solar electricity on money demand to provide disaggregated evidence of the effects of energy on economic growth.

4.2.5 Consumption, financial innovation, and money demand nexus

Another aspect of the consumption of solar electricity in the sampled countries is facilitated by financial innovation, namely mobile money. The mobile money payment system is the dominant financial innovation for solar electricity payments and has contributed to the increased number of solar and non-solar transactions in some countries in SSA. Financial innovation is credited for the significant reduction of liquidity constraints related to consumption and deregulating financial markets, therefore leading to a significant increase in consumption (Bayoumi, 1993). Financial innovation such as mobile money enhances household consumption expenditure through the convenience of shopping online, a wider choice of cost-efficient commodities, and a reduction of transaction and time costs (Li, Wu, & Xiao, 2020).

Liu, Pan, and Yin (2020) also allude to the evidence that these mobile digital payments improve transaction efficiency, therefore, facilitating consumption. They also boost rural households' consumption by improving the convenience of consumption activities in rural areas. This impact is also witnessed in socially vulnerable groups such as the elderly, low-income earners, and those with low literacy levels (Zhao, Wu, & Guo, 2022; Zhang, Zhang, and Gong, 2021). However, Luo, Sun, and Zhou (2022) found that the promoting effects of financial innovation on consumption are more prevalent in economically developed areas and high-wealth households than the rural areas and poor households.

The effect of mobile money on consumption can influence money demand as suggested by Dunne & Kasekende (2018) and Thompson (2016) that financial innovation has significant and negative effects on money demand. Earlier innovations such as ATMs were also accredited with reducing households' demand for money because technological progression reduced the cost of withdrawals, therefore, reducing the need to hold cash for precautionary motives (Lippi & Secchi, 2009). Financial innovations can change the structure and motivation of holding money by making financial instruments highly liquid. Therefore, rendering the motivation to hold money for transaction and speculation motives negligible (Dou, 2018). This could have an impact on monetary policy, therefore central banks may have to integrate financial innovation in formulating and implementing monetary policy. However, some authors argue that the increased adoption of financial innovation makes it difficult for monetary authorities to monitor and measure the monetary base (Cohen, 2001; Friedman, 1999). This is because electronic financial instruments induce variation in the velocity of money, therefore constraining the determination of interest rates which destabilises the demand for money.

Empirical studies provide inconclusive evidence on the effects of mobile money on monetary policy. Mawejje and Lakuma (2019) applied the Vector Error Correction Methodology (VECM) to estimate the effects of mobile money on money demand in Uganda. The results showed moderate positive effects of mobile money on money demand. Another strand of the literature shows that mobile money has minimal effects on monetary policy. Ndirangu and Nyamongo (2015) estimated the effect of financial innovation on the stability of money demand in Kenya using the ARDL method. The results showed that the waves of financial innovation that had occurred in Kenya in the period between 1998 and 2013 had not impacted the long-run money demand function. In India, Adil, Hatekar, and Sahoo (2020) estimated the money demand function for India using various financial innovation variables. They employed the ARDL approach to cointegration and found that financial innovation has a positive and significant effect on money demand, implying that it plays a critical role in the specification and stability of money demand.

Djaballah (2020) examined the relationship between financial innovation (ATMs and mobile money) and money supply in the Maghreb countries using the panel ARDL framework. The results showed that mobile money had a positive and significant relationship with both narrow and broad money. Whereas ATMs only had a positive but not significant relationship with broad money. Nnyanzi (2018) examined the direct and indirect effects of technological advances and diversification of the financial sector on money demand in Uganda using the ARDL framework. The results showed that financial innovation played a significant role in decreasing money demand, and the effects are indirectly evident via real income and inflation rates both in the short and long run.

Another strand of literature included financial development in analysing money demand stability. Ahad (2017) investigated the effects of financial development, industrial development, income, and exchange rate on money demand in Pakistan by applying the Vector Error Correction Model (VECM). The results show that financial development has a positive and strong relationship with money demand in Pakistan both in the short and long run. This implies that monetary authorities have to control financial development to ensure financial stability in Pakistan. Apanisile and Osinubi (2020) examined the effects of financial development on the effectiveness of monetary policy in Nigeria. They employed the Bayesian estimation technique and financial development was measured by commercial bank credit to the private sector and terms of trade. Other variables were GDP, interest rate, inflation rate, and exchange rate. The results show that financial development has strong effects on the effectiveness of monetary policy, primarily through commercial bank credit to the private sector. Exchange rate and interest rate also have a strong association with money demand. This means that financial development is a prerequisite for the effective implementation of monetary policy in Nigeria. Adil, Hatekar, Fatima, Nurudeen, and Mohammad (2022) also investigated the effect of financial development on narrow money and broad money in India using the

ARDL approach. The results showed financial development is positively associated with narrow money, therefore showing that the financial reforms in India are yielding positive effects.

However, in South Africa, Sanusi and Meyer (2018) found that financial development measured by credit to the private sector has insignificant effects on money demand. They employed the Bai-Perron Multiple breakpoint tests and the ARDL to analyse the determinants of money demand in South Africa using GDP, interest rate, inflation rate, exchange rate, and financial development. All the other variables were cointegrated with money demand, except for financial development and exchange rate. This implies that in South Africa, financial development is not a significant determinant of money demand. Ma and Lin (2016) dispute the positive association of financial development with monetary policy contrary to most of the existing literature. They conclude that monetary policy declines as financial systems develop, and this is evident in developed economies.

In summary, these studies confirm the significant role of financial innovation on money demand, particularly in developing countries. The studies advance that financial innovation enhances consumption, therefore, bolstering the effects of consumption on money demand. However, the tripartite link between consumption, financial innovation, and money demand has not been explored in previous studies. Most of the studies only linked consumption to financial innovation and financial innovation to money demand, without attempting to estimate the potential link between the three concepts. This gap has motivated the undertaking of this study to provide empirical evidence on whether financial innovation moderates the link between solar electricity consumption and money demand. This is an important link to determine because there is growing consumption of solar electricity facilitated through mobile money payment systems in SSA. Therefore, it is important to examine the effect of the uptake of solar electricity and mobile money on money demand.

4.3 Research Methodology

4.3.1 Data

To estimate the effect of solar electricity consumption and mobile money on money demand (M2), the study employed a sample of 15 countries in SSA namely: Burkina Faso, Cameroon, Côte d'Ivoire, Kenya, Malawi, Mali, Mozambique, Niger, Rwanda, Senegal, Tanzania, Uganda, Togo, Zambia, and Zimbabwe. The study focused on the period between 2010 and 2019.

4.3.1.1 Dependent variable

Money demand is the dependent variable, proxied by broad money (M2) divided by the GDP deflator (Real M2). Broad money includes everyday transactions of money as a form of payment, less liquid assets such as time deposits at commercial banks, savings and loans, and, money market mutual funds (Sriram, 1999). M2 also includes the precautionary motive of holding money, therefore, is a suitable monetary aggregate for the study (Ruxanda & Muraru, 2011). Data on broad money was sourced from the Worldwide Development Indicators (WDI) database published by the World Bank.

Recent studies in developing countries use M2 instead of narrow money (M1) or M3 as a proxy for money demand due to the availability of data on broad money compared to narrow money. Benati, Lucas, Nicolini, and Weber (2021) also state that in recent years, many economists and monetary authorities have doubted the appropriateness of M1 as a measure of monetary supply. One of the reasons is that shocks to real money demand tend to be volatile therefore money-based rules in monetary policy may induce significant volatility. Whereas interest rate rules protect the economy from those shocks because they are immune to such shocks. Also, the level of financial development in developing countries is not at the level where M3 can be used.

Some of the studies that have used M2 as a proxy for money demand include Asongu, Folarin, and Biekpe (2019) in West Africa and, Ben-Salha and Jaidi (2014) in Tunisia, to name a few.

4.3.1.2 Independent variables

This study introduces the disaggregated approach to determining the scale variable for money demand in the 15 countries and introduces consumption as a scale variable, particularly solar electricity consumption into the demand function. Data was sourced from the Our World in Data database published by the Oxford Martin School at the University of Oxford, and the database contains data on solar energy consumption for about 20 African countries for the period between 1965 and 2019. It is the only database with up-to-date data on solar electricity consumption for selected African countries, however, it covers a shorter period.

4.3.1.3 Moderating variable

Mobile money is included as a moderating variable to examine if it moderates the relationship between solar electricity consumption on money demand, particularly in SSA. Mobile money is used as a moderating variable because it is mostly used in solar electricity transactions in the selected countries. The GSMA (2020) also reports that the increase in solar electricity consumption leads to an increase in the broader usage of mobile money for other non-solar transactions. Also, mobile money plays a significant role in increasing the uptake of renewable electricity consumption in developing countries (Dunne & Kasekende, 2018). Therefore, it is expected to moderate the relationship between solar electricity consumption and money demand. Consequently it is used as a moderating variable in this model. Mobile money is measured by various indicators; however, this study used the value of mobile money transactions (VMMT) during the reference year as a percentage of GDP to reflect the mobile money expenditure. Data was sourced from the Financial Access Surveys (FAS**Error! Bookmark not defined.**) database published by the IMF.

4.3.1.4 Control variables

Financial development is one of the control variables. In the existing literature, several proxies are used to capture financial development. However, this study will use the ratio of private credit to GDP as a proxy for financial development due to the unavailability of comprehensive data on the other proxies for the countries studied. This proxy has been used by several studies including a panel data study by Ma and Lin (2016) and single country studies by Ahad (2017) in Pakistan and Adil et al. (2022) in India to name a few. It is expected that a higher ratio implies an increase in domestic investment and therefore higher financial development. However, this is likely to increase money demand, therefore, compromising financial stability (Adil et al., 2022). Data on financial development was obtained from the IMF International Financial Statistics (IFS) which contains worldwide data on financial indicators.

The opportunity cost of holding money is another control variable proxied by interest rate. Interest rates and inflation can be used independently or simultaneously in the money demand function in developing countries (Bashier & Dahlan, 2011). However, inflation could not be used in this model because of the unavailability and poor quality of data on inflation in most of these countries.

The use of lending rate as a proxy for holding money has become a trend in money demand studies and this is justifiable if future short-term interest rates are expected to have a larger effect on money than the real short-term interest rates (Adhikari, 2019). Interest rate is expected to be negatively associated with real money balances. Data on interest rates was sourced from the International Financial Statistics (IFS) published by the IMF.

Table 4.1: Summary of variables

Variables	Notation	Description	Source
Real Money Balances	RealM2	Broad money (% of GDP) divided by GDP deflator	WDI
Solar PV Consumption	SPV	Solar electricity consumption per capita	Oxford Martin School, University of Oxford
Value of mobile money transactions	VMMT	Value of mobile money transactions (during the reference year) (% of GDP)	IMF FAS
Financial development	FD	Private credit to the domestic market as a percentage of GDP	IMF IFS
Interest rates	IR	Lending rate	IMF IFS

4.3.2 Theoretical model

The theory of money demand indicates that real income and the opportunity cost of holding money (interest rates or inflation) determine money demand (Ben-Salha and Jaidi, (2014). This is generally expressed as:

$$\frac{M}{P} = f(Y, I) \qquad (4.4)$$

where *M (*real money balances) and *P* (Consumer Price Index) denote money demand (M/P) as a function of real income (Y) and Interest rates (I). The relationship between money demand and real income is expected to be positive, whilst a negative relationship between interest rates and money demand is expected.

From this general money demand function, we use the demand for broad money (M2) balances to denote money demand and introduce consumption as a disaggregated component of real income and a scale variable, following Mankiw and Summers (1986). Therefore, the money demand function is expressed as:

$$\frac{M2}{P} = f(C, IR) \qquad (4.5)$$

In this study, the proxy for consumption is solar electricity consumption per capita. Interest rates represent the opportunity of holding money. Financial development is included as a control variable. Therefore, the money demand function is expressed as:

$$\frac{M2}{P} = f(SPV, FD, IR) \qquad (4.6)$$

where the demand for real money balances is a function of solar electricity consumption (SPV), financial development (FD), and interest rates (IR). This money demand function addresses the following hypothesis:

Hypothesis 1: Solar electricity consumption influences money demand in SSA

$H_{0:}$ Solar electricity consumption does not influence money demand

$H_{1:}$ Solar electricity consumption influences money demand in SSA.

This hypothesis is based on the transaction theory of money demand which argues that consumption instead of real income is a scale variable for money demand because household consumption expenditures induce more demand for money than other types of transactions (Tang, 2007). Ruxanda and Muraru (2011) also verify that a shock in consumption has an upward effect on money demand, therefore consumption is a determinant of the money demand function.

To estimate the relationship between solar electricity consumption and money demand, the following equation was used:

$$lRealM2_{it} = \beta_0 + \beta_1 SPV_{it} + \beta_2 FD_{it} + \beta_3 IR_{it} + \mu_{it} \qquad (4.7)$$

where i= 1, 2,… .,N, t=1,2, … ., T

Therefore, the demand for real money balances proxied by $lRealM2_{it}$ is a function of solar electricity consumption (SPV), financial development (FD), and interest rates *(IR)*. β_0 is the constant and μ is the error term.

Hypothesis 2: Mobile money moderates the relationship between solar electricity consumption and money demand

H_0: Mobile money does not moderate the relationship between solar electricity consumption and money demand

H_1: Mobile money moderates the relationship between solar electricity consumption and money demand.

This hypothesis is based on the view that financial innovation has positive and significant effects on money demand stability (Thompson, 2016). Also, mobile money enhances household consumption expenditure by providing consumers with convenient online shopping, and a wider variety of products and reducing time and transaction costs (Li et al., 2020). Based on this backdrop, mobile money is introduced to estimate its effect on the relationship between solar electricity consumption and real money balances, and the equation is expressed as:

$$lRealM2_{it} = \beta_0 + \beta_1 SPV_{it} + \beta_2 VMMT_{it} + \beta_3 (SPV_{it} * VMMT_{it}) + \beta_4 IR_{it} + \mu_{it} \tag{4.8}$$

where i= 1, 2,… .,N, t=1,2, … ., T

lRealM2 denotes real money balances, *SPV* denotes solar electricity consumption, *VMMT* represents the value of mobile money transactions, the interaction term (SPV*VMMT), and interest rates are denoted by IR.

4.3.3 Estimation strategy

The relationship between solar electricity consumption, mobile money, and money demand is estimated using a panel Autoregressive Distributed Lag (ARDL) model. The ARDL method is widely used in energy-growth studies because of its flexibility to accommodate the shifts and shocks that shape the energy sector, tolerates different lags in different variables, and provides unbiased estimates and t-statistics, irrespective of the endogeneity of some of the regressors (Menegaki, 2019).

Generally, for small *T* samples, fixed effects, instrumental variables, and generalized method-of-moments (GMM) estimators are proposed as suitable estimators (Pesaran and Smith, 1995). However, because for this panel data, the slope coefficients are not identical and differ significantly across the groups, adopting these traditional estimators would imply stronger homogeneity assumptions across the groups which is inconsistent and can be misleading. Therefore, an estimator with a weaker homogeneity assumption will be ideal which is the panel ARDL with Pooled Mean Group (PMG and Dynamic Fixed Effects (DFE) estimators (Pesaran et al., 1999). Several studies that have used the panel ARDL for small *T* samples include Oluoch, Lal, & Susaeta (2021) that applied the panel ARDL to investigate the factors that influence renewable energy consumption in 23 SSA countries from 1998 to 2014 (16 years). Esen and Bayrak (2017) also applied the panel ARDL in a sample of 75 energy-importing countries from 1990 to 2012 (22 years) to examine the effects of energy consumption on economic growth. Androniceanu and Georgescu (2023) also applied the panel ARDL to examine the impact of carbon emissions and energy consumption on economic growth in a panel of 25 EU member states for the period between 2000-2020 (20 years).

The panel ARDL can be used where the order of integration of the variables is mixed, such as I(0), I(1), or a mixture of both but not I(2). This approach simultaneously produces short and long-run coefficients and unbiased estimates even when there are endogenous covariates. It also provides consistent coefficients because it includes lags of the dependent and independent variables, despite endogeneity problems (Pesaran, Shin, & Smith, 2001). Therefore, this estimation method will address the endogeneity problems that arise from the correlation between solar electricity consumption, money demand, and other unobserved factors that explain money demand.

In carrying out the estimation strategy, the study followed the panel ARDL implementation steps outlined by Menegaki (2019). The first step was to examine the pairwise correlation among the variables. The second step was to undertake panel unit root tests to test whether these variables were stationary or not. The Augmented Dicky-Fuller (ADF)-Fischer test as proposed by (Dickey & Fuller, 1981), was used to test the null hypothesis of unit root tests against the alternative hypothesis. The ADF-Fischer test is considered because it is superior to the Dicky-Fuller (DF) test and it can take care of possible autocorrelation in the error term by adding the lagged difference term of the dependent variable (Nkoro & Uko, 2016). An additional unit root test was also conducted using the Phillips-Perroni (PP) test developed by Kwiatkowski, Phillips, Schmidt, and Shin (1992) to confirm that none of the data sets is integrated of order 2 (i.e., I(2)).

The third stage tested for panel cointegration based on whether stationarity was evident or not. Several tests, such as Kao (1999), Pedroni (2004), and Westerlund (2005) tests are used for panel data. Pedroni (2004) is based on examining residues to determine cointegration. It uses seven cointegration tests that account for heterogeneity in the sample by using specific parameters that are allowed to vary across individual sample units. Unlike other cointegration tests, the Pedroni tests do not report the number of cointegration relationships but provide the degree of evidence or lack thereof of the cointegration among the variables in the panel (Neal, 2014).

On the other hand, Kao's (1999) cointegration test assumes that the vectors of cointegration are homogeneous. Whereas Westerlund's (2005) test uses variance ratio tests that can accommodate individual and specific short-run dynamics, intercept and trend terms, and slope parameters. The null hypothesis of panel cointegration states that there is no cointegration in all panels, whereas the alternative hypothesis is that all panels are cointegrated as shown below:

$$H_0 = \theta_1 = \theta_2 = \theta_3 = \theta_4 = \theta_5;$$

$$H_1 \neq \theta_1 \neq \theta_2 \neq \theta_3 \neq \theta_4 \neq \theta_5. \tag{4.9}$$

where θ represents the long-run coefficients corresponding to long-run relationships. The significance of the θ coefficients determines the long-run cointegration.

The last stage was the regression of the short and long-run relationships by applying the panel ARDL framework. The panel ARDL has three approaches to test panel cointegration: the Mean Group (MG), Pooled Mean Group (PMG), and Dynamic Fixed Effects (DFE). The Mean Group (MG) developed by Pesaran and Smith (1995) allows separate regressions for each country and the coefficients to vary and be heterogenous in both the short and long run. The main assumption of the MG estimator is that the cross-country and time-series dimension must be large because the MG is sensitive to outliers. The MG is, therefore, not an appropriate estimator for this study because the time dimension is not large.

The DFE estimator restricts the slope coefficient and error variances to be equal. It also restricts the speed of adjustment coefficient and the short-run coefficient to be equal as well across all countries. It also features country-specific intercepts as opposed to homogenous intercepts. However, this estimator is subject to a simultaneous-equation bias because of endogeneity between the error term and the lagged dependent variables, particularly in small samples.

The PMG approach proposed by Pesaran, Shin, and Smith (1999) is regarded as the best among the three approaches because it provides an increase in the efficiency of the estimates for mean group estimators. According to Pesaran et al. (1999), the PMG allows the short-run coefficients, the intercept, the speed of adjustment to the long-run equilibrium values, and error variances to be heterogeneous country by country while the long-run slope coefficients are homogeneous across countries.

The main assumptions that have to be fulfilled to ensure the validity, efficiency, and consistency of the PMG estimator include the following: a long-run relationship among the variables of interest must exist, the resulting residual of the error correction model must be serially uncorrelated, and the dynamic specification of the model should be sufficiently augmented so that the explanatory variables can be treated as exogenous variables (Samargandi, Fidrmuc, & Ghosh, 2015). If cointegration is confirmed, the MG and PMG can be used as estimators. However, if cointegration is not confirmed, either the random effects or fixed effects estimators can be applied (Menegaki, 2019).

4.3.4 Model specification

Following Mahanty et al. (2021) on the focus on disaggregating real income components to include consumption, an ARDL equation for equation 4.7 can be written as:

$$lRealM2_{it} = \alpha_i + \sum_{l=1}^{p} \beta_0\, lRealM2_{i,t-l} + \sum_{l=0}^{q} \beta_1\, SPV_{i,t-l} + \sum_{l=0}^{q} \beta_2\, x_{i,t-l} + \mu_{it} \qquad (4.10)$$

Equation 4.10 can be re-written as:

$$\Delta lRealM2_{it} = \alpha_i + \phi_i + \left(lRealM2_{i,t-l} - \theta_1 SPV_{i,t-l} - \theta_2 X_{i,t-l}\right) + \sum_{l=1}^{p-1} \lambda_{il}\, \Delta lRealM2_{i,t-l} + \sum_{l=0}^{q-1} \lambda'_{il}\, \Delta SPV_{i,t-l} + \sum_{l=0}^{q-1} \lambda''_{il}\, \Delta X_{i,t-l} + \mu_{it} \qquad (4.11)$$

where *lRealM2* is the dependent variable denoted by the natural logarithm of real money balances (M2), SPV denotes solar electricity consumption per capita, x denotes a set of control variables that include, financial development (FD) and interest rate (IR), λ denotes the short-run coefficients, θ denotes long-run coefficients, ϕ represents the speed of adjustment and *I* and *t* denote country and time respectively and μ is the error term. Lastly, p and q denote the lags of the dependent variable and the regressors respectively.

When introducing mobile money into the model, Equation 4.8 can be written as below:

$$
\begin{aligned}
\Delta lRealM2_{it} = {} & \alpha_i + \phi_i \\
& + \left(lRealM2_{i,t-l} - \theta_1 SPV_{i,t-l} - \theta_2 VMMT_{i,t-l} - \theta_3 \left(SPV_{i,t-l} * VMMT_{i,t-l}\right)\right. \\
& \left. - \theta_4 IR_{i,t-l}\right) + \sum_{l=1}^{p-1} \lambda_{il}\, \Delta lRealM2_{i,t-l} + \sum_{l=0}^{q-1} \lambda'_{il}\, \Delta SPV_{i,t-l} \\
& + \sum_{l=0}^{q-1} \lambda''_{il}\, \Delta VMMT_{i,t-l} + \sum_{l=0}^{q-1} \lambda'''_{il}\, \Delta\left(SPV_{i,t-l} * VMMT_{i.t-l}\right) \\
& + \sum_{l=0}^{q-1} \lambda''''_{il}\, \Delta IR_{i,t-l} + \mu_{it} \qquad (4.12)
\end{aligned}
$$

where the moderating variable: mobile money is included in the money demand function and denoted by the value of mobile money transactions (*VMMT)*.

4.3.3.1 Estimation method for robustness

To test for the validity of the long-run results, the study employed the Dynamic Ordinary Least Squares (DOLS) introduced by Kao and Chiang (2000) to estimate the coefficients of the long-run money demand function in the 15 countries in SSA. The DOLS technique is superior that the OLS and FMOLS in terms of the mean biases because it does not require initial estimation and non-parametric correction. The DOLS also performs better in both cases of homogenous and heterogenous panels (Kao & Chiang, 2000).

In the DOLS regression, the estimation of the long-run coefficients is enhanced by leads and lags of the explanatory variables, and this deals with problems of endogeneity and serial correlations (Mark & Sul, 2003). The DOLS estimator remains consistent in long-run cointegration and robust to exclusion of variables that are weak in the long-run relationship (Foresti & Napolitano, 2013). The DOLS estimator has been used by several studies when estimating the long-run money demand. Following Kao and Chiang (2000), we obtained the DOLS results by running the following equation:

$$y_{it} = \alpha_i + X'_{it}\beta + \sum_{j=-p}^{q} C_{ij}\,\Delta X_{it+j} + \mu_{it} \qquad (4.13)$$

In the DOLS framework, equation 4.7 can be re-written as below:

$$lRealM2_{it} = \alpha_i + \beta_1 SPV_{it} + \beta_2 FD_{it} + \beta_3 IR_{it} + \sum_{j=-p}^{q} \theta_{1ij}\,\Delta SPV_{it+j} + \sum_{j=-p}^{q} \theta_{2i}\;\; \Delta FD_{it+j} + \sum_{j=-p}^{q} \theta_{2ij}\,\Delta IR_{it+j} + \mu_{it} \qquad (4.14)$$

The introduction of the interaction term in equation 4.8 is estimated using the following DOLS equation:

$$lRealM2_{it} = \alpha_i + \beta_1 SPV_{it} + \beta_2 VMMT_{it} + \beta_3 (SPV_{it} * VMMT_{it}) + \beta_4 IR_{it} + \sum_{j=-p}^{q} \theta_{1ij}\,\Delta SPV_{it+j} + \sum_{j=-p}^{q} \theta_{2ij}\,\Delta VMMT_{it+j} + \sum_{j=-p}^{q} \theta_{3i}\;\; \Delta\big(SPV_{it+j} * VMMT_{it+j}\big) + \sum_{j=-p}^{q} \theta_{4ij}\,\Delta IR_{it+j} + \mu_{it} \qquad (4.15)$$

where q denotes leads and p denotes lags, θ_{1ij}, θ_{2ij}, θ_{3ij}, θ_{4ij} denote the coefficients of lead and lag differences that handle problems of endogeneity and serial correlation to provide unbiased estimates.

4.4 Empirical results

This section discusses the results of the study, starting with the descriptive statistics, pairwise correlation, panel unit root tests, cointegration tests, and the regression output. The study reports two sets of ARDL results. The first set of results has no mobile money variable, whilst the second set has the mobile money variable.

4.4.1 Descriptive statistics

The descriptive statistics explain the degree of reliability and variation in the variables used in this study. The dependent and independent variables must have significant variation, and this will be evident by a high value of standard deviation and a large difference between the minimum and maximum values. Table 4.2 presents the descriptive statistics for the variables used in the ARDL model. The results show significant variation within the dependent and independent variables. The total number of observations was 150.

The dependent variable: broad money (real money balances) has a mean of 0.249, a standard deviation of 0.101, and minimum and maximum values of 0.060 and 0.517 respectively. This implies that money demand in SSA has not changed considerably over the years. Solar electricity consumption has a mean of 0.893, a standard deviation of 1.717, and minimum and maximum values of 0.004 and 10.841 respectively. FD has a mean of 19.593 and a standard deviation of 7.555, implying that financial development has varied significantly over the years in SSA. Interest rate has a mean of 12.13, a standard deviation of 9.177, and minimum and maximum values of 2.45 and 46.011. The value of mobile money transactions (VMMT) has a mean of 20.343, a standard deviation of 48.05, and minimum and maximum values of 0.005 and 535.732. The results imply that the region has experienced variations in interest rates and mobile money transactions in the period under study. In summary, the standard deviations are large enough to explore the variations in the data.

Table 4.2: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
RealM2	150	0.249	0.101	0.060	0.517
SPV	150	0.893	1.717	0.004	10.841
FD	150	19.593	7.555	6.753	40.204
IR	150	12.130	9.177	2.45	46.011
VMMT	150	20.343	48.050	0.005	535.732

Note: M2=Broad Money, SPV=Solar electricity consumption, FD=Financial development, IR=Interest rate, VMMT=Value of mobile money transactions

4.4.2 Pairwise correlation matrix

The statistics in the pairwise correlation matrix in Table 4.3 show the level of correlations among the variables. The correlation analysis is important to identify if multicollinearity is evident in this series. The correlation shows that solar electricity consumption and interest rates are negatively correlated with broad money. However, financial development and the value of mobile money transactions are positively correlated with broad money. This analysis shows no evidence of multicollinearity meaning that the variables do not have a linear dependence on each other. Therefore, all the variables are fit to be used in this model.

Table 4.3: Pairwise correlation matrix

Variables	RealM2	SPV	FD	IR	VMMT
RealM2	1.000				
SPV	-0.021	1.000			
FD	0.777	0.208	1.000		
IR	-0.438	0.054	-0.236	1.000	
VMMT	0.035	0.069	-0.087	0.059	1.000

Note: M2=Broad Money, SPV=Solar electricity consumption, FD=Financial development, IR=Interest rate, VMMT=Value of mobile money transactions

4.4.3 Unit root test results

The ADF-Fischer and PP-Fischer unit root tests were employed to determine the order of integration of the variables. The unit root test results as presented in Table 4.4 and Table 4.5. The null hypothesis of the ADF-Fischer unit root test is that there is a unit root (non-stationarity of the time series), whereas the alternative hypothesis is that there is no unit root test (stationarity of the time series). The ADF-Fischer and PP-Fischer unit root tests show that some of the data sets are integrated of I(0) and I(1). The ADF-Fischer test results show that all the variables except for solar electricity consumption are integrated to the order I(0) and significant at 1% level. Solar electricity consumption is integrated to the order I(1) and significant at 1% significance level at first differencing.

The PP-Fischer unit test results also show that only financial development is stationary at levels I(0), and the remaining data sets are stationary at first differencing I(1). Therefore, we reject the null hypothesis of non-stationarity and accept the alternative hypothesis that all panels are stationary. Also, since none of the variables are integrated of order two I(2), the ARDL approach is the appropriate estimation method.

Table 4.4: ADF-Fischer unit root test results

Variables	Level	1^{st} Difference	Order of Integration
lRealM2	0.0001***	0.0000***	I(0)
SPV	1.0000	0.0000***	I(1)
FD	0.0000***	0.0000***	I(0)
IR	0.0001***	0.0000***	I(0)
VMMT	0.0011***	0.0000***	I(0)

Note: Standard errors in parentheses. *** significant at 1%, ** significant at 5%, * significant at 10%

M2=Broad Money, SPV=Solar electricity consumption, FD=Financial development, IR=Interest rate, VMMT=Value of mobile money transactions

Table 4.5: PP-Fischer unit root test results

Variables	Level	1st Difference	Order of Integration
lRealM2	0.4316	0.0000***	I(1)
SPV	1.0000	0.0000***	I(1)
FD	0.0000***	0.0000***	I(0)
IR	0.9476	0.000***	I(1)
VMMT	0.1269	0.000***	I(1)

Note: Standard errors in parentheses. *** significant at 1%, ** significant at 5%, * significant at 10%

M2=Broad Money, SPV=Solar electricity consumption, FD=Financial development, IR=Interest rate, VMMT=Value of mobile money transactions

4.4.4 Cointegration test results

The cointegration tests were performed to verify the presence of long-run relations between the data variables using Pedroni (2004) tests. Pedroni (2004) uses seven tests to assess panel cointegration among variables and these include the panel variance ratio test, panel rho test, panel t-test and panel ADF test, group rho test, group t-test, and group ADF test.

The Pedroni tests are divided into two categories, panel statistics, and group-mean statistics. The panel statistics pool the test statistics of individual countries along the within-dimension, whereas the group-mean statistics average the results of the test statistics of individual countries (Neal, 2014). The panel cointegration statistics, also known as the within-dimension-based statistics,[6] are the first four statistics: the panel variance ratio, panel rho, panel t-statistic, and ADF test. These tests are non-parametric except for the ADF test, which is parametric (Pedroni, 1999, 2004). Whereas group-mean statistics, also known as the between-dimension-based statistics,[7] entail the last three statistics: the group rho statistics, group t-statistics, and the group ADF tests that are parametric statistics (Pedroni, 1999, 2004). To test for cointegration, the

[6] They are constructed by pooling the statistics of individual countries across the within dimension of the panel Pedroni (1999, 2004)

[7] They are constructed through pooling the statistics along the within dimension of the panel Pedroni (1999, 2004)

panel variance statistics diverge to positive infinity under the alternative hypothesis. Large positive values of the panel variance statistics imply that the null hypothesis of no cointegration must be rejected. The remaining six statistics diverge to negative infinity under the alternative hypothesis, therefore when their negative values are large, the null hypothesis of no cointegration is rejected (Pedroni, 1999).

The results from the panel cointegration tests of Pedroni (2004) are presented in Table 4.6 below. The large negative values in the four tests out of the six tests imply that we must reject the null hypothesis of no cointegration and confirm that there is a long-run relationship among the variables. The Westerlund cointegration test also confirmed cointegration among the variable at 10% significance levels as shown in Table 4.7 below.

Table 4.6: Pedroni test for cointegration

Test Statistics	Panel	Group
Variance ratio test	-1.501	.
Rho-test	2.579	4.379
t-test	-4.902	-5.316
adf-test	-3.102	-3.175

Table 4.7: Westerlund test for cointegration

	Statistic	*p*-value
Variance ratio	1.4400	0.0749*

*** significant at 1%, ** significant at 5%, * significant at 10%

4.4.5 ARDL results for the estimation of the relationship between solar electricity consumption and money demand

The study applied the ARDL approach with PMG and DFE estimators to estimate the effect of solar electricity consumption on money demand in 15 countries in SSA. The analysis did not provide output for the MG because it is very sensitive to outlying country estimates obtained from small *T*, therefore it becomes very inefficient. As a result, the study used the PMG and DFE estimators.

The DFE estimator restricts the speed of adjustment of the coefficient and the short-run coefficient to be equal as well across all countries. It also features country-specific intercepts as opposed to homogenous intercepts. Whereas the PMG allows the short-run coefficients, the intercept, the speed of adjustment to the long-run equilibrium values, and error variances to be heterogeneous country by country while the long-run slope coefficients are homogeneous across countries. The main advantage of the PMG estimator is its ability to deal with small samples, simultaneously correct auto-correlation, and shows minimum sensitivity in the presence of outliers (Pesaran et al., (1999). The optimal lag structure of the ARDL model is (1,1,1,1).

The Hausman test was employed to decide on the appropriate estimator (either DFE or PMG) to be used in the study. The rule of the Hausman test is that if the p-value is <0.05, one accepts the null (Fixed effects) and rejects the alternative (PMG). For this study, the Hausman test results show a test statistic of 15.45 with a p-value of 0.0015 (p-value <0.05) suggesting that we accept the null (the DFE) and reject the alternative i.e., the PMG model. This implies that the results will show country-specific intercepts as opposed to homogenous intercepts. Therefore, this study reports the DFE results and uses the PMG results for comparison as presented in Table 4.8. The short-run estimation results show the error correction term (ECT) that measures the speed at which the variables converge to equilibrium in the long run. The

DFE results show that the ECT has a negative coefficient and is statistically significant at 1%. This implies that the cointegration among the variables is statistically significant at 1% and any deviation from the long-run equilibrium is adjusted in the short run at a 14% adjustment speed.

When estimating the effect of solar electricity consumption on money demand, the short-run estimation results show a negative and insignificant relationship. This implies that a percentage increase in solar electricity consumption will have a negative but insignificant impact on money demand in the short run. However, financial development has a positive coefficient and is statistically significant at a 1% significance level with broad money in the short run. Therefore, a percentage increase in financial development will significantly increase the demand for broad money in the short run. Interest rates have a negative coefficient and are statistically significant at 1% with broad money, implying that a percentage increase in interest rates will decrease demand for broad money. Therefore, these results imply that only financial development and interest rates affect broad money in the short run.

In the long-run, solar electricity consumption still has a negative and insignificant relationship with broad money balances. This implies that the effect of solar electricity consumption on broad money balances is weak, even though negative. Financial development also has a positive coefficient and is statistically significant at 5%, whilst interest rates also have a negative coefficient and are significant at 5%.

In essence, the results, imply that solar electricity consumption has no significant impact on broad money both in the short run and the long run and will, therefore, not influence the monetary policy of these countries in SSA. Therefore, the study does not reject the null hypothesis that solar electricity consumption does not influence money demand.

Table 4.8: ARDL results for the effect of solar electricity consumption on money demand

	DFE		PMG	
Variables	Long-Run	Short-Run	Long-Run	Short-Run
ECT		-0.1448***		-0.5005***
		(0.0579)		(0.1267)
ΔSPV		-0.0071		0.0029
		(0.0109)		(0.1857)
ΔFD		0.0218***		0.0256***
		(0.0044)		(0.0098)
ΔIR		-0.0124***		0.0591*
		(0.0043)		(0.0339)
SPV	-0.0229		0.0017	
	(0.0479)		(0.0091)	
FD	0.0574**		0.0343***	
	(0.0283)		(0.0017)	
IR	-0.0631**		-0.1539***	
	(0.0321)		(0.0138)	
Constant		-0.2810**		-0.4176**
		(0.1213)		(0.1689)

Hausman test (DFE, PMG)
$Chi^2(3) = 15.45$
Chi^2 *p*-value = 0.0015

Note: M2=Broad Money, SPV=Solar electricity consumption, FD=Financial development, IR=Interest rate, VMMT=Value of mobile money transactions

4.4.5.1 Robustness checks for the relationship between solar electricity consumption and money demand

A robustness check was performed in two ways. Firstly, the DFE results were compared to the PMG results shown in Table 4.8 and secondly, the results of the Dynamic Ordinary Least Squares (DOLS) in Table 4.9 were used to validate the results of the DFE estimator.

The PMG results show a negative and statistically significant error term, which implies that there is a long-run cointegration relationship among the variables that are statistically significant at 1% with an adjustment speed of 50%. However, the results show that in the short run, only financial development and interest rates have a significant effect on broad money. Solar electricity consumption has a positive coefficient but is statistically insignificant both in the short and long run. Even though the coefficient is positive, the results align with the DFE estimation results and confirm the insignificant effect of solar electricity consumption on broad money.

Financial development has a positive and statistically significant relationship with broad money at a 1% significance level both in the short run and the long run. This is in line with the results of the DFE estimator. Interest rates also have a negative and statistically significant relationship with broad money at 10% in the short run and 1% in the long run. These results align with the DFE estimation results. In summary, the PMG results are in line with the DFE results, except for the different coefficients of solar electricity but the significance levels are the same.

The second robustness test was done using the DOLS estimation technique as developed by Kao and Chiang (2000). The DOLS follows a parametric approach and introduces lags and leads of the explanatory variables to handle the problem of autocorrelation. It is also good for small samples and handling heterogeneity. The results reported here were selected with no lead and no lag and had an R^2 of 0.88.

The DOLS results in Table 4.9 show that solar electricity consumption has a negative coefficient and is insignificant to broad money balances in the long run. However, financial development has a positive and statistically significant relationship at 1% significance levels. Therefore a 1% increase in financial development will increase broad money balances by 0.04%.

Whereas interest rates have a negative coefficient and are statistically significant at 10% in the long- run. This implies that a 1% increase in interest rates will reduce broad money balances by 0.01%. In summary, the significance level, and the signs of the coefficients of the variables in the DOLS results are consistent with that of the DFE results. Therefore, it can be confirmed that the DFE is a robust model for estimating the short-run and long-run relationship between solar electricity consumption and broad money.

Table 4.9: Dynamic OLS results for the effect of solar electricity consumption on money demand

Dependent variable: lRealM2	Coefficient	Standard Error	*p*-value
SPV	-0.0133	0.0185	0.474
FD	0.0443	0.0073	0.000***
IR	-0.0144	0.0074	0.051**
R-Squared = 0.8843			
Wald Chi^2 (3) = 43.83			
Prob Chi^2 = 0.000***			

Note: Standard errors in parentheses. *** significant at 1%, ** significant at 5%, * significant at 10%
M2=Broad Money, SPV=Solar electricity consumption, FD=Financial development, IR=Interest rate, VMMT=Value of mobile money transactions

4.4.6 ARDL results for the estimation of the effect of the interaction of solar electricity consumption and mobile money on money demand

This section reports the ARDL results of the interaction between mobile money and solar electricity and the effect on money demand, estimated with the DFE and PMG estimators as shown in Table 4.10. The analysis did not provide output for the MG because it is very sensitive to outlying country estimates obtained from small *T*, therefore it becomes very inefficient. As a result, the study used the PMG and DFE estimators.

To ensure that the appropriate estimator is used, the Hausman test was conducted, and the results showed a Chi statistic of 5.04 and a *p*-value of 0.2830. Therefore, the study rejects the null hypothesis (DFE) and accepts the alternative hypothesis (PMG) using the rule that the *p*-value must be <0.05 to accept the null (DFE). Therefore, the appropriate estimator for this estimation is the PMG. However, the study presents both PMG and DFE results for comparison. The optimal lag structure for the ARDL model is (1,1,0,0,1). Before analysing the coefficients of the variables, it is worth mentioning that the coefficient of the ECT is negative and statistically significant at 1% with an adjustment speed of 51%. This confirms the existence of a long-run cointegration among the variables.

When introducing mobile money as an interacting term with solar electricity consumption in a short-run model, the results show that only interest rates affect broad money in the short run at a 10% significance level with a negative coefficient of 0.04. Solar electricity consumption has a positive coefficient but is insignificant. Mobile money also enters the model with a negative but insignificant coefficient. The interaction term also enters with a positive but insignificant coefficient. This implies that mobile money does not appear to moderate the effects of solar electricity consumption on money demand in the short run.

However, the long-run estimation results show that the coefficients of all the variables are statistically significant at a 1% significance level. Solar electricity consumption has a long-run and positive relationship with money demand, suggesting that a 1% increase in solar electricity consumption will increase broad money by 0.11%. This implies that solar electricity consumption is a determinant of the long-run money demand function when mobile money is included in the money demand function. This insinuates an adverse effect of solar electricity consumption on the stability of the monetary policy in these countries. Therefore, policymakers should monitor the effects of the increasing integration of financial innovation into solar electricity consumption to minimize the effects on the demand for real money balances.

Mobile money also has a positive and significant association with money demand. This implies that the increase in mobile money transactions increases the demand for broad money balances and this can present challenges in maintaining financial stability in these countries. When mobile money interacts with solar electricity consumption, the results show a positive and statistically significant long-run relationship. Therefore a 1% increase in the interaction of mobile money and solar electricity increases the demand for holding broad money by 0.001% in these countries. This implies an adverse effect of mobile money on the relationship between solar electricity consumption and money demand in the long run.

Interest rates have a negative and significant coefficient, suggesting that a 1% increase in interest rates will decrease broad money demand by 0.14%. Therefore, the study does not reject the null hypothesis that mobile money does not moderate the relationship between solar electricity consumption and money demand.

Table 4.10: ARDL results for the effect of the interaction of solar electricity consumption with mobile money on money demand

Dependent variable: Money demand (lRealM2)

	DFE		PMG	
Variables	Long Run	Short Run	Long Run	Short Run
ECT		-0.108*		-0.5110***
		(0.0587)		(0.1397)
ΔSPV		-0.0090		0.3940
		(0.0172)		(0.6947)
ΔVMMT		-0.0023		-0.0080
		(0.0015)		(0.0311)
ΔSPV*VMMT		0.0008		0.298
		(0.0013)		(0.225)
ΔIR		-0.0118***		-0.0453*
		(0.0045)		(0.0271)
SPV	0.1099		0.117***	
	(0.1460)		(0.0277)	
VMMT	0.0085		0.0014***	
	(0.0102)		(0.0005)	
SPV*VMMT	-0.0079		0.0019***	
	(0.0093)		(0.0004)	
IR	-0.1083*		-0.1461***	
	(0.0629)		(0.0061)	
Constant		-0.0263		-0.144
		(0.0920)		(0.168)
Hausman test: (DFE, PMG)				
$Chi^2(4) = 5.04$				
$Prob\ Chi^2 = 0.2830$				

Note: Standard errors in parentheses. *** significant at 1%, ** significant at 5%, * significant at 10%

M2=Broad Money, SPV=Solar electricity consumption, VMMT=Value of mobile money transactions, IR=Interest rate

4.4.6.1. Robustness checks for the relationship between solar electricity consumption and money demand

To confirm the validity of these results, the study tested for robustness in two ways. First, the PMG results were compared with those of the DFE in Table 4.10, and secondly, the DOLS technique was used to validate the PMG results and the results are presented in Table 4.11.

The DFE estimation results show that there is a long-run cointegration among the variables. This is evident from the ECT which is negative and statistically significant at 10% with an adjustment speed of 10%. The short-run results show that only interest rates have a significant effect on broad money at 1% significance levels. Solar electricity consumption and mobile money have a negative and insignificant relationship. Also, the interaction between solar electricity consumption and mobile money is insignificant but has positive effects on broad money. The significance levels of the short-run results are consistent with those of the PMG and the coefficient signs are also consistent except for solar electricity consumption which has a positive sign even though insignificant.

The long-run results also show that only interest rates significantly impact broad money in the long run. Solar electricity consumption and mobile have positive coefficients and are insignificant. When solar electricity consumption interacts with mobile money the coefficient is negative but insignificant. This is the only variable that has a coefficient sign that is inconsistent with that of the same variable in the PMG estimator. Interest rates have a negative and significant coefficient.

Therefore, the long-run results are consistent with those of the PMG, the only difference is that the significance level is weaker and the interaction between solar electricity consumption and mobile money is negative, whereas the PMG reports a positive coefficient.

The second robustness tests report the results of the DOLS in Table 4.11. The best DOLS model was selected with 1 lead and l lag and the highest R^2. The DOLS results are consistent with those of the long-run PMG estimator, except for solar electricity consumption. Solar electricity consumption in the DOLS model has a negative and insignificant effect on broad money, which is inconsistent with the positive and significant effect reported in the PMG model. Mobile money has a positive and significant effect, and this effect is also evident when solar electricity interacts with mobile money.

This is consistent with the base results reported by the PMG estimator. Interest rate also has a negative and significant coefficient as reported in the PMG. Therefore, we can conclude that the DOLS results are consistent with the PMG estimator except for the effect of solar electricity consumption.

Table 4.11: Dynamic OLS results for the effect of the interaction between solar electricity consumption and mobile money on money demand

Dependent variable: lRealM2	Coefficient	Standard Error	*p*-value
SPV	-0.0259	0.0317	0.4140
VMMT	0.0056	0.0009	0.0000***
SPV*VMMT	0.0016	0.0009	0.0890*
IR	-0.0244	0.0068	0.0000***
R-Squared = 0.9729 Wald Chi^2 (3) = 322.65 Prob Chi^2 = 0.000***			

Note: Standard errors in parentheses. *** significant at 1%, ** significant at 5%, * significant at 10%
SPV=Solar electricity consumption VMMT=Value of mobile money transactions, IR=Interest rate

4.5 Discussion of Results

4.5.1 Discussion of the results of the estimation of the relationship between solar electricity consumption and money demand

This section discusses the short-run and long-run estimation results for the relationship between solar electricity consumption and money demand, in 15 countries in SSA for the period from 2010 to 2019. The results reveal that the effects of solar electricity consumption on money demand are negative and insignificant both in the short and long run. The negative effect though insignificant implies that a decrease in solar electricity consumption due to a hike in the price of solar technologies among other reasons, will lead consumers to borrow more money to supplement their electricity needs. Therefore, the demand for real money balances will increase in the short-run (Alsamara et al., 2017; Brown & Yücel, 2002). This means policy makers need to promote policies that lead to an increase in solar electricity consumption to ensure that consumers have stable electricity access, increase industrial production and employment decrease demand for real money balances.

Further, the insignificant impact of solar electricity consumption on money demand both in the short-run and long-run results supports the findings of Dahalan et al. (2007) that concluded that if the monetary aggregate M2 is used in a demand function with consumption as a scale variable, the results are inconclusive or insignificant. They attributed the insignificant impact to the smaller share of household consumption in the economic output of Malaysia, implying that the economy of Malaysia is not driven by household consumption. Therefore, it can also be stated that solar electricity consumption in these countries in SSA holds a smaller portion of economic output, hence the results are insignificant both in the short run and long run. In that case, monetary authorities may not be concerned about the rapid deployment of solar technologies and the increased consumption of solar electricity across SSA.

On the other hand, financial development has a strong and positive effect on money demand in these countries. This suggests that several financial reforms and innovations that most countries in SSA have implemented and developed respectively may have adverse effects on financial development both in the short and long run. These results have serious implications for policy makers because they should monitor the scale and frequency of these reforms and innovations to ensure financial stability. These results are corroborated by Apanisile and Osinubi (2020) that found that financial development has a strong effect on the effectiveness of monetary policy in Nigeria.

However, interest rates are found to have a negative and strong association with real money balances both in the short and long run. This implies that when interest rates increase, consumers will demand less money both in the short and the long run. These findings support the findings of Nepal and Paija (2020) that found a negative relationship between interest rates and broad money. Therefore, monetary policy authorities may consider interest rates as an instrument for monetary policy.

4.5.2 Discussion of the results of the effects of the interaction of solar electricity consumption and mobile money on money demand

This section discusses the moderating effect of mobile money on the relationship between solar electricity consumption on money demand in 15 countries in SSA for the period between 2010 and 2019. The short-run results show that when mobile money is included in the money demand function, the relationship between solar electricity consumption becomes positive but still insignificant. This shows that the addition of mobile money changes the direction of the effect solar of electricity consumption on money demand, but the impact is weaker. The positive direction of the effect of solar electricity consumption on money demand supports the findings of Lizardo and Mollick (2010) that show that a decrease in energy consumption due to an increase in prices will decrease the value of the local currency, therefore, reducing money demand. Policy makers need to monitor the rollout of mobile money services and their impact on key macro-economic indicators such as money demand to ensure financial and economic stability.

Subsequently, when mobile money interacts with solar electricity, the impact on money demand remains positive but insignificant. This implies that mobile money does not moderate the relationship between solar electricity consumption and money demand in the short run. These results confirm the findings of Mawejje and Lakuma (2019) and Ndirangu and Nyamongo (2015) that found positive and moderate effects of mobile money on monetary policy in Uganda.

However, the long-run estimation reveals that when mobile money is added to the money demand function, solar electricity consumption has a positive and strong relationship with money demand. These results are in line with Adhikari (2019); Ben-Salha and Jaidi (2014); Mahanty et al. (2021) that hold that an increase in consumption has an upward effect on money demand, particularly broad money. These results also support the findings of Chrystal and Mizen (2005) who state that consumption is directly proportional to money demand. Further, the results support the findings of Arshad et al. (2016) and Brown and Yücel (2002) that in the long term, when energy consumption is low due to high energy prices, industrial production decline, therefore, decreasing the real wage, and increasing unemployment, inflation and interest rates. As a result, demand for real money balances will decline as well, implying a positive impact between energy consumption and money demand in the long run.

These results contradict the view that consumption has a negative effect on money demand that is held by Algaeed (2016) in Saudi Arabia. Therefore the theoretical argument advanced by Dutkowsky and Foote (1992); Mankiw and Summers (1986); Saving (1971) on the importance of consumption on the specification of the money demand, particularly in developing countries is strongly supported by the results of this study. The results also confirm the importance of the disaggregation of real income when specifying the money demand function. These results also confirm the views of (Aitken, 2007; Bacon et al., 2010) that energy expenditure holds a significant portion of household spending in developing countries.

The results also show that mobile money also has an upward effect on increasing money demand. These results are in line with the theoretical view of Cohen (2001) and Friedman (1999) that posit that financial innovation induces volatility in the velocity of money, therefore making it difficult to monitor the monetary base. The results also support the findings of Djaballah (2020) who states that mobile money had a positive and significant relationship with both narrow and broad money in Maghreb countries in the long run. The results are also in line with those of Adil et al. (2020) that found a positive effect of financial innovation on money demand in India. These results are however in contradiction to those of Kasekende (2018); Nnyanzi (2018) who found that financial innovation has negative effects on money demand in SSA, and Dou (2018) that argued that financial innovation makes financial instruments highly liquid, therefore making the transactional and speculative motive of holding money negligible. This suggests that other financial innovations may have adverse effects on monetary policy. Therefore it is important to analyse the impact of each component of financial innovation to provide a direct and accurate policy prescription.

The interaction between mobile money and solar electricity consumption increases money demand. This confirms that mobile money does not moderate the relationship between solar electricity consumption and money demand. In other words, the higher the transactions of mobile money, the greater the effects of solar electricity on money demand. The results support the argument made by Li et al. (2020) and Liu et al. (2020) that mobile money enhances household consumption expenditure through the reduction of transaction and time costs, therefore increasing the spending expenditure and frequency of expenditure. This increased solar electricity consumption expenditure however increases money demand, therefore, leading to adverse effects on the financial stability of these countries. These findings also support the results of the GSMA (2020) that state that the use of mobile money in solar electricity transactions increases non-solar transactions leading to an increase in money demand because customers can convert their mobile money balances to cash and can also deposit cash into their mobile money accounts. This increases the propensity to hold money, not just for solar electricity payments but for other non-solar payments as well.

Overall, policy makers should consider solar electricity consumption as a determinant of the long-run money demand function when mobile money is prevalent in the economy. Also, policy makers should monitor the integration of mobile money into solar electricity consumption as it may have adverse effects in the long run. If access to solar electricity ought to be a benefit to developing countries, rather than a risk, policy makers should pay attention to the long-run effects of the mobile money payment system to ensure stability of money demand.

4.6 Conclusion

The growing demand for solar electricity consumption in developing countries continues to impact other economic development indicators such as money demand. It remained unknown that solar electricity can impact money demand until this study analysed the relationship. This study pursued the argument of analysing the disaggregated components of real income, particularly consumption, to ensure that accurate policy recommendation is provided. This study took the argument a step further by focusing on sectoral consumption, i.e., solar electricity consumption, an approach that had not been adopted by previous scholars. The study applied the panel ARDL estimation technique and examined the effect of solar electricity consumption on money demand, particularly broad money in 15 countries in SSA for the period between 2010 and 2019. The results confirmed that solar electricity consumption is negatively but insignificantly correlated with money demand in both the short-run and the long-run.

Therefore, it cannot be regarded as a determinant of the long-run money demand function in SSA.

However, when mobile money is introduced into the money demand function, solar electricity consumption remains insignificant in the short run but positive and significant in the long run. Therefore, it can be said in the presence of mobile money, solar electricity consumption is a significant determinant of the long-run money demand function in SSA. On the other hand, the interaction between solar electricity consumption and mobile money also produces positive and significant effects on money demand in the long run. This implies that mobile money does not moderate the effects of solar electricity on money demand, however, it induces an upward effect that has adverse effects on money demand. Therefore, policymakers should monitor the effects of the integration of mobile money into solar electricity consumption to ensure financial stability in the long run.

4.7 Recommendation

The findings of the study have important recommendations to policy makers in SSA. Firstly, it is recommended that policy makers should promote the rapid uptake of solar electricity technologies in SSA. This will not only improve access to electricity but will also promote the adoption of financial innovation services such as mobile money. Secondly, it also recommended that policy makers should promote the development of financial innovation products and services that will ensure that households and firms hold minimum cash to reduce the demand for cash, particularly for electricity purchases. This will require a collaborative effort from policymakers, energy service providers, telecommunication companies, and the central bank. Thirdly, it is recommended that monetary policy authorities should monitor the effects of the various components of consumption expenditure, particularly solar electricity consumption, to control fluctuation in the price of goods and services in the long run.

Lastly, it is also recommended that central banks should play an active role in the ongoing transition to renewable energy sources, to fully appreciate the effects of the transition on monetary policy. The transition to renewable energy may alter household consumption behaviour, therefore introducing new types of transactions and depositors into the financial system. The transition may also alter the size and quality of the depositors' base in commercial banks, especially because of the integration of mobile money into solar electricity consumption. Further, the transition may also alter the motives of holding money, therefore impacting the demand for real money balances in the economy. It is therefore critical that central banks develop a comprehensive regulatory framework for evaluating the opportunities and risks to the financial sector associated with the transition to a low-carbon economy.

The study faced several limitations that pertain to the availability and quality of data. The study envisioned including several variables in specifying the money demand function. However, data was not available on some of the variables and for those that had data, the quality was not good to include in the model. This led to the selection of the variables used in the study.

Nonetheless, the study makes a significant contribution to the body of literature on the determinants of the money demand function in SSA. It introduces the novel concept of using disaggregated and sectoral consumption in the money demand function to recommend accurate policy interventions. It would however be recommended that future studies employ the narrow monetary aggregate (M1) and inflation to ascertain the effect of solar electricity on narrow money balances.

CHAPTER FIVE

THE EFFECTS OF WELFARE ON SOLAR ELECTRICITY DEMAND IN SUB-SAHARAN AFRICA

5.1 Introduction

This chapter investigates the effects of welfare on solar electricity demand in SSA. The well-being of society, also known as welfare, has been challenged over the years, particularly in developing countries. Most developing countries are characterised by acute poverty[8] and income inequality. This has been aggravated by the recent Covid-19 pandemic that has left society worse off. As a result, there has been an increase in many inequalities across the world such as social instability and fragmentation, and a rise in authoritarianism (United Nations Development Programme [UNDP], 2020).

The efforts of countries toward eliminating poverty were first published in the first Human Development Index (HDI) report published by the UNDP in 1990. In that report, the UNDP states that the most valuable asset any nation has is its people, therefore the basic objective of development should be to create an enabling environment for people to enjoy a long and quality lifestyle. The UNDP also asserts that even though economic development may be measured by national income growth (GDP), human development is a better measure of economic growth because it provides an understanding of how that income growth translates to, or fails to translate to, the welfare of societies (United Nations Development Programme [UNDP], 1990).

Recent reports of the HDI reveal that some African countries have made significant progress in human development; however, most African countries still have an HDI below the median,

[8] According to the global Multidimensional Poverty Index (MPI), poverty encapsulates three dimensions: education, health, and standard of living. The education dimension covers the years of schooling and attendance of school by a child, whereas the health dimension covers child mortality and nutrition. The standard of living dimension covers access to electricity, safe drinking water, improved sanitation, flooring, cooking fuel, and assets (UNDP, 1990).

except for South Africa, Botswana, Algeria, and Lybia which are classified as high human development countries (UNDP, 2020). The low levels of human development, in as much as it is not declining, are bound to negatively influence the quality of life and lifestyle of citizens. Access to electricity is one of the areas where such negative effects can be dominant. Some scholars have recently advanced the proposition that the HDI classification of an economy is highly correlated with the quality and level of energy consumption (Yumashev, Ślusarczyk, Kondrashev, & Mikhaylov, 2020). This is also corroborated by the conservation hypothesis of the energy growth nexus, which advances the proposition that economic growth influences energy consumption[9] (Apergis & Payne, 2011).

Regrettably, in low HDI countries, access to modern renewable energy technologies is not sufficient and affordable to a wider population due to economic hardships and limited income (Sovacool, Burke, Baker, Kotikalapudi, & Wlokas, 2017). Several programs have attempted to encourage households to adopt cleaner and more efficient forms of energy, but with limited success. A majority of poor households revert to traditional fuels at the end of these subsidised programs, which hampers the efforts to transition to cleaner fuels (Yadav, Davies, & Asumadu-Sarkodie, 2021). Hence, even though the cost of renewable technologies has been declining over the decade to 2021, developing countries are still taking longer than developed countries to transition to cleaner energy sources (Akrofi, 2021).

The GSMA (2020) also reports a decline in the frequency of solar electricity transactions in some countries in SSA, while other countries experience an increase in transactions over time. The GSMA study which covered five African countries (Uganda, Rwanda, Benin, Côte d'Ivoire, and Zambia) also revealed that the growth in the value of solar electricity transactions in these countries is lower than the growth in the frequency of transactions. It implies that

[9] Economic growth also influences renewable electricity consumption (Kula, 2014; Odhiambo, 2021).

households tend to do smaller and more frequent transactions, and the reasons have not been explained. Other scholars such as Bisu, Kuhe, and Iortyer (2016) reveal that in Nigeria, solar electricity has the least consumption rate compared to other energy sources due to a lack of access to the appropriate technology. In Pakistan, barriers such as the high initial cost of the solar PV system, lack of technical expertise, and poor renewable energy policies impede the adoption of solar PV (Khan & Latif, 2010). In Rwanda, Grimm, Lenz, Peters, & Sievert (2020) report that solar technologies are still expensive and not affordable to poor households. Regrettably, for the transition to cleaner fuels to happen, easy and affordable access to modern and cleaner fuels is necessary (Muller & Yan, 2018).

This background, therefore, points to a need to investigate how welfare influences the accessibility of these technologies by poor households in SSA. The body of literature examining the factors influencing solar electricity consumption in developing countries is still in the nascent stages. Most literature focused on country-level case studies using household data, that provides country-specific results. Other studies also focus on factors that influence total renewable electricity consumption, without focusing on the various sources of renewable electricity. This approach may not give accurate policy recommendations because renewable electricity sources in SSA are dominated by hydroelectricity. Therefore, any study that does not fully segment the electricity sources may not provide direct policy action. Further, no study could be found that focused on a panel of countries that sought to influence policy direction at the regional level on the effects of welfare on solar electricity deployment.

In an endeavour to shed light on this under-researched area, this study examines the effect of welfare on the demand for solar electricity in SSA. It applies a robust estimation technique - Quantile regression which reveals different effects of welfare along the distribution or quantiles of solar electricity consumption. This methodology provides a comprehensive picture of the effects of welfare on solar electricity consumption which is intended to be useful for formulating policy according to the level of solar electricity consumption in the distribution[10]. This framework also outlines the factors that drive solar electricity demand in SSA to assist policy makers to monitor and promote these factors in policy formulation. Energy Service Providers (ESPs) may also use such results for due diligence when entering new renewable electricity markets or growing their market share in SSA.

5.1.1 Socio-economic overview of Africa

Economic growth in Africa took a deep slump in 2020 due to the Covid-19 pandemic, however, a rebound was witnessed in 2021 where a 6.9% growth in GDP was observed on average across the continent (African Development Bank [AfDB], 2022). North Africa and East Africa had the highest growth rate at 11.7% and 4.8% respectively in 2021 (AfDB, 2022).

Between 2010 and 2018, Africa experienced a decrease in poverty, as the proportion of households with an income below US$1.9 per day fell from 40.2% to 34.4% (United Nations Conference on Trade and Development [UNCTAD], 2022). However, the Covid-19 pandemic reversed the improvement that had been made in poverty alleviation across regions. Inflation increased during the pandemic, mostly driven by food prices, from 2% in 2019 to 11% in 2021 (IMF, 2021). Inequality remains a challenge as the growth experienced in previous years was not inclusive and was not reflected in the human development outcomes. Most African countries are classified as low HDI countries, contributing to the inequitable distribution of income in most countries (UNDP, 2020).

Unemployment also remains a challenge in Africa as the economic growth in previous years has not created sufficient jobs and has not contributed to sustainable development. In 2019, one in three Africans aged 25 and above, was unemployed (UNCTAD, 2022). The healthcare

[10] The Quantile regression estimation method can reveal the effects of welfare on countries with low, medium, and high solar electricity consumption. Each country in the sample belongs to one of the levels or classifications of solar electricity consumption.

system in most countries is also wanting, as revealed by the life expectancy at birth which is still below the world average. The level of education is also a challenge as not all children have access to free, equitable, and quality education (UNCTAD, 2022).

Population growth and urbanisation are also placing huge pressure on infrastructure development for key economic sectors such as energy, telecommunication, roads, railways, etc (AfDB, 2022). Governments have limited scope for fiscal stimulus due to limited resources. As a result, access to reliable and affordable clean electricity remains a challenge in Africa as about 600 million people do not have access to electricity (AfDB, 2022). Therefore, Africa needs to accelerate efforts to increase electricity production and consumption to eradicate energy poverty and build climate resilience (African Union Commission [AUC] & Organisation for Economic Co-operation and Development [OECD], 2022).

Nonetheless, SSA appears to be making significant progress in the adoption of smartphone technology and internet connectivity which are also critical infrastructures for improving energy access. Between 2015 and 2020, smartphone adoption had doubled in SSA, and this uptake was accelerated by the shift to online platforms due to the Covid-19 pandemic. Therefore, Mobile Network Operators (MNOs) witnessed a sharp increase in data subscriptions and usage. However, more work still has to be done to ensure that the remaining 700 million people in SSA that do not have access to internet connectivity are included in the emerging digital opportunities (GSMA, 2021a).

This chapter has seven sections: Section one is the introduction, Section two reviews the theory and empirical literature that underpins welfare and energy demand, and Section three discusses the research methodology. Section four provides an interpretation of the results whereas Section five entails a discussion of the results and their policy implications. Section six provides a conclusion and Section seven discusses policy recommendations, limitations of the study, and recommendations for future studies.

5.2 Theoretical Literature

The welfare of a community is the sum of the utilities of all of the individuals that constitute the community (Lange, 1942). The welfare of society should, ideally, not decline over time to ensure sustainability across generations, otherwise, the level of economic development will be undermined (Gowdy, 2005).

This study analyses the impact of welfare on energy demand (solar electricity) and this relationship is complex because energy consumption is dependent on a myriad of factors such as availability (supply), affordability (energy price), income, and various other social factors such as household demographics (Hartono, Hastuti, Balya, & Pramono, 2020). Therefore, this study employs two consumer behaviour theories to link the welfare of society and solar electricity demand. The study further reviews literature that links the disaggregated components of welfare with solar electricity demand.

5.2.1 Consumer behaviour theories

The nexus between welfare and energy consumption is premised on the economic theory of consumer behaviour. The consumer behaviour theory states that a consumer has a set of preferences that can be described using a utility function and the consumers seek to maximise the utility function based on their income level (Drakopoulos, 1992). Therefore when income increases, households consume more of the same good and they also shift to more sophisticated goods with higher quality (Hosier & Kipondya, 1993). To link the consumer behaviour theory to energy choices, Leach (1992) developed a theory known as the energy ladder theory. The energy ladder theory states that households start with total dependence on inferior fuels such as biomass, as their income increase, they use intermediate fuels such as coal and kerosene, and finally use clean and modern fuels such as electricity and gas (Muller and Yan, 2018).

However, this theory had policy limitations, especially in developing countries because households continue to demand biomass together with other sophisticated energy sources. Hence another household-level approach to this theory had to be developed to capture the changes in energy consumption due to changes in the level of economic development in developing countries and this is known as the fuel stacking theory. These theories are discussed in detail below.

5.2.1.1 The Energy Ladder Theory

The household-level theoretical approach argues that the income level of consumers explains the dynamics of energy use among households and this is known as the energy ladder theory (Leach, 1992). The energy ladder theory states that households face numerous energy supply choices, and these choices can be ordered according to their level of technological sophistication. It outlines a three-stage fuel switching model, which has clean energy such as electricity and LPG at the top of the ladder, transition fuels such as coal, and kerosene at the second stage, and biomass fuels at the bottom and third stage (Heltberg, 2005; Muller and Yan, 2018). This theory holds that if the welfare of households increases, they move up the energy ladder to cleaner energy sources. Therefore, the dominant fuel in low-income households (firewood), will be replaced by electricity and other commercial fuels that offer cleanliness, efficiency, and convenience as household income increases. However, if their welfare decreases due to either a decrease in income or an increase in fuel prices, the household is expected to move down the energy ladder towards biomass fuels or other less sophisticated energy sources (van der Kroon, Brouwer, & van Beukering, 2013).

The tenets of the energy ladder theory are widely supported by the seminal work of various scholars (Chen & Pitt, 2017; Olang, Esteban, & Gasparatos, 2018; Ravindra, Kaur-Sidhu, Mor, & John, 2019). Many of the studies are single-country studies that applied the Probit and Logit estimation models to assess the effect of household welfare on energy consumption. The first strand of studies was conducted in Africa. In Ghana, it was found that sociodemographic factors, household wealth status, and geographic location influence households' access to energy (Crentsil, Asuman, and Fenny, 2019; Karimu, 2015; Twumasi, Jiang, Ameyaw, Danquah, and Acheampong, 2020). Crentsil et al. (2019) assessed the determinants of energy poverty between 2008 and 2014. They applied the Logit regression technique and the results showed that age, gender, level of education, wealth and geographic location, and the level of multidimensional energy poverty have a strong influence on access to energy. Therefore, they recommended that policy makers in Ghana may adopt energy policies that target the under-served population groups and may introduce direct subsidies to incentivise these groups to adopt clean energy sources.

In Nigeria, Adamu, Adamu, Ade, and Akeh (2020) also examined households' behaviour toward energy consumption and their results confirmed the energy ladder hypothesis. Households' demand for energy sources at the bottom of the ladder is interrelated to socio-economic factors that influence energy consumption, and these factors vary across countries. In Ethiopia, Guta (2018) applied the logit model to cross-sectional data collected from two neighbourhoods in central Ethiopia to analyse the factors influencing the adoption of solar technology by these households. The results show that household income and the education level of the head of the household positively influence solar electricity adoption in Ethiopia. This implies that policy makers should develop policies that will enhance income and education of households, particularly rural households to enhance the uptake of solar technologies.

In Kenya, Baek, Jung, and Kang (2020) applied the Multinomial Logit (MNL) model to examine the socio-economic factors that influence household choice of lighting fuel in Kenya. The study separated the choices for on-and off-grid households. The results confirmed the energy ladder hypothesis and showed that when households' income rises, the probability of choosing solar panels as the main lighting fuel increases too. They also confirmed that both on-grid and off-grid households have a high probability of choosing modern fuels for lighting if the head of the household is a female, and if household income, wealth, and education improve. In Mozambique, Broto, Arthur, and Guibrunet (2020) highlight that factors such as dwelling characteristics, household location, and household characteristics have a strong influence on energy demand. They concluded that policymakers do not need to formulate separate policies for influencing household behaviour to clean energy transition.

The second strand of literature focuses on single-country studies conducted on other continents. In Mexico, Rodríguez-Oreggia and Yepez-Garcia (2014) analysed the relationship between households' levels of income and their energy consumption in Mexico, using Tobit and Ordinary Least Squares (OLS) estimation techniques. The results revealed that there is a positive relationship between income and energy demand in Mexico. They concluded that policy makers need to take into consideration the variation in income levels when designing policies that promote the use of different energy sources in Mexico. In India, Hanna and Oliva (2015) studied an asset transfer program to understand the effects of an increase in economic well-being on households' fuel choices. Their results showed that an increase in economic status due to the asset transfer program led to increased consumption of electricity for light. This positive effect was evident even in the poorest members of society.

Another strand of literature that supports the energy ladder theory includes panel data studies such as Borozan (2018) in their study which sought to identify the determinants of energy consumption in households in Europe and whether they are sensitive to the region's level of economic development. They applied the system GMM method and found that the level of economic development in the region influences households' energy consumption patterns. This implies that countries with a low level of economic development may have poor energy consumption. Therefore, policy makers should consider growing their economies to improve energy consumption.

Ai, Du, Li, Li, and Liao (2021) examined the pattern of energy consumption in households for a panel of large population economies from 1990 to 2016. They applied the Seemingly Unrelated Regression (SUR) method and the results showed that average income has a negative and significant association with bioenergy, coal, and oil. Whereas a positive and significant association is evident between electricity, natural gas, and modern renewable technologies. This research shows that a country's energy mix is representative of the pattern of transition of households to clean energy.

Rahut, Behera, and Ali (2017) applied the multinomial logit and ordered probit to data from a Living Standard Measurement (LSM) study in three countries: Malawi, Tanzania, and Ethiopia, to determine factors that influence household use of renewable energy for lighting purposes. The results showed that households headed by females, and wealthy and educated households use renewable electricity for lighting. The study also found that households in Ethiopia and Malawi are highly likely to use renewable electricity compared to households in Tanzania.

However, Alkon, Harish, and Urpelainen (2016) found results that are contrary to the proponents of the energy ladder theory. They found that in India, the cost of energy increases with access to modern fuels, and changes in household income do not explain spending on energy., The energy ladder theory has been criticised for assuming a linear progression of energy adoption, which is in contrast with reality. In reality, households can switch between energy fuels or use a combination of fuels depending on their needs, preferences, and affordability (Bisaga & Parikh, 2018; Kowsari & Zerriffi, 2011). Heltberg (2005) also criticised the energy ladder for emphasising strong income dependence on energy choices, whilst Hanna and Oliva (2015) argue that household welfare does not influence the shift between fuels, but the extent to which electricity is used by households when their welfare increases influence the shift between fuels. Subsequently, scholars developed a complementary theory to the energy ladder theory, known as the fuel stacking or multiple fuel use theory.

5.2.1.2 Fuel Stacking Theory

The fuel stacking theory holds that household decision-making under conditions of energy scarcity or uncertainty is influenced by affordability, technical characteristics of the energy source, cultural preferences, and health impacts (Masera, Saatkamp, & Kammen, 2000; Yadav et al., 2021). The fuel stacking theory also holds that once a household adopts modern fuels, they continue using traditional fuels partially. The reason may be that households may use traditional fuels as insurance against modern fuels that are sometimes unreliable and increase significantly in cost (Kowsari & Zerriffi, 2011). However, Cheng and Urpelainen (2014) argue that fuel stacking varies depending on the available energy sources, the purpose for which the energy source is used, and the geographic context (rural and urban areas). In some contexts, fuel stacking is more relevant to cooking fuels than lighting fuels and sometimes more relevant to rural areas than urban areas.

A review of empirical literature analysing the fuel stacking theory shows that households continue to use multiple fuels as their welfare improves, contrary to the argument advanced by the energy ladder theory by Makonese, Ifegbesan, and Rampedi (2018); Baiyegunhi and Hassan (2014). The first strand of literature focuses on single-country studies in Africa. In Ethiopia, Alem, Beyene, Köhlin, and Mekonnen (2016) examined the factors that determine the choice of fuel by households in Ethiopia's urban sector and how these choices change over time as households' income changes. They employed the multinomial logit model in panel data for the period between 2000 and 2009. Their results show that there was no major shift from traditional fuels to modern fuels, however, as households got richer, they used multiple fuels. This implies that households' economic status matters but an increase in household income does not cause households to stop using traditional fuels. These results were corroborated by Wassie, Rannestad, and Adaramola (2021) in a study they conducted in Southern Ethiopia.

In Tanzania, Choumert-Nkolo, Motel, and Le Roux (2019) applied a panel multinomial-logit approach to determine the fuel choices of households in Tanzania from 2008 to 2013. Their results showed that even though household income has a strong influence on households' transition to modern and clean fuels, the transition is characterised by the significant use of multiple energy fuels. The downside of this phenomenon is that fuel stacking may erode the environmental and socio-economic benefits of access to clean energy.

In Rwanda, Grimm et al. (2020) investigated the willingness to pay for off-grid solar technologies by rural households in Rwanda using a Randomised Control Trial (RCT) method. The study revealed that rural households are willing to pay half of the current market prices for solar power technologies. Further, rural households preferred payment schemes that enabled them to invest in solar technologies with as little change as possible to their cashflow over time, which implies that they need a longer repayment period. High-interest rates also attribute to the need for a longer repayment period. This implies that solar technologies are still deemed expensive relative to rural household income.

There have been several studies conducted in non-African countries. Trac (2011) investigated the use of energy by households in a Chinese village where electricity and fuelwood are accessible and available. Their results show that households continued to use both electricity and fuelwood. This does not demonstrate fuel switching but fuel stacking because the households used multiple energy fuels at the same time, which leads to an overall increase in energy consumption. Sharma (2019) examined the determinants of fuel transition in Nepal. Their results showed that households' behaviour resembled fuel stacking behaviour due to heavy dependence on firewood even though they had access to gas and electricity. Çelik and Oktay (2019) examined the factors that determine household fuel choices in Turkey for the period between 2011 and 2013. Their results show that young and educated households demand modern fuels whereas large households will demand traditional fuels. This implies that policy makers should consider these factors when encouraging the transition from traditional fuels to modern fuels.

Nawaz and Iqbal (2020) examined the impact of a cash transfer program that had a positive income effect on fuel choices for poor households in Pakistan using the regression discontinuity design (RDD) method. Their results showed that the program increased the use of modern fuels and reduced the use of traditional fuels. In some households, the program improved the use of both intermediate and traditional fuels, therefore the fuel stacking hypothesis was confirmed. This implies that policy makers in Pakistan should formulate policies that will promote the availability and accessibility of modern fuels to overcome the increasing demand for traditional fuels.

Panel data studies on the fuel stacking theory are limited but include Kamaludin (2013) who examined the factors that influence electricity consumption in 32 developing countries using the one-step and two-step GMM method. The results revealed that the level of economic development and price of substitute energy fuels in developing countries influence electricity consumption. Rahut et al. (2017) applied the multinomial logit and ordered probit methods to analyse the factors that influence household use of renewable and clean energy sources in Ethiopia, Tanzania, and Malawi. The results are that wealthy and educated households in SSA are highly likely to adopt solar electricity technologies because they are more aware of the adverse effects of fossil fuels and have a higher income capacity which allows them to invest in these technologies.

In summary, the theories and empirical studies reviewed above identify the critical role of household welfare in energy consumption. However, most of those studies have used household data which limited the analysis to in-country studies and smaller locations within a country. It is less frequent that authors compile data from a panel of countries to test the energy ladder theory. Theory and the fuel stacking theory. This approach is not feasible in developing countries because household-level data is limited and not always up to date, hence the panel data approach to examining the welfare effects can offset the effects of data limitations. This finding drawn from the preceding literature review, motivated the choice in this study to use panel data study in SSA, thus taking into consideration the gap in the literature regarding the welfare effects on solar electricity demand.

5.2.2 Human development and energy demand

The UNDP introduced a human development indicator that advocates the welfare of people as the best indicator of economic development. In doing so the UNDP (1990) argued that defining development goes beyond income and wealth but encapsulates the expansion of people's choices. People's choices entail three essential components which are to lead a long and healthy life, acquire knowledge, and access to resources required for a decent standard of living. Also, the UNDP (1990) argues that even though growth in GDP is a good measure of economic development, it conceals important information on how growth translates into human development. Hence the ranking of countries based on GDP provides different results from the HDI country rankings.

For example, the 2020 HDI report reveals that Cameroon ranks high on the Gross National Income (GNI) per capita ranking compared to Zambia and Zimbabwe. However, Cameroon has a low HDI ranking with a value of 0.563 and a position of 153 out of 189 compared to Zambia and Zimbabwe which had values of 0.584 and 0.571 and positions 145 and 150 out of 189 respectively (UNDP, 2020). However, HDI and GDP remain correlated because other components of the index have a non-linear relationship with GDP (Fleurbaey & Blanchet, 2013).

The importance of HDI has gained traction as a measure of economic development and scholars have classified HDI according to an economy's ability to provide access to energy for its population. This argument is premised on the conservation hypothesis of the energy growth nexus which states that economic growth influences energy consumption (Apergis & Payne, 2011). Therefore, countries with a high HDI (developed countries) typically have better access to energy, whereas countries with a low HDI (developing countries) typically have populations with poorer access to energy (Bhattacharyya, 2012).

Also, as countries develop, not only does their energy consumption increase but the mix of energy sources increases as well. This implies that countries rely on biomass energy at a low level of development. However, when they progress towards industrialisation, their demand for petroleum and electricity increases, whereas the demand for biomass decreases (Hosier & Dowd, 1987). Hence countries with the highest HDI use fossil fuels, whereas those with the lowest HDI use traditional fuels. Hence the highest carbon emissions per capita come from high HDI economies (Ray, 2014). Also, low HDI countries have low access to clean and modern electricity compared to their counterparts in high HDI countries (Sovacool et al., 2017).

Several studies have explored the link between human development and energy demand including Martínez and Ebenhack (2008) who examined the link between per capita energy consumption and HDI in many countries. Their results revealed that HDI had a significant effect on energy consumption in most countries and the effect was more significant in low HDI countries. This is mainly because, in the early stages of development, countries tend to focus on growing income per capita, which leads to further environmental degradation. However, when the required income levels were reached, countries shift their focus to promoting environmental sustainability (Abdullah & Morley, 2014).

Van Tran, van Tran, Do, Dinh, and Do (2019) examined the relationship between HDI, energy consumption, and carbon emissions in 93 countries. They applied the system GMM technique, and their results revealed that HDI has a long-run inverse relationship with energy consumption, but a positive relationship with electricity consumption. Azam, Khan, Zaman, and Ahmad (2015) examined the link between HDI and energy consumption in 3-ASEAN countries (Indonesia, Malaysia, and Thailand). Their results revealed that HDI has a positive and significant effect on energy consumption across all those countries. This implies that the economic development policy framework needs to be orientated toward increasing energy supply to ensure sustainable economic growth.

In summary, the effect of HDI on energy consumption is mixed and inconclusive. One reason for this is that there is a dearth of studies that analysed this relationship. Also, none of the existing studies were conducted in low-to-medium HDI countries where energy consumption is also at its lowest. It is in these countries where knowledge of the effect of HDI on energy consumption is critical to enhance policy formulation.

5.2.3 Income inequality and energy demand

Income distribution is one of the welfare factors influencing economic growth in developing countries because of its strong association with poverty (Bagchi & Svejnar, 2015; Brueckner & Lederman, 2015; Lee & Son, 2016). According to Todaro and Smith (2012), income distribution can be divided into two main components: functional distribution and size distribution. However, other authors also include wider functional distribution as a third component. Functional distribution relates to the share of national income allocated to the primary factors of production i.e., land, labour, and capital. Whereas size distribution refers to the share of income allocated to households, the total population in the form of profits either from operating income, gifts, inheritance, etc.

Stiglitz (2015) argues that income inequality hurts economic growth by weakening aggregate demand and widening the inequality of opportunity. This leads to societies that may not make investments in public services such as infrastructure, education, health, etc. that would enhance productivity. However, income distribution may influence economic growth differently based on the stage of economic development Kuznets (2019), implying that income inequality may have negative effects on economic growth at the early stage of economic development, and a positive effect at the mature stage of economic development (Barro, 2000; Mdingi & Ho, 2021; Shin, 2012).

To capture the significance of income inequality to economic growth, it is important to first understand the effect of income inequality on environmental sustainability. This effect is premised on the political economy approach introduced by Boyce (1994). This approach posits that the power and income gap between the rich and poor influences the behaviour of consumers towards the environment and they either follow a consumerist or individualistic approach to environmental quality. For example, if income distribution is not equitable, individuals, both poor and rich, may lose concern for the future of the environment, and consequently engage in behaviour that may lead to environmental degradation (Berthe & Elie, 2015; Ekeocha, 2021).

Many scholars have confirmed the dire effects of income inequality on the environment where a widening income gap in societies increases carbon emissions leading to environmental degradation (Alataş & Akın, 2022). This was confirmed in the seminal work of Masud, Kari, Banna, and Saifullah (2018) which investigated the causal relationship between income inequality and environmental sustainability among ASEAN members. Their study concluded that income inequality has a negative impact on environmental sustainability. Income inequality increases carbon emissions, leading to a decline in environmental sustainability. Therefore, a proper balance between economic growth and resource exploitation would be required to ensure a fair distribution of income in all segments of society.

Wolde-Rufael and Idowu (2017) found the opposite; no significant impact of income inequality on carbon emissions in India and China. However, they still concluded that even though the impact is insignificant, China would benefit from reducing income inequality, whereas in India income redistribution may not reduce carbon emissions.

This background then leads to the strand of literature that examines the effect of income inequality on renewable electricity consumption to reduce carbon emissions and ensure environmental sustainability. Uzar (2020) explores this area and argues that societies with high-income inequality may not support renewable energy technologies because such societies base their resource allocation on the price and costs of deploying renewable energy technologies. Therefore, implying that a fairer income distribution would improve access to clean renewable energy sources. This implies that policy makers can promote the adoption of renewable energy technologies through policies that promote income equality, which would be a significant milestone in the development agenda of developing countries as this will mean targeting two components of the sustainable development goals in a single policy objective.

Churchill, Ivanovski, and Munyanyi (2021) applied time-varying and non-time-varying panel estimation techniques to estimate the effect of income inequality on renewable energy and its components in 17 nations. The non-time-varying results revealed an insignificant effect of income inequality on renewable energy and its components. However, the time-varying panel estimation techniques revealed a negative and significant relationship between income inequality and renewable energy consumption. The components of renewable energy also had varying results. Income inequality has an insignificant effect on hydroelectricity, whereas the effect of income inequality on solar electricity, wind, and biomass is negative and significant. This implies that the estimation technique and the source of electricity play an important role in determining the effect of income inequality on renewable energy consumption. It also means that income inequality could significantly hinder the increase in renewable energy consumption. Therefore, policy makers may consider including income equality targets in the formulation of renewable energy policies, particularly in energy transition policies.

Oluoch, Lal, & Susaeta (2021) applied the ARDL framework and examined the determinants of renewable energy consumption in SSA. They analysed the effect of GDP, life expectancy index, education index, corruption perception index, and carbon emissions on renewable energy consumption. Their results revealed that the GDP and education indexes have a positive and long-run relationship with renewable energy consumption. Whereas carbon emissions and life expectancy have a negative long-run relationship with renewable energy consumption. This implies that socio-economic factors play a significant role in the adoption of clean renewable energy technologies. Therefore, policymakers should consider such factors in policy formulation.

Asongu and Odhiambo (2021) investigated how increasing income inequality affects renewable energy consumption in 39 SSA countries. Their results show that in low- and middle-income countries, higher income inequality leads to a decrease in renewable energy consumption. However, in upper-income countries, higher income inequality increases renewable energy consumption. This implies that countries in SSA need to promote policies that favour income equality and equitable redistribution of income to promote renewable energy consumption. Dong and Hao (2018) also applied the GMM estimation technique to investigate whether the widening income gap in China impacts electricity consumption. The results reveal that the widening income gap had a negative impact on electricity consumption, implying that an increase in the income gap reduces electricity consumption in China. Therefore, the Chinese government should strengthen reforms of the income distribution system and ensure that policies are developed to narrow the income gap. Overall, existing literature establishes the significance of income distribution on the adoption of renewable electricity technologies, however, does not go further to assess the impact on the various sources of renewable electricity.

5.2.4 Learning and energy demand

Learning influences consumer behaviour on environmental issues as consumers that have more knowledge of environmental issues have the willingness to pay a higher price for environmentally friendly products (Rowlands, Parker, & Scott, 2002). Education motivates individuals to use green energy technologies and observe environmental regulations because they become aware of the value of resource conservation and environmental preservation (Jian, Sohail, Ullah, and Majeed, 2021).

Climate education has taken centre stage in many policy discussions, particularly energy policy discussions because the effects of climate change are impacting human development and energy carriers are big contributors to emissions (Shobande & Asongu, 2022). Faiers, Cook, and Neame (2007) attest that consumers analyse products and services to learn about them. Such an analysis requires a certain level of knowledge and is born from the beliefs that consumers have about that product. Therefore education is an indispensable factor in the transition to modern clean renewable energy sources (Zafar, Saleem, Destek, & Caglar, 2022). Zafar, Shahbaz, Sinha, Sengupta, and Qin (2020) also state that education gives an economy the level of awareness required to retain environmental quality and provides several opportunities that shape the future of renewable energy technologies.

To provide a holistic view of the importance of education, it is important to start by reviewing the role of education in environmental sustainability. Bello, Agabo, and Adedoyin (2021) examined the role of education in alleviating carbon emissions in SSA by applying four econometric methods: Pooled OLS, Fixed Effects, Random Effects, and System-GMM. The results were inconclusive as they showed both a positive and negative impact of education on environmental quality depending on the econometric method applied. The authors concluded that in some countries, the current education system does not educate people on environmental sustainability whereas some countries have an education system that educates people on environmental sustainability.

Zafar et al. (2020) also examined the impact of education on carbon emissions in 27 OECD countries. They applied the "continuously updated fully modified (Cup-FM)" and "continuously updated bias-corrected (Cup-BC)" estimation methods to estimate the long-run effects of education. The results showed that education reduces carbon emissions, endorsing the importance of environmental education in an economy. Li, Khattak and Ahmad (2021) also investigated the effect of higher education on environmental sustainability in 30 provinces in China. They applied the DOLS and FMOLS estimation techniques and used carbon emissions as a proxy for environmental sustainability. Their results revealed a negative and significant relationship between higher education and carbon emissions which implies that higher education improves environmental sustainability. This has been achieved because of the energy conservation projects that higher education institutions have developed to minimise their impact on the environment.

A second strand of the literature examines the effect of education on energy consumption. Jian et al. (2021) also investigated the role of education on energy consumption and carbon emissions in China by applying the ARDL bounds testing approach. Their results showed that education had a negative impact on energy consumption, implying that policymakers should reinforce policies that create awareness about energy efficiency in China. Liu, Sohail, Khan, and Majeed (2022) also analysed the impact of education and education expenditure on renewable energy consumption and carbon emissions in BRICS economies. They applied the non-linear ARDL framework, and the results showed that education and education expenditure have positive long-run effects on renewable energy consumption in BRICS economies. This implies that an increase in levels of education and government expenditure on education encourages individuals and societies to observe environmental regulations thereby preserving the quality of the environment. Also, education makes individuals seek to conserve energy and natural resources, promoting the use of clean energy sources. Therefore, BRICS economies should increase their spending on education to increase renewable energy consumption and alleviate pollution.

Katircioğlu (2014) investigated the effect of higher education (tertiary) on electricity and oil consumption in Cyprus by applying the ARDL estimation technique. Their results showed that an increase in higher education enrolments in Cyprus led to an increase in electricity and oil consumption. This is because Cyprus has invested in developing higher education institutions in the last three decades, which have attracted many international students. This led to an increase in electricity and oil consumption in both the short and long term. This implies that the higher education sector in Cyprus plays an active role in promoting electricity consumption. However, the rapid increase in electricity consumption may have unintended environmental consequences in the future. Therefore, it is recommended that Cyprus adopts energy conservation policies that will promote energy efficiency and the use of clean energy sources such as solar electricity.

In summary, the importance of government spending on education, and the integration of climate education in the current education curriculum will serve developing nations well because citizens will have a better appreciation of how their behaviour impacts their environment. The studies surveyed above confirm the positive effects of education on renewable energy consumption. However, few studies focus on SSA, and this leaves a gap in the literature that this study seeks to reduce. With the rapid deployment of solar technologies, it is important to understand the role of education in promoting the adoption of these technologies.

5.2.5 Public health and energy demand

It is commonly assumed that a country's health policy reflects the state of the nation. This is because a quality healthcare system increases the stock of human capital required for higher productivity and income, thereby improving economic output (Boachie, 2017). Therefore, an investment in public health is a welfare-enhancing activity.

The health of a population can be measured by two broad indicators[11]: life expectancy at birth and the infant mortality rate. Life expectancy at birth shows the number of years that a new-born baby is expected to live (Weil, 2014). Therefore, an increase in life expectancy will initially lead to population growth which reduces the capital-to-labour and land-to-labour ratios, thereby depressing income per capita. However, at the later stages of population growth, the decrease in capital and labour ratios attracts more people to enter the labour force therefore improving productivity and increasing income per capita to levels that may even exceed the initial levels (Acemoglu and Johnson, 2007).

On the other hand, the World Health Organisation (WHO) defines infant mortality as the probability of a child born at a specific period dying before they reach the age of one (World Health Organisation [WHO], 2022). Reducing infant mortality is important to developing countries because a majority have high infant mortality, and this negatively impacts the welfare of the total population (Sari & Prasetyani, 2021). At the same time, these developing countries have most of the population without access to clean energy and are greatly affected by climate change. Therefore, it becomes important to investigate the link between health and energy access.

[11] Other individual health measures include years lost to disability, anemia, birth weight and intelligence. Intelligence borders on health and educational development however evidence shows that the biological aspect that relates to health has grown over the years (Weil, 2014).

Most studies have investigated the nature of this relationship and found that access to clean energy sources improves the health and welfare of the population (Arafat et al., 2022; Rahman & Alam, 2021; Shobande, 2020). Clean renewable energy provides a stimulus for the utilisation of modern medical technologies and the storage of valuable medicines (Rahman & Alam, 2021). Whereas, non-renewable energy sources also negatively impact the health of a population by increasing infant mortality and reducing life expectancy (Rasoulinezhad, Taghizadeh-Hesary, & Taghizadeh-Hesary, 2020; Zhang, Chen, & Li, 2021). Fossil fuels contribute significantly to air pollution thereby affecting all living organisms, particularly humans (Sial, Arshed, Amjad, & Khan, 2022).

However, the effect of population health on the demand for renewable electricity remains under-explored. According to the author's knowledge, there is only one study that investigated the effect of health outcomes on energy consumption. This study was conducted by Youssef, Lannes, Rault, and Soucat (2015) and investigated the causality relationship between energy consumption and health outcomes in Africa. The study employed the panel VAR approach and used infant mortality and life expectancy as proxies for health outcomes. The study found a bidirectional relationship between energy consumption and infant mortality in Cameroon and Ghana. The novelty lies in the explanation of the effect of infant mortality on energy consumption. Youssef et al. (2015) state that a possible explanation is that a decrease in infant mortality will lead to an improvement in the quality of human capital in these countries, therefore, improving productivity and output growth. As a result, energy consumption will increase as well.

The study also found a bidirectional causality relationship between energy consumption and life expectancy in Tanzania. Also, evidence of a unidirectional causal relationship running from life expectancy to energy consumption was found in Mozambique. A possible explanation of the effect of life expectancy on energy consumption is that as the quality of health in Tanzania and Mozambique improves, life expectancy increases which then induces an increase in energy consumption. In summary, the varying impact of quality health on energy demand and the dearth of literature analysing this relationship shows the need for more studies that will assess this nexus in SSA.

5.2.6 Information and communication technology and energy demand

ICT is a tool for human development because it is used to seek information and communicate with others and this information becomes knowledge that contributes to human development (Bankole, Shirazi, & Brown, 2011). ICT is also responsible for expanding human freedoms which leads to better efficiency in human activities (Sen, 2010). ICT also provides societies with access to information, facilitates social interaction and access to education and healthcare, and creates new entrepreneurial opportunities (Aksentijević, Ježić, & Zaninović, 2021). Asongu and Le Roux (2017), and Acheampong, Opoku, Dzator, and Kufuor (2022) also assert that increasing ICT enhances inclusive human development in SSA. Countries that have achieved high levels of human and economic development are those that have increased their level of ICT investment and use (Cortés & Navarro, 2011). Therefore, access to ICT can be used as an indicator of human well-being.

The nexus between energy and ICT dates back to the oil price shocks in the 1970s when ways to reduce energy consumption were sought by countries that were greatly affected by the oil price shocks (Sadorsky, 2012). According to Walker (1985), information technology provides a tool for promoting energy efficiency, therefore strengthening the preference for clean energy, particularly electricity. Information technology also impacts energy consumption by increasing the ease and efficiency with which consumers can purchase energy and energy products and services through online and mobile-based applications. ICT also reduces intermediaries in the supply of energy and improves the interaction between consumers and producers, therefore allowing consumers to react swiftly to changes in energy supply and prices (Walker, 1985).

ICT also impacts the supply side of energy by reducing costs and lead times for construction of power plants and enhancing the diversity and performance of energy supply technologies.

Several empirical studies have examined the impact of ICT on electricity consumption, and these include Sadorsky (2012) who examined the impact of ICT on electricity consumption in developing countries. They applied the GMM estimation technique, and the results showed that internet connectivity and mobile phone adoption increase electricity consumption. This implies that policies aimed at improving energy access and consumption in developing countries should take into account the enhancing effects of information communication technology on energy consumption. Saidi, Toumi, and Zaidi (2017) also found a positive and strong relationship between information communication technology proxied by mobile phone subscriptions and internet connections and electricity consumption in 67 global economies using the GMM estimation technique as well. This further confirms the need for deepening ICT capital in developing countries to improve energy access and consumption. Salahuddin and Alam (2015) also examined the short and long-run effects of internet usage on electricity consumption in Australia using the ARDL bounds test for cointegration. The results showed that internet usage stimulates electricity consumption in Australia. This implies that Australia is yet to achieve electricity gains from information communication technology.

Nadimi and Tokimatsu (2018) examined the effects of technology on energy consumption in 112 worldwide countries using the one-way analysis of variance (ANOVA). Their results showed that technology has significant positive effects on energy consumption per capita and the effects are more prevalent in developing countries than in developed countries. Shobande and Asongu (2022) also investigated the effect of education and ICT on environmental sustainability in Eastern and Southern Africa. They applied the panel VAR/VEC Granger causality test and found that ICT and education matter for alleviating carbon emissions and they can be used in a complementary strategy for promoting environmental sustainability.

In summary, the empirical literature confirms the positive effects of ICT on electricity demand, particularly in developing countries. However, ICT products and services can be broad in a way that they may influence electricity consumption differently. In SSA, mobile phone adoption and internet connectivity are the most used ICT components. They, therefore, provide useful data in efforts to analyse how they influence renewable electricity consumption, particularly when solar electricity transactions are facilitated by mobile phones and through the internet.

5.2.7 Unemployment and energy demand

Economic theory does not provide conclusive results on the impact of unemployment, on energy consumption. Earlier theorists such as Krohn (1976) posit that unemployment is not significantly related to energy consumption. However, Mbarek, Abdelkafi, and Feki (2018) hold that there is an interdependent relationship between unemployment and renewable energy generation. Adesina and Mwamba (2019) advance an inverse relationship between unemployment rate and energy consumption. They concluded that a low level of unemployment will lead to an increase in energy consumption and this effect is more evident in low-income countries.

This argument is also asserted by Ng, Yii, Lau, and Go (2022) when investigating the impact of the unemployment rate on ecological footprint using the Augmented Mean Group (AMG) in OECD countries. The results revealed that the unemployment rate has a negative effect on ecological footprint, implying that an increase in the unemployment rate would lead to a decrease in ecological footprint. It also implies that low levels of unemployment have a dire effect on the environment leading to environmental degradation (Adesina & Mwamba, 2019). In summary, the limited literature exploring the link between unemployment and electricity consumption shows that this relationship has not been widely explored, particularly in SSA.

5.2.8 Inflation and energy demand

Socio-economic development factors such as inflation also tend to influence energy consumption, particularly in developing countries. An increase in inflation may induce a shock to energy prices, which could lead to a fall in energy consumption, therefore implying a negative relationship between high inflation and energy consumption (Kamaludin, 2013). Inflation instability creates uncertainty that could reduce total productivity in an economy and delay investment projects that could have increased energy consumption. As a result of inflation instability, the environment is protected from degradation and pollution resulting from fossil-based energy sources (Ahmad, Ullah, Ozturk, & Majeed, 2021).

An increase in inflation also impacts consumers' living standards by lowering their purchasing power, reducing their wealth, inadvertently hurting the economy, and decreasing energy consumption as well. This was concluded by Bilal, Khan, Tan, Azam, and Tauseef Hassan (2022) in their study where they investigated the link between inflation and ecological footprint in Germany. They found a negative and statistically significant link, implying that an increase in inflation may improve environmental quality.

5.2.8 Urbanisation and energy demand

Urbanisation relates to the migration of the rural population to urban areas leading to a suburban concentration in cities and industrial areas (Chace & Walsh, 2006). This leads to an increase in demand for modern energy services and requires simultaneous investment in clean energy sources (Ali, 2021). This is because of the complexity of urbanisation which includes a change in economic, social, spatial, and technological processes. Urbanisation shifts societies from a rural lifestyle that is less energy-intensive to a lifestyle that increases the concentration of economic activities in urban areas, therefore increasing energy consumption (Zhao & Zhang, 2018).

This impact was investigated by Ali (2021) using a panel of 49 countries in SSA. They found that indeed urbanisation positively impacts energy consumption, however, it negatively impacts electricity consumption. This implies that the effect of urbanisation varies based on the source of energy. Solarin and Shahbaz (2013) applied the ARDL bounds test to examine the effect of urbanisation on electricity consumption in Angola. The results showed evidence of a long-run bidirectional relationship between urbanisation and electricity consumption.

To conclude this literature review, it is evident that most studies confirm the effect of welfare on energy consumption. However, they do not investigate the effect of welfare on the different sources of energy, particularly renewable energy sources. This approach is important because the transition to clean energy sources is shifting the focus from fossil fuels to renewable energy technologies, therefore requiring new research that will evaluate the impact of welfare on these energy sources. Secondly, the impact of welfare on energy consumption is diverse and inconclusive as some studies posit a positive impact, some posit a negative impact and others reflect no impact at all. This may be influenced by the methodological procedures applied in the different studies. Most studies use time-series data which provides country-specific results that isolate the effects on a single country, not considering the integration of economies in regions nowadays and the fact that single-country policies are influenced by and can influence other neighbouring countries.

Hence there is a need for a shift towards using panel data to estimate how a change in welfare in each country influences a panel of countries or a region. From the literature survey in this chapter, there are a few panel studies, and they employ various estimation techniques which also lead to diverse results on the impact of welfare on renewable energy consumption. It is also noted from the literature that there is a dearth of studies that examine the effect of welfare on renewable energy consumption in Africa. Several factors may contribute to this including the unavailability of data and low consumption of renewable energy in SSA among others.

Therefore, this leaves a knowledge gap that should be minimised to ensure that SSA benefits from the energy transition. It is for these reasons that this study explores the effect of welfare on solar electricity consumption, to provide empirical evidence that will support accurate policy formulation and implementation for the deployment of renewable energy technologies.

5.3 Research Methodology

5.3.1 Data

To estimate the extent to which the welfare of households influences solar electricity consumption, this study uses panel data from 15 SSA countries for the period between 2010 and 2019. The countries are Burkina Faso, Cameroon, Côte d'Ivoire, Kenya, Malawi, Mali, Mozambique, Niger, Rwanda, Senegal, Tanzania, Uganda, Togo, Zambia, and Zimbabwe. This sample of countries was selected based on their high levels of adoption and use of off-grid solar technologies in SSA. According to the author's knowledge, these countries did not have CSP plants during the period under study; therefore, a very significant portion, if not all, of the solar electricity consumed during the period under study was supplied by off-grid solar electricity technologies.

5.3.1.1 Dependent variable

The dependent variable is solar electricity demand proxied by solar electricity consumption per capita. Data on solar electricity consumption per capita was obtained from the Oxford Martin School at the University of Oxford. Their database contains data from about 20 African countries, covering the period between 2008 and 2019. However, data for African countries is mainly available from 2010 to 2019, hence the period selected for this study.

5.3.1.2 Independent variable

The independent variable is welfare and is proxied by various indicators, including the HDI, inequality in income, infant mortality rate (under-five mortality rate per 1,000 live births), government spending on education, mobile phone subscriptions, and internet users. The unemployment rate is an additional independent variable because of the effect of labour on the production function.

The link between HDI and solar electricity consumption stems from the conservation hypothesis of the energy-growth nexus, which states that economic growth drives renewable electricity consumption (Apergis & Payne, 2011). Empirical studies have also confirmed that HDI has a significant effect on energy consumption in most countries, particularly in low HDI countries (Martínez and Ebenhack, 2008).

HDI has three essential elements: longevity, knowledge, and standard of living. Longevity relates to the quality of health which is measured by life expectancy at birth. The second essential is knowledge which measures a country's overall quality of knowledge and is denoted by the years of schooling for adults aged 25 years and more and the expected years of schooling for children of school entering age literacy rate among adults over 25 years. The third essential element measures the country's standard of living which is denoted by GDP per capita in purchasing power parity terms. The value of the index for each dimension is computed on a scale between 0 and 1, where 0 corresponds to the minimum and 1 corresponds to the maximum value of the indicator. The HDI is then computed as the arithmetic average of the three indices (UNDP, 1990).

Another proxy for welfare that could have been used is GDP per capita. However, it has not been used because GDP does not provide information about income distribution, which is an important phenomenon in assessing welfare (Jones & Klenow, 2016). Energy studies that have used HDI as a variable include Azam et al. (2015); van Tran et al. (2019) and it is expected that an increase in HDI will have a positive effect on solar electricity consumption. Data on HDI was sourced from the Human Development Index database published by the UNDP.

Since the HDI only captures the human development aspect of welfare, instead of poverty, government expenditure, etc., it is important to include other indicators that will provide a holistic view of the effects of welfare on solar electricity consumption to get a broader view. Hence other indicators such as inequality in income, government expenditure on education, infant mortality, mobile phone subscription, and internet usage have been included in the study.

Another proxy for welfare is inequality in income which measures the inequality in the distribution of income in an economy. This variable is associated with poverty because poverty contributes significantly to inequality in the distribution of income. An increase in income inequality can lead to environmental degradation as households revert to cheaper energy sources with high carbon emissions (Wolde-Rufael & Idowu, 2017). Data were obtained from the UNDP database published by the United Nations.

Another proxy is the quality of the healthcare system measured by the infant mortality rate (under-five mortality rate per 1,000 live births). Existing literature reveals a link between infant mortality and energy consumption by stating that a decrease in infant mortality improves the quality of human capital, thus improving productivity and output growth which drives energy consumption (Youssef et al., 2015). However, this relationship has not been explored by existing literature.

The health of a population is generally measured using life expectancy and infant mortality rate. However, this study uses the infant mortality rate because it captures the most significant and observable impact of diseases and reflects the state of the healthcare system, and can signal areas of improvement (Barua, Adeleye, Akam, Ogunrinola, & Shafiq, 2022). Infant mortality is expected to have an inverse relationship with solar electricity consumption. Other studies that have used this variable include Shobande (2020). Data was sourced from the World Development Indicators database published by the World Bank.

Another proxy for welfare is government spending on education as a percentage of GDP[12]. This proxy measures the education aspect of welfare. Education provides an economy with the level of awareness required to maintain environmental quality and adopt renewable energy technologies (Zafar, Shahbaz, Sinha, Sengupta, and Qin (2020).

Previous studies have used primary school enrolment Bello et al. (2021), secondary school enrolment[13] Zafar et al. (2020), and the total number of graduate and postgraduate students in a country Balaguer, Cantavella, and Manuel (2018) as proxies for education. The UNDP used the years of schooling for adults aged 25 years and more and expected years of schooling for children of school-entering age to denote the knowledge aspect of the index. Liu et al. (2022) used government spending on education together with primary school enrolments as proxies for education.

This study also used government spending on education because it reveals the government's policy direction and commitment to improving school enrolments and literacy levels. Also, government spending on education may influence school enrolment, particularly in Africa where education (primary education) is a public good and widely provided by the government (Oseni, Akinbode, Babalola, & Adegboyega, 2020). However, the evidence of the correlation between government spending on education and school enrolments is mixed and inconclusive[14]. Therefore, employing government expenditure on education as a proxy for education in this study even though the HDI also has an educational aspect to it will not result in double counting. Instead, it will broaden the understanding of the effect of education on solar electricity demand. It is expected that government spending on education has a positive impact

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[12] Government spending on education entails current and capital expenditure and includes government spending on public and private educational institutions, education administration and subsidies for students, households and other private entities (Craigwell, Bynoe, and Lowe (2012).

[13] Zafar et al. (2020) argues that an individual requires at least high school education to comprehend environmental issues and take appropriate action for environmental preservation.

[14] Mingat and Tan (2003) found no correlation between government expenditure on education and school enrolment, Baldacci, Guin-Siu, and Mello (2003) found a negative correlation, Oseni et al. (2020) found a positive correlation.

on solar electricity consumption. Data were obtained from the World Development Indicators database published by the World Bank.

Another proxy for welfare is access to ICT and this is included because ICT is a tool for human development. It provides societies with access to information, facilitates social interaction and access to education and healthcare, and creates new entrepreneurial opportunities (Aksentijević et al., 2021). ICT also plays a significant role in electricity consumption because it improves the efficiency with which consumers can purchase energy products and interact with suppliers (Walker, 1985). There are two measures of ICT that are used in this study: mobile phone subscriptions per 100 people and number of internet users which is the number of individuals using the Internet as % of the population.

Mobile phone subscriptions measure the subscriptions to a public mobile telephone service using cellular technology but exclude subscriptions via data cards and other mobile data services. In SSA, mobile phones present a compelling technology that provides access to products and services that can translate to diverse economic and social benefits (Monga & Lin, 2015). Data was sourced from the World Development Indicators database published by the World Bank. Internet connectivity measures the number of individuals that have used the internet from any location (computer, mobile phone, TV, etc) in the last 3 months. Edquist, Goodridge, Haskel, Li, and Lindquist (2018) posit that increased adoption of mobile broadband has positive effects on GDP. However, the effect on energy consumption has not been explored. Data was sourced from the World Development Indicators database published by the World Bank.

Lastly, unemployment rate is another independent variable. It is argued that an increase in unemployment rate leads to a decline in energy consumption (Adesina & Mwamba, 2019). Therefore, an inverse relationship is expected between unemployment and solar electricity demand. Data on employment rate was sourced from the World Development Indicators published by the World Bank.

5.3.1.3 Control variables

CPI and urbanisation were included to control the effects of the macroeconomic environment. This is because a high inflation rate increases the price of goods thereby negatively affecting consumption (Furuoka, 2017). Whereas an increase in urbanisation positively influences energy consumption (Zhao & Zhang, 2018). Data was sourced from the World Development Indicators published by the World Bank.

The list of variables is therefore summarised in Table 5.1 below where the notation, description, and database information are outlined.

Table 5.1: Summary of variables

Variables	**Notation**	**Description**	**Source**
Solar PV consumption	SPV	Solar electricity consumption per capita	Oxford Martin School, University of Oxford
Human Development Index	HDI	Measures average achievement in terms of a long and healthy life, knowledge, and a decent standard of living	UNDP
Income inequality	INC	Inequality in income (%)	UNDP
Education	EDC	General government expenditure on education (current, capital, and transfers) is expressed as a percentage of GDP	WDI, World Bank
Infant mortality rate	MORT	Mortality rate, under-5 (per 1,000 live births)	UNDP
Mobile phone subscriptions	MOB	Mobile cellular subscriptions (per 100 people)	WDI, World Bank
Internet users	INT	Individuals using the Internet (% of population)	WDI, World Bank
Unemployment rate	UR	Unemployment, total (% of total labour force)	WDI, World Bank
Consumer Price Index (Inflation rate)	CPI	Annual percentage change in consumer prices	WDI, World Bank
Urbanisation	URB	Urban population (% of total population)	WDI, World Bank

5.3.2 Theoretical model

The theoretical model for estimating the effects of welfare on solar electricity demand is based on the following hypotheses:

Hypothesis 1: An increase in the HDI increases solar electricity demand.

Hypothesis 2: An increase in income inequality decreases solar electricity demand.

Hypothesis 3: An increase in government spending on education increases solar electricity demand.

Hypothesis 4: An increase in infant mortality decreases solar electricity demand.

Hypothesis 5: An increase in ICT adoption increases solar electricity demand.

These hypotheses are underpinned by the energy-growth nexus that establishes a link between electricity consumption and economic growth. The study uses the augmented Cobb-Douglas production developed by Arrow, Chenery, Minhas, & Solow (1961) to examine the linkage between welfare and solar electricity consumption. Compared to other production functions, this production function allows several factors of production (energy, technological change, capital, and labour) and their elasticities to determine output (Brockway, Heun, Santos, & Barrett, 2017). Therefore, the production function is expressed as:

$$Y = A(t), K, L, E \tag{5.1}$$

Where *Y* denotes economic output, *A(t)* denotes technological change, *K* denotes capital, *L* denotes labour and *E* denotes electricity. Therefore, this production function suggests that economic output is a function of technological change, capital, labour, and energy. This hypothesis is supported by the growth hypothesis of the energy-growth nexus.

However, the conservation hypothesis of the energy-growth nexus states that economic growth drives energy consumption (Apergis & Payne, 2011). Therefore the production function can be expressed as:

$$E = f(A(t), Y, K, L) \tag{5.2}$$

To allocate proxies to these factors of production, energy is proxied by solar electricity consumption, economic output is proxied by other welfare indicators (instead of GDP) that include human development, income distribution, education, and health. Technological change is proxied by ICT and labour is proxied by unemployment rate.

Therefore, the augmented Cobb-Douglas production function for the relationship between welfare and energy consumption can be expressed as:

$$SPV = f(HDI, INC, EDC, HE, ICT, UR) \tag{5.3}$$

where solar electricity consumption (SPV) is a function of human development (HDI), income distribution (INC), education (EDC), health (HE), ICT and unemployment rate (UR). When introducing indicators for these variables, solar electricity consumption is proxied by solar electricity consumption per capita (SPV), income distribution is measured by inequality in income (INC), education is proxied by government spending on education (EDC), health is measured by infant mortality rate (MORT), ICT is measured by mobile phone subscriptions (per 100 people) and internet users (individuals using the Internet as a % of the population).

Therefore, the relationship between welfare and solar electricity consumption is estimated using the following equation:

$$SPV_{it} = \beta_0 + \beta_1 HDI_{it} + \beta_2 INC_{it} + \beta_3 EDC_{it} + \beta_4 MORT_{it} + \beta_5 MOB_{it} + \beta_6 INT_{it} + \beta_7 UR_{it} + \beta_8 X_{it} + \mu_{it} \tag{5.4}$$

where SPV_{it} denotes solar electricity consumption per capita, *HDI, INC, EDC, MORT, MOB, INT,* and *UR* denote Human Development Index, income inequality, government spending on education, infant mortality rate, mobile phone subscriptions, internet users, and unemployment rate. X represents control variables which include CPI and urbanisation. B_0 is the constant and μ_{it} is the error term.

5.3.3 Estimation strategy

Before estimating the regression model, the study tested the stationarity properties of all the variables. The study applied the ADF panel unit root test developed by (Dickey & Fuller, 1981) and the Phillips-Perron (PP) unit root test developed by Kwiatkowski et al. (1992).

The study applied the Quantile regression estimation technique to estimate the effects of welfare on solar electricity consumption in SSA. Quantile regression models allow the characterisation of the dependent variable conditional distribution based on the explanatory variables (Koenker & Bisset, 1978). Quantile regressions use different parameter estimations for different percentiles, which are interpreted as differences in the behaviour of the dependent variable due to changes in the explanatory variables. Quantile regressions are appealing because of their ability to estimate quantile-specific effects that explain the impact of covariates on the centre and tails of the outcome distribution (Chernozhukov & Hansen, 2008). This makes Quantile regression models better than OLS because OLS minimises the sum of the squares of the residuals, whilst Quantile regression minimises the weighted sum of the absolute residuals (Buchinsky, 1998). Also, OLS estimators with Fixed Effects in dynamic panel models are biased when the time dimension of the panel is short and in the presence of lagged dependent variables as regressors (Chernozhukov & Hansen, 2008).

However, Koenker (2004) states that when quantile regressions are applied to panel data with large number of cross-sectional units and short periods, this may lead to a large number of individual fixed effects that can alter the estimation of the parameters of interest. This is evident in the panel quantile regression with additive fixed effects which treats individual fixed effects as pure location shift parameters that are common to all conditional quantiles and may shrink toward a common value (Koenker, 2004; Rosen, 2012). The additive fixed effect term separates the disturbance term into different components. This alters the interpretation of the parameters of interest because it assumes that the parameters vary based on the time-varying components of the disturbance term (Powell, 2016). It also alters the interpretation of the parameters because the additive fixed effects could change the meaning of the quantile point (Yu, Hu, Li, & Chen, 2020).

Powell (2016, 2022) developed a quantile regression with nonadditive fixed effects to correct this weakness. The quantile regression with nonadditive fixed effects does not separate the disturbance term and assumes a within-individual variation of the disturbance term. Therefore, the fixed estimates are not estimated, and the parameter estimates remain consistent even for short panels. Due to the reverse causality between solar electricity consumption and welfare as stated by Van Tran, van Tran, Do, Dinh, and Do (2019) and Ahn, Chu and Lee (2021), it means that there is endogeneity among the variables. The quantile regression with nonadditive fixed effects can deal with the endogeneity problem.

Further, the quantile regression with nonadditive fixed effects uses the adaptive Markov Chain Monte Carlo (MCMC) method developed by Baker (2014) as an optimisation method. The MCMC optimisation method draws samples from a given or arbitrary probability distribution and these samples are used to estimate quantities related to the probability distribution. It is mainly used in complicated Bayesian statistics to draw parameter values from the posterior distribution (Yang, Wang, & He, 2016).

Another optimisation method that is used in regressions is the grid-searching optimisation method. The grid-searching optimisation method uses a grid of values of pre-selected substitution parameters. These pre-selected values can include zero, which is then used as a starting point for subsequent estimations. The remainder of the parameters is estimated using non-linear least squares whilst holding the substitution parameters constant at each combination of the pre-selected values (Henningsen & Henningsen, 2012). However, it is not suitable for quantile regressions because it does not perform well when explanatory variables exceed two (Yu et al., 2020). Whereas, the unique feature of the adaptive MCMC method is that even in the presence of additional control variables, the nonadditive fixed effects method creates unconditional quantile treatment, thereby accommodating endogeneity and the addition of instruments and control variables (Baker, 2014; Powell, 2016; 2022).

5.3.4 Model specification

Following the model by Powell (2022) and Sarkodie and Strezov (2019), the equation for the panel quantile regression with nonadditive fixed effects is expressed as:

$$Y_{it} = X'_{it}\beta(U^*_{it}), \qquad U^*_{it} \sim U(0,1) \tag{5.5}$$

where t = 1…, T; I = 1,…, n,

Y_{it} denotes the dependent variable, X'_{it} is a set of explanatory variables for country I at time t and are assumed to include a constant Term. β represents an unknown parameter, whereas U^*_{it} is the non-separable disturbance term and it is a function of an individual fixed effect and an observable specific disturbance term. U^*_{it} ~ U(0,1) and $X'_{it}\beta(\tau)$ is increasing in quantile τ.

Therefore, the structural quantile function for Equation 5.5 can be expressed as:

$$S_Y(\tau/d) = d'\beta(\tau), \qquad \tau\epsilon(0,1) \tag{5.6}$$

where the structural quantile function explains the quantile of the latent outcome variable $Y_d = d'\beta(U^*)$ for randomly selected $U^*\sim U(0,1)$ and the fixed potential value of the treatment effect d. Therefore, to estimate the effects of welfare on solar electricity consumption, the panel quantile regression is expressed as:

$$SPV_{it}(\tau/\alpha_i, \delta_t, x_{it}) = \alpha_i + \delta_t + \beta_{1,\tau}HDI_{it} + \beta_{2,\tau}INC_{it} + \beta_{3,\tau}EDC_{it} + \beta_{4,\tau}MORT_{it} + \beta_{5,\tau}MOB_{it} + \beta_{6,\tau}INT_{it} + \beta_{7,\tau}UR_{it} + \beta_8 X_{it} + u_{it} \quad (5.7)$$

where SPV_{it} denotes per capita solar electricity consumption for country *i* at time *t,* τ denotes the quantile*,* α_i represents non-additive fixed effects, *HDI, INC, EDC, MORT, MOB, INT, UR* denote the explanatory variables, X_{it} represents the vector of control variables, including CPI, and urbanisation. The estimation performs numerical optimization using the adaptive MCMC optimization method.

Equation 5.7 can be simplified and re-written as:

$$SPV_{it} = \alpha_i + \beta_1 HDI_{it} + \beta_2 INC_{it} + \beta_3 EDC_{it} + \beta_4 MORT_{it} + \beta_5 MOB_{it} + \beta_6 INT_{it} + \beta_7 UR_{it} + \beta_8 X_{it} + u_{it} \quad (5.8)$$

The application of Quantile regression models in energy and environmental studies is gaining momentum. This is because the data used in these studies usually contain peaks or ‘fat tails’ and it is mostly panel data that contains heterogeneity factors that cannot be ignored in estimation. Otherwise, that would lead to biased estimations. Therefore, using quantile regression allows for heterogeneity and produces more robust results than conditional mean regression methods (Koenker & Bisset, 1978). Khan, Khan, and Binh (2020) used Quantile regression models on panel data involving 192 countries to estimate the role of renewable energy in carbon emissions. Chen and Lei (2018) also used Quantile regression models on panel data involving 30 countries to examine the impacts of renewable energy and technological innovation on the environment-energy-growth nexus. This background has therefore influenced the suitability of quantile regression for use in this study.

5.3.4.1 Robustness Check

This study conducted a robustness check using the panel Dynamic Ordinary Least Squares (DOLS) estimator developed by Kao and Chiang (2000). The panel DOLS estimates long-run relationships for a heterogeneous panel by applying different approaches to correct biases from endogeneity and serial correlation. It uses lags and leads of the independent variables and follows a parametric approach. This estimation method is applauded for its ability to deal with panel data samples with a small time dimension, and it does not require initial estimation and nonparametric correction compared to the Fully Modified Ordinary Least Squares (FMOLS) estimator (Kao & Chiang, 2000).

Therefore, the panel DOLS equation is expressed as:

$$y_{it} = \alpha_i + X'_{it}\beta + \sum_{j=-p}^{q} C_{ij}\,\Delta X_{it+j} + \mu_{it} \tag{5.9}$$

Equation 5.9 can be re-written as below:

$$\begin{aligned} SPV_{it} &= \alpha_i + \beta_1 HDI_{it} + \beta_2 INC_{it} + \beta_3 EDC_{it} + \beta_4 MORT_{it} + \beta_5 MOB_{it} + \beta_6 INT_{it} + \beta_7 UR_{it} + \beta_8 X_{it} \\ &+ \sum_{j=-p}^{q} \theta_{1ij}\,\Delta HDI_{it+j} + \sum_{j=-p}^{q} \theta_{2ij}\,\Delta INC_{it} + \sum_{j=-p}^{q} \theta_{3ij}\,\Delta EDC_{it} + \sum_{j=-p}^{q} \theta_{4ij}\,\Delta MORT_{it+j} \\ &+ \sum_{j=-p}^{q} \theta_{5i}\ \Delta MOB_{it+j} + \sum_{j=-p}^{q} \theta_{6ij}\,\Delta INT_{it+j} + \sum_{j=-p}^{q} \theta_{7i}\ \Delta UR_{it+j} + \sum_{j=-p}^{q} \theta_{8ij}\Delta X_{it+j} \\ &+ \mu_{it} \end{aligned} \tag{5.10}$$

where q denotes the leads and p denotes the lags, θ_{1ij} represents the coefficients of the lead and lag differences that generate unbiased estimates of $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7$ by eliminating problems of endogeneity and serial correlation.

5.4 Empirical Results

5.4.1 Descriptive statistics

The summary of descriptive statistics for all the variables used in the study is presented in Table 5.2. The descriptive statistics reveal that the average solar electricity consumption per capita (SPV) was 0.8929kWh with minimum and maximum values of 0.0040kWh and 10.8411kWh, respectively. This indicates that in general the average level of solar electricity consumption is improving over the period from 2010 to 2019. The standard deviation is 1.7167kWh showing that most of the data points are far from the mean.

The independent variables, HDI had a mean of 0.4905, a standard deviation of 0.0613, and minimum and maximum values of 0.331 and 0.601, respectively. These statistics show an improvement in HDI over the 10 years from 2010 to 2019 and the variability of the data is generally far from the mean. Inequality in income recorded a mean of 27.3349, a standard deviation of 8.0257, and minimum and maximum values of 12.3 and 58.1, respectively. This reveals that the average level of income inequality is still high in most countries in the sample. Government spending on education recorded an average of 4.1647, a standard deviation of 1.1289, and minimum and maximum values of 1.5440 and 6.8763, respectively. This reveals that most governments in the sample have increased their spending on education over the years.

Infant mortality had an average of 73.878, a standard deviation of 22.1107, and minimum and maximum values of 35.3 and 131.5, respectively. These results reveal that the level of infant mortality is still very high in these countries. Mobile phone subscriptions had an average of 69.7096, a standard deviation of 25.5669, and minimum and maximum values of 21.4 and 138.8. These results show that the adoption and usage of mobile phones in SSA were improving.

Internet users had a mean of 13.8838, a standard deviation of 10.0060, and minimum and maximum values of 0.8 and 46.8, respectively. These results show that the level of internet usage remains low in SSA. The unemployment rate has an average of 4.3775, a standard deviation of 2.7416, and minimum and maximum values of 0.32 and 13.19. The results show that unemployment is relatively low in these countries.

Table 5.2: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
SPV	150	0.8929	1.7167	0.0040	10.8411
HDI	150	0.4905	0.0613	0.3310	0.601
INC	150	27.3349	8.0257	12.3	58.1
EDC	150	4.1647	1.1289	1.5440	6.8763
MORT	150	73.8780	22.1107	35.3	131.5
MOB	150	69.7096	25.5669	21.4	138.8
INT	150	13.8838	10.0060	0.8	46.8
UR	150	4.3775	2.7416	0.32	13.19
CPI	150	4.5286	5.4308	-3.233389	27.2833
URB	150	32.8327	11.8912	15.5	57

Notes: SPV=Solar PV per capita, HDI=Human Development Index, INC=Income inequality, EDC= Education, MORT=Infant mortality rate, MOB=Mobile phone subscription, INT=Internet users, UR=Unemployment rate, CPI=Consumer Price Index, URB=Urbanisation

The control variables, CPI, and urbanization had an average of 4.5286 and 32.8327 respectively. The standard deviation statistics show that most of the data points are far from each average. The results also show that CPI is relatively low whilst urbanization is increasing.

5.4.2 Mean of selected variables

A preliminary investigation of the distribution of the mean for the variables was conducted and presented in Table 5.3. The statistics present the countries according to their average consumption per capita of solar electricity, starting with the country that has the highest average solar electricity consumption to the country that has the lowest average consumption.

The statistics reveal that Senegal has the highest average solar electricity consumption per capita, followed by Rwanda, Kenya, Malawi, and Uganda. Countries with the lowest consumption of solar electricity are Mali, Zambia, Niger, Côte d'Ivoire, and Mozambique. In terms of HDI ranking, the top five countries are Kenya, Zambia, Zimbabwe, Cameroon, and Uganda. Whereas countries with the lowest HDI ranking are Malawi, Mozambique, Mali, Burkina Faso, and Niger. The results also reveal that even though Côte d'Ivoire has the lowest solar electricity consumption than Senegal, its HDI ranking is higher than that of Senegal. This means countries with high solar electricity consumption may not necessarily have a high HDI ranking.

Regarding mobile phone subscriptions, countries with the highest number of mobile phone subscriptions are Mali, Côte d'Ivoire, Senegal, Zimbabwe, and Kenya. Countries with the lowest mobile phone subscriptions are Togo, Uganda, Mozambique, Niger, and Malawi. The statistics also reveal that countries with the highest consumption per capita of solar electricity have the lowest mobile phone subscriptions.

5.4.3 Pairwise correlation matrix

To test for the possibility of multicollinearity among the variables, the study used the pairwise correlation matrix that indicates the possibility of the presence or absence of multi-collinearity. If multicollinearity is present, it means the variables are weak and may not be fit for the estimation. Whereas, if multicollinearity is absent, it denotes the strength and good fit of the variables in the estimation.

The pairwise correlation results are presented in Table 5.4. The results reveal that there is no evidence of multicollinearity among the variables, therefore, they are a good fit for this model. The statistics also show that HDI, inequality in income, education, mobile phone subscription, and internet users have a positive correlation with solar electricity consumption. Infant mortality, unemployment rate, CPI, and urbanization are negatively correlated with solar electricity consumption.

Table 5.3: Mean of variables from 2010-2019

Country	SPV	HDI	INC	EDC	MORT	MOB	INT	UR	CPI	URB
Senegal	3.9011	0.4974	25.29	21.13	52.92	93.31	24.33	7.933	1.01	45.68
Rwanda	2.6672	0.5207	35.3	14.83	45.29	64.65	14.54	1.098	4.24	17.03
Kenya	1.3079	0.5802	33.83	34.81	47.87	76.25	14.22	2.776	7.07	25.49
Malawi	1.2830	0.4612	27.69	24.11	64.77	35.14	7.82	5.817	16.42	16.27
Uganda	0.9926	0.5209	26.78	32.85	58.83	52.95	18.22	2.348	6.17	21.83
Burkina Faso	0.8904	0.4186	22.96	11.66	91.56	72.65	10.29	5.402	0.74	27.25
Zimbabwe	0.4486	0.5404	32.2	66.63	60.37	88.29	18.44	5.245	2.25	32.55
Cameroon	0.3826	0.54	25.89	38	89.39	68.34	15.65	3.623	1.85	54.3
Togo	0.3015	0.494	23.11	48.73	78.71	62.78	7.59	2.685	1.41	39.85
Tanzania	0.2779	0.5075	21.53	45.41	61.06	65.97	12.55	2.486	7.19	31.28
Mali	0.2521	0.4197	18.68	15.77	112.58	106.18	7.72	7.161	0.97	39.59
Zambia	0.2456	0.5612	40.86	49	67.29	70.21	18.06	10.586	8.74	41.69
Cote d'Ivoire	0.17672	0.5017	27.84	32.58	92.60	104.39	25.60	4.414	1.23	49.25
Mozambique	0.0415	0.4271	31.97	21.56	85.89	48.28	9.79	3.327	7.57	34.15
Average	0.8929	0.4904	27.33	31.03	73.87	69.70	13.88	4.375	4.52	32.83

Notes: SPV=Solar PV per capita, HDI=Human Development Index, INC=Income inequality, EDC= Education, MORT=Infant mortality rate, MOB=Mobile phone subscription, INT=Internet users, UR=Unemployment rate, CPI=Consumer Price Index, URB=Urbanisation

Table 5.4: Pairwise correlation matrix

Variable	SPV	HDI	INC	EDC	MORT	MOB	INT	UR	CPI	URB
SPV	1.000									
HDI	0.201	1.000								
INC	0.135	0.545	1.000							
EDC	0.023	0.038	0.251	1.000						
MORT	-0.464	-0.712	-0.435	-0.187	1.000					
MOB	0.208	0.346	0.044	0.144	-0.101	1.000				
INT	0.465	0.560	0.271	-0.014	-0.480	0.611	1.000			
UR	-0.014	0.101	0.212	0.175	0.097	0.289	0.068	1.000		
CPI	-0.012	0.118	0.313	0.060	-0.260	-0.415	-0.154	0.124	1.000	
URB	-0.057	0.290	0.032	0.067	0.239	0.565	0.371	0.423	-0.344	1.000

Notes: SPV=Solar PV per capita, HDI=Human Development Index, INC=Income inequality, EDC= Education, MORT=Infant mortality rate, MOB=Mobile phone subscription, INT=Internet users, UR=Unemployment rate, CPI=Consumer Price Index, URB=Urbanisation

5.4.4 Unit root test results

The ADF-Fischer and PP-Fischer tests were used to test stationarity in the variables. The results presented in Table 5.5 show a combination of stationarity tests at levels and first difference for all the variables. The ADF-Fischer unit root results show that HDI, inequality in income, education, infant mortality, mobile phone subscriptions, and CPI are stationary at levels. However, solar electricity consumption, internet users, unemployment rate, and urbanisation are stationary at first differencing.

The PP-Fischer unit root test results are shown in Table 5.6. The results are consistent with the results of the ADF-Fischer unit root test results. These results show that the variables are integrated into the order I(0) and I(1). None of the variables are integrated into the order I(2), therefore all the variables can be used in this estimation.

Table 5.5: ADF-Fischer unit root test results

Variables	Level	1st Difference	Order of Integration
SPV	1.000	0.0000***	I(1)
HDI	0.0000***	0.0000***	I(0)
INC	0.0000***	0.0000***	I(0)
EDC	0.0035***	0.0000***	I(0)
MORT	0.0000***	0.0000***	I(0)
MOB	0.0002***	0.0000***	I(0)
INT	0.9963	0.0000***	I(1)
UR	0.8558	0.0000***	I(1)
CPI	0.0160**	0.0000***	I(0)
URB	0.9640	0.0000***	I(1)

Standard errors in parentheses. *** significant at 1%, ** significant at 5%, * significant at 10%
Notes: SPV=Solar PV per capita, HDI=Human Development Index, INC=Income inequality, EDC= Education, MORT=Infant mortality rate, MOB=Mobile phone subscription, INT=Internet users, UR=Unemployment rate, CPI=Consumer Price Index, URB=Urbanisation

Table 5.6: PP-Fischer unit root test results

Variables	Level	1st Difference	Order of Integration
SPV	1.000	0.0000***	I(1)
HDI	0.0000***	0.0000***	I(0)
INC	0.0000***	0.0000***	I(0)
EDC	0.0035***	0.0000***	I(0)
MORT	0.0000***	0.0000***	I(0)
MOB	0.0002***	0.0000***	I(0)
INT	0.9963	0.0000***	I(1)
UR	0.8558	0.0000***	I(1)
CPI	0.0160**	0.0000***	I(0)
URB	0.9647	0.0000***	I(1)

Standard errors in parentheses. *** significant at 1%, ** significant at 5%, * significant at 10%
Notes: SPV=Solar PV per capita, HDI=Human Development Index, INC=Income inequality, EDC= Education, MORT=Infant mortality rate, MOB=Mobile phone subscriptions, INT=Internet users, UR=Unemployment rate, CPI=Consumer Price Index, URB=Urbanisation

5.4.5 Quantile regression results for the relationship between welfare and solar electricity demand

The study employed a quantile regression with nonadditive fixed effects estimation method to estimate the impact of welfare on solar electricity demand in SSA under different distributions of solar electricity consumption. Quantile regression, in general, is very useful for estimating the effect of the explanatory variable on the dependent variable under different conditional distributions, hence it is used in this study instead of OLS.

The study applied the adaptive MCMC optimisation procedure of the nonadditive fixed effects quantile as an optimisation method. The adaptive MCMC optimisation method's algorithm performed 1000 draws and dropped 100 draws and the acceptance rate was set at 0.5[15].

Table 5.7 presents the quantile regression results based on Powell (2016) quantile regression with non-additive fixed effects at different quantiles ranging from the 10th quantile to the 90th quantile. The estimation results show that HDI has a negative and significant effect on solar electricity consumption at a 1% significance level, from the 10th to the 90th quantile except for the 30th quantile. This means that for every 10% increase in HDI, ceteris paribus, solar electricity consumption will decrease by 7.12% to 194.71%.

This implies that HDI plays an inhibitory role in adopting solar electricity technologies and consumption thereof in SSA. Also, the absolute value of the coefficients is less than 1 at the 10th and 20th quantiles and reaches the highest coefficients in the 80th and 90th quantiles. This implies that the effect is relatively strong in countries with low and high solar electricity consumption compared to countries with moderate solar electricity consumption. However, for the 30th quantile, the effect of HDI on solar electricity consumption is positive and significant

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[15] This is the sequence of draws that the algorithm performs from the posterior distribution of the parameter (Baker, 2014).

at a 1% significance level. This implies that in the 30th quantile, a 10% increase in HDI will increase solar electricity consumption by 4.09%.

For inequality in income, the effect on solar electricity consumption is negative and significant at a 1% significance level for the 10th and 30th quantiles. This means that a 10% increase in income inequality will decrease solar electricity consumption by 0.016% to 0.023% in the 10th and 30th quantiles. However, from the median to the 90th quantile, the effect on solar electricity consumption becomes positive and significant at a 1% significance level. Therefore, it means that from the median quantile, a 10% increase in income inequality will increase solar electricity consumption by 0.031% to 0.475%. Also, the coefficients are close to zero at the lower quantiles and move away from zero at higher quantiles implying that the effect is stronger in countries with higher levels of solar electricity consumption.

For education, the results show that the effect on solar electricity consumption is negative and significant at 1% significance level in all quantiles except for the 80th quantile, which has a 10% significance level. This implies that a 10% increase in government spending on education will lead to a decrease in solar electricity consumption by 0.40% to 4.83%. This effect is pronounced in countries with low and high solar electricity consumption. A possible explanation of these results may be linked to the results obtained when analysing the link between HDI and solar electricity demand. This means as the education levels increase, HDI improves but solar electricity decreases because consumers use other sources of electricity.

For infant mortality, the effect on solar electricity consumption is negative and significant at 1% significance level, throughout the quantiles. This implies that a 10% increase in infant mortality will lead to a decrease in solar electricity consumption by 0.06% to 2.55%. This effect is stronger in countries with median to high solar electricity consumption. This result is expected as it means that when infant mortality increases, the quality of the health of the population decreases therefore negatively affecting productivity and growth, resulting in low demand for solar electricity.

Mobile phone subscriptions have a positive and significant effect on solar electricity consumption in all the quantiles except for the 70th and 80th quantiles. The effect is stronger up to the 60th quantile, after which the effect is insignificant and only becomes significant again in the 90th quantile. Therefore, a 10% increase in mobile phone subscriptions will lead to an increase in solar electricity consumption by 0.01% to 0.06%. This implies that in countries with low levels of solar electricity consumption, the effect of mobile phone subscriptions on solar electricity consumption will be stronger. However, in countries with higher solar electricity consumption, the effect of mobile phone subscriptions on solar electricity consumption becomes weaker.

Internet connectivity has a negative and significant effect on solar electricity consumption at 1% and 5% significance levels at the 10th and median quantiles respectively. However, the effect on solar electricity consumption is positive and significant at 1% significance level at 30th, 60th, 70th, 80th and 90th quantiles. This means that a 10% increase in the number of internet users will lead to a decrease in solar electricity consumption by 0.008% to 0.010% in countries with low solar electricity consumption. However, in countries with high solar electricity consumption, a 10% increase in the number of internet users will lead to an increase in solar electricity consumption by 0.02% to 1.99%.

The unemployment rate positively and significantly affects solar electricity consumption in the lower to median quantiles. However, from the 60th quantile, the effect is negative and significant, particularly for the 60th and 70th quantiles. Therefore, in the lower quantiles, a 10% increase in the unemployment rate will increase solar electricity consumption by 0.045% to 0.087%. However, in the 60th and 70th quantiles, a 10% increase in the unemployment rate will decrease solar electricity consumption by 0.03% to 0.10%.

Table 5.7: Quantile regression and DOLS estimation results

Variable	10th Quantile	20th Quantile	30th Quantile	40th Quantile	Median	60th Quantile	70th Quantile	80th Quantile	90th Quantile	DOLS
HDI	-0.8951***	-0.7124***	0.4095***	-1.1320***	-1.8500***	-4.4040***	-6.332***	-18.646***	-19.471***	-23.05742
	(0.0035)	(0.1323)	(0.0067)	(0.3416)	(0.0982)	(0.3501)	(0.0722)	(3.3840)	(0.8398)	(52.73859)
INC	-0.0023***	-0.0013	-0.0016***	0.0015	0.0031***	0.0070***	0.0104***	-0.0032	0.0475***	0.2243***
	(0.0000)	(0.0013)	(0.0000)	(0.0010)	(0.0002)	(0.0012)	(0.0002)	(0.0056)	(0.0048)	(0.063269)
EDC	-0.0431***	-0.0400***	-0.0551***	-0.0935***	-0.1170***	-0.1432***	-0.1859***	-0.1243*	-0.4833***	-1.3084**
	(0.0001)	(0.0058)	(0.0001)	(0.0092)	(0.0022)	(0.0060)	(0.0008)	(0.0650)	(0.0385)	(0.517792)
MORT	-0.0096***	-0.0088***	-0.0066***	-0.0134***	-0.0146***	-0.0199***	-0.2553***	-0.0616***	-0.0408***	-0.0721562
	(0.0000)	(0.0004)	(9.2806)	(0.0011)	(0.0002)	(0.0012)	(0.0002)	(0.0087)	(0.0025)	(0.098063)
MOB	0.0011***	0.0012**	0.0018***	0.0025***	0.0053***	0.0059***	0.0063	0.0015	0.0062**	0.0378406
	(0.0000)	(0.0006)	(4.8206)	(0.0005)	(0.0002)	(0.0002)	(0.0000)	(0.0024)	(0.0025)	(0.037032)
INT	-0.0010***	0.0016	0.0020***	0.0015	-0.0008**	0.0133***	0.0108***	0.0846***	0.1997***	-0.3586***
	(0.0000)	(0.0013)	(0.0000)	(0.0011)	(0.0004)	(0.0018)	(0.0002)	(0.0274)	(0.0041)	(0.087300)
UR	0.0047***	0.0013	0.0087***	0.0046**	0.0077***	-0.0109***	-0.0030***	0.0857***	-0.0022	-0.10236
	(0.0000)	(0.0049)	(0.0000)	(0.0019)	(0.0012)	(0.0027)	(0.0008)	(0.0228)	(0.0098)	(0.446779)
CPI	-0.0015***	-0.0073***	-0.0065***	-0.0114***	-0.0059***	-0.0080***	0.0087***	-0.0355***	-0.0338***	-0.4537***
	(0.0000)	(0.0006)	(0.0000)	(0.0015)	(0.0006)	(0.0025)	(0.0002)	(0.0115)	(0.0071)	(0.10237)
URB	0.0096***	-0.00096	-0.0105***	-0.0098***	-0.0081***	-0.0024***	0.0016***	0.0182***	0.0157***	0.151094
	(0.0000)	(0.0009)	(0.0000)	(0.0016)	0.0005	(0.0012)	(0.0004)	(0.0075)	(0.0019)	(0.357516)

Standard errors in parentheses. *** significant at 1%, ** significant at 5%, * significant at 10%
Notes: SPV=Solar PV per capita, HDI=Human Development Index, INC=Income inequality, EDC= Education, MORT=Infant mortality rate, MOB=Mobile phone subscription, INT=Internet users, UR=Unemployment rate, CPI=Consumer Price Index, URB=Urbanisation

For the control variables, CPI has a negative and significant effect on solar electricity consumption at 1% significance level throughout all the quantiles. Therefore, a 10% increase in CPI will decrease solar electricity consumption by 0.01% to 0.35%. For urbanisation, the effect is positive and significant at the 10th Quantile, but changes to a negative effect from the 20th quantile to the 60th quantile. From the 70th quantile, the effect becomes positive and significant again.

This means that in countries with very low and very high solar electricity consumption, an increase in urbanisation will lead to an increase in solar electricity consumption. However, in countries with moderate to high solar electricity consumption, an increase in urbanisation will lead to a decrease in solar electricity consumption.

5.4.6 Dynamic Ordinary Least Squares results for the relationship between welfare and solar electricity demand

To perform robustness checks, the study applied the panel Dynamic OLS estimation technique developed by Kao (1999; 2000). The DOLS estimation included two leads and three lags, and R^2 is 0.9455. The DOLS results are compared with the median results of the quantile regression.

For HDI, the DOLS results reveal a negative but insignificant effect of HDI on solar electricity consumption. These results are consistent with the main results even though the significance level is weak. Income inequality has a positive and significant effect on solar electricity consumption at a 1% significance level. These results are consistent with the main results. Government expenditure on education negatively and significantly affects solar electricity consumption. These results are also consistent with the main results.

Infant mortality has a negative but insignificant effect on solar electricity consumption. These results are consistent with the main results even though the significance level is weaker. Mobile subscription has a positive but insignificant effect on solar electricity consumption. These results are consistent with the main results even though the significance level is weaker. Internet usage has a negative and significant effect on solar electricity consumption. These results are also consistent with the main results. The unemployment rate has an insignificant effect on solar electricity consumption.

For the control variables, CPI has a negative and significant effect on solar electricity consumption. These results are consistent with the main results. Urbanisation has an insignificant effect on solar electricity consumption. The sign of the coefficients is not consistent with the results of the median quantile; however, these results are evident in other quantiles. All in all, the DOLS results confirm the robustness and validity of the quantile regression results.

5.5 Discussion of Findings

The results presented above represent the effect of welfare on solar electricity demand in SSA. The results reveal that the welfare of societies as measured by HDI has a negative effect on solar electricity consumption across all quantiles except the 30^{th} quantile. Compared to the intermediate level, this effect is greater after the median to the tail end of the solar electricity consumption. This effect holds across countries regardless of the level of solar electricity consumption (low, moderate, and high). This means that as the level of welfare increases, more households reduce their consumption of solar electricity, possibly due to fuel stacking or multiple fuel use because they can afford other fuels. These results are consistent with the fuel stacking theory that posits that even though households adopt clean fuels, they will not use only one source of fuel but multiple sources that will serve as backup supply because clean fuels are sometimes unreliable, and their cost may increase significantly (Kowsari & Zerriffi, 2011).

Another possible explanation is that recently, an increasing number of low-quality and fake solar PV technologies have entered the African market. These low-quality products have limited and poor functionality but are affordable to the poor population, mostly in developing countries. As a result, the trust of consumers in solar PV technologies has decreased (Groenewoudt, Romijn, & Alkemade, 2020). Therefore, as the human development indicators improve, consumers will reduce their consumption of solar PV technologies.

This finding has significant implications for developing countries because it reveals that the potential benefits of solar electricity in the transition to clean energy may not be realised as swiftly as envisioned. The results are also consistent with the findings of Alem et al. (2016) who state that households' economic status matters but does not make households stop using traditional fuels. It is also consistent with Choumert-Nkolo et al. (2019), who state that the use of multiple fuels may prejudice clean fuels, eroding the environmental and socio-economic benefits of access to clean electricity.

However, the results of the 30th quantile show a strong positive effect of HDI on solar electricity consumption. These results are in direct contrast with the results of the rest of the quantiles. A possible explanation is that the countries in the 30th quantile had implemented cash transfer programs and incentives that were aimed at improving household consumption of solar electricity. As a result, household welfare and solar electricity consumption increased simultaneously. The results align with the findings of Nawaz and Iqbal (2020) who found that cash transfer programs improve the welfare of households, the use of clean energy fuels increases, and the use of fossil fuels decreases, even though households did not fully neglect the fossil fuels, confirming the fuel stacking theory.

This implies that the effect of a higher HDI is generally negative on the adoption of solar electricity technologies in most countries, except for those countries with low to median levels of solar electricity consumption. Therefore, as policymakers develop welfare policies, they should integrate programs that will also promote the use of clean energy sources. Policy makers may also consider establishing quality assurance and control standards for solar technologies to curb the entry of poor quality and fake products into the market.

Regarding income inequality, the effect is mixed and inconclusive. For countries with low solar electricity consumption, the effect is negative and strong, implying that an increase in inequality in income significantly reduces the consumption of solar electricity in countries with low solar electricity consumption. This means that as income inequality increases in these countries, solar electricity technologies become unaffordable, leading to a decrease in consumption. These results are consistent with the findings of Berthe & Elie (2015) and Ekeocha (2021) that conclude that if income inequality is high, poor and rich individuals may disregard environmental concerns and engage in activities that degrade the environment.

These results are also consistent with the findings of Uzar (2020), that state that high-income inequality may not support renewable electricity technologies because as income inequality increases, societies will base their resource allocation on the price and costs of deploying renewable electricity technologies. Therefore, policymakers in countries with low solar electricity consumption need to maintain an equitable distribution of income because an increase in income inequality will decrease solar electricity consumption and endanger the environment.

However, in countries with moderate-to-high solar electricity consumption, an increase in income inequality will lead to high solar electricity consumption. This implies that the widening of the income gap will increase solar electricity consumption. This is also explained above that there is an influx of low-quality solar technologies in the market that have limited functionality but are affordable to the poor (Groenewoudt et al., 2020). Therefore, as inequality in income increases, most people will not afford high-quality solar technologies. Instead, they will consume low-quality solar PV technologies because they are affordable, in that way solar electricity consumption increases.

These results are in contradiction to the findings of most scholars and introduce new knowledge in the study of the effect of income distribution on solar electricity consumption. Therefore, policy makers in SSA need to formulate policies that will regulate the quality and cost of solar electricity technologies to ensure that both the poor and rich can adopt them.

On the other hand, an increase in government spending on education negatively impacts solar electricity consumption across all the countries in the study. This implies that all the countries, regardless of their level of solar electricity consumption, will observe a decrease in solar electricity consumption due to an increase in government spending on education. This may happen if a significant portion of the government's education budget is allocated to primary education relative to higher education. If a smaller portion of resources is devoted to higher education, higher education institutions may not be able to develop programs and curricula and collaborate with other institutions to develop energy conservation projects aimed at reducing carbon emissions and promoting clean electricity technologies such as solar technologies (Katircioğlu, 2014; Li, H. et al., 2021).

Also, the government may be spending on salaries and wages instead of school infrastructure, curriculum development, equipment, and supplies that could expose learners to the importance of environmental preservation through using solar electricity and other clean energy sources instead of biomass (Mingat & Tan, 2003). Lastly, these results may be linked to the initial findings that revealed that an increase in HDI leads to a decrease in solar electricity consumption. This means as the education levels increase, HDI increases which leads to a decrease in solar electricity consumption.

These results are consistent with the findings of Jian et al. (2021) who found negative effects of education on energy consumption in China. The results also corroborate the findings of Bello et al. (2021) that found the negative effects of education on energy consumption because the current education system in most countries in SSA does not educate people on environmental quality. The results are in contrast with the findings of Liu et al. (2022) that revealed a positive long-run relationship between education expenditure and renewable energy consumption in BRICS countries.

Regarding infant mortality, an increase in the infant mortality rate will lead to a decrease in solar electricity consumption across all the countries in the study. This can be explained by that high infant mortality will negatively impact human capital development in an economy, therefore, restricting labour force participation and productivity (Novignon, Nonvignon, & Arthur, 2015). This would adversely impact economic growth, leading to a decline in energy consumption, particularly clean energy sources such as solar electricity whose adoption rates are still low (Youssef et al., 2015).

Also, an increase in infant mortality rate would reduce the size and growth of the population, therefore decreasing the rate of demand for energy as advanced by Yu & Zhu (2012) that a change in population size directly affects the amount and type of energy consumption. Therefore, policy makers should promote policies and programs that will reduce infant mortality to improve economic growth and solar electricity consumption.

On the other hand, an increase in mobile phone subscriptions will lead to an increase in solar electricity consumption in countries with low to moderate solar electricity consumption. This implies that in these countries, mobile phones are used mostly to facilitate solar electricity transactions hence the increase in solar electricity consumption.

However, in countries with higher solar electricity consumption, the effect is insignificant. Also, an increase in internet connectivity leads to an increase in solar electricity consumption. The possible explanation is that since all ICT products require electricity to operate, a rapid increase in the use of ICT products will lead to increasing demand for electricity (Salahuddin & Alam, 2015). Also, ICT products increase electricity consumption by improving the ease and efficiency with which consumers purchase electricity and by removing intermediaries so to enhance the interaction between consumers and producers (Walker, 1985).

These results are consistent with the findings of Sadorsky (2012), Saidi et al. (2017), and Salahuddin and Alam (2015) that found a positive effect of mobile phone subscription and internet connectivity on electricity consumption. These results imply that policy makers need to accelerate the roll-out of ICT infrastructure in countries with low solar electricity consumption to boost the consumption levels of solar electricity.

On the other hand, an increase in unemployment, particularly in countries with low to median solar electricity consumption, leads to an increase in solar electricity consumption. These results are in contradiction with the results of Adesina and Mwamba (2019) and Ng et al. (2022) that found an inverse relationship between the unemployment rate and energy consumption. In this study, the inverse relationship is only observed in countries with higher levels of solar electricity consumption.

Among the control variables, an increase in CPI leads to a decrease in solar electricity consumption across all levels. These results are consistent with the findings of Kamaludin (2013) who states that an increase in inflation may lead to a decrease in energy consumption because high inflation may induce a shock to energy prices. Urbanisation has a positive effect on solar electricity consumption in countries with low and higher solar electricity consumption. The effect is negative in countries with a moderate level of solar electricity consumption. These results are consistent with the findings of Ali (2021) that found that urbanisation negatively impacts electricity consumption.

Overall, the study reveals that welfare has a significant impact on solar electricity demand. Also, welfare could be one of the contributing factors to the decline in the frequency of solar electricity transactions in some countries in SSA as stated by GSMA (2020), and the low consumption rate of solar electricity compared to other electricity sources in most countries in SSA as stated by Bisu et al. (2016) and Grimm et al. (2020). Therefore, policy makers and ESPs should take into consideration these welfare effects to ensure that solar electricity achieves the goal of increasing access to electricity in developing countries.

5.6 Conclusion

The importance of welfare in the energy transition cannot be overstated. This necessitated the probe into the effects of welfare on the demand for solar electricity in 15 SSA countries for the period between 2010 to 2019. The study applied the panel Quantile regression with non-additive fixed effects and conducted a robustness check using the panel DOLS estimator. The study found that HDI, education, and infant mortality have a strong and inverse effect on solar electricity demand. Whereas income inequality has a negative and significant effect in countries with low solar electricity consumption, but a positive and significant in countries with moderate-to-high solar electricity consumption. Mobile phone subscriptions have a positive and significant effect on solar electricity demand across all the countries, whereas internet connectivity has negative effects on countries in the lower and upper quantile of solar electricity consumption. These results were consistent with those of the panel DOLS estimator. These results imply that policy makers should develop welfare-enhancing policies to promote solar electricity demand and enhance the transition to clean and modern electricity in SSA.

5.7 Recommendation

The results of this study provide several policy implications for SSA. Firstly, policy makers should develop welfare policies that will promote the use of solar electricity technologies by consumers across SSA. The current status-quo shows that as the level of human development and education improves, the demand for solar technologies decreases. Therefore, policy makers should develop frameworks to regulate quality standards of solar technologies to ensure that they meet the needs of all households across all income segments.

Secondly, policy makers should develop policies that will promote climate education across all schooling years. As revealed by this study, even though government spending on education increases, solar electricity consumption decreases. It is therefore recommended that government spending on education extends towards climate change curriculum development to ensure that awareness is created on the importance of good behaviour towards the environment.

Thirdly, the results conclude that in countries with higher solar electricity consumption, as income inequality increases, solar electricity increases as well. Therefore, and perhaps counter-intuitively, as the income gap widens, the demand for solar electricity increases as well implying that as households get poorer, solar electricity becomes more affordable to them, and they consume more solar electricity. It is therefore recommended that as countries develop economic growth policies, they should incorporate policy goals and targets that will enhance access to renewable energy technologies across all income groups of the population. This will ensure that an increase in solar electricity consumption does not only occur when income inequality increases.

Fourthly, it is also recommended that policy makers should promote the rapid roll-out of ICT infrastructure in SSA to enhance wider access to solar electricity, particularly in countries with low solar electricity consumption. Policy makers should liberalise the telecommunications sector and promote its participation in energy supply by facilitating communication and payment platforms required to ensure wider access to electricity. Also, policy makers should promote competition in the off-grid electricity supply sector to ensure that the technologies are affordable to most of the population in SSA. Overall, it is important that policy makers consider the effects of welfare when designing goals and targets for increasing solar electricity demand.

It is also important to note that the study had limitations. The main limitation of the study is that the period of the study could not be extended due to the unavailability of data for the dependent variable. Most databases do not segregate renewable electricity data, particularly for developing countries. Therefore, the study had to rely on the data available to carry out the empirical analysis. Nonetheless, the results of the study make a valuable contribution to the body of energy studies that seek to reveal the transitions from fossil fuels to cleaner electricity sources. It is, however, recommended that future scholars test the effects of welfare on solar electricity consumption by employing other welfare indicators to contribute to the body of knowledge.

CHAPTER SIX

SUMMARY, CONCLUSION AND POLICY RECOMMENDATIONS

6.1 Introduction

This chapter provides the summary, conclusion, and policy recommendations of the study. It is divided into four sections. Section one provides the introduction, Section two provides a summary of the study and conclusions, Section three discusses policy recommendations, Section four outlines the limitations and suggestions for future studies.

6.2 Summary and conclusions of the study

The adoption of solar electricity technologies in SSA is increasing and impacting various spheres of society, including access to finance. Access to finance and access to energy are key overarching economic development challenges in SSA. Consumers without access to electricity usually also have limited access to financial services, implying that access to electricity may be a channel through which people may be excluded or included in the financial system. This has been witnessed in most parts of SSA where most of the population without access to electricity is also excluded from the modern financial system.

However, many Energy Service Providers (ESPs) have entered the African market to provide off-grid solar technologies to improve access to electricity by the poor. Subsequently, a growing trend of business models that facilitate the purchase of these technologies and actual electricity using mobile money has emerged, implying that an increase in solar electricity consumption will provide countries in SSA with an opportunity to include financially excluded consumers into the financial system and improve their access to electricity. However, the impact of solar electricity consumption has not been explored widely to provide a comprehensive view of other inherent economic benefits other than improved access to electricity. Therefore, this study investigated whether the uptake of solar electricity impacts financial inclusion in SSA.

Existing literature also reveals that the relationship between energy and finance may be both linear and non-linear, suggesting the existence of threshold effects. Therefore, the study established whether there are threshold effects of solar electricity consumption on financial inclusion with a view to fully capture the effects for effective policy recommendations.

On the other hand, the increase in solar electricity consumption, facilitated through mobile money, has led to an increase in non-solar electricity transactions such as cash-in and cash-out transactions (remittances), airtime purchases, merchant payments, and person-to-person payments. Existing literature records that an increase in these transactions may impact price stability and influence money demand (Ziramba, 2007). Therefore, this study analysed the effect of the increased adoption of solar electricity on money demand. It went on to ascertain if the facilitation of solar electricity transactions through mobile money ameliorates the effects of solar electricity consumption on money demand.

Lastly, even though the adoption of solar electricity technologies is growing, their share in the energy mix in SSA is still small, with limited capability to support and enhance a transition to cleaner electricity. Several macro-economic factors that relate to welfare rather than purely income growth is influencing households' demand for solar electricity. Therefore, this study investigated the effects of welfare on the demand for solar electricity, with a specific focus on human development indicators and ICT infrastructure development.

In essence, this study sought to answer the following research questions:

1. What is the linear and non-linear relationship between solar electricity consumption and financial inclusion in sub-Saharan Africa?

2. To what extent do solar electricity consumption and mobile money influence money demand in sub-Saharan Africa?

3. To what extent does welfare influence solar electricity demand in sub-Saharan Africa?

6.2.1 Solar electricity consumption and financial inclusion in sub-Saharan Africa

The energy-finance nexus underpins the relationship between solar electricity consumption and financial inclusion. The energy-finance nexus advances that energy consumption induces the development of and access to financial products and services (Haseeb et al., 2019; Lee and Chien, 2010). Therefore, this study sought to establish whether this theory holds in the relationship between solar electricity consumption and financial inclusion in SSA.

The study found that solar electricity consumption has a positive and significant impact on financial inclusion in SSA. When considering the various constructs of the financial inclusion index, the study found that solar electricity consumption positively impacts the number of depositors in commercial banks (DCB) and the number of registered mobile money outlets (RMMO) in SSA. However, solar electricity consumption negatively impacts the number of commercial bank branches (CBB) and the number of ATMs. The study did not find a significant impact of solar electricity consumption on outstanding deposits in commercial banks (ODCB), outstanding loans in commercial banks (OLCB), the value of mobile money transactions (VMMT), and the number of mobile money transactions (NMMT).

The study, therefore, concludes that, solar electricity consumption has a strong and positive influence on financial inclusion in SSA. Among the three dimensions of financial inclusion (accessibility, availability, and usage), solar electricity consumption significantly impacts the accessibility and availability of financial services. It increases accessibility by deepening the penetration of the banking system through increasing the number of depositors in commercial banks. However, it has a mixed impact on the availability of financial services because it decreases the number of commercial banks and the number of ATMs but increases the number of registered mobile money outlets. It can also be concluded that solar electricity consumption has no significant impact on the usage of both banking and mobile money products and services.

The study further analysed the threshold effect of solar electricity consumption on financial inclusion in sub-Saharan Africa. Theoretical evidence of the energy-finance nexus signifies that a threshold effect may be present in the relationship between solar electricity consumption and financial inclusion. Therefore, the study investigated whether there is evidence of a non-linear relationship between solar electricity consumption and financial inclusion in SSA. The study found that solar electricity consumption has a non-linear relationship with financial inclusion and the effect is positive.

Among the constructs of financial inclusion, the study found a positive relationship between solar electricity consumption and the registered number of mobile money accounts (RMMA), and a negative relationship with outstanding deposits at commercial banks (ODCB) and the number of mobile money transactions (NMMT). However, the study did not find a non-linear relationship between the number of depositors in commercial banks (DCB), the number of commercial bank branches (CBB), number of ATMs (ATMs), registered mobile money outlets (RMMO), outstanding loans at commercial banks (OLCB) and value of mobile money transactions (VMMT).

Regarding the thresholds, the study found that the threshold level of solar electricity on financial inclusion is 5.02%. It also found that there is a threshold level of solar electricity consumption on all the components of financial inclusion except for the value of mobile money transactions (VMMT). The highest threshold level is on the number of mobile money transactions (NMMT), recorded at 5.79%. The study also found the effect of solar electricity consumption after the threshold point is continuous but in a declining kink slope. Therefore, the study concludes that solar electricity consumption has both a linear and non-linear relationship with financial inclusion in SSA.

6.2.2 Solar electricity consumption, mobile money, and money demand in sub-Saharan Africa

An increase in real income or consumption in an economy leads to an increase in the value of transactions, which also increases the demand for real money balances (Ziramba, 2007). This was observed in the consumption of solar electricity in SSA where an increase in solar electricity consumption led to an increase in both solar and non-solar transactions as reported by GSMA (2020). The growth in transactions may impact demand for real money balances because according to (Arshad et al., 2016; Brown & Yücel, 2002), when consumers anticipate an increase in energy prices, they will borrow more than save to smoothen their energy consumption. This will increase the demand for money in the short term. However, as more consumers borrow, interest rates will increase, therefore slowing economic growth which will then lead to a fall in real money demand in the long run (Arshad et al., 2016; Brown & Yücel, 2002).

This study, therefore, investigated the effect of solar electricity consumption on money demand in SSA. It found that solar electricity consumption has no significant effect on demand for real broad money balances both in the short and long-run. However, the introduction of financial innovation (mobile money) in the consumption of solar electricity influences the effect of solar electricity on money demand. Financial innovation significantly reduces liquidity constraints that affect consumption and financial markets, thereby increasing consumption (Bayoumi, 1993). As a result, the structure and motivation of holding money changes, making the motivation for holding money for transaction and speculation motives negligible (Dou, 2018).

The study also found that when mobile money is introduced into the money demand function, solar electricity has a positive and significant effect on money demand in the long run. Also, when solar electricity consumption interacts with mobile money, the demand for money increases in the long run. Therefore, the study concluded that solar electricity consumption is a determinant of money demand when mobile money is used as a payment platform. It also concluded that mobile money does not moderate the effect of solar electricity consumption on money demand.

6.2.3 Welfare and solar electricity demand in sub-Saharan Africa

As countries develop, their energy consumption increases, and the energy mix broadens. At low levels of economic development, countries rely on biomass energy, but as they develop towards industrialisation, they demand petroleum and electricity, reducing reliance on biomass (Hosier & Dowd, 1987). However, they continue to use traditional fuels, partially to supplement renewable electricity sources that are sometimes unreliable and costly. Therefore it can be inferred that economic growth drives energy demand (Apergis & Payne, 2011).

However, economic growth measured in real income is concerned with income growth, it conceals important information about how the growth translates to human development. Hence this study used welfare instead of income growth to ascertain the factors that influence the demand for solar electricity in SSA. Welfare was measured by HDI, inequality in income, education, infant mortality, and ICT infrastructure.

The study found that welfare has a significant effect on solar electricity demand in SSA. An increase in HDI negatively impacts the demand for solar electricity across all countries regardless of whether they have low, moderate, or high solar electricity consumption. Inequality in income negatively affects solar electricity consumption in countries with low levels of solar electricity consumption. However, in countries with moderate to high solar electricity consumption, the effect of income inequality is positive and significant. The study also found that an increase in government spending on education and an increase in infant mortality have negative effects on solar electricity consumption.

Regarding ICT, the study found that mobile phone subscriptions have a positive effect on solar electricity consumption in countries with low-to-moderate solar electricity consumption. However, in countries with high solar electricity consumption, the effect of mobile phone subscriptions is insignificant. The study also found that internet usage negatively impacts solar electricity consumption in countries with low and median consumption of solar electricity. However, the effect is positive in countries with high solar electricity consumption. Therefore, it was concluded that welfare has a significant impact on solar electricity demand, implying that policy makers should consider the effects of welfare when designing policies that seek to promote solar electricity consumption.

Overall, this thesis supports the theoretical argument which advances that the demand for renewable electricity induces the development of and access to financial services (energy-finance nexus). It further aligns with the tenets of the energy-growth nexus that holds that energy consumption drives economic growth (growth hypothesis) and that economic growth factors drive energy consumption (conservation hypothesis).

6.3 Policy Recommendations

The findings of the study provide several recommendations to policy makers in SSA. It is recommended that policymakers should strengthen market interventions that promote the deployment of solar electricity technologies in SSA, particularly off-grid solar technologies. This is because the study revealed that the promotion of solar electricity will not only reduce energy poverty but improve financial inclusion as well.

It is also recommended that policy makers design policies that promote financial innovation and mobile network coverage in SSA. This is intended to ensure that a wider population in SSA can access solar electricity and financial services via mobile phones to reduce the dependence on traditional finance and physical outlets. It is also recommended that policy makers should integrate financial inclusion targets into energy policies to ensure that they achieve both improved access to energy and improved access to finance which will lead to economic growth.

It is further recommended that policy makers should establish and strengthen regulatory frameworks that will improve the operational environment for Energy Service Providers (ESPs), Mobile Network Operators (MNOs) and mobile money operators. These regulatory frameworks should address issues that relate to funding, cyber security, quality of technologies, operating and licensing requirements to name a few of the critical issues. This is critical because the pursuit of regulation and compliance must not constrain the development impact of the services and products offered by ESPs, MNOs, and mobile money operators.

It is also recommended that monetary policy authorities should strengthen oversight and monitoring of the effects of the increase in the depositors' base due to increased solar electricity transactions. This is critical to ensure financial stability because a large undiversified depositors' base may harm the financial stability of these economies, particularly in a financial crisis.

Regarding the effects of solar electricity consumption and mobile money on money demand, it is also recommended that policy makers should promote the development of financial innovation products and services that will ensure that households and firms hold minimum cash. This will reduce the demand for cash, particularly for electricity purchases. It is also recommended that monetary policy authorities monitor the effects of the various components of household consumption expenditure on money demand, particularly solar electricity consumption. This will enable better management of price fluctuation in the economy in the long run.

It is also recommended that central banks consider playing an active role in the ongoing transition to clean renewable energy sources, to evaluate the effects of the transition on the financial sector. The transition to renewable energy may alter household consumption behaviour and introduce new types of transactions and depositors into the financial system. The transition may also alter the size and quality of the depositors' base in commercial banks, especially because of the integration of mobile money into solar electricity consumption.

Further, the transition may also alter the motives of holding money, therefore impacting the demand for real money balances in the economy. It is therefore critical that central banks develop a comprehensive regulatory framework for evaluating opportunities and risks to the financial sector associated with the transition to a low-carbon economy.

Regarding the effects of welfare on the demand for solar electricity, it is recommended that policy makers should design policies that will regulate the quality of solar electricity technologies that enter their markets. This will minimise the influx of poor quality and fake solar technologies, which may be contributing to the decrease in solar electricity consumption when HDI increases. It is also recommended that a significant portion of governments' spending on education should go towards curriculum redesign so that all facets of the education system have components of climate change and environmental management. Lastly, it is also recommended that policy makers should design policies that will promote investment in ICT infrastructure, particularly in countries with low access to solar electricity.

Overall, the thesis recommends the integration of all activities aimed at improving access to solar electricity and economic growth in sub-Saharan Africa, to leverage the economic development opportunities inherent in solar electricity, alleviate energy poverty and promote financial access and stability in sub-Saharan Africa.

??????????????? refers to the integration of all activities related to pursuing energy policy planning and economic development and growth, taking advantage of the economic development opportunities inherent in clean energy sources to create new and innovative economic growth.

6.4 Limitations and suggestions for future studies

The limitations of this study were mainly centred around data availability due to the novelty of the study. Firstly, financial innovation data, particularly mobile money data, is not readily available in most countries. In some instances, even when it is available, some data pockets make the data difficult to use. Secondly, the integration of financial innovation in solar electricity consumption in SSA started about a decade ago, therefore the scope of data that is available for research purposes is limited. It is, therefore, recommended that future studies may consider extending the period of the study and determine whether there is causality in the relationship between solar electricity consumption and financial inclusion. Further, it is recommended that future studies test for the existence of threshold effects found in this study, on a larger sample.

When assessing the effect of solar electricity consumption on the money demand function, the study envisioned including several variables in specifying the money demand function. However, data was not available on some of the variables and for those that had data, the quality of the data was not good enough to include in the model. It is, therefore, recommended that future studies employ the narrow monetary aggregate (M1) and inflation to ascertain the effect of solar electricity on narrow money balances. Further, the study did not test for cross-section dependence, however it relied on the ADF-Fischer and PP-Fisher unit root tests. It is therefore recommended that future studies should test for cross-section dependence.

When assessing the effects of welfare on solar electricity consumption, the study faced limitations on the availability of welfare variables that could be used in the study. It is, therefore, recommended that future scholars employ other welfare indicators to investigate the effects of welfare on solar electricity consumption to provide a holistic policy recommendation for countries as they develop their energy transition policies.

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Appendix A

Figure A3.1: Mean of financial inclusion

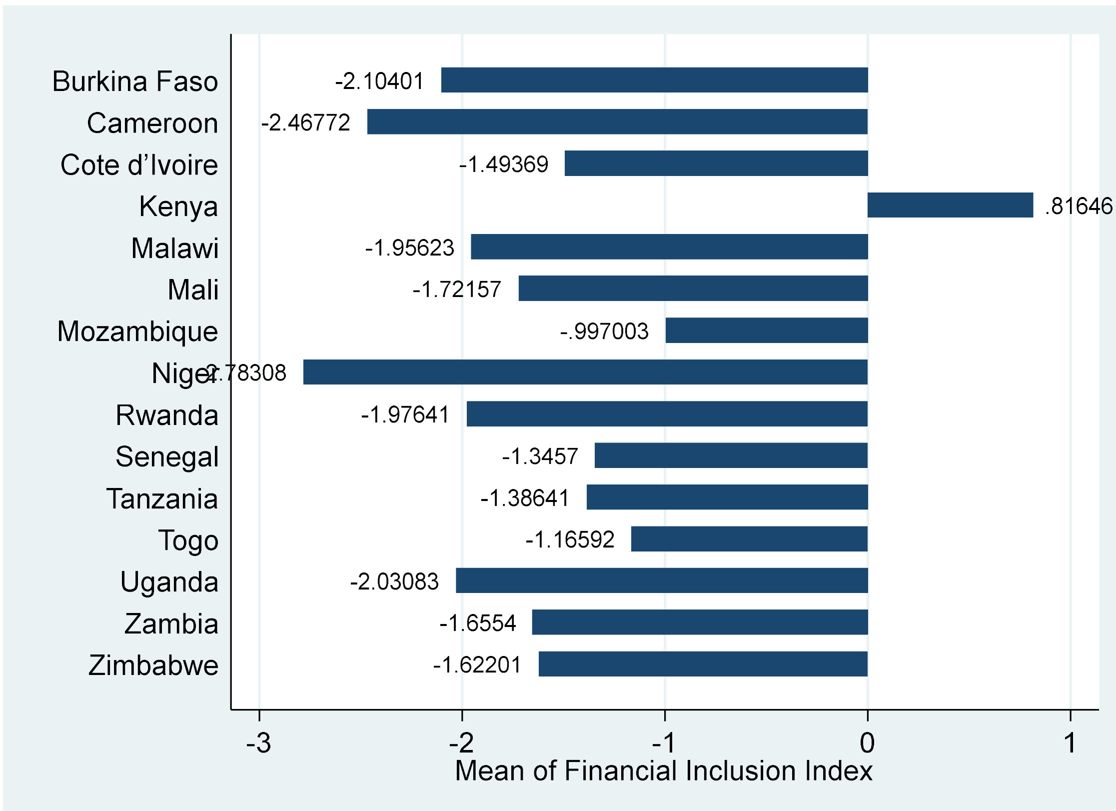
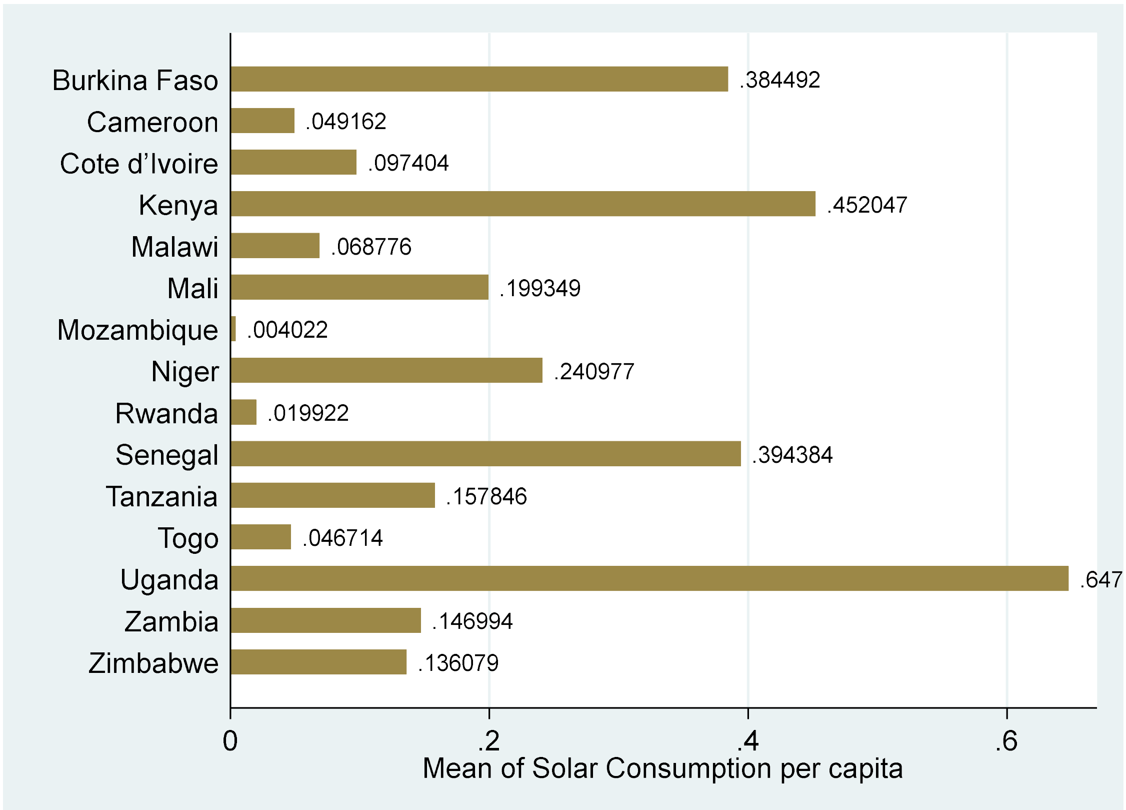
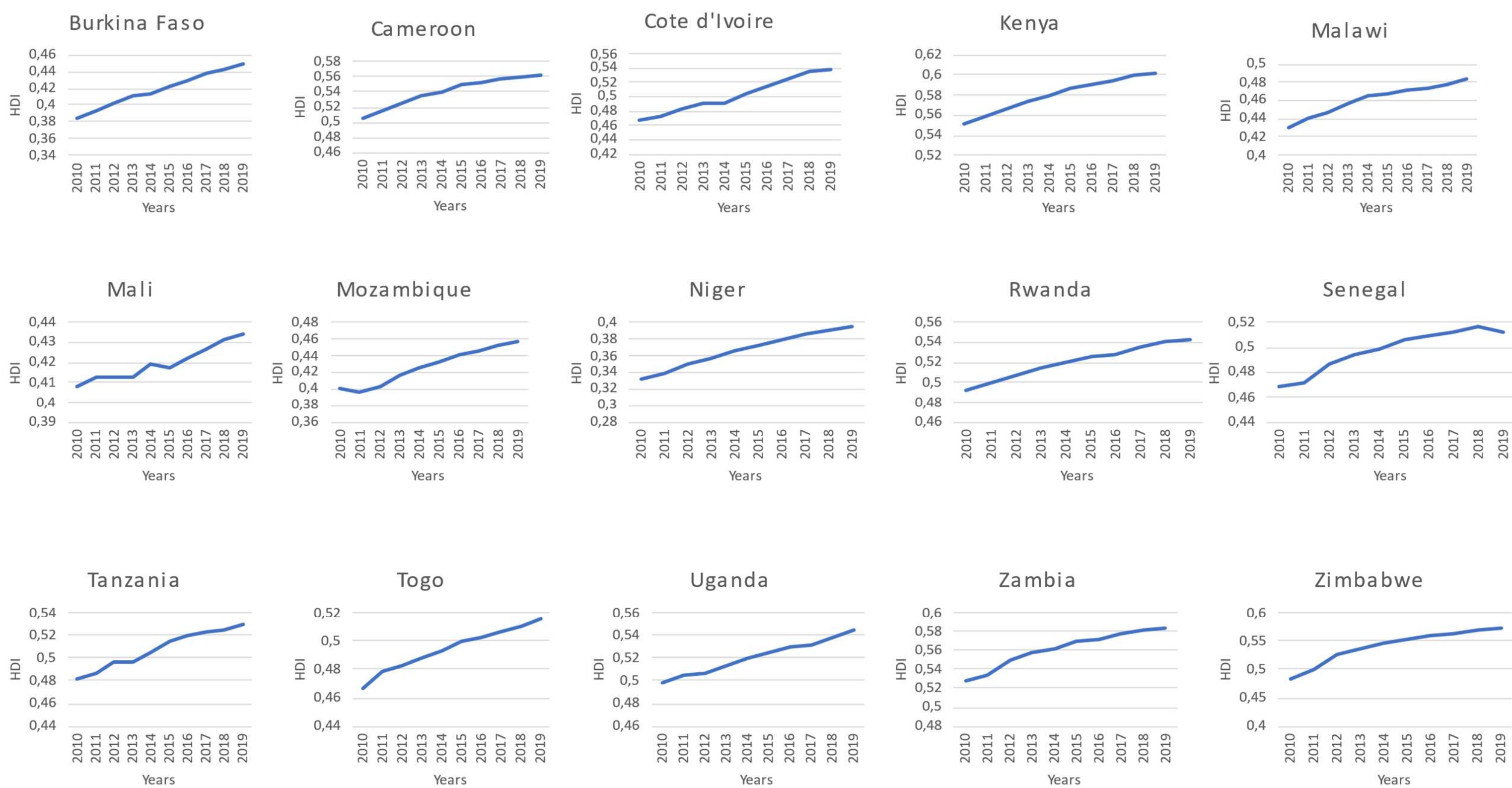


Figure A3.2: Mean of solar consumption per capita



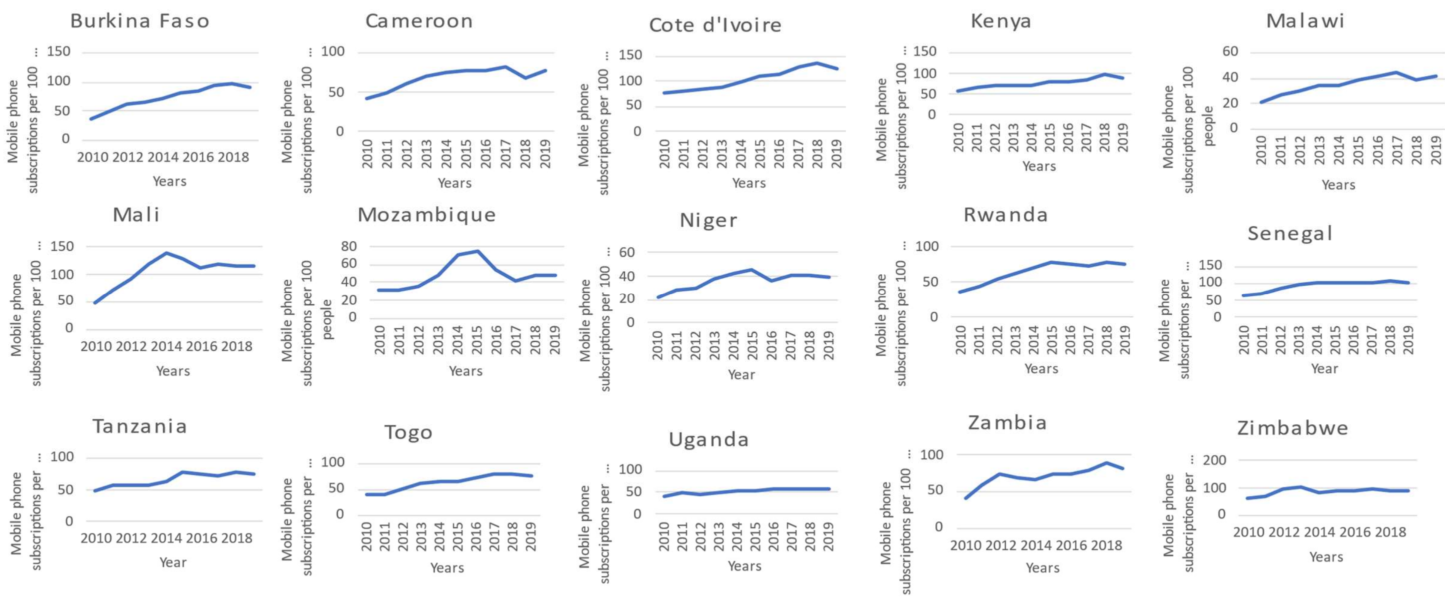
Appendix B

Figure B5.1: Human Development Index in sub-Saharan Africa in 2010-2019



Source: UNDP (2020)

Figure B5.2: Mobile phone subscriptions in sub-Saharan Africa in 2010 to 2019



Source: The World Bank (2022)