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ASSESSMENT OF CLIMATE CHANGE IMPACT AND RENEWABLE ENERGY GENERATION IN WEST AFRICA: A CASE STUDY OF OFF-GRID SOLAR ACCESS IN RURAL TOGO

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Acronyms

AfDB	African Development Bank
AgriV	Agriculture added value
AIMS	African Institute for Mathematical Sciences
An-Temp	Annual Average Temperature
ARSE	Electricity Regulatory authority
AT2ER	Togolese Rural Electrification and Renewable Energy Agency
CCKP	World Bank Climate Change Knowledge Portal
CEB	Compagnie Electrique du Benin/ Benin Electricity Company
CEET	Compagnie Energie Electrique du Togo/ Togolese Energy Electric Company
Chang-Temp	Change in Temperature
CIZO	On Light (local light)
CMM	Choice Modeling Method
COVID-19	Corona-Virus Diseases -19
CR	Contingent Ranking
CRED	Centre for Research on the Epidemiology of Disasters
CSSP	Climate Smart Solar Pump
CVM	Contingent Valuation Method
DGE	Direction General d'Energie/ General Energy Office
DICE	Dynamic Integrated Climate Economy Modeling
DSICE	Dynamic Stochastic Integrated Climate Economy Modeling
ECOWAS	Economic Community of West African States
ECREEE	ECOWAS Centre for Renewable Energy and Energy Efficiency
EM-DAT	Emergency Event Database
EREP	ECOWAS Renewable Energy Policy
ESMAP	Energy Sector Management Assistance Program
FAAPA	Atlantic Federation of African Press Agencies
FAO	Food and Agriculture Organization
FUND	Climate Framework for Uncertainty Negotiation and Distribution
GCAM	Global Change Analysis Model
GDP	Gross Domestic Product

GFCF	Gross Fixed Capital Formation
GHG	Greenhouse Gas
GMM	General Method of Moment
G-MNL	Generalized Multinomial Logit
GWh	Giga Watt hour
HDI	Human Development Index
IAM	Integrated Assessment Modeling
IEA	International Energy Agency
IGSM	Integrated Global System Model
IMAGE-TIMER	Integrated Model to Assess the Global Environment -Targets Image Energy Regional model
IPCC	The Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
KEC	Kuznets Environmental Curve
KgOE	Kilogram per Oil Equivalence
KMO	Kaiser-Meyer Olkin
LIHC	Low-Income high Cost
LPG	Liquefied Petroleum Gas
LSMS	Living Standard Measurement Survey
MDGs	Millennium Development Goals
MEPI	Multidimensional Energy Poverty Index
MERGE	Model for Estimating the Regional and Global Effects of greenhouse gas reductions
NDP	National Development Plan
NOAA	National Oceanic and Atmospheric administration
NPRE	National Program for Rural Electrification
OPHI	Oxford Poverty Index Development Initiative
PAYG	Pay As You Go
PECM	Panel Error Correction Model
PPP	Parity of Purchase Price
PV	Photo Voltaic

RE	Renewable Energy
ROC	Receiver Operating Characteristic
SDG	Sustainable Development Goals
SEFA	Africa Sustainable Energy Fund
SHS	Solar Home System
SIE	Systeme d'Information Energetique / Energy Information System
SOLEVA	Solar Electric Van Project
TFP	Total Frontier Productivity
ITC	Information Technology and Communication
TV	Television
UN	United Nation
UNDP	United Nations Development Programme
UNEP-FI	United Nations Environment Programme Finance Initiative
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
VIF	Variance Inflation Factors
WA	West Africa
WAEMU	West African Economic and Monetary Union
WDI	World Development Indicators
WITCH	World Induced Technical Change Hybrid
WTA	Willingness To Accept
WTP	Willingness To Pay

Abstract

This study examines the relationship between climate change and access to modern energy services in West Africa. The researchers used a Panel Error Correction Regression Model (PECM) based on climate and macroeconomic data collected from 12 West African countries between 1990 and 2019. The results of the study indicate that climate change reduces agricultural value added, while renewable energy consumption increases agricultural participation in the economy by about 47% in the long run. In addition, renewable energy consumption reduces the economic impact of climate change in both the short and long term. The researchers also conducted a household survey of 327 households in the rural Plateau region of Togo to estimate Multidimensional Energy Poverty Indices (MEPI). The results showed that energy poverty in rural Togo is mainly due to expenditure-based energy poverty and the type of energy used for cooking. Female-headed households are more vulnerable to energy poverty in the region. The researchers also used a choice modelling approach based on the same target population to estimate farmers' willingness to pay for the adoption of off-grid solar systems in rural Togo. The results showed that awareness of weather risk challenges plays a role in increasing willingness to pay for modern energy solutions in rural areas. To combat climate change and reduce energy poverty in West Africa, promoting the adoption of renewable energy services is crucial. Off-grid solar systems should be targeted for the development of small-scale economic activities, not just for household lighting. This could generate additional income that could be used to address energy affordability issues.

Keywords: Climate change, off-grid solar, energy poverty, willingness to pay, West Africa.

Résumé

Cette étude analyse le lien entre le changement climatique et l'accès au service énergétiques moderne dans la région de l'Afrique de l'Ouest. Le modèle de régression à correction d'erreur en panel est utilisé avec des données climatiques et macroéconomiques collectées dans 12 pays d'Afrique de l'Ouest de 1990 à 2019. Le résultat montre que le changement climatique diminue la valeur ajoutée agricole à l'économie tandis que la consommation d'énergie renouvelable augmente la participation agricole à l'économie sur le long terme d'environ 47%. Aussi, la consommation d'énergies renouvelables réduit l'impact économique du changement climatique à court et à long terme. Une enquête auprès de 327 ménages ruraux dans la région des Plateaux au Togo est utilisée pour estimer l'Indices Multidimensionnels de Pauvreté Énergétique. Les résultats révèlent que le niveau élevé de pauvreté énergétique dans les zones rurales au Togo est lié à une dépense énergétique très élevé et le type d'énergie utilisé pour la cuisson dans les ménages. En outre, la modélisation a choix discrets a été utiliser pour estimer le consentement à payer des ménages agricoles pour avoir accès aux services énergétiques renouvelables. Il ressort que la sensibilisation aux défis du risque climatique joue un rôle dans l'augmentation du consentement à payer pour des solutions énergétiques modernes dans les zones rurales. Pour lutter contre le changement climatique et réduire la pauvreté énergétique en Afrique de l'Ouest, il est nécessaire de promouvoir l'adoption des énergies renouvelables. Les systèmes solaires hors réseau devraient être ciblés pour le développement d'activités économiques à petite échelle, et pour l'éclairage domestique. Cela pourrait générer des revenus supplémentaires qui pourraient être utilisés pour résoudre les problèmes d'accessibilité à l'énergie.

Mots clés : Changement climatique, system solaire hors réseaux, pauvreté énergétique, consentement à payer, Afrique de l'ouest.

General Introduction

Understanding the economic implications of climate change, and the ability of households to adapt to its effects are crucial for policy implementation in building resilience to weather patterns, and improving well-being in low-income countries (Batten, 2018; Dagnachew et al., 2018; Gillingham et al., 2018; Kahn et al., 2019). Starting from the work of the 2018 Nobel Prize winner, William Nordhaus(1992), the economic implication of climate change has gained more attention in recent theoretical and empirical literature. Nordhaus has the merit for being the first economist who integrated the issue of climate change into the long-term macroeconomic analysis, making the difference from earlier studies that put natural resource depletion (scarcity of fossil fuel) in front as the major threat to the economic growth (Kuznets, 1955; Solow, 1974; Stiglitz, 1974). In his work, Nordhaus raised the issues of greenhouse gas (GHG) concentration in the atmosphere to be detrimental to the economy, and estimated the economic damages associated to climate change (Nordhaus, 1992, 1993, 2015, 2018). After his work, several attempts to quantify the long-term impact of climate change on the economic performance are fast growing (Kahn et al., 2019; Kalkuhl et Wenz, 2020; Tol, 2018).

Greenhouse gas concentration in the atmosphere is well acknowledged as resulting from human activities, basically as one of the consequences of the industrial revolution (Stern, 2007). It is an externality that the market fails to correct in order to achieve a greatest social welfare (Harris et al., 2017). In the economic theory of social welfare, market failure describes a situation in which “private decision based on market signal (prices) fails to generate an efficient allocation of resources, in order to make at least one person better off without making anyone else worse off” (Hanley et al., 1997). When it occurs, an economic agent finds itself not only depending on his own activities but also on another agent’s activities without any market compensation taking into account the damages or benefits created (Tietenberg et Lewis, 2014). This is called an externality.

The externality also is seen in the economic theory as the failure of the economy to create potential market in some goods or clearly defined property rights (Arrow, 1969; Hanley et al., 2001a). Thus, GHGs, principal source of global warming occasioning the weather variability (Kalkuhl & Wenz, 2020), create unprecedented environmental externality damageable for the global economic systems. Mainly characterized by a persistent rise in temperature and irregularity in rainfall, climate change has been shown to have major impacts on the economic activity (Dell et al., 2014; Tol, 2018), and

human well-being (Hsiang et al., 2013). The transmission channels through which climate change affects the economic activities include agricultural yields (Kahn et al., 2019; Tol, 2021), energy system (Silva et al., 2020), labor productivity (Zander et al., 2015), commodity prices (Kahn et al., 2019) and human health system (Deschenes, 2014; IPCC, 2014).

These consequences are increasingly worrying the world and pushed political actions to reduce greenhouse gas emissions (Nordhaus, 2019; Schubert, 2019; UNFCCC, 2015). In the same line, the Intergovernmental Panel on Climate Change (IPCC) has called for political actions to limit the global warming to 1.5⁰C and to build resilience to climate change (IPCC, 2014). Climate mitigation actions include an effort to reduce greenhouse gas emissions from fossil fuels' combustion, energy efficiency and end-use innovations, and reducing carbon emissions through avoiding deforestation (Barbier, 2014). Therefore, some approaches were developed for the achievement of these goals. Such approaches include command and control regulation, clean and green technology adoption, property rights definition, and tradable permits programs (Heinzerling, 2012; Tietenberg & Lewis, 2014).

The idea behind these approaches is to internalize the damage caused by the externality in the production system, using price intervention, and avoid government intervention. This is consistence with Coase, (1960), who argues in the same vein and claiming that environmental problems can be resolved, and the market allocation can be optimal, if property rights are well defined and transaction costs are null. Following recent works of Brock & Taylor, (2004, 2010), green technology development is also promoted as a solution for pollution abatement. Despite these market-based solutions provided for the internalization of damages caused by environmental degradation, externalities resulting from climate change remain complex and requires more attention.

Recently, sustainable development concept has emerged as a fundamental strategy for equitable economic growth and environmental management (Shi et al., 2019). The concept refers to how human beings have to exploit wealth from the nature to satisfy its current basic need without compromising future generation to satisfy their basic one (Xinzhang, 2012). From this perspective, target solution should conciliate economic, social and environmental aspect in development. For instance, 17 Sustainable Development Goals (SDGs) have been adopted by United Nation in 2015

in whether to ensure sustainable economic growth that incorporate dignity, human beings, the planet, prosperity, justice , and partnership (Shi et al., 2019; Stafford-Smith et al., 2017).

It is also well acknowledged that the energy sector is the main driver of Greenhouse gas emissions (Bourcet, 2020; IEA, 2018), principally from fossil fuels energy consumption (Jebali et al., 2017; Patterson, 1996). Climate mitigation policies requires the adoption of low-carbon technologies and new energy sources (renewable energy for example) that can reduce the negative impact of energy consumption on climate variability (Brock & Taylor, 2010). Renewable energy sources used for electricity generation could include: solar, geothermal, ocean, wind energies, bioenergy, green hydrogen, and hydropower. However, such actions in favor of climate change mitigation and externalities' internalization have to be implemented according to the country specific context, and its capability in such policy implementations. In Africa, compared to the rest of the world for example, countries are low GHGs emitters but highly suffer from its consequences. In addition, the energy sector in the region requires more attention due to the fact that its population remains in chronic energy poverty.

According to Streimikiene et al. (2020) energy poverty is defined as the situation in which households are spending a high share of their real incomes on their energy needs or that households cannot meet their basic energy needs due to the lack of energy access or insufficient income to get access it. Characterized by a lack of energy access, West African (WA) countries remain dependent on fossil fuel importation. Less than 42% of its population have access to electricity and the electricity shortage is recurrent in the area (ECREEE & World Bank, 2019). However, the region's wind, hydro and solar potential is enough to power the population many times over, as 93% of Africa's natural and renewable energy resources remain untapped (IRENA, 2012). To meet the unprecedented increase in electricity demands by 2030 and contributing to the objectives of the sustainable development, the Paris Agreement, (Antwi-Agyei et al., 2018; IRENA, 2015), West African countries have adopted countries' energy policy targets envisioning a mix of renewable electricity sources in the future typically solar, wind, green hydrogen, and hydropower.

In this line, the Economic Community of West African States (ECOWAS) has established its renewable energy and energy efficiency center. It has Renewable Energy Policy (EREP) that aims to achieve this goal which also foresees strong growth in solar, wind, and hydropower capacity up

to 2030 (ECREEE, 2015). This adoption goes with the achievement of SDGs-7 of the Sustainable Development Goals initiative which is to deploy and integrate distributed resources and generation into the current power grid, which can increase system reliability and energy efficiency (Zhu et al., 2012), and then alleviate energy poverty in the region. Energy efficiency in relation to sustainable development gained considerable attention from scholars and policymakers. It is pointed out as one of the solutions for the current challenges (Climate change and Energy poverty) faced by the world. By definition, energy efficiency is a way of managing and restraining the growth in energy consumption (IEA, 2010; Jebali et al., 2017). Therefore, energy-efficient aims to deliver more services with the same energy input, or the same energy services with less energy input”.

The specific case of Togo is very worrisome. Firstly, categorized as low-income country, the country’s economy repose mainly on small-scale agricultural production (WDI, 2022; World Bank, 2022). It represents more than 40% of the GDP and employs nearly 70% of the country’s workforce in 2019 (Ali, 2021b). Moreover, with climate change impact, Togo is experiencing food insecurity situation in term of availability and accessibility of food. For instance, it is reported that, since 1999, Togo has had a relatively low average value of food production per capita (about US\$113.70 per capita) and is below West Africa’s average value of food production (about US\$192.70 per capita) (FAO, 2019). Also, Togo has recorded a critical and relatively high prevalence of severe food insecurity in its population over the last 5 years (33.25%), representing almost the double of the average in the West African region (15.95%).

The energy sector in Togo has almost the same characteristic as the rest of WA countries. Its energy consumption comes from three (3) principal sources: biomass, petroleum product, and electricity from non and renewable sources. The first source of biomass consumption comes entirely from domestic resources such as firewood (used by 35% of households). Its total production is evaluated at 31.788 GWh of the country’s primary energy generation. Almost all the remaining biomass is converted into charcoal. As reported by “Systeme d'Information Energetique” du Togo (SIE), the conversion takes place with an energy efficiency of 29.5%, resulting in the final consumption of 5.974 GWh (SIE, 2017). The report also shows that a very small amount of waste (279 GWh) is also transformed into energy sources.

The second source of energy (from petroleum products) is completely imported. A large part is directly consumed by the transport sector and 12% is used for electricity generation. The third source of energy (electricity) is mainly dominated by importation from the countries of the sub-region (Ghana, Nigeria, Cote d'Ivoire). The total amount of electricity imported in 2017 (953GWh), represents more than 70% of the total amount produced in the country (1162 GWh). The local production comes mainly from hydropower generation (209GWh) and renewable energy sources (2GWh) (SIE, 2017). The poor quality of the existing grid causes about 16% of transmission-losses of the total electricity produced. Added to the problem of poor quality of the existing grids, energy affordability remains a big challenge in the rural areas (Gafa et al., 2022; Gafa & Egbendewe, 2021). Most of the population are living without any access to electricity. In 2018 less than 45% has access to electricity (Global Lightning, 2018). This access rate is unequally redistributed between urban and rural areas. The urban access rate represents 88.8% against less than 8% in rural areas (Global Lightning, 2018). This share is very low in accordance with the total energy share of the country. In detail, 92% of households living in Lomé (the capital city of Togo) have access to electricity, 20% for the Maritime region, 14% for the Plateau region, 18% for the central region, and 11% for the Savanna region (Global Lightning, 2018).

Togo recognizes that access to electricity is an essential element of its energy poverty alleviation, economic development, and inclusive growth policy. It constitutes one of the major pillars that will enable the implementation of its National Development Plan. The country's aim is to ensure universal electricity access for all Togolese by 2030, with a 100% access rate over the next ten years. This will be achieved through an intelligent combination of network extension and off-grid solutions (Mini-Grids and solar-kits). The implementation of the "CIZO Program" (lighting up in the local language), seeks to increase rural electrification rates to 45 percent by 2023. In this line, the Government is partnering with off-grid companies to supply Solar Home Systems (SHS) for rural customers. Then, Power Africa partner BBOX signed an agreement with the government to deliver more than 500,000 systems to rural Togolese over the next five years and Greenlight Planet, a U.S. company, also signed an agreement to deliver more than 300,000 solar home systems. Recently other partners were added (SOLEVA, Fenix, Moon, and Solergie).

Renewable energy adoption has strong synergy effects on climate change mitigation and energy poverty alleviation throughout sustainable development by providing clean energy (low-carbon)

for economic growth, a new opportunity for industrialization, and job creations to reduce unemployment. It has also the potential to make agriculture more productive and thus contribute to increasing producers' income and food security (Kane et al., 2018). This can be observed through the installation of photovoltaic systems and moto pumps for water irrigation to cope with climate change's impact on crop production. In addition, renewable energy systems were also used for healthcare facilities and clean water supplying for essential hygiene (World Bank, 2020a). Also, Off-grid solar system gives an opportunity to increase educational systems in rural areas and avoid migration from rural places to urban areas. Affordable and clean energy will also help to reduce indoor and air pollution, sustain forests by replacing the need to collect firewood by the use of a clean cookstove. Despite the unlimited list of benefits from modern energy adoption, the most important enquiry remains on the capability and the ability of households to be involved in, and adopt the off-grid solar system.

Additionally, despite the large potential of renewable energy sources that Africa have, and the actions taken by its governments for its transformation, electricity access remains inaccessible to some of the people in this region. It is worrying to acknowledge that the continent remains in a deep energy poverty condition with the lowest access rate. Over 600 million people lack access to electricity (IEA, 2018, 2019), representing 70% of its population without access to modern energy services (clean cooking facilities) (Aung et al., 2021; IEA, 2017). This evidence shows that there is a need to move forward in transforming the large potential that the continent has. Nevertheless, some scholars warned that there could be some environmental impact of climate change that could affect the process of renewable energy sources transformation into energy services (Solaun & Cerdá, 2019). For instance, change in rainfall patterns could impact river flows and water levels affecting hydropower generation (Ebinger & Vergara, 2011). Also, change in sola irradiation and cloudiness have been shown to negatively affect electricity generation from solar panels (Solaun & Cerdá, 2019).

Even though, several studies have investigated impacts of climate change (Solaun et Cerdá, 2019, 2020), the role of renewable energy in climate-economy assessment in developing countries received less attention. Very few scholars have drawn the attention to the effect of climatic factors on economic outcome (Gillingham et al., 2018; Kahn et al., 2019; Kalkuhl & Wenz, 2020; Nordhaus, 2019; Silva et al., 2020). For instance, Silva et al., (2020) investigated the climate

change impacts on electricity demand for the southern European country (Portugal) using electricity consumption which is a function of economic activity, electricity price and temperature indicator. In the same line, Kalkuhl et Wenz, (2020) also investigated the impact of climatic conditions on economic production for more than 1500 regions in 77 countries.

Furthermore, a study by Kahn et al., (2019) highlighted the long-term impact of climate change on economic activity across 174 countries by using a stochastic growth model. In their work, economic productivity is affected by deviation of temperature and precipitation from their long-term moving average historical norms. Gillingham et al., (2018) also explored uncertainty in baseline trajectories using multiple integrated assessment models. The focused on three key uncertain parameters: population growth, total factor productivity growth, and equilibrium climate sensitivity. In Sub-Saharan African context, an exception is given to Arndt et al., (2015), which investigated the economic implication of climate change for Ghana's electricity generation and other channels: agriculture, infrastructure and coastal inundation from sea level rise. Dagnachew et al., (2018) however, used IMAGE-TIMER integrated assessment model to analyze trade-offs and synergy between achieving universal electricity access and climate change mitigation in Sub-Saharan Africa.

Research Question

The main question raised by this study is: What is the link or the trade-off between climate change and renewable energy generation in West Africa?

From this principal question, the study attempts to find answers to three sub-questions:

- What is the role of renewable energy consumption in climate-economy relationships in West African region?
- Does climate policy such as off-grid solar system reduces energy poverty in rural West Africa?
- What are the drivers of farmer's preferences for off-grid solar access in Togolese rural area?

Objectives of the study

The principal objective of this research is to investigate the trade-off between climate change and modern energy services access in West Africa.

Thus, this dissertation has three specific objectives:

- Analyze the role of renewable energy access in climate-economy relationship in West Africa countries,
- Assess the socioeconomic impact of climate change mitigation policies on energy poverty alleviation in rural Togo
- Examine farmers' preference and Willingness to pay to access Off-grid solar solution.

Hypothesis

- An Increasing in the total share of renewable energy consumption in total final energy consumption lowers climatic change impact on West Africa's economic growth.
- Climate change mitigation policies allows energy poverty alleviation in rural Togo
- Weather risk challenges awareness enhances farmers willingness to pay for off-grid solar system in rural Togo.

Contribution

The contribution of this study can be summarized in three points. Firstly, the research contributes to the existing literature by attempting to give an understanding to the economic implication of climate change in developing countries, most specifically in West African countries. Making a difference from the existing literature which focused mainly on a long-term analysis of economic impact of climate change (Gillingham et al., 2018; Kahn et al., 2019; Kalkuhl et Wenz, 2020; Nordhaus, 2019; Silva et al., 2020), this study uses Panel Error Correction Model (PECM) to assess the short and long-run causality among climatic change, renewable energy consumption, domestic investment and agricultural development in West Africa region. The advantage of using PECM is that it considers all variables endogenous and gives the short-run and long-run causal effect among variables (Ali, 2021a).

The second contribution of this study resides in the construction of the Multidimensional Energy Poverty Index (MEPI) for rural Togo and linking it to climate change mitigation policies implemented by government. Following the existing literature (Gafa et Egbendewe, 2021; Nussbaumer et al., 2012; Sadath et Acharya, 2017a; D. Zhang et al., 2019), this study constructs new MEPI integrating energy affordability, accessibility, as well as energy facilities (Convenience and safety) concerns in rural Plateau region in Togo. This helps in proposing insightful policy recommendation that should allow simultaneously energy poverty alleviation and climate change mitigation.

Finally, this study contributes to providing empirical evidence of factors that govern preference and choice making of rural households in the adoption of off-grid solar systems in rural Togo. The novelty of the willingness to pay approach that is used in this study resides in the designing of the choice set. Different from Elegbede et al., (2021)'s method, this study confronts two different types of Off-grid solar solutions, solar home system basically for lighting, and climate smart solar solution for crops production. The interest is to provide successful policy recommendation that could be implemented for the successful achievement of the seventh global Sustainable Development Goal (SDG 7.1) which is “to ensure access to affordable, reliable and modern energy services for all by 2030” (UN, 2015). Furthermore, this research brings out, farmers basic needs in terms of modern energy services and their ability to afford it. Based on these findings, solar companies, renewable energy investors and government could make good decisions for SHS deployment to satisfy households basic needs to alleviate energy poverty in rural area.

Plan Activities

The dissertation is organized in three essays. The first essay covers the first objective which is on the assessment of the role of renewable energy consumption in climate-economy relationship in West Africa. it aims to investigate and contribute to the understanding and awareness of the economic impact of climate change. The second essay focuses on the second objective of this research. The objective is to assess the socioeconomic impacts of climate change mitigation policy on energy poverty alleviation in rural Togo. Finally, the third essay focuses on the third objective of the research, which tackles famers preference and Willingness to pay to access Off-grid solar

solution in rural Togo. This third objective aims to investigate factors that drive farmer's preference for SHS choice in Togolese rural area where national grid solution is not evident.

1. Essay1: Climate-economy relationship in West Africa.

1.1. Introduction

Understanding and quantifying the macroeconomic effect of climatic change in low-income countries are crucial for policy implementation in resilience to weather patterns (Batten, 2018). Climatic change through rising in global temperature and irregularity in rainfall has a considerable impact on economic activities (Auffhammer, 2018; Dell et al., 2014; Kahn et al., 2021; Kalkuhl & Wenz, 2020) and affect human living conditions (Deschenes, 2014; Hsiang et al., 2013). These changes have adverse effects on agricultural productivity, domestic investment, economic growth, and energy production (Mendelsohn et al., 1994; Tol, 2021). It is known that climatic change in terms of weather patterns have short and long-term macroeconomic effects in low-income countries as well as in advanced economies (Dell et al., 2014; Kahn et al., 2021). However, the size of these effects could vary depending on geographical conditions and a country's ability to adapt.

From recent studies estimating the economic impact of climate change, it is known that climatic change and weather extremes affect economic growth (Auffhammer, 2018; Kahn et al., 2021; Kalkuhl & Wenz, 2020; Newell et al., 2021; Tol, 2021). However, there is a debate surrounding this relationship and the economic response to these phenomena. Several scholars argue for a linear relationship (Burke et al., 2018; Dell et al., 2012), while others postulate non-linear relationship (Burke et al., 2015; Deryugina & Hsiang, 2017; Hsiang, 2010). For instance, Burke et al., (2015) highlighted that warming countries are severely hit by climatic change than cold countries. Auffhammer, (2018) has distinguished between weather variability impact and climatic change impact and analyzed the interaction between climate and weather on potential output and output gap. In the same line with Burke et al., (2015), Newell et al., (2021) found that weather variability severely hit economic growth in low-income countries more than in advanced economies. Similarly, Kalkuhl & Wenz, (2020) underline the same findings for tropical and poor regions. Tol, (2021) also stated that temperature and rainfall determine production possibility in both rich and poor countries.

Therefore, reducing climate change's impact on economic growth would depend on the country's ability to develop sustainable and inclusive growth policies that could absorb climate weather variabilities. Bowen et al., (2012) pointed out that there is a need to focus on factors that are highly correlated with economic growth. Those factors in West Africa's context include agricultural sectors, good institutions, well-developed financial sectors, and strong health, sanitation, and education systems. Ferreira et al., (2020) also, insisted on climate-smart and inclusive technologies development. Therefore, it remains a pertinent question of how a country's adaptative policies interact with climatic changes and weather variability to affect economic growth in low-income countries?

The nature of these climate-related risks can be categorized in two groups: physical and transitional risks. The physical risk is assessed as a long-term effect resulting in a shift from historical climate conditions. Notedly, a persistent rise in temperature combined with changes in precipitation (rainfall) could affect labor productivity and slow down agricultural yields in a historically dry region, whilst the adverse effect could be observed in the cold region (Kahn et al., 2021; Tol, 2021). In addition, economic growth is demonstrated to decrease globally by 1.0-3.3% by 2060 under a temperature rise of 1.5-4°C (UNEP-FI, 2022).

In terms of energy production, the electricity market could be disrupted by increases in the frequency and severity of weather events (Ciscar & Dowling, 2014; Govorukha et al., 2020). The expected effects also could be positive or negative. For instance, changes in temperature, humidity, wind, solar irradiation, and precipitation could threaten electricity generation from renewable sources (Silva et al., 2020). Hydropower generation is expected to decrease under warming climate conditions, and river flow decreases. The increasing global temperature could also affect solar panel efficiency and power output (Solaun & Cerdá, 2019). The positive side effect, however, could be observed under the geographical and local climate conditions. In local cold climate conditions, for example, an increase in temperature could reduce household space heating costs (Moral-Carcedo & Vicéns-Otero, 2005; Peters & Hertel, 2016).

The transitional risks however are assessed as a short-term effect resulting in a shift from historical climate conditions (Hantzsche et al., 2018; UNEP-FI, 2022). It consists of climate policy implementation for a structural change to a low-carbon economy. For example, electricity

generation from renewable energy sources could benefit both climate change mitigation and economic development in developing countries (Dagnachew et al., 2018). Indeed, the use of low-carbon technologies, such as hydropower, solar panels, and biomass, reduce greenhouse gas emissions. It serves as a basis for providing affordable, reliable, and modern electricity to poor households in areas not connected to the grid. Thus, having access to renewable electricity could improve living standards in terms of health care access, education, and increase in households' income, and also reducing climate change impact on agricultural production (Abdul-Salam et al., 2019; Dagnachew et al., 2017). Therefore, electricity generation from renewable energy sources is given to be the key solution for achieving universal electricity access by 2030, one of the Sustainable Development Goals objectives (SDG) (UNFCCC, 2015). However, policies such as carbon taxes implementation could increase production costs, reduce profits and increase prices. These may decrease investments, reduce households' disposable income, and lower consumption. Finally, the gross domestic product (GDP) could decrease. A short-term transitional risk could also occur in terms of unemployment, inflation, energy demand, and government revenue and debt as highlighted in the United Environment Program Finance Initiative (UNEP-FI) report 2022 (UNEP-FI, 2022).

Therefore, this brief review shows that having an understanding of the macroeconomic implication of climate change and renewable energy access is relevant for public policies designed to absorb climate stress. This is more relevant for low-income countries located in warm climate conditions. For example, West Africa is one of the most vulnerable regions to climate change (drought, flooding), with an unprecedented impact on livelihoods, food security, and economic and government stability (USAID, 2018). About 621 million people lack access to electricity, representing three-quarters of the world's global population without access to electricity (IEA, 2019). Moreover, the international Energy Agency recent report showed that energy poverty situation ECOWAS country is deteriorating. In fact, the region is the only one in the world where the number of people living without electricity access is increasing (Ritchie et al., 2022). The macroeconomic and development risks assessment report of the African Development Bank in 2019 shows that African countries will be severely hit by climate change and weather variability, and about 15 percent of the region's gross domestic product could be lost by 2050 (AfDB, 2019).

Yet studies have analyzed climate-economy relationship in west Africa considering countries adaptative response to climate change. This study assesses this relationship and shed light on the role of domestic investment and renewable energy consumption in climate-economy relationship in the region. Due to the fact that agricultural production constitutes the principal activities of more than 70% of the region's population, its contribution to the economic growth is considered as the economic variable in the studies.

Research question

Therefore, this study tries to answer this question: what is the state of climate-economy relationship in West Africa climate context?

Specifically,

- Does renewable energy deployment in West African countries contribute to the reduction of climatic change effect on agricultural Added value to the economy?
- What is the role of domestic investment in this relationship?

Objectives of the Essay

This study aims to assess the state of climate-economy relationship in West Africa. Specifically,

- Examine the role of renewable energy consumption in climate-economy nexus with a focus on agricultural contribution to economy
- Analyze the role of domestic investment in climate-economy relationship.

Hypothesis

The main hypothesis behind this research is that sustainable policy implementation reduces climate change's impact on economic growth in low-income countries. Mainly,

- Increasing the total share of renewable energy consumption in the country's total final energy consumption reduces climatic change effect on agricultural participation to low-income countries' economy.

- Stimulating domestic investment positively contributes to reduce climatic change effect on agricultural participation to low-income countries' economy.

Contribution

Thus, this essay assesses West African countries economic response to climatic change and analyze how economy interacts with climatic change variables to lower climate damage on economic growth in the region. Particular attention is given to agricultural system mechanization and domestic investment. Although, the assessment of the macroeconomic impact of climate change is complex, there is a few modeling studies that considered the complexity and the uncertainty surrounds its long-term effects (Bosetti et al., 2007; Gillingham et al., 2018; Nordhaus, 2018). Considering that climatic change impact is stochastic (Ali, 2021a; Kalkuhl & Wenz, 2020; Tol, 2021), this study uses Panel Error Correction model (PECM) to assess climatic change impact on economic outcomes. It contributes in understanding both short and long- run causal relationship among variables. Different from Ali, (2021a) that use dioxide carbon emissions level to measure climatic change impact for West Africa countries, which not really reflect climatic change level in the region, this study use change in annual average temperature as climatic change measure. The PECM method also gives the short-run to long-run adjustment coefficient of the error term. All variables in the model are treated as an endogenous variable. In addition, the study emphasizes on the optimal economic response to climatic change that could reduce climate change impact on economic outcome in West Africa context.

Plan activities

This essay is organized in 6 sections. The first section covers the introduction to the essay. It gives an overview of the essay, the objectives, the hypothesis and the plan activities of the essay. The second and third section sheds light on the Background and related literature to the essay. In section four, the methodology part of the study is developed. Then, the section five presents the results and analysis the finding from the empirical methods. Also, it discusses the findings. Finally, the last section, section six, concludes the study with the results implication and suggestion for further studies.

1.2. Background on West Africa's socioeconomic and climatic change situation

This section presents an overview of socioeconomic and climatic change situation in West Africa. The West African region, composed of 16 countries, covers two distinct climatic zones. Northern or Sahel zone has semi-arid and hyper-arid (desert) climate. This zone includes Burkina Faso, Gambia, Mali, Mauritania, Niger and Senegal. The second climate zone is the south or coastal subregion. It has tropical savannah and tropical monsoon climate. This subregion includes coastal countries such as Benin, Cabo Verde, Cote d'Ivoire, Ghana, Guinea, Guinea-Bissau, Liberia, Nigeria, Sierra Leone and Togo (AfDB, 2019; Ayugi et al., 2022). These two subregions have been differently affected by climatic changes and weather patterns. The Sahel countries are severely hit by change in temperature and droughts while coastal countries are subject to severe effect of precipitation pattern and floodings. According to the Emergency Events Database (EM-DAT) (CRED, 2022), drought disaster occurred in West Africa 48 times between 1990 and 2022, with 40 times occurrences reported for Sahel subregion and 8 times occurrences for Coastal countries. Moreover, 154 cases of floodings occurrences were recorded in Western African region with 64 times occurrences observed for Sahel countries while Coastal countries record 90 times floodings occurrences. This statistic shows that Sahel countries are more frequently exposed to these two extremes' events (dry and wet) while Coastal countries are mostly exposed to flooding extremes event from 1990 to 2022.

Consequently, these climatic and extremes weather patterns caused numerous socioeconomic damages in term of deaths and infrastructure destruction, crops failure, food shortage and famine. Agricultural sector is the most affected by the extremes event due to the fact that Western African countries farming activities are largely rainfed (Ayugi et al., 2022; Gadédjisso-Tossou, 2015). Indeed, rainfed agricultural practices remain the principal activities of more than 70% of the West African population (Zougmore & Partey, 2022). Also, it constitutes the main driver of the region's economic growth with more than 35% share of Gros Domestic Product (GDP) (AfDB, 2019; Ali, 2021a). With this large share of rainfed agriculture of GDP, West African economy is highly sensitive to drought and flooding. Studies have associated the causes of these climatic changes and weather pattern to two mains factors. Firstly, the influence of land-use practices was highlighted. For example, Charney, (1975) pointed out the significant effect of vegetation reduction on rainfall in the Sahel. Vegetation change has decreased trend on rainfall, about 40% in the Sahel during

the rainy season (Charney, 1975). Secondly, in most recent studies, sea surface temperature changes were indicated as the major factor accelerating drought in West Africa (Ayugi et al., 2022; Bader & Latif, 2011; Rodríguez-Fonseca et al., 2015). The following graph reports climate-related disaster occurrences in West Africa region.

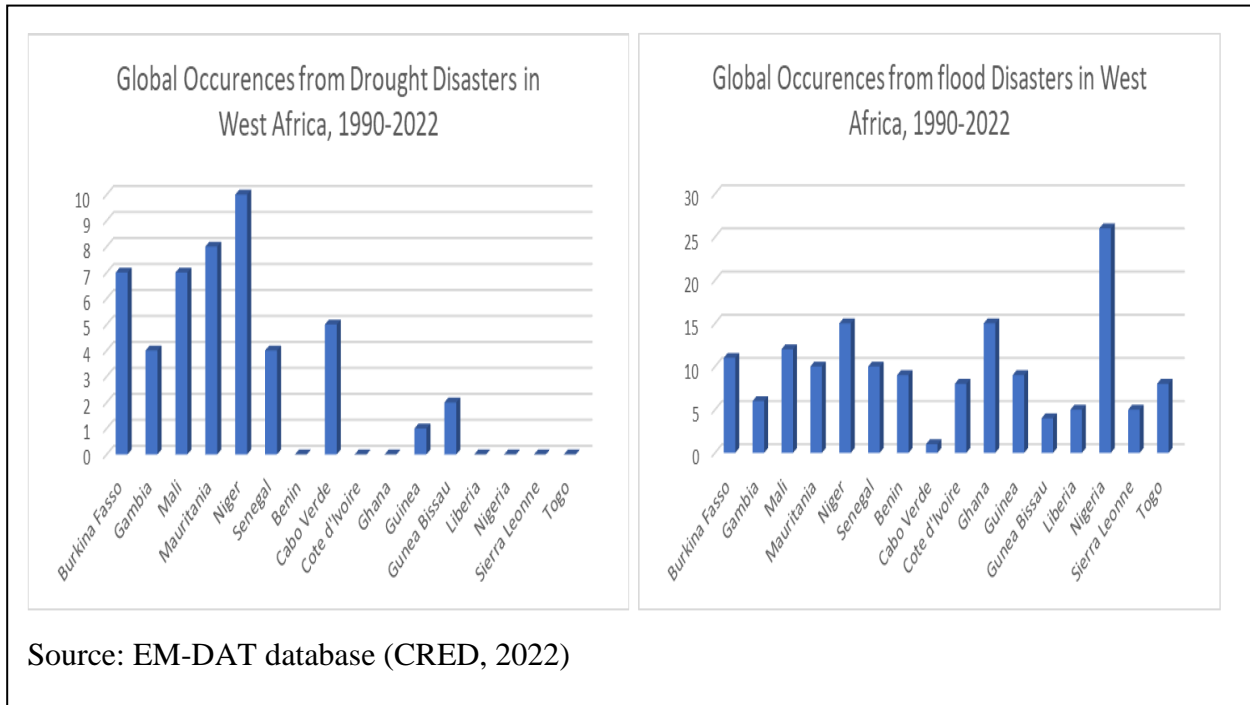


Figure 1: Climate-related disaster occurrences in West Africa region (1990-2022)

- Historical climate observation in West African Sahel and Coastal areas.

West Africa countries in general have a progressive increasing trend in temperature and decline trend in rainfall over the historical observation period 1950-2020. However, temperature increasing in Sahel zone is likely higher than that in coastal zone. The maximum average temperature observed in Sahel zone is around 30°C while around 27°C is observed for Coastal countries. A rapid decline in rainfall is observable for Sahel countries while relatively low trend is observable for Coastal countries.

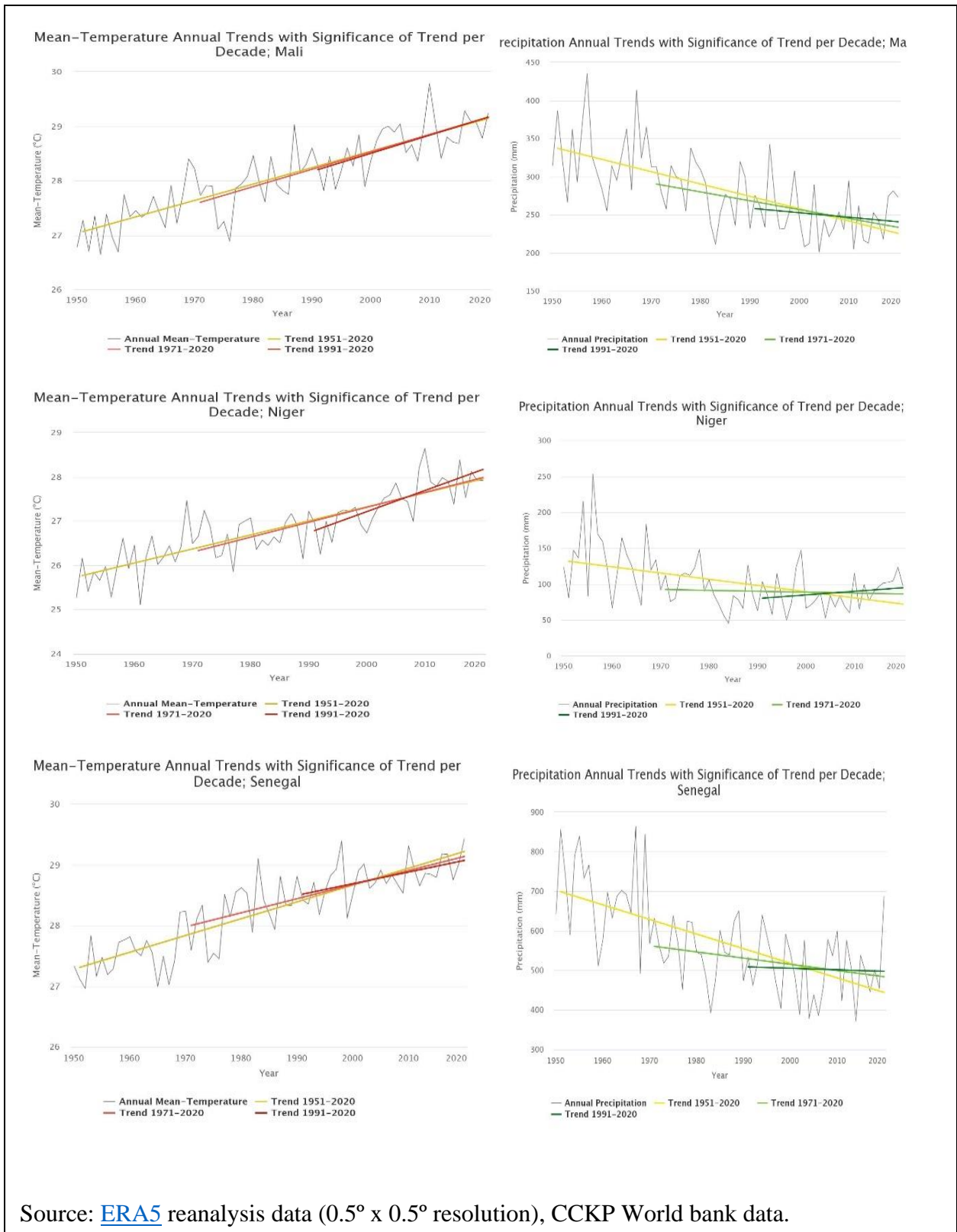


Figure 2: Historical climate observation in West African Sahel region.

Moreover, it can be observed that Niger presents a relatively high trend of annual mean temperature and a relatively low annual precipitation trend. This makes the country very sensitive to extreme dry event. For instance, Niger is the most affected by climate change over the past three decades in West Africa region. Also, the maximum drought occurrences in the region were recorded in the county.

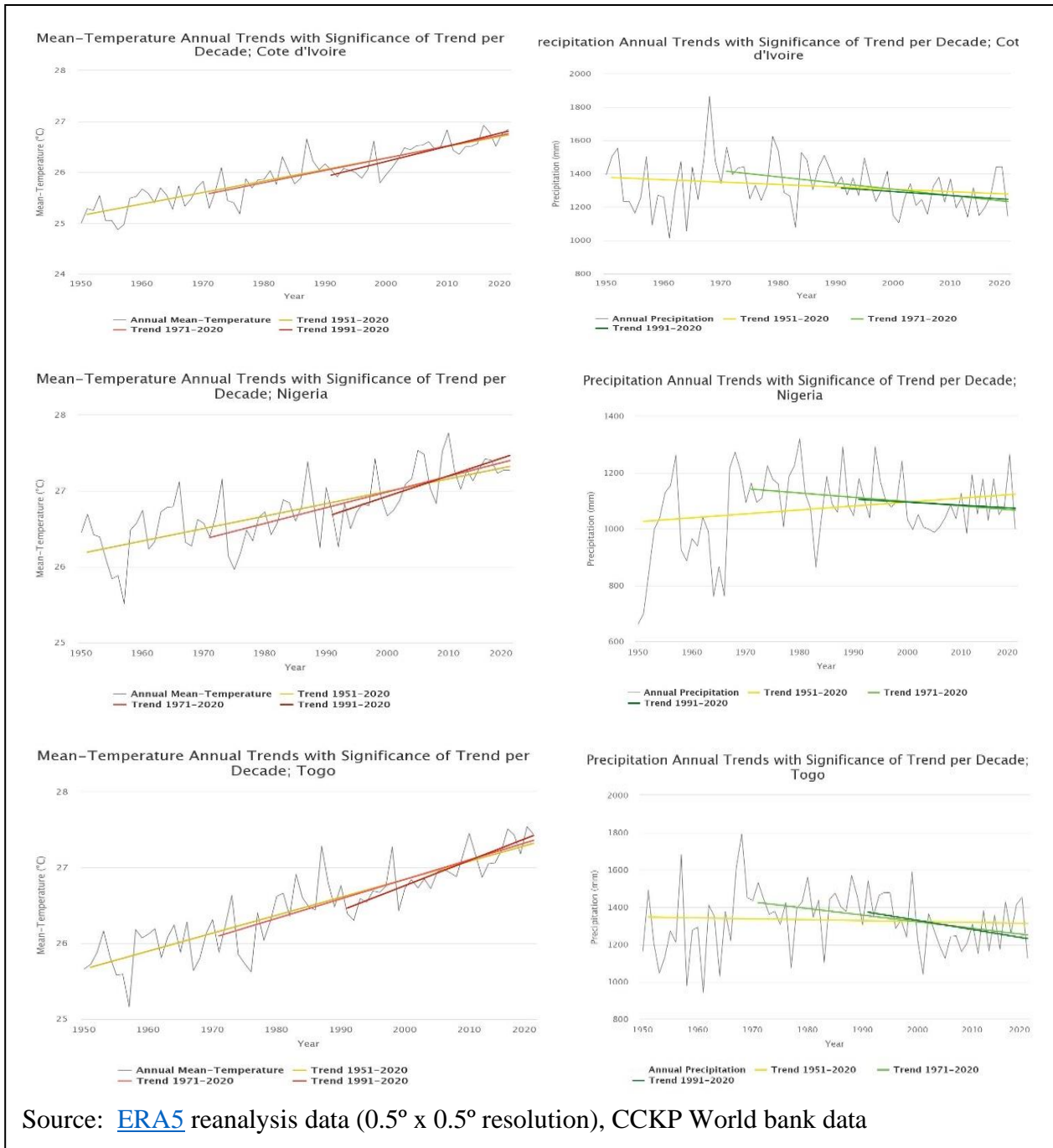


Figure 3: Historical climate observation in West African Coastal region.

Nonetheless, Nigeria is likely to face extremes wet events. The country records a relatively increasing trend in annual precipitation over the period 1950-2020. However, the observation shows a relative decreasing trend in the country's annual precipitation over 1991-2020.

- Macroeconomic and climatic change trend

Globally, West African countries have growing trend of economic growth during the past decade. On average, the region has reached 3.4 percent of growth in 2018, and 3.6 percent in 2019. Despite the effects of the COVID-19 crisis on the region's economic growth in 2020, which reduced growth to -1.5 percent, the countries rebounded with 4.3 percent growth in 2021 and expect to maintain this growth for the year 2022 (AfDB, 2021). However, with the large participation of agricultural sector to the region's economic growth, the sector is very sensitive to Change in temperature and irregularity in rainfall. These climatic changes are expected to both negative and positive impact West Africa economy. For instance, more wet event is required in Sahel area, while more wet event could increase flooding risk in Coastal area. The following graph shows the sensitivity of agricultural sector to the change in temperature over the period 1990-2019 and its participation to GDP growth.

It can be observed that an increasing in mean annual temperature over 27° is detrimental for agricultural participation to GDP growth in West Africa. Indeed, an increasing in annual temperature can be associated with dry event that could affect crops survival and agricultural output, and in turn reduce agriculture contribution to Gross domestic product. In addition, cereal crops main agricultural practiced in West Africa, maize, millet, sorghum and peanut for example, have the highest exposure rate to drought (Kamali et al., 2018).

Therefore, climate adaptive solution is needed to sustain agricultural participation to economic growth and reduce climatic changes impact on West African's economy. Providing access to renewable technology for agricultural transformation could play an important role in the region. Renewable energy such as solar, wind, bioenergy, green hydrogen, hydropower has gained more attention in West Africa Countries due to the major role that it could play in their strategy for rural electrification plan, resilience to climate change, and the available potential that the area is disposed of (Bourcet, 2020; Diallo & Moussa, 2020). This great potential offers the ability to develop renewable energy project such as off-grid solar projects, mini-grid systems for electricity

access. The Off-grid system solution is projected to eradicate the lack of access to energy and for crops irrigation which is critical for economic growth in the areas (Abdul-Salam & Phimister, 2016).

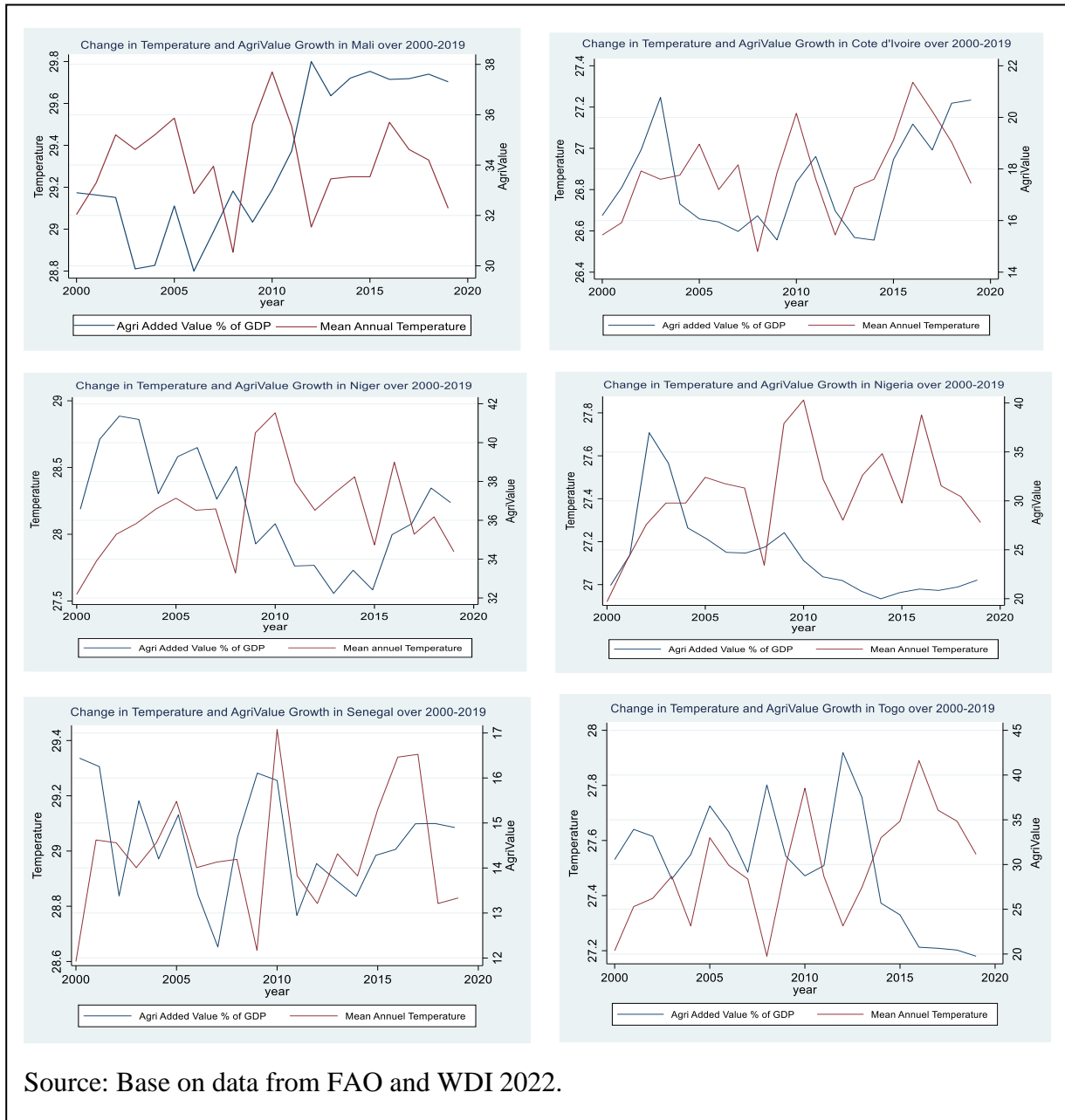


Figure 4: Climatic change and agricultural development (2000-2019)

International Energy Agency (IEA) in 2018 insisted on the role that the decentralized systems (mini-grids and stand-alone systems) will play in agricultural transformation and electricity access in Sub-Saharan Africa with specific regard to solar technologies which will represent 60% of the hole connections (IEA, 2018).

1.3. Literature review

The growing challenges caused by climatic change to economic outcomes has increased attention to understand the climate-economy relationships in a large literature (Dell et al., 2012; Kalkuhl & Wenz, 2020; Kumar & Khanna, 2019; Newell et al., 2021). This section emphasizes on the theoretical and empirical over view of the climate-economy relationship. Firstly, the theoretical view explores the climate-economic relationship as proposed by Nordhaus, (1976, 1991), as well as the theory of green growth and sustainable development (Brock & Taylor, 2010; Meadows et al., 1972). Secondly, the empirical overview highlights recent empirical analysis, including channels by which climatic change affects the economy, and the role of modern and sustainable energy in reducing climate damage on the economic outcomes.

1.3.1- Climate-economy relationship in the theoretical literature.

In the early studies, the long-term macroeconomy analysis has focused on natural resources depletion as the major threat to future economic growth (Kuznets, 1955; Meadows et al., 1972; Stiglitz, 1974). Indeed, the first concerns about the capacity of natural resources to cope with the pressure exerted on them by the galloping development of the population date back to Malthus, (1872). He stated that the population increases exponentially while the resources grow at an arithmetical rate, and drew the attention of humanity, from the eighteenth century, to the need for a rational management of natural resources because they are exhaustible. This logic of idea is supported by authors known as proponents of de-growth, such as Georgescu-Roegen, (1977), who maintains that the unbridled search for growth exerts an unsustainable pressure on natural resources and therefore on the environment. This inverse relationship between growth and sustainable development is highlighted by Meadows et al., (1972), who assert that if current economic and environmental trends continue, many natural resources will be depleted, which will limit or even prevent future growth.

Kuznets, (1955) analyzes these concerns between economic growth and growing inequality, and finds that there is an inverted "U" shaped relationship between per capita income growth and environmental degradation, known as the Kuznets Environmental Curve Hypothesis (KEC). This relationship describes, in a first step, a trend in the same direction of growth and inequality. Then follows a threshold, where inequality falls while growth remains sustained and increasing. Thus, the improvement in the quality of the environment in an economy is only achieved beyond a certain threshold of per capita income. This work was taken up by Grossman & Krueger, (1991), highlighting the dynamic aspect of the relationship. These were followed by Jorgenson and Wilcoxon, (1993), who through an intertemporal general equilibrium model, also theorized this dynamic relationship between energy consumption, economic growth and environmental quality.

However, climate-economy relationship is founded on Nordhaus, (1991, 1994) works that raised the issues of greenhouse gas (GHG) concentration in the atmosphere to be detrimental to the economy. The 2018 Nobel prize has the merit for being the first economist that integrated the issue of climate change into the long-term macroeconomic analysis, making the difference from earlier studies that put natural resource depletion (scarcity of fossil fuel) in front as the major threat to the economic growth. Therefore, in the climate-economy relationship assessment, it is assumed a dynamics and feedbacks effects in the interconnexion of climate and macroeconomic variables (Letta & Tol, 2019). Arguably, the idea behind the climate-economy relationship assessment is to capture the negative impact of climate change and its future potential damage on human welfare. Thus, knowing this relationship should help in estimating the social cost of carbon and the modest Pigouvian carbon tax (Letta & Tol, 2019; Tol, 2018).

Concerning the climate-economy relationships in theoretical studies, a number of studies hypothesized a static or a "level effect" of climate change on human welfare (Tol, 2018), while others argued dynamic or 'growth' effects of climate change on economic activities (Dietz & Stern, 2015; Fankhauser & Tol, 2005; Moyer et al., 2014). The static effects are temporary and intrinsically reversible impact of weather pattern on economic activities in a given year. This short-run relationship is criticized for being unable to capture the long run effect of climate change damage. For instance, temporal effect of hot temperature or irregularity in rainfall on agricultural production in a given year can be assessed as static or level impact. However, the dynamic or growth effect occurs when the economy ability to growth factors such as labor or capital

productivity, are affected by climatic change shifting its future path. Thus, the growth effect occurs over time and permanently reduce economic output (Letta & Tol, 2019). For example, a persistence effect of climate change affecting infrastructures, investment or institution shifting the economy ability to grow is growth effect (Fankhauser, 2017; Fankhauser & Tol, 2005).

Most of recent literatures emphasized on the dynamic or growth impact and hypothesized that the estimation of the Pigou tax (social cost of carbon) should increase drastically if climatic change negatively affect total factor productivity (TFP) (Kumar & Khanna, 2019; Letta & Tol, 2019; Moore & Diaz, 2015; Moyer et al., 2014). Therefore TFP, defined as combination of labor and capital productivity following neoclassic framework, represents the central element of climate-economy relationships assessment. It is widely used in most recent studies assessing channels by which climatic changes affect economic activities (Dell et al., 2012; Deryugina & Hsiang, 2014; Hsiang, 2010; Kumar & Khanna, 2019; Tol, 2021; Zhang et al., 2018). For example, Dell et al., (2012) have assessed the climate-economy relationship and observed linear effects of increasing in temperature on economic growth for developing countries. Other authors such as Burke et al., (2015); Heal & Millner, (2014) concluded negative impact of increasing in temperature on per capita in hot climate zone, while a positive effect is concluded for cold regions. However, Deryugina & Hsiang, (2014) and Hsiang, (2010) argued that there is non-linear relationship between climatic change and GDP level.

Using the Dynamic Integrated Climate-Economy model (DICE), Tsigaris & Wood, (2016) have argued that climate change can affect the growth rate of TFP and directly reduce aggregate output. In their modeling, the total factor productivity is determined exogenously. This way of considering the TFP exogenous was criticized and several studies assumed that climate change impact on TFP could alter its long-term growth (Dietz & Stern, 2015; Moyer et al., 2014). For instance, Dietz and Stern, (2015) assume a dynamic relationship between climate change and TFP, and change DICE framework. Their result shows that if climate change affect and reduce the annual global TFP by 0.20 percentage points, the consumption per capita will decrease by 11.4-15 time in 2105 relatively to 2005. Moyer et al., (2014) also have changed DICE and allow the dynamic effect of climatic change on TFP growth and showed that climate change harm TFP growth by lowering the productivity of factors such as agricultural land and labor. However, this way of assessing climate-economy relationship is also criticized for assuming that the dynamic effect of climate change on

TFP is the same across countries. But, difference in climate zone and the country's ability to adapt may have different long-run economic growth effect at country level.

Agricultural sector in particular has been pointed out to be sensitive to climate change mostly in developing countries where Agricultural remains the main source of livelihood (Mendelsohn et al., 1994; Mikémina, 2013; Moyer et al., 2014). For instance, Mendelsohn et al., (1994) developed a Ricardian approach to measure the value of climate change in US agriculture based on the assumption that there is a direct cause and effect of climatic changes on farm value. Indeed, the Ricardian approach examines how climatic change in different places affect agricultural land values instead of a specific crop yield. It reflects the benefits and costs of implicit adaptation strategies (Mikémina, 2013). Mikémina, (2013) has followed this approach and used agricultural added value as proxy to net farm revenue, and assess the climatic change effect on agricultural performance in Togo. Considering crop and non-crop periods, Mikémina's study found a non-linear relationship between agricultural added value and recorded precipitation during the cropping period.

Recent theoretical literature also pledged in favor of green and sustainable development in crops production process with clean and renewable technologies (Adelaja & Hailu, 2008; Chel & Kaushik, 2011; Hickel & Kallis, 2020; Liu et al., 2017; Lyytimäki, 2018; Oubraham & Zaccour, 2018). Indeed, energy sector is arguably the key element in climate-economy relationship assessment. It not only contributes to economic growth, but also constitutes the main drivers of climatic change. Country's adaptive solution should include clean and renewable technology in their crop production process. Therefore, to take in consideration future generation in today's natural resource management, investing in renewable energy technologies adoption could be useful in reducing climatic change effect on agricultural added value to economic growth and then boost developing countries economy. For instance, based on the theory of economic growth developed by Solow, (1956), Hickel & Kallis, (2020) show that technological change and substitution will highly contribute to economic expansion by decoupling GDP growth from resource use and carbon emissions. Also, Brock & Taylor, (2010) insisted on the technological development as the prominent factor that will contribute to pollution abatement and promote growth. They developed the green Solow model by assuming that the Solow model and the

Kuznets Environmental Curve are intimately linked by the change in technology (Brock & Taylor, 2004, 2010).

1.3.2- Climate-economy relationship in empirical study

Large and Growing body of empirical studies have attempted to quantify climate change impact on economic performance (economic growth, agricultural production, labor productivity commodity prices) using econometric evidence (Dell et al., 2012; Kalkuhl & Wenz, 2020; Letta & Tol, 2019; Newell et al., 2021; Tol, 2021). However, some misfunctioning points can be raised about their respective empirical methodology and their findings (Kahn et al., 2021). Three questioned points was raised by Kahn et al., (2021) about these misfunctioning of econometric evidence of climate impact on economic performance.

Firstly, related studies that have used cross-sectional regression analysis failed to incorporate some important variables that could explain climate and economy relationship (e.g., renewable technology growth, institution) and the temporal invariance (Nordhaus, 2006). Cross-sectional approach is criticized for been subjected to omitted bias. Indeed, using this approach, earlier scholar argued that geography and climate are the fundamental factors drivers of economic performance (Olsson & Hibbs, 2005). For Gallup et al., (1999) geography and climate are important, but technology improvement could modify their impact. Moreover, institutional factors also have been found to be determinant in economic development (Acemoglu et al., 2001; Anderson et al., 2017).

Secondly, to address the endogeneity and confounders effect in cross-section analysis of climate-economy relationship, a robust panel study has emerged in the literature (Burke et al., 2015; Dell et al., 2009, 2012, 2014; Hsiang, 2016). For instance, Dell et al., (2009) compared cross-sectional and panel estimation approach and found that adaptation policies are very important in reducing weather variability effects on economic development (reduces half of the negative impact of weather shocks). Dell et al., (2012) also examine how annual variation in temperature and precipitation affects per-capita income in a world sample from 1950 to 2003 using panel data. It results that warming increasing by one degree 1 °C reduces per-capita income by 1.4 percent only in poor countries. It also highlights that economic growth in hotter and richer counties are less vulnerable to climatic condition. In that same way, Letta & Tol, (2019) examined the nature of

climate-economy relationship in a world panel for the period 1960-2006 and also found a negative relationship in poor countries. Similar result was also found by Newell et al., (2021).

Thirdly, other studies using panel-data showed that, instead, hotter countries are hardly hit by climatic change (Burke et al., 2015; Henseler & Schumacher, 2019; Kalkuhl & Wenz, 2020; Tol, 2021). Burke et al., (2015) assessing non-linear effect of temperature on economy observed that a hotter, richer world, would be more vulnerable to climatic variability. Similarly, Henseler & Schumacher, (2019) examined the impact of weather on growth and its production using panel-data. Their study finds that for higher levels of temperature, the poor countries are much more strongly impacted than the rich countries. Moreover, a study proposed by Kahn et al., (2019) highlighted the long-term impact of climate change on economic activity across 174 countries by using a stochastic growth model. In their work, economic productivity is affected by deviation of temperature and precipitation from their long-term moving average historical norms. Gillingham et al., (2018) also explored uncertainty in baseline trajectories using multiple integrated assessment models. Also, Kalkuhl & Wenz, (2020) investigated the impact of climate conditions on economic production for more than 1500 regions in 77 countries and observed similar results. In their study, they focused on three key uncertain parameters: population growth, total factor productivity growth, and equilibrium climate sensitivity.

There is also a growing body of literature highlighting the role of renewable technology in economic development, but less attention has been given to its role in climate-economy relationship (Ali, 2021a; Apergis & Payne, 2014; Dagnachew et al., 2017; Ezzo & Keho, 2016). Concerning its contribution to economic development, there is also a divergence among decision makers about energy policy and its recommendation in developing countries for economic development (Ali, 2021a). Even if some studies found that the deployment of renewable energy is positively correlated with economic growth, a sustainable and resilient environment (Cai et al., 2011), other studies have pointed out that there is a need to take in consideration short or long-term Analysis. Therefore, analyzing the relationship between the sustainable economy and green job creation in China, Cai et al., (2011) found that for every one percent increase in solar PV production in China, there could be a 0.68% increase in total employment. Apergis & Danuletiu, (2014) and Apergis & Payne, (2014) have also considered the causal link between RE and economic growth by integrating the capital factor and the labor factor from previous analyses.

They conducted their research on 80 countries in the world over the period 1990-2012. Using the error correction model (ECM) and the long-run causality test developed by Canning & Pedroni, (2008), they find positive long-run bidirectional causality between RE and economic growth. Moreover, testing for the feedback hypothesis between renewable energy consumption and economic growth by using Granger causality test, Ben Jebli & Ben Youssef, (2015) concluded unidirectional causality between economic growth and REC and agricultural value-added, non-REC and agricultural value-added, and between CO₂ emissions and RE in the short run. Rafindadi & Ozturk, (2017) recently concluded that renewable energy consumption could strengthen the German economy.

However, Esso & Keho, (2016) evaluate the causality between energy consumption, GDP and CO₂ emission in 12 sub-Saharan African countries over the period 1971-2010. They used Bond test for cointegration developed by Pesaran et al, (2001) to assess this causal link. The result showed that in the short run, GDP causes CO₂ emission for Benin, Ghana, Nigeria, DRC and Senegal. This indicates that for these countries, growth cannot be achieved without affecting the environment. The opposite effect is observed for Gabon, Nigeria and Togo. Thus, for these countries, any effort to reduce CO₂ emissions is combined with a reduction in economic growth. This implication reveals the need to use energies that are compatible with the reduction of CO₂ emissions and economic growth. Other authors such as Bandy & Aneja, (2019); Mohsin et al., (2021) and Oliveira & Moutinho, (2021) have also addressed this link.

Motivated by issues of sustainable development in Africa, Asongu & Nwachukwu, (2017) offers a comparative analysis of the sustainability of development in Sub-Saharan African countries over the period of 2000-2012. With the GMM, he deduces a persistence in CO₂ emission for middle-income countries, a dependence on fossil energy for countries with French civilization. In the same line, Ali, (2021a) investigated short and long-run nexus between climate change, REC trade openness, and agricultural development within the West African countries using panel cointegration method. It results unidimensional relationship between agricultural added value, CO₂ emission, and renewable energy consumption. But also, bidirectional relationship between renewable energy consumption, trade openness, and agricultural added value was highlighted.

Therefore, this study assesses the long-run economic growth effect of climate change on TFP by considering differences in climatic zone in developing country. Thereby, it highlights the country

capacity and ability to adapt and reduce climate change effect on agricultural added value to the economy. The study follows Kalkuhl et Wenz, (2020) and Kumar et Khanna, (2019) approaches.

1.4. Methodology and data

1.4.1-Theoretical model

This section gives an overview of the conceptual background of the climate-economic relationship in the context of green growth theory. From the literature (Hickel & Kallis, 2020; Kahn et al., 2021; Kalkuhl and Wenz, 2020; Letta & Tol, 2019; Newell et al., 2021; Tol, 2021), the green growth theory is based on neoclassic growth model with a focus on technological progress and efficiency in a combination of factors of production. This essay follows Kahn and al., (2021); Kalkuhl and Wenz,(2020) and Tol, (2021) approaches, and consider a stochastic growth model for developing countries that share a common technology with difference in weather patterns. The model is a Cobb-Douglas production function (homogeneous of degree one) and is displayed as follow:

$$Y_{it} = \Theta_{it}f(\Lambda_{it}L_{it}, K_{it}) \dots\dots\dots (1.1)$$

Where Y_{it} is the output variable and L_{it}, K_{it} are labor and capital inputs in country i at time t . Λ_{it} represents labor productivity factor in entire economy i at time t . It is assumed that Λ_{it} is governed by technological change factor and the country-specific climatic conditions. Θ_{it} is Nordhaus, (1992) economy damage function. It is assumed that the aggregate productivity level decreases in temperature T_{it} , with T_{it} indicating changes in country i mean temperature warming above the historical level. Following this assumption, Θ_{it} could be written as follows: $\Theta_{it} = \Theta(T_{it})$. Considering Ali, (2021a) and Mikémina, (2013) model specification, the output value is captured by the agricultural added value to the economy, which is mainly affected by change in climatic variable (Temperature), and progress in renewable technology (renewable energy consumption).

As $f(\Lambda L, K)$ is linearly homogeneous in $\Lambda L, K$, it can be derived and rewritten following (Kalkuhl and Wenz, 2020).

$$\frac{\partial f}{\partial \Lambda L} = \frac{f - \frac{\partial f}{\partial K}K}{\Lambda L} \dots\dots\dots (1.2)$$

With Euler's Theorem and taking the logarithm for of the dependent variable, equation (1.2) becomes:

$$\begin{aligned} \frac{d\ln(Y)}{dt} &= \frac{\Theta'(T)}{\Theta(T)} \dot{T} + \frac{1}{f} \left(\frac{\partial f}{\partial K} \frac{dK}{dt} + \frac{\partial f}{\partial(\Lambda L)} \frac{d(\Lambda L)}{dt} \right) \\ &= \frac{\Theta'(T)}{\Theta(T)} \dot{T} + \frac{1}{f} \left(\frac{\partial f}{\partial K} \frac{dK}{dt} + \left(f - \frac{\partial f}{\partial(K)} K \right) \frac{d(\Lambda L)}{dt} \right) \\ &= \frac{\Theta'(T)}{\Theta(T)} \dot{T} + \Phi \frac{1}{K} \frac{dK}{dt} + (1 - \Phi) g_{\Lambda L} \dots\dots\dots (1.3) \end{aligned}$$

Where $g_{\Lambda L}$ is factors productive growth rate. \dot{T} is the time derivative of T and $\Phi = \frac{\partial f}{\partial K} \frac{K}{f}$.

Considering that the capital stock depreciates in each period at rate δ and changes also with the investment I , considering also s the saving rate with $0 \leq s \leq 1$, $\frac{dK}{dt}$ can be expressed as follows.

$\frac{dK}{dt} = 1 - \delta K = sY - \delta K$. Then equation (1.3) can be rewritten as follow

$$g_y = \frac{d\ln(y)}{dt} = \frac{d\ln\left(\frac{Y}{L}\right)}{dt} = \frac{d\ln(Y)}{dt} - g_L = \frac{\Theta'(T)}{\Theta(T)} \dot{T} + \Phi \left(s \frac{Y}{K} - \delta \right) + (1 - \Phi)(g_{\Lambda}(T) + g_L) - g_L \quad (1.4)$$

Where g_y , g_L and g_{Λ} denoting respectively the output growth rate, labor growth rate and factor productivity growth rate. Three components can be identified when rewritten equation (1.4)

$$g_y = \underbrace{\frac{\Theta'(T)}{\Theta(T)} \dot{T}}_1 + \underbrace{\Phi \left(s \frac{Y}{K} - \delta - g_{\Lambda}(T) - g_L \right)}_2 + \underbrace{g_{\Lambda}(T)}_3 \dots\dots\dots (1.5)$$

1-Short-term effect 2-Transitory effect 3-Long-run productivity effect

Equation 1.5 can be displayed in a simple way as follow:

$$g_y = G(T)\Delta T + F(T) \dots\dots\dots (1.6)$$

With $G(T) = \frac{\Theta'(T)}{\Theta(T)}$, $\Delta T = \dot{T}$ is temperature changes between two periods and $F(T) = \Phi \left(s \frac{Y}{K} - \delta - g_{\Lambda}(T) - g_L \right) + g_{\Lambda}(T)$ (See also Kalkuhl and Wenz, 2020).

1.4.2- Empirical specification

For empirical specification, the model is reformulated as a Panel Error-Correction one with the log form. It also integrates other variables that could explain agricultural added value to economic growth in developing countries ($AgriV_{i,t}$) following Ali, (2021a); Kalkuhl and Wenz, (2020). $G(T)$ is defined as linear function $G(T) = \alpha + \alpha_1 T$, while $F(T)$ a quadratic function of weather variability $F(T) = \gamma_1 T + \gamma_2 T^2$. Hence, the regression model is presented as follow.

$$\Delta \ln(AgriV_{i,t}) = \beta \Delta \ln(REC_{it}) + \sum_{i=1}^n \phi_i \Delta X_{i,t} + \eta_t + \Delta v_{i,t} - \Delta \mu_{i,t} \dots \dots \dots (1.7)$$

$$\text{With } \Delta \mu_{it} = \delta_0 + \delta_1 \Delta T_{i,t} + \delta_2 T_{i,t} \Delta T_{i,t} + \gamma_1 T_{i,t} + \gamma_2 T_{i,t}^2 + \varphi_i + \varepsilon_{i,t} \dots \dots \dots (1.8)$$

Where REC_{it} is the possible technological change that can affect agricultural added value growth in country i at time t . Here, it represents the total share of renewable energy consumption in total final energy consumption of country i at time t . $X_{i,t}$ is a vector of control variable that may also affect the output variables. It includes Gross fixed capital formation (GFCF) representing domestic investment and trade openness (Trade) (Ali, 2021a). ΔT describes the respective change in weather patterns and $T_{i,t}$ the vector of annual mean temperature levels. φ_i controls for country specific effect while η_t time specific effect in the regression. The coefficients δ_1 and δ_2 capture the short-term effect of weather variability on output variables while γ_1 and γ_2 capture transitory and long-run growth effect depending on temperature level.

The regression is based on Kalkuhl & Wenz, (2020) estimation method which adopt three (3) different steps. The first (1) adopts Dell et al., (2012) linear approach, where $\delta_1, \delta_2,$ and γ_2 are excluded in equation (1.8). the second (2) considers the quadratic component of weather variables following Burke et al., (2015) and excludes $\delta_1,$ and δ_2 in equation (1.8). The third (3) approach estimates the model with the quadratic component and the interaction term as in Kalkuhl and Wenz, (2020). However, in this study, only the linear approach following Kalkuhl and Wenz, (2020) is used.

For panel model estimation, two tests are mostly used to assess the cross-sectional dependency within individuals in the panel: Pesaran CD test and Breusch & Pagan, (1980) test. In this study, cross-sectional dependency within individuals in the panel is tested using Breusch Pagan and Pesaran CD test (Breusch & Pagan, 1980) due to the fact that the number of individual in the panel

(12) is less than the time dimension (30). In case the test fails to reject the cross-dependency within variables in the model, second generation unit root test proposed by Pesaran, (2007) will be proceed. If one failed to reject the null hypothesis that there is homogenous non-stationarity, Panel cointegration test will be considered. In case variables are cointegrated at level or/and at first level, a long-run relationship between variables will be estimated based on panel error correlation model (PECM). The model can be presented as follows:

$$\begin{bmatrix} \Delta AgrV_{it} \\ \Delta Renc_{it} \\ \Delta GFCE_{it} \\ \Delta Opens_{it} \\ \Delta Temp_{it} \\ \Delta Preci_{it} \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \\ \alpha_6 \end{bmatrix} + \sum_{k=1}^p \begin{bmatrix} \vartheta_{11p} & \vartheta_{12p} & \vartheta_{13p} & \vartheta_{14p} & \vartheta_{15p} & \vartheta_{16p} \\ \vartheta_{21p} & \vartheta_{22p} & \vartheta_{23p} & \vartheta_{24p} & \vartheta_{25p} & \vartheta_{26p} \\ \vartheta_{31p} & \vartheta_{32p} & \vartheta_{33p} & \vartheta_{34p} & \vartheta_{35p} & \vartheta_{36p} \\ \vartheta_{41p} & \vartheta_{42p} & \vartheta_{43p} & \vartheta_{44p} & \vartheta_{45p} & \vartheta_{46p} \\ \vartheta_{51p} & \vartheta_{52p} & \vartheta_{53p} & \vartheta_{54p} & \vartheta_{55p} & \vartheta_{56p} \\ \vartheta_{61p} & \vartheta_{62p} & \vartheta_{63p} & \vartheta_{64p} & \vartheta_{65p} & \vartheta_{66p} \end{bmatrix} \times \begin{bmatrix} \Delta AgrV_{it-1} \\ \Delta Renc_{it-1} \\ \Delta GFCE_{it-1} \\ \Delta Opens_{it-1} \\ \Delta Temp_{it-1} \\ \Delta Preci_{it-1} \end{bmatrix} + \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \\ \delta_5 \\ \delta_6 \end{bmatrix} ECT_{it-1} + \begin{bmatrix} \mu_{1it} \\ \mu_{2it} \\ \mu_{3it} \\ \mu_{4it} \\ \mu_{5it} \\ \mu_{6it} \end{bmatrix} \dots\dots\dots(1.9)$$

Where Δ is the first difference for each variable in the model. ECT_{it-1} is the error correction term that captures the long-run relationship between variables. μ_{1it} represent the random error term.

1.4.3- Data.

The study covers 12 West Africa countries, and climatic and economic data were collected from three (3) principal sources over the period of 1990 to 2019. Climatic data is collected from world bank climate change Knowledge Portal (CCKP, 2022) and FAO stat. Following the literature (Kahn et al., 2021; Kalkuhl et Wenz, 2020; Tol, 2021), climate change variables include change in annual average temperature, annual average temperature, and annual average precipitation during crop season. These climate data have the resolution of 0.5 x 0.5 degrees and correspond roughly to 55 x55 kilometers at the equator. Economic data is collected from the World Bank Indicator (WDI, 2022). It includes agricultural added value to economic growth, the share of renewable energy consumption in total energy consumption, and domestic investment represented here by Gross Fixed Capital Formation (GFCF) (see also Ali, 2021a; Mikémina, 2013).

As presents in table1 economic growth was, on average for the 12 countries, 4.01% over the period 1990-2019. The highest Agricultural added value to gross domestic production (GDP) in the region reached, on average, 50.35%, indicating the first role that agricultural production has in the country’s economic growth. The average over the period 1990-2019 for the 12 countries accounts

for 29.47 % of GDP. Moreover, renewable energy consumption in the region reached, on average, 73.74% of the total final energy consumed in the West Africa over the study period. However, domestic investment remains low in the region with an average of 18.53% share of the region GDP.

Table 1: Summary statistics of variables

Countries	GDP Growth	Agri added Value %GDP	REC %of total EC	Openness %	GFCF %GDP	Temp change	Temp annual average °C	Rainfall annual average (mm)
Benin	4.66	28.69	65.74	26.40	17.79	0.88	28.05	1041.38
Burkina Faso	5.47	26.37	82.94	21.46	19.23	0.88	29.24	821.89
Ivory Coast	3.33	19.66	71.19	29.02	16.34	0.94	26.78	1292.84
Gambia	3.16	23.92	57.40	27.55	13.71	1.26	28.32	984.25
Ghana	5.47	31.30	62.21	37.62	20.57	0.91	27.64	1203.736
Guinea	4.35	19.40	81.28	32.85	21.00	0.95	25.82	1782.985
Guinea-Bissau	2.62	46.29	88.32	25.30	15.70	1.20	28.01	1600.935
Mali	4.54	35.13	82.41	28.18	19.13	1.00	29.20	325.95
Nigeria	4.55	24.28	85.06	18.63	28.11	0.88	27.29	1181.67
Senegal	3.67	15.78	45.98	26.54	19.80	1.17	28.88	717.424
Sierra Leone	3.07	50.35	84.89	27.59	12.22	0.83	26.52	2642.304
Togo	3.31	32.34	77.53	39.13	18.78	0.90	27.31	1211.286
West Africa	4.01	29.47	73.74	28.36	18.53	0.99	27.75	1233.888

Nevertheless, climatic variables show an average change in temperature of 0,99 over 1990-2019, with specific pic of annual average temperature change of 29.24 °C in Sahel region. The region's average is established at 27.75 °C. Burkina Faso, Mali and Senegal recorded the highest warming condition over the study period in the region. On average, it accounts respectively 29.24, 29.20 and 28.88 °C.

1.5. Results et discussion

This section exposes the model estimation process the findings and the positioning of the results with existing literature.

1.5.1- Results

Table2 summarizes the correlation between variables and multicollinearity test. It shows that the average variance inflation factors (VIF=1.78) are less than 5%, indicating that multicollinearity between variables in the model is not a problem in the estimation process (Ali, 2021a; O'brien,

2007). As indicated in table2, positive and significant correlation is observed between renewable energy consumption and agricultural development in one hand, and change in precipitation and agricultural development in other hand. But negative and significant correlation is observed between agricultural development and domestic investment. However, negative and significant correlation at 10% threshold is observed for change in temperature and agricultural development. Annual average temperature has also negative but non-significant correlation with agricultural development. Moreover, negative and significant correlation is observed between renewable energy consumption and temperature variables while a positive correlation is observed between renewable energy consumption and rainfall. The econometric test will give more precision on these correlations among variables.

Table 2: Correlation between variables and multicollinearity test

Variables	AgriV	RENC	GFCF	OPNES	Chang_Temp	An_Temp	Rainfall
AgriValue	1						
RENC	0.512*	1					
GFCF	-0.223*	-0.039	1				
OPNES	0.009	-0.211*	0.154*	1			
Chang_Temp	-0.1502*	-0.395*	-0.008	-0.051	1		
An_Temp	-0.079	-0.305*	0.006	-0.195*	0.359*	1	
Rainfall	0.434*	0.3013*	-0.187*	0.083	-0.097*	-0.735*	1
VIF	-	1.38	1.11	1.17	1.44	2.93	2.67
Mean VIF	1.78						

- Cross-sectional dependency test

The existence of cross-sectional dependency within countries was tested using Breusch et Pagan, (1980) approach. The results exposed in table 3 show that the probability value of all variables is less than 1% level. Thus, the hypothesis of cross-sectional dependency within individual cannot be rejected. This implies that the first-generation unit root test is no longer appropriate. Therefore, the second-generation unit root test following Pesaran, (2007) is applied.

Table 3 : Cross-sectional dependency test

Variables	Chi-squared statistics	p-value
Agri added value (AgriV	831.96	0.000
Renewable energy consumption (RENC)	1600.45	0.000
Domestic investment (GFCF)	190.95	0.000
Trade Openness (Openness)	539.96	0.000
Change in A. average temperature (Chang_Temp)	295.40	0.000
Annual average temperature (An_Temp)	1724.55	0.000
Annual average rainfall (Rainfall)	1553.32	0.000

- Pesaran Panel Unit root test with cross-sectional.

In table 4 is resumed Pesaran panel unit root test with cross-sectional (CIPS). The results shows that the Pesaran statistic value (CIPS) for some variables (Opens, change in temperature, annual average temperature, and precipitation) are all greater than their critical values at 1% level. This means that Opens, change in temperature, annual average temperature, and precipitation are stationary at level. However, Pesaran statistic value (CIPS) for Agricultural added value to the economy, renewable energy consumption and domestic investment are non-stationary at level but stationary at first difference. Consequently, there is a need to do cointegration test. To check for the existence of long-run relationship between variables, Westerlund panel cointegration test were proceeded (Westerlund, 2007).

Table 4: Pesaran panel unit root test with cross-sectional

Variable	CIPS	Critical value		
		10%	5%	1%
Agri Value	-2.392	-2.6	-2.7	-2.89
RENC	-2.033	-2.6	-2.7	-2.89
GFCF	-2.544	-2.6	-2.7	-2.89
Opens	-3.281	-2.59	-2.69	-2.88
Chang_Temp	-4.851	-2.6	-2.6	-2.89
Annual_Temp	-5.169	-2.59	-2.69	-2.88
Rainfall	-5.167	-2.59	-2.69	-2.88
d.AgriValue	-5.421	-2.59	-2.69	-2.88
d.Renc	-5.047	-2.69	-2.69	-2.88
d.GFCF	-5.225	-2.59	-2.69	-2.88

- Westerlund panel cointegration test

Following existing literature, Westerlund panel cointegration test is more appropriate than by other cointegration performed test if there is cross-sectional dependency within individual. Thus, this study adopts Westerlund panel cointegration instead of using Predoni or Kao cointegration test. The results for Westerlund panel cointegration test are presented in the following Table 5.

Table 5: Westerlund ECM panel cointegration test.

Westerlund	Statistic	Value	Z-value	P-value
Agri Value	Gt	-3.131	-3.344	0.000
	Ga	-17.219	-2.771	0.003
	Pt	-9.601	-2.658	0.004
	Pa	-13.222	-2.475	0.007
Chang_Temp	Gt	-4.714	-10.587	0.000
	Ga	-23.942	-6.529	0.000
	Pt	-16.94	-10.858	0.000
	Pa	-25.11	-9.752	0.000
Renc	Gt	-4.903	-10.986	0.000
	Ga	-32.957	-10.967	0.000
	Pt	-17.637	-12.018	0.000
	Pa	-29.065	-11.663	0.000
GFCF	Gt	-3.274	-3.959	0.000
	Ga	-16.796	-2.551	0.005
	Pt	-9.403	-2.427	0.008
	Pa	-12.493	-2.053	0.020
Openes	Gt	-3.519	-5.014	0.000
	Ga	-19.639	-4.032	0.000
	Pt	-10.109	-3.250	0.001
	Pa	-13.681	-2.742	0.003

The null hypothesis state that there is no cointegration between variables in the model. The results displayed in Table5 report that all statistics are significant at least at 5% for the p-values. This means that the null hypothesis of no cointegration between variables can be rejected, hence the existence of a long-run cointegration among variables.

- Hausman test

Hausman test is performed to determine the best estimator between dynamic fixed effect (DEF) estimator and Pooled Mean Group (PMG) estimator that should be used for the panel error correction estimation. The null hypothesis of this test is based on the assumption that there is not

significant difference between DEF and PMG estimators but PMG is more efficient. If the p-value is greater than 5% we cannot reject the null hypothesis and then the PMG estimator is more consistent. Hausman test result shows that the Chi-squared statistic is $\text{Chi}^2(5) = 8.82$, with $\text{Prob} > \text{chi}^2 = 0.1163$. This p-value is greater than %5 ($0.1163 > 0.005$) indicating that the null hypothesis cannot be rejected. This implies that the PMG estimator is more efficient. Therefore, the panel error correction model is estimated using the pooled mean group estimator.

- PECM estimation.

Table 6: Panel Error Correction Model estimating long run and short-run causality with linear equation

Variables	$\Delta(\text{AgriV})$	$\Delta(\text{Renc})$	$\Delta(\text{GFCF})$	$\Delta(\text{Opnes})$	$\Delta(\text{Tempe})$	$\Delta(\text{Rainfall})$
Long-run						
AgriV	-	0.924***	-0.211*	0.216**	0.012**	0.28
	-	(0.000)	(0.052)	(0.043)	(0.001)	(0.762)
Renc	0.472***	-	0.303**	0.061	-0.026***	-1.834**
	(0.000)	-	(0.012)	(0.479)	(0.000)	(0.016)
GFCF	-0.081	0.477**	-	0.079	0.0011	1.60*
	(0.387)	(0.030)	-	(0.195)	(0.783)	(0.071)
Opnes	0.226**	-0.408***	0.521***	-	-0.001	-0.123
	(0.026)	(0.005)	(0.000)	-	(0.834)	(0.890)
Chang_Temp	-7.095**	-20.26***	3.942**	3.098	-	21.65
	(0.013)	(0.000)	(0.046)	(0.115)	-	(0.113)
Rainfall	0.0155	0.013	0.015**	0.008	-0.001***	-
	(0.115)	(0.256)	(0.028)	(0.154)	(0.000)	-
Short-run						
ECt-1	-0.194***	-0.995***	-0.257***	-0.303***	-0.678***	-1.071***
	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)
$\Delta(\text{AgriVt-1})$	-	-0.073	-0.135**	0.026	-0.0071	6.513
	-	(0.200)	(0.043)	(0.699)	(0.172)	(0.131)
$\Delta(\text{Renct-1})$	-0.131	-	-0.079	-0.326**	0.186*	6.537**
	(0.491)	-	(0.551)	(0.025)	(0.091)	(0.049)
$\Delta(\text{GFCFt-1})$	-0.268***	-0.054	-	0.365***	0.020**	1.801
	(0.002)	(0.336)	-	(0.000)	(0.017)	(0.597)
$\Delta(\text{Openest-1})$	0.104	-0.048	0.239***	-	-0.0088	0.604***
	(0.128)	(0.381)	(0.001)	-	(0.229)	(0.006)
$\Delta(\text{Tempct-1})$	2.413***	1.35***	1.017*	-1.92***	-	-76.298***
	(0.000)	(0.002)	(0.072)	(0.000)	-	(0.000)
$\Delta(\text{Rainfallt-1})$	0.0003	0.001	-0.001	-0.001	0.0002**	-
	(0.807)	(0.495)	(0.191)	(0.364)	(0.046)	-
C	-4.733	4.779	-10.88	0.254	2.459	1469.156
	(0.001)	(0.001)	(0.004)	(0.775)	(0.000)	(0.000)
R ²	0.38	0.43	0.11	0.12	0.16	0.22
Adj. R ²	0.37	0.42	0.10	0.10	0.15	0.21

NB: *** significant at 1% threshold, ** significant at 5% threshold, * significant at 10% threshold

Table 6 shows that all error term coefficients (ECt-1) are negative and statistically significant at 1% threshold, indicating that the model has a mechanism for error correction. Thus, the long-run causality result indicates that there is a bidirectional relationship between agricultural added value, renewable energy consumption and trade openness. This implies that there will be a feedback effect of any change in renewable energy consumption, trade openness and agricultural added value to the economy. Indeed, the long-run positive and statistically significant relationship between agricultural development and renewable energy consumption suggests that renewable energy could be a key solution to agricultural transformation in West Africa. The application of this technology can be used in the production of crops (irrigation, transportation, harvesting), as well as in the post-harvest process (food transformation, storage, and conservation) (Ali, 2021a).

Moreover, this positive long-run causality between trade openness and agricultural development corroborates the idea that trade openness facilitates transactions between countries. In fact, West Africa countries export their raw materials as well as import most of the transformed agricultural goods. This result corroborates the findings by Ali, (2021a); Ben Jebli & Ben Youssef, (2017).

However, a negative relationship is observed between trade openness and renewable energy consumption. This indicates that trade openness doesn't promote local transformation of raw materials. This may require more renewable energy for the transformation process and then create more added value to the economy. Similarly, Ben Jebli et Ben Youssef, (2017) found that trade openness may contribute to global warming because raw material and mineral extraction require more fossil fuel energy. In contrast, Raeni et al., (2019), claim there is no causal relationship between trade and REC. However, no causal relationship was found between change in temperature and trade openness, similar to Raeni et al., (2019).

At a 5% threshold, there is a negative and statistically significant long-run causal relationship between changing temperatures and agricultural added value to the economy. This means that change in temperature has a long-term negative causal relationship with agricultural development in West African countries. It can be explained by the fact that the region's agricultural production is highly dependent on climate conditions. And any change in these climate conditions will directly impact agricultural output. This result contrasts with Mikémina, (2013) findings that report no long-run causal relationship between non-cropping, cropping average temperature and agricultural added value in Togo. However it corroborates Ali, (2021a) findings in the West Africa context.

Additionally, renewable energy reduces the impact of climate change in the study area. It has a long-run negative and static significant relationship with changes in temperature variables. As a result, renewable energy is environmentally friendly and emits fewer greenhouse gases. It can also be used as an adaptive irrigation method in warm climate conditions.

Furthermore, no statistically significant long-run causality relation between domestic investment and agricultural development was found. The reason for this is that West African domestic investment is predominantly in other sectors (extractive mineral industries, raw material production) and very few are in agriculture raw material transformation. Similar results were found by Ali, (2021a)

Regarding the short-run causality, let's mention that the long-run adjustment coefficient is all negative and statistically significant at the 1% threshold level. The adjustment amount of agricultural added value from short-run to long-run is 0.194. This suggests any previous shock on renewable energy consumption, domestic investment, trade openness, change in temperature and precipitation will decrease agricultural added value to economic growth by 19.4%. A similar result was found by Ali, (2021a) and Raeni et al., (2019).

Domestic investment and change in temperature were found to have a statistically significant short-run causal relationship with agricultural development at the 1% threshold, while renewable energy consumption and trade openness have no short-run causal relationship with agricultural development. The sign associated with domestic investment is negative while the sign associated with temperature change is positive. This suggests that combined with the adjustment coefficient, any previous shock to domestic investment will positively contribute to increasing agricultural added value to the economy. In contrast, any previous shock resulting from a temperature change lowers agricultural participation in the economy. Additionally, this finding is in agreement with Ali, (2021a); Ben Jebli et Ben Youssef, (2017). Negative short-run causal relationship is also found between renewable energy consumption and change in temperature indicating that any previous shock to renewable energy consumption will reduce change in temperature by 0.678 points..

1.5.2- Discussion

This study shows that there is a negative relationship between climatic change and agricultural contribution to the economy in the West Africa region. Any change in temperature has a short-

and long-term adverse causal relationship with agricultural development. This result corroborates a number of studies that conclude the negative relationship of climatic change on developing countries' economies (Burke et al., 2015; Kalkuhl & Wenz, 2020; Newell et al., 2021), specifically, on crop productivity in the West Africa region (Ali, 2021a; Ali et al., 2020; Mikémina, 2013).

Moreover, the study results highlight that any change in renewable energy consumption has a short and long-run causal impact on climatic change and agricultural development in the West Africa region. This highlighted the strategic role of renewable technology adoption in sustainable agricultural development in the West Africa region. A similar finding has been reported in an Iranian case study by Raeeni et al., (2019). The stability of the long-run relationship is tested using the inverse root of the Eigenvalue stability condition. The results show in the following figure that at least one eigenvalue lies outside the unit circle. This implies that the long-run relationship between variables is structurally stable; therefore, policy recommendations from this study could be validated.

Furthermore, the panel error correction model results displayed that domestic investment and change in temperature have short-run causal impact on agricultural development, while renewable energy consumption, trade openness and climatic change have long-run causal impact on agricultural development in the West Africa region. Domestic investment and renewable energy consumption should boost agricultural development while trade openness and climatic change lower agricultural development and economic growth in the region. In the West Africa region, domestic investment and trade openness should focus on the transfer and implementation of renewable technologies. Renewable energy technologies implementations have played a key role in West Africa's economic response to climate change.

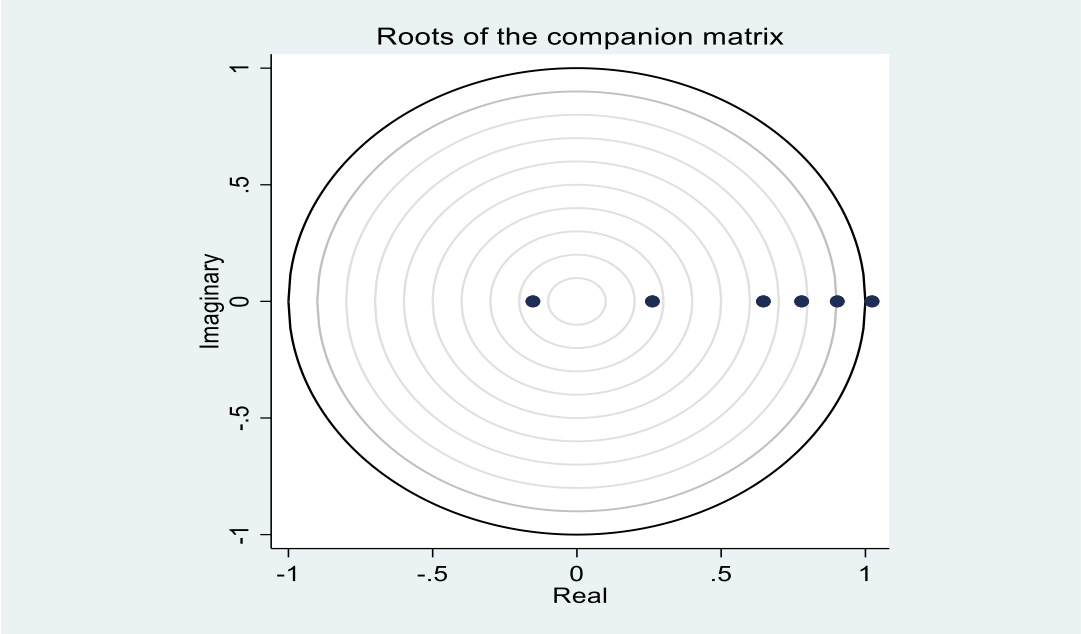


Figure 5: Inverse roots stability test

1.6. Partial Conclusion

Recent studies have examined the relationship between climate and economics, but there is no consensus regarding its impact on both developing and developed countries. This study aimed to deep the analysis of the relationship between climate and economy in West Africa. Specifically, it assesses the role of renewable energy consumption and domestic investment in the climate-economy relationship in the West Africa region. Particular attention is given to agricultural added value to the economy as a proxy for economic growth. This is due to the fact that the agricultural sector remains the main driver of the West Africa regions' economic development.

Breusch et Pagan (1980) inter-individual dependency tests, second-generation panel unit root tests and Westerlund cointegration methods were applied to data from 12 West African countries from 1990 to 2019. A panel error correction model was used to determine short- and long-term causal relationships between variables. The long-run relationship was also tested using the inverse root of the Eigenvalue stability condition. The study results show that there is a negative relationship between climatic change and agriculture's contribution to the economy in the West Africa region. Any change in temperature has both a short- and long-term adverse causal relationship with agricultural development. Also, the findings show that renewable energy consumption has a short and long-term positive causal impact on climatic change and agricultural development in the West Africa region. Moreover, domestic investment has a short-run positive causal relationship with agricultural development while a negative causal effect is observed for climatic change. To address climate change in West Africa, policies should focus on renewable energy technology implementation and domestic investment for agricultural development. Trade policy also has to encourage local transformation of agriculture goods based on environmentally friendly and clean technologies. This should avoid the exportation of more agricultural commodities as raw material, which would result in additional added-value to the economy. However, local adoption of modern and renewable technologies has to be explored.

2. Essay2: Climate change mitigation policy for energy poverty alleviation in West Africa: A case study of off-grid solar Access in Togo

2.1. Introduction

Energy poverty alleviation constitutes one of the main challenges for human well-being in West African countries where access to electricity services is fundamental to their development, and the assurance of quality human life (Day et al., 2016; Gafa & Egbendewe, 2021; Sovacool, 2012). Despite the lowest participation in climate pollution, households in the region suffer the highest impacts of climate change (USAID, 2018). Those impacts could be listed as severe drought, flooding, global warming caused by global temperature rise, as well as instability in rainfalls. Consequently, livelihoods are affected through agricultural systems, water resources accessibilities and energy expenditure (Arndt et al., 2015). The effectiveness of energy poverty in West African countries is characterized by the lack of access to energy services, its affordability and reliable production (Gafa et al., 2022; Pachauri et al., 2004). According to Reddy et al., (2000), energy poverty concept is defined as poor access to adequate, affordable, reliable, high-quality, safe and environmentally friendly energy services to support economic and human development. It also refers to the absence of modern energy access for cooking, lighting, and for households' productive activities (Gaye, 2008)¹. These two definitions give a clear overview of energy poverty situation in West Africa.

Existing literature have given the access to modern energy services such as off-grid solar system, as the solution for rural household electrification, and thus, to the energy poverty alleviation in the areas (Chakravarty et Tavoni, 2013; Rosenthal et al., 2018). This evidence was also illustrated by few studies (Abdul-Salam et Phimister, 2016, 2019; Diallo et Moussa, 2020; Guta, 2018; van Vuuren et al., 2012; Würzburg et al., 2013), in which renewable energy systems including mini-grids, small stand-alone solar PV systems have been shown to significantly affect rural household electricity access and its livelihoods. The impact ranges from environmental sustainability to socio-economic development of rural inhabitants and could have a positive or negative impact (Bertheau, 2020; Diallo et Moussa, 2020; Guta, 2018; Hussein et al., 2013; Maciejowska, 2020;

¹ United nation view of energy poverty concept. Access to energy and human development. Human Development Report, 2008.

Ürge-Vorsatz et Tirado Herrero, 2012; Wassie et Adaramola, 2021). Though, environmental benefits result from greenhouse gas reduction, which leads to increase energy security and economic decarbonization (Kaya et al., 2019), clean energy usage by households for cooking reduces indoor pollution and improves household welfare (Diallo et Moussa, 2020). In this sense, the off-grid solar systems become a high climate change mitigation policy.

Renewable energy sources such as solar, wind, bioenergy, hydrogen, hydropower have gained more attention in West Africa Countries due to the major role that it could play in their rural electrification strategy (Bourcet, 2020; Diallo et Moussa, 2020). This offers the development of renewable energy projects such as off-grid solar and mini-grid systems for electricity access. The Off-grid system solution is projected to eradicate the lack of access to energy which is critical for economic growth in remote places (Abdul-Salam et Phimister, 2016). International Energy Agency (IEA) in 2018 insisted on the role that the decentralized systems (mini-grids and stand-alone systems) will play in electricity access in Sub-Saharan Africa with specific regard to solar technologies which will represent 60% of the whole connections. It is of substantial benefit to the welfare in rural areas by providing lighting sources, appliances usage like mobile phones, radios, televisions and fans (Dagnachew et al., 2018; World Bank, 2008).

Therefore, an off-grid solar system is seen as the key solution for both climate change mitigation and energy poverty alleviation through its affordable and reliable access in order to meet the universal energy access goal by 2030 (IEA, 2014; UN, 2015). It is projected to satisfy 22% of the rural population by 2020 and 25% by 2030, with approximately 60 million people in the same period (ECREEE, 2019). This is also relevant for Togo which is still classified as low-income country in ECOWAS region (World Bank, 2022). Moreover, the country's population highly reliance on using biomass for cooking and is also one of the highest depending on biomass resource in Sub-Saharan African countries (95% of the population) (Gafa et Egbendewe, 2021).

Thus, the socio-economic impacts could be assessed through farmers income improvement, health facilities, better education system, and reduction in household energy expenditures (Wassie et Adaramola, 2021). Other authors also argued that climate change mitigation policies could negatively affect household energy expenditure through energy price increase and this could slow down the transition from traditional biomass energy usage to new and clean energy technologies

(Cameron et al., 2016; Daioglou et al., 2012). Despite these studies on the role of off-grid solar systems in rural electricity access, we acknowledge a lack of studies analyzing the socio-economic impact of climate change mitigation policy (off-grid solar access) on energy poverty alleviation in West African countries. Some of these studies were conducted in Eastern African countries such as Malawi (Aung et al., 2021), Ethiopian (Gebreslassie, 2020), Rwanda (Lenz et al., 2017), and Uganda (Chen et al., 2017) with less regard on climate change mitigation policy implication for energy poverty alleviation in the region. In West Africa, except the studies by Diallo & Moussa, (2020) and Martey (2019) which tackle respectively how solar home systems access impact household income, education, health in Cote d'Ivoire, and how variations in tenure mode influence the choice of energy sources for lighting and cooking in Ghana; studies linking climate change mitigation policy and energy poverty alleviation are very scarce.

Research questions

So, the key question raised by this study is: does climate change mitigation policies implemented in the Togolese rural areas, allow alleviation of energy poverty? Specifically,

- How significant off-grid solar system access impact household energy poverty in its multidimensionality?
- What are the benefits of government program of modern energy access on energy poverty alleviation in rural Plateau region?

Objective

The objective of this essay is to analyze the link between climate change mitigation policies and energy poverty alleviation in Togo. Specifically,

- Analyze off-grid solar access impact on energy poverty alleviation in Togo
- Assess the effect of modern energy access subsidies on households' well-being through the energy poverty alleviation in Togo.

To address these objectives of this research, off-grid solar and government subsidies for modern energy access are used as a proxy of climate change mitigation policy.

Hypothesis

The hypotheses behind this research can be stated as follows:

- Off-grid solar access positively contribute to energy poverty alleviation in all it dimensions.
- Government action in term of off-grid solar subsidies ameliorate households' access to energy services.

Contribution

The contribution of this research resides in the construction of the Multidimensional Energy Poverty Index (MEPI) for rural Togo and linking it to climate change mitigation policies implemented by government. Following the existing literature (Gafa & Egbendewe, 2021; Nussbaumer et al., 2012; Sadath & Acharya, 2017a; Zhang et al., 2019), this research constructs new MEPI integrating energy affordability, accessibility, as well as energy facilities concerns in the country. This helps in proposing insightful policy recommendation that should allow simultaneously energy poverty alleviation and climate change mitigation in rural areas.

Plan Activities

This essay is organized in six (6) sections. The first section covers the introduction part of the essay. The second section explored the literature review both theoretical and empirical on climate change mitigation policy and energy poverty alleviation is given. The methodology part includes the Multidimensional energy poverty index construction and logistic regression method are presented in the third section. This section also describes the survey design and collection process. In the fourth section, the empirical results are provided. Then, Section 5 focuses on analysis and discussion of the study findings. Finally, the section 6 concludes this essay with polices recommendations based on the study findings.

2.2. Background on energy poverty context in Togo.

This subsection presents an overview of energy situation in Togo. It underlines firstly, the principal energy sources that characterizes the country, and its accessibility per region. Secondly, the section highlights the country's effort to overcome the energy deficit through solar home systems solutions.

2.2.1- Energy balance

The electricity access is challenging for the country, but we can note a little progress in its access rate (from 17% in 2000, 45% in 2018 to 52.44% in 2020)²(AT2ER, 2018). Despite this progress attributed to the off grid solar market development, the electricity access rate remains unequally shared between urban (88.8%) and rural areas (8%). Within the regions we can note 11% for Savannah regions, 20% for Kara region, 18% for Central region, 14% for Plateau region, 20% for Maritime region, and 92% access in Lomé (Global Lightning, 2018). The national electricity production is not sufficient to supply household's energy demand, and most of national demand is imported from the countries of the sub-region (Ghana, Nigeria, Cote d'Ivoire...). Moreover, the electricity sector generally has limited performance in terms of continuity and quality of electricity supply. Outages are frequent, especially during peak hours, and voltage variations in distribution networks are characteristic of the electricity grid. This weakness of electricity access underlines also the challenges of households to use the basic energy services. It is also important to mention that the energy consumption per capita in Togo remains the lowest in West African region with 0.29 toe over the period 2000-2017 against an average of 0.6 toe for the Africa region (FAAPA, 2018).

In line with Paris agreement adoption (UNFCCC, 2015), Togo has also implemented its National Program for Rural Electrification (NPRE) in which renewable energy occupied the most important and significant role. The target of Togo Electrification Strategies is to provide electricity for half (50%) of its total population (7,5million) by 2020, 75% by 2025, and reached universal access by 2030. In this case, the program is implemented in three phases over 12 years from 2018 to 2030, with investment costs estimated to USD 1.8 billion (ECREEE & World Bank, 2019) under the

² [Togo Energy Situation - energypedia.info](http://energypedia.info)

platform called the CIZO program. The aim of this strategy is to combine grid extensions, mini-grids, and stand-alone solar systems to achieve the energy access goal in the country. Based on standard alone solar kit deployment target for rural households, the government projected to give access to 1.970 locations with 555,000 solar kits. Under the CIZO initiative, the Government gives financial support to rural households to offset the purchase of solar home systems through subsidies. The subsidies cover essentially the price of the solar equipment, and households have to pay only the cost of their energy consumption on a Pay-As-You-Go (PAYG) basis. The three phases of Stand-alone Solar Kit Deployment Targets, 2018-2030, are distributed as follows, first phase 2018-2020, 100,000 solar kits are projected to be distributed to 355 locations. The second phase will start from 2021-2025 in which 780 locations are expected to be reached with 220,000 solar kits. The last phase covers the period 2026-2030 with an expectation of 835 locations and 235,000 solar kits distributed (ECREEE, 2019).

2.2.2- Off-grid solar market potentiality in Togo

The off-grid solar market is very promising in Togo with a large potential in southern regions where more households are able to pay for SHS. This potential of the off-grid solar market is very sensitive to the market price and the household income. Three instalment pricing point at daily expenditure (85 FCFA (\$0.15), 160 FCFA (\$0.29) and 280 FCFA (\$0.50)) have been used to estimate the off-grid market potential in Togo (Global Lightning, 2018). It revealed that at the currently market price which is 160FCFA, the potential market is around 280,000 units for products sold. This represents 30% of off-grid population. But if the current market price is reduced to 85 FCA, the potential market would grow to more than 500,000 Units, or more than 56% of Togolese population could afford off-grid solar system. Moreover, at 280 FCFA/day, the market potential is very small and only a few household in rural Maritime and Plateau region could afford it (Global Lightning, 2018).

The market size by region can be presented as follow at 160 FCFA per day pricing. The Plateau region represent the highest market size 103,000 Units, due to the fact that the region is the most populous and have the highest income level. This region is followed by the Maritime region with 73,000 market size. The third region with a great market size is the Savannah region with 42,000 Units. However, this region represents the lowest grid electrification rate in the country (11%),

which means that wealthier households are likely to be off grid. Reason why this region has also a high market potential compared to the population in the region. The central region is the fourth region with 30,000 Units market size and the last is Kara region with 25,000 Units market size. Finally, we have to note that due to income level, only proportion of households in Plateau and Maritime region could afford or are able to pay for off-grid solar products at 160 FCFA. The next table present the market sensitiveness to the different price points. Table7 resumes the market sensitiveness to different prices points

Table 7: Market sensitiveness to different price points

Region	Pricing points					
	85 FCFA		160 FCFA		280 FCFA	
	Able to pay	Unable to pay	Able to pay	Unable to pay	Able to pay	Unable to pay
Savanah	42%	58%	31%	69%	13%	87%
Kara	38%	62%	23%	77%	8%	92%
Central	44%	56%	26%	77%	8%	92%
Plateau	66%	35%	32%	68%	18%	82%
Maritime	71%	29%	32%	68%	15%	85%

Source : Global Lightning, (2018)

2.3. Energy poverty concept in literature.

This section includes an overview of energy poverty situation in some West African countries and in Togo specifically. The theoretical framework and empirical review of energy poverty alleviation and climate change mitigation conception in developing countries are presented. The theoretical framework gives an overview of energy poverty concept, how it differs with traditional poverty concept, and the link of climate change mitigation policies to energy poverty alleviation. it also underlines the capability theory as set by Amartya Sen (1981) as a basic framework of this research. The empirical review investigates the off-grid solution and modern energy subsidies as climate change mitigation policies and energy poverty alleviation instrument in developing countries.

2.3.1. Theoretical background

Understanding energy poverty concept and it links with climate change, is crucial to undertake good policies for its alleviation. This requires a thorough analyses starting from the concept

definition under capability theory and behavioral economics frameworks, to its link with climate change mitigation policies.

2.3.1.1. Energy poverty concept and capability framework.

The importance of energy poverty issues both in developed and developing countries has received increasing attention from scientific researchers but there is no universally agreed definition of the concept. Generally, energy poverty concept refers to a situation wherein a household is unable to afford or have access to energy service. Scholars refer to the problem as energy affordability and access to modern energy sources issues and give its definition according to the country context, developed or developing level (Aung et al., 2021; Bouzarovski et al., 2012; Day et al., 2016; Li et al., 2014; Pachauri & Spreng, 2011; Sadath & Acharya, 2017b; Streimikiene et al., 2020). Energy poverty is also known as one of the various dimensions of general poverty such as energy, food, health, and sanitation (Chakravarty & Tavoni, 2013).

Following Schervish, (1981), poverty refers to the situation in which families or groups in the population lack the resource or the capability to obtain their basic need in terms of diet, participation in social activities, and living condition (Schervish, 1981). This definition of poverty underlines some base needs that are essential to be fulfilled in the societies as diet, shelters, sanitation, etc. World Bank institute in 2009, viewed poverty in the monetary term and claimed that the poor are those who do not have enough income or consumption to put them above some adequate minimum threshold. In this sense, poverty is seen as “pronounced deprivation in well-being” (Haughton & Khandker, 2009).

The term capability was integrated in economic theory in 1981 by the 1998 Nobel Prize in economics, the Indian Economist and Philosopher Amartya Sen. For Sen, (1981), poverty is understood as deprivation of capability to live a good life. This deprivation of capability can include, inadequacy in proper energy needs for basic usage, inadequate income or education, poor health, powerlessness, or absence of political freedom. Based on these definitions, it results that poverty analysis has to be completed in its multidimensionality, including energy, food, education, health, shelters, and sanitation (Chakravarty & Tavoni, 2013; Parajuli, 2011). Thus, providing an adequate energy service both in developed and developing countries, will be relevant for poverty eradication.

In its origin, the concept energy poverty was associated with fuel poverty and was defined as inability to purchase energy services (Wang et al., 2015) or lack of capability of households to ensure an adequate thermal regime in their living space (Ürge-Vorsatz & Tirado Herrero, 2012). These definitions prevailed in developed countries where the general poverty has been more or less been eradicated but households still face high energy price for their heating comfort. In this case energy poverty refers to the fact that households are spending high share of their real income on their energy needs (Sadath & Acharya, 2017b; Streimikiene et al., 2020; D. Zhang et al., 2019). Originated from United Kingdom (UK) in 1970s, and seen as Central and Eastern Europe energy poverty conception (Biermann, 2016; Boardman, 1991, 2010; Buzar, 2007), the term fuel poverty was criticized for its “arbitrary calculation and estimation”. Boardman’s 1991 first definition used a reference threshold to qualify household in fuel poverty called Fuel poverty rate. Then, household is classified to be in fuel poverty, if the household spend more than 10% of his income for indoor temperature regime satisfactory (Li et al., 2014).

Later in 2010, Boardman reviewed the first definition and referred to fuel poverty as household’s inability to afford energy service (Boardman, 2010). Li et al., (2014) analyzed the similarity and differences between energy poverty and fuel poverty, and called for a dissociation of the two concepts. They thought fuel poverty covers just the energy inefficient in housing and heating system, low incomes aspect of energy poverty, and obstructs health, well-being and social equity aspects of energy poverty. Zhang et al., (2019) states that, although developed countries have full access to modern energy, some households are suffering from insufficiency in the supply of energy due to some economic reasons. Thus, fuel poverty concept drafts energy affordability issues as lack of resource to afford energy system, but energy poverty concept concerns both energy availability and its affordability issues. Therefore, lack of sufficient Income to afford energy service or high cost associated with energy service could be identified as the main causes of energy poverty in developed economies.

The availability problem describes the energy poverty conception in developing countries better. From the availability concept, energy poverty can be defined as lack of access to energy service or modern energy service. Here, energy service or modern energy service includes households access to electricity and commercial fuel on the one hand or households access to electricity and clean cooking facilities on the other hand (IEA, 2010, 2017). Generally, in developing countries,

energy poverty phenomenon is associated with the lack access to electricity by households. Some scholars argued that electricity access is crucial for world development and household electrification is important for energy poverty alleviation in developing countries (Aung et al., 2021; Birol, 2007; Lenz et al., 2017; Li et al., 2014; Pereira et al., 2011; Sagar, 2005; Sharma et al., 2019). In fact, electricity access gives an opportunity for job creation which is favorable in an unemployment rate reduction, allows for the improvement in educational system, health and sanitation systems. Lack of access to electricity will contribute to the persistence of energy poverty. This way of viewing the concept is in line with the United Nation institute concept definition which states that “Energy poverty is a lack of access to basic energy provision services such as electricity, heating, food cooling, cooking, etc.” (Streimikiene et al., 2020; UN, 2010).

In the same line, Sharma et al., (2019) assessed the concept as lack of electricity access in India households and underlined its social, economic and environmental effects. On social side, household healthcare and education systems are shown to be highly affected by lack of electricity. In fact, continual supply of electricity is requested for medicine storage and vaccines refrigeration, necessary for preventing and treating diseases and infections in developing countries. In addition, having information through the use of electricity appliance (TV, radio, computers, etc.) is important for improving household access to knowledge. So, the lack of electricity access negatively affects their education system. On economic side, the authors linked energy poverty issue to the excessive cost of an electricity connection and consumption. In this way, households have to spend high share of their income to access electricity from the main grid (often absent in remote areas) worsening their living standards. The environmental side pointed out energy poverty as lack access to modern energy service. It has been shown that households who are not provided with clean energy are compelled to use biomass and fossil fuel for cooking. By so doing, they are always exposed to various harmful indoor air pollutants and deforestation issues.

All these three dimensions of energy poverty concepts are also similar in Sub-Saharan Africa. Aung et al., (2021) and Diallo & Moussa, (2020) have also linked energy poverty concept to lack of access to modern energy due to low income issues. Aung et al., (2021) in this perspective, described energy poverty issues in Malawi by tackling energy availability and household capacity to pay for it when it is available. They mainly focused on ultra-poor households which are faced with obstacles in overcoming energy poverty due to very low income and asset portfolios, labor

constraints, disabilities and other challenges. Diallo & Moussa, (2020) refer to the expensive cost of conventional grid connection and modern energy technology (Solar PV system) as the major problems of electricity access in most Sub-Saharan Africa countries.

Therefore, energy poverty has to be assessed according to the country's context. We could describe it in West Africa context as both availability and affordability problems. In this line, the concept could be viewed as a situation in which human basic energy needs such as lighting and cooking are not achieved due to an inadequate energy system and lack of the resource to afford it. For instance, this aspect of the energy poverty concurs with Day et al., (2016); Nussbaumer et al., (2013); Sadath & Acharya, (2017b); and Zhang et al., (2019) notions on the energy poverty concept definition, in which the authors underline the fact that it is important to perceive energy poverty in its comprehensive multidimensional way including the notion of capability and energy justice of Sen, (1981) and Nussbaumer et al., (2012). Thus, it results that energy poverty phenomenon is led by multiple factors including energy efficiency in household residential buildings, household income level (ability to purchase energy for the household basic needs), and the energy price referring to the access cost. Consequently, its alleviation necessitates a different remediation approach which calls for more attention into government and households' behavior in economic decision making relative to energy choice.

2.3.1.2. Capability theory and behavioral economics

Capability framework as proposed by Amartya Sen has been settled as useful framework for understanding what really is energy poverty and how to overcome this problem (Sadath & Acharya, 2017b; Wang et al., 2015). This can be pointed out through the important role of energy resources in the promotion of social welfare and life facilities (health, education, income). As mentioned above, the three dimensions through which energy services affect human well-being: social, economic and environmental dimensions, the lack of access to energy services could be treated as one of the forms of deprivation in the society or incapability state. The capability theory offers the ability to analyze this deprivation not only at household level but also integrating collective and government efforts for its alleviation.

Even though this approach has been discussed in several works (Bouzarovski & Petrova, 2015; DellaValle, 2019; DellaValle & Sareen, 2020) without providing systematic review and

development of clear theoretical concept. But it remains highly cited for energy poverty analysis. DellaValle, (2019) claimed that behavioral economics framework is the best way to analyze the energy poverty phenomenon. Their study highlighted that energy poverty can result from some behavioral factors, affecting the quality of individual decisions making. This could affect households' budgeting ability, energy consumption and energy efficiency adoption decision. In other words, behavioral economics offers the ability to integrate the influence of cognitive biases on economic decisions making for energy poverty alleviation. Critically, households living in scarcity condition are more exposed to poor decision-making in their energy choice. This way of viewing energy poverty concepts can be described as the affordability issues in household level and doesn't account for energy availability issue.

Therefore, the capability approach gives us the ability to evaluate the energy poverty from its availability and affordability points. For instance, Streimikiene et al., (2020) state that capability theory constitutes an ideal framework to analyze energy poverty issue in the context of climate change. Moreover, Sen recently claimed that "making it easier to produce energy with better environmental correlates (and greater efficiency of energy use) may be a contribution not just to environmental planning, but also to making it possible for a great number of deprived people to lead a fuller and freer life"(Sen, 2014). Hence, the capability theory of Amartya Sen is used in a comprehensive way to evaluate energy poverty issues in climate change context in this study.

2.3.2. Empirical background

In this section, we first, review previous studies establishing a link between climate change mitigation policies and energy poverty alleviation, and second, we underline some key energy poverty measurement instrument that have been used to evaluate the energy poverty. Concerning climate change mitigation policies, we consider two policies interventions: renewable energy deployment and government subsidies for modern energy access.

2.3.2.1. Climate mitigation policies for Energy poverty alleviation review

An inefficient use of energy service is seen as the root of both climate change and energy poverty phenomena. In this sense, elaborate policies based on energy service to promote energy poverty alleviation and climate change mitigation could have negative or positive effect on both phenomena. For example, promote energy poverty alleviation through target policies such as fuel

payments, social subsidies to help with income poverty or energy price subsidies, increase the expansion of the access and consumption of the energy resources such as fossil fuel and could be detrimental to the environment by causing an increase in carbon emission and global warming (Sadath & Acharya, 2017b). In the same way, target policies such as increasing energy prices, imposed taxes on carbon emissions (carbon pricing) to reduce carbon emission and promote climate change mitigation, but could deteriorate energy poor households' habitats by affecting household's income and household's energy expenditure.

This trade-off between climate change and energy poverty has been investigated in the literature (Chakravarty & Tavoni, 2013; González-Eguino, 2015; Malla, 2013; Ürge-Vorsatz & Tirado Herrero, 2012). From González-Eguino, (2015), it has been well demonstrated that countries with higher per capita energy consumption share the higher per capita CO₂, reason why the USA, China, and Saudi Arabia have a higher level of fuel energy consumption share and a higher per capita carbon dioxide comparatively to the rest of the world. Chakravarty & Tavoni, (2013) also made the empirical evidence that increasing carbon emission results in increasing global final energy consumption. The study estimated a rise in global warming by 0.13°C by 2030, as a result of an increase in energy demand by 7%.

Therefore, the relevant policies that could eradicate energy poverty and climate change challenges in developing countries is necessary for the integration of environmental sustainability issues and household economic situations. This put in the radar of policies implementation the central role that renewable energy could play in energy poverty alleviation and climate change mitigation on one hand, and the urgent need to orient energy subsidies towards modern and clean energy deployment on the other hand.

Regarding the environmental implications of energy poverty alleviation in India, Bhide & Rodríguez-Monroy, (2011) have explored the greater role of integrating renewable energy sources in energy poverty alleviation policies implementation and reported that India government should explore the potential of renewable and clean energy that the country disposed, so that it should be used to reduce energy poverty in the countryside. González-Eguino, (2015) conducted similar research and reiterated this view about the role of renewable energy sources in reducing global energy poverty. An interesting study have been also conducted by Kaygusuz, (2011) concerning

the environmental implication of energy poverty alleviation. The study investigated the evident trade-off between reducing energy poverty and achieving environmental sustainability and called for an integrated approach to energy policies and general welfare programs of the government taking into consideration the specific nature and needs of the region. In the same vein, Sadath & Acharya, (2017) added that an inefficient use of biomass mostly firewood (collected by women in traditional India households) and biomass fuel are found to be detrimental for human well-being and responsible of health hazards in India community.

Recently, several scholars from Sub-Saharan Africa have demonstrated the benefits of having access to modern energy service on human welfare and environmental sustainability. Diallo & Moussa, (2020) used household-level data gleaned from 2015 Living Standards Measurement Surveys (LSMS) to investigate the welfare benefits of using solar home system as a source of electricity in remote areas in Cote d'Ivoire. Based on a regression model with an endogenous treatment, it was found that the use of Solar Home System increases the household consumption per capita and the household average years of schooling by 41.96% and 1.79 years respectively and reduces the number of household members that report an illness by 2.35. In the same line, Wassie & Adaramola, (2021) analyzed the socio-economic and environmental impacts of rural electrification with Solar Photovoltaic systems in Ethiopia. Using binomial logit, and multivariate probit modeling, they found that electrified rural household with Solar Photovoltaic (PV) systems ensure the environmental sustainability by saving the consumption of 43.68 L of kerosene and emission of 107 kg CO₂ per year compared with a non-electrified one. This could allow a rural household to save between US\$ 65 and \$75 per year from avoided energy costs and mobile charging expenses.

Similar result was reported by SolarAid, (2014) conducting a study in five African countries (Kenya, Tanzania, Zambia, Malawi, and Senegal). The results showed that after purchasing off-grid system specifically solar Pico PV light, households reduced their kerosene consumption on average savings of 4.1 L per household per month. These savings are linked with the financial savings of US\$ 60–\$70 and emissions avoidance of 123 kg CO₂ per household per year. Therefore, these empirical results shows that SHS is very important for climate change mitigation by the reduction of GHG emissions and urgent need in energy poverty alleviation process. Its accesses in

West Africa are a necessity. Thus, some studies suggest governments intervention through subsidies modern energy access.

2.3.2.2. Subsidies for modern energy

The empirical evidence on the expansion of subsidies for households' access to modern energy services, for energy poverty alleviation and its economic and social benefits has been also investigated in the literature. The idea of assisting household with subsidies is based on the fact that households are unable to afford energy services due to income poverty. For example, Sharma et al., (2019) analyzing the socio-economic determinants of energy poverty amongst Indian households noted that the dominant factor inducing energy poverty in millions of households in India is linked to economy poverty, mainly on the consumption expenditure of a household, and it varies across income groups. However, several authors have critical point of view on the use of subsidy to promote energy access and they emphasized on the type of energy service that could be subsidized. In fact, subsidies such as fuels payment, could be detrimental to environmental sustainability because it will raise unclear energy consumption and GHG emissions (Sadath & Acharya, 2017b; Ürge-Vorsatz & Tirado Herrero, 2012). Therefore, government needs a well oriented subsidies for the access to clean and modern energy services.

Based on a comprehensive study, Ürge-Vorsatz & Tirado Herrero, (2012) underlined three main factors that contribute to energy poverty phenomenon, and claimed that those underlying factors provide an analytical framework for key entry points into energy poverty alleviation policy-making. The three elements to consider are household income, energy prices and energy efficiency. For the first element, the authors argued “that providing a long-term solution to the energy poverty problem via households' income (e.g., through subsidies to energy costs or fuel payments) is often difficult because extra income may not be used by households for covering their unmet energy service needs or for improving the energy efficiency of their dwellings”. This means that government needs to find a mechanism which could allow the allocation of energy subsidies directly to the modern energy access. The second element highlights the energy price as the way through which energy poverty has been traditionally addressed. Here, Ürge-Vorsatz & Tirado Herrero, (2012) reported that subsidized energy prices to address energy poverty need to be carefully undertaken and it has to be combined with energy efficient measures to avoid counterproductive (such as adoption of low-efficiency equipment and infrastructure) effect in

solving the problem. The third key entry point is regarding the efficiency of the households' energy using capital stock in residential buildings.

Moreover, countries that experimented the use of subsidies for modern energy access reported the positive and significant effect that it could have on energy poverty alleviation. Pereira et al., (2011) have reported the significant economic and social benefits of access to electricity and LPG (Liquefied Petroleum Gas) for Brazilian households through a concerted effort made by the government to expand reliable electrification. This evidence has been highlighted in Indonesia by Andadari et al., (2013), where the government expanded reliable electrification through the expansion of subsidized LPG programs to households. Well thought, addressing the energy poverty with adequate lighting facilities has an enormous potential to improve their business and thereby their standard of living.

The clarification gave by Wang et al., (2015) related to the evidence of a decrease in energy poverty in China proved that according more attention to the improvement of energy service availability, energy affordability, and energy efficiency is crucial for reducing energy poverty and climate change challenges. However, their work underlined the fact that the freedom from income poverty does not necessarily imply the freedom from energy poverty. Indeed, despite the fact that China has achieved full access to energy service for their population (Zhang et al., 2019), most of their households are using biomass for cooking because they are constrained by the price of modern energy services (Sadath & Acharya, 2017b).

Aung et al., (2021) recently analyzed the role of unconditional social cash transfers on ultra-poor energy access in Malawi. They found that unconditional social cash transfer payments contribute to improved energy access for the ultra-poor. This result suggest that modern energy subsidies and unconditional social cash transfer remain an option in the process of energy poverty alleviation in developing countries and can also be used as climate change mitigation policies. This study will look carefully on its role in energy poverty alleviation in Western Africa countries.

2.4. Methodology

The aim of this study is to assess the climate change mitigation policies impact on energy poverty alleviation in the Togolese rural area. This section firstly, describe energy poverty measurement

process and underline the empirical methodology linking climate change mitigation policies and energy poverty indicators. Secondly, it exposes the data use in the study's collection process.

2.4.1. Energy poverty measures

As defined earlier, energy poverty following the countries context, its measurements also are defined following the type of energy issues faced by the household. Therefore, various indicators such as an objective energy expenditure-income indicator, the Low Income-high Cost (LIHC) indicator, self-reported subjective measures, the Multidimensional Energy Poverty Index (MEPI), and the Multitier Framework for Measuring Energy Access, were proposed for energy poverty measurement both in developed and developing countries. In the following sub-section, energy poverty measurements indicators are grouped in two categories. The first category is named unidimensional energy poverty measurement methods, and the second is MEPI measurements methods.

2.4.1.1. Unidimensional energy poverty estimation methods

Considering the three unidimensional approaches used in the empirical literature for energy poverty measurement, this study adopts three different thresholds estimation methods. The first method is based on the physical energy threshold and demand-based approach. In line with Gafa & Egbendewe, (2021), and Barnes et al., (2011), and considering the non-existence of grid and mini-grid for electricity access in the study area, the study assesses household physical energy demand by calculating its monthly per capita energy consumption in kilogram per oil equivalent (KgOE). This approach is expected to provide information about the energy consumption level where household energy demand starts raising with income (Gafa & Egbendewe, 2021). The second estimation method, however, is based on the energy expenditure-income indicator. 10% threshold is used for lighting energy expenditure and 5% threshold is used for cooking type energy expenditures (Bhatia & Angelou, 2015). The last approach refers to income poverty assessment based on general income poverty line. Here, the general income poverty line is used, the equivalent of Us\$1.90 a day in 2011 PPP to define if the household is energy poor or not. The expenditure-income indicator however, brings the evidence of household ability to afford the energy system available in the area. Once all the thresholds are estimated for each approach, energy poverty levels

are captured for rural household in three districts (Agou, Haho and Ogou) of Togo, Plateau region, using the headcount ratio³. It is mathematically formulated as follow:

$$EP = \frac{H_p}{N} \times 100 \dots\dots\dots (2.1)$$

where EP is the energy poverty rate (in %), H_p is the number of energy poor households, N is the total number of households.

2.4.1.2. Multidimensional energy poverty index (MEPI) estimation

Following Nussbaumer et al., (2012, 2013), the MEPI is a composite index designed to capture both the incidence and intensity of energy poverty and evaluate a set of energy deprivation that affect a household. As said, this index provides “valuable insights allowing the analysis of determinants of energy poverty, and subsequently insights into policy efficacy”(Nussbaumer et al., 2012, 2013). The MEPI is designed to measure energy poverty in D variables across a population of N individuals ($D \geq 2$). The aim is to capture both the incidence and the intensity of the energy poverty. Let $Y = [y_{ij}]$ be the matrix $N \times D$ of achievement describing the level of achievement of the variable j for the individual i . The row vector $y_i = (y_{i1}, y_{i2}, \dots, y_{iD})$ constitutes the achievement of individual i in the different indicators, and the vector column $y_j = (y_{1j}, y_{2j}, \dots, y_{Nj})$ represents the distribution of the indicator j across the individuals. y_{ij} is defined to be 1 or 0 according to the individual i achievement in variable j .

The deprivation cut-off of individual i in variable j is noted if $y_{ij} > 0$ and a weighting vector w composed of the elements $w_j = (w_1, \dots, w_D)$ is applied to each variable j . The weights are defined to be $0 < w_j < 1$ and $\sum_{j=1}^D w_j = 1$. z_j is then defined as the deprivation cut-off in variable j and the deprivation matrix $g = [g_{ij}]$ is constructed with $g_{ij} = w_j$ when $y_{ij} < z_j$ and $g_{ij} = 0$ when $y_{ij} \geq z_j$. This will allow for the construction of a column vector c representing the sum of weighted deprivation suffered by the individual i such as $c_i = \sum_{j=1}^D g_{ij}$. Once this column vector is constructed, the individuals multi-dimensionally energy poor are identified by using a cut-off $k > 0$ across the column vector, and a person can be considered as energy poor if her weighted

³ The headcount ratio, also known as the Foster-Greer-Thorbecke (FGT) P_0 measure of poverty.

deprivation c_i exceeds k . Then, the censored vector of deprivation counts is defined as follow:

$$c_i(k) = \begin{cases} 0 & \text{if } c_i \leq k \\ c_i & \text{if } c_i > k \end{cases}.$$

This means that the censored vector of deprivation counts zero for those who are not identified as multi-dimensionally energy poor. Therefore, the incidence of multidimensional energy poor can be calculated by considering the proportion of people that are reported as energy poor Q , ($c_i > k$), and the total of the N individuals. This is also called the headcount ratio $H = Q/N$. The intensity of multidimensional energy poor A is calculated by using the censored weighted deprivation counts $c_i(k)$ as follow: $A = \sum_{i=1}^N c_i(k)/Q$. Finally, the MEPI is defined as:

$$MEPI = H \times A \dots\dots\dots (2.2)$$

This way to conceptualize the energy poverty have been followed by several scholars (Ogwumike & Ozughalu, 2016; Sadath & Acharya, 2017b; Sher et al., 2014; Wang et al., 2015; D. Zhang et al., 2019). For example, (Wang et al., 2015) constructed a comprehensive evaluation index based on three type of energy poverty measurement such as energy service availability, energy service quality, and satisfaction of energy demand, to demonstrate regional energy poverty in China.

Sadath & Acharya, (2017) have proposed a simple multidimensional measure of energy poverty in India. For them, the MEPI captures a set of energy deprivation which may affect a household and it is composed of eight dimensions of different types of energy used, grouped in three categories. The first category is lighting, which concern access to electricity. The second category is cooking including access to LPG and Stove Type. The last category is named Additional Measures composed of Firewood, Dung Cake, Crop residue, Kerosene, Coal or Charcoal. They authors weighted equally the three categories' elements with a weight score of 33.33% and divided this weight within the broad category elements. Once the set of energy deprivation is well defined, Sadath & Acharya, (2017) proposed to assign each category with a binary value (0 or 1) depending on whether the presence of an attribute is a sign of energy poverty or not.

It can be noticed that, this MEPI proposed by Sadath & Acharya, (2017) is based on energy accessibility issues and integrated multiple energy source in their multidimensional measures, but failed to consider the case where household is unable to afford energy services due to income

poverty. This point has been noted by Zhang et al., (2019), who claimed that the MEPI proposed by previous scholars failed to incorporate affordability into their framework and , thus, omit some important information that can be important for energy poverty measurement. Therefore, they proposed a multidimensional measurement integrating both affordability and accessibility to evaluate energy poverty in China. Their MEPI generation can be described as follows. For accessibility measurement, the study considered that households that use solid fuel for cooking are in energy poverty and thus generate a dummy variable P_{it}^s that equals to 1 if they use solid fuel and 0 otherwise. Two alternative methods are used to measure energy affordability. Firstly, Energy-Income Ratio (EIR) is calculated by dividing the household energy expenditure by the household total income, and secondly a discrete variable P_{it}^f that equals 1 is assigned if that ratio exceeds a fixed threshold (i.e., 10%) or 0 otherwise. This can be illustrated mathematically as follows.

- Accessibility measurement

$$P_{it}^s = \begin{cases} 1 & \text{if household use solid fuel for cooking} \\ 0 & \text{if otherwise} \end{cases} \dots\dots\dots (2.3)$$

With P_{it}^s showing the energy deprivation from energy accessibility issues

- Affordability measurement

$$EIR = \frac{\text{Household energy expenditure}}{\text{Household Total income}} \dots\dots\dots (2.4)$$

$$P_{it}^f = \begin{cases} 1 & \text{if EIR exceeds a fixed threshold} \\ 0 & \text{if otherwise} \end{cases} \dots\dots\dots (2.5)$$

With P_{it}^f showing the energy deprivation from energy affordability issues. Once the two parameters are defined, an equal weighted method, following (Sadath & Acharya, 2017b) MEPI estimation, is used to combine them for the construction of multidimensional index.

As this study aims to analyze the socio-economic impacts of climate change mitigation policies on energy poverty alleviation in West Africa using a case study of off-grid solar access in Togo, the MEPI developed by (Sadath & Acharya, 2017b; Zhang et al., 2019) offers a good analytical framework for this study. The next table (Table8) summarizes the relative weight used by some studies, associated to the different dimensions and respective indicators.

Table 8:Energy poverty dimensions for MEPI

Dimension	Indicator	Nussbaumer et al., (2013) Weight (%)	Sadath et Acharya, 2017 Weight (%)	Zhang et al., (2019) Weight (%)
Lighting	Electricity access	20	33.33	20
Cooking	Modern Cooking Fuel	20	16.66	10
Service provided by means of household appliances	Indoor pollution	20	16.66	10
	Household appliance ownership	13.33	-	-
	Education appliance ownership	13.33	-	-
Entertainment/ education	Education appliance ownership	13.33	-	-
Communication	Telecommunication means	13.33	-	-
Additional Measures	Firewood	-	6.66	8
	Dung cake	-	6.66	8
	Crop residue	-	6.66	8
	Kerosene	-	6.66	8
	Coal/Charcoal	-	6.66	8
Energy expenditures	Energy-income ratio	-	-	20

Source: Nussbaumer et al., (2012); Sadath & Acharya, (2017); Zhang et al., (2019)

2.4.2. Model specification

To analyze the socio-economic impact of climate change mitigation policies on energy poverty alleviation in Togo, this study firstly constructs the MEPI for its households, and secondly link it with climate change mitigation variables (access to SHS and Modern energy subsidy) and socio-economic variables such as household's level of education, health and income information.

2.4.2.1. MEPI construction

The MEPI is constructed here by adopting the methodology proposed by Zhang et al., (2019), (Sadath & Acharya, 2017a), and (Gafa & Egbendewe, 2021). In fact, this methodology has been proposed to complete the weakness of the previous methodology suggested by (Nussbaumer et al., 2013; Sadath & Acharya, 2017b) which did not include both the affordability and accessibility issues of energy access in their MEPIs constructions. It captures both affordability and accessibility, as well as integrating household's energy expenditure information into the same

framework. Moreover, this methodology reflects Amartya Sen’s conception of energy poverty as a deprivation and lack of capability related to household access of basic needs of energy services. For developing countries especially Togo, the MEPI proposed by (Zhang et al., 2019) allows to measure household access to energy service by introducing all variables that capture at the same time the incidence of energy poverty (number of household’s that are energy poor) and the intensity of energy poverty (at which point the households are energy poor). The next table (Table 9) summarizes all the variables with their weights.

Table 9: Energy poverty dimensions for the present MEPI calculation

Dimension	Indicator	Variables	Deprivation cut-off (energy poor if...)	Weight
Lighting	Electricity access	Has access to electricity (mini-grid and off-grid)	False	0.13
		Solar Kits	False	0.06
		Kerosene wicks	True	0.06
Cooking	Modern cooking fuel	LPG, Natural gas, biogas	False	0.13
	Indoor pollution	Firewood	True	0.06
		Coal/Charcoal	True	0.06
	Lighting energy-income ratio	Lighting energy expenditure, household’s total income	True if exceed a reference threshold (10%).	0.13
Energy expenditure	Cooking energy expenditure-income ratio	Cooking energy expenditure, household total income	True if exceed a reference threshold (5%).	0.12
	Household appliances	Has Fan or fridge	False	0.05
Energy facilities and convenience	Education Communication	Has radio or television,	False	0.05
		Has a phone land line or mobile phone?	False	0.05
	Cooking convenience	Cooking duration	“More than 30 min”	0.05
	Safety	Report Accidents	True	0.05

Source: Auteur, Following Gafa & Egbendewe, (2021), and Nussbaumer et al., (2012)

2.4.2.2. *MEPI linked with climate change mitigation variables*

Once the MEPI is constructed for each household, a multiple regression based on linear probability equation following (Munyanyi & Awaworyi Churchill, 2020; Sharma et al., 2019) is adopted. Munyanyi & Awaworyi Churchill, (2020) linked household access to subnational aid to energy poverty through a linear probability equation. This allows them to examine four channels through which aid could influence energy (income poverty, education, health and economic growth). It was pointed out that income poverty, education and economic growth are mechanisms through which aid transmits to energy poverty. Consistent with literature, this linear probability equation can be presented as follow:

$$MEPI_i = \beta_0 + \beta_1 Sub_i + \alpha_j X_{ji} + \varepsilon_i \dots \dots \dots (2.6)$$

Where, $MEPI_i$ measures the energy poverty status of household i . Sub_i represents the household i access to modern energy sponsored by the government and is binary variable equal to 1 if household benefits from government modern energy sponsored and 0 otherwise. X_{ji} represents the vectors of the socioeconomic variables such as education, health, and income information for the household i . ε_i is the error term. β_0, β_1 , are the parameters. α_j is the coefficient attached to the explanatory variable X_j .

2.4.2.3. *Estimation of the link between MEPI and climate change mitigation variables*

Following the empirical review investigating the determinants of energy poverty in developing countries, logistic regression is adopted to estimate the model (2.10), linking energy poverty variables to climate change mitigation variables (Gafa & Egbendewe, 2021).

$$logit(P_i) = \ln\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 Sub_i + \alpha_j X_{ji} \dots \dots \dots (2.7)$$

with, $i = 1, 2, 3 \dots n$, and where, P_i is the probability of being energy poor is given as follow.

$$P_i = E(Z_{ji}), \text{ with, } Z_{ji} = \beta_0 + \beta_1 Sub_i + \alpha_j X_{ji}$$

$$P_i = F(\alpha + \gamma_j Z_{ji})$$

$$P_i = \frac{\exp(\alpha + \gamma_j Z_{ji})}{1 + \exp(\alpha + \gamma_j Z_{ji})} \dots \dots \dots (2.8)$$

Where Z_{ji} regroup all the independent variables. The parameter γ_j gives the log odds of the dependent variable and α is a constant. The odds ratio that represents the probability of occurrence of an event relative to non-occurrence is showed as follow.

$$\frac{P_i}{(1+P_i)} = \exp(\alpha + \gamma_j Z_{ji}) \dots \dots \dots (2.9)$$

The marginal effect however, is calculated as follows

$$\frac{\partial P}{\partial Z_j} = \frac{\sum_{i=0}^n F'(\alpha + \gamma_j Z_{ji})}{n} \gamma_j \dots \dots \dots (2.10)$$

2.4.3. Data and study area

The aim is to investigate the socioeconomic impact of climate change mitigation on energy poverty alleviation in the Togolese rural area, in this section, we describe the area where the study is conducted, and how the data to achieved our objectives is collected.

2.4.3.1. Study area

Located in West Africa with an area of 56,790 km², Togo is bordered by Ghana to the west, Benin to the east, Burkina Faso to the north and the Atlantic Ocean to the south and located between latitudes 6° and 11°N and longitudes 0° and 2°E. In 2020, the country's population was over 8.2 million with of a growing rate of 2.4% per year. Administratively, the country contains five regions such as: Maritime, Plateau, Central, Kara and Savannah regions. This study was conducted in the rural area of four districts in Plateau region, named, Agou, Amou, Haho and Ogou districts. The region occupies an area of 16,974Km² with 81 people per Km², and has 1,375,165 inhabitants (DB-city, 2022). It is bordered to the north by the Central Region, to the south by the Maritime Region, to the east by Benin and to the west by Ghana. The region is the largest of all the regions of the country and is located between 6° 9 and 8° 5 North latitude (Gadédjisso-Tossou, 2015).

Straddling the sub-equatorial, equatorial and humid tropical climates, the Plateau region climate is favorable to agricultural production and more than 31% of the agricultural population of the country is living the area (Gadédjisso-Tossou, 2015). Moreover, the study area is marked by two

rainy seasons and two dry seasons. The main long rainy season spreads from April to July, followed by the short dry season until August, while the short rainy season runs from September to October, followed by the main dry season which spreads until March (Kohnert, 2021). These seasonal diversities allow the diversification of agricultural practices in the region.

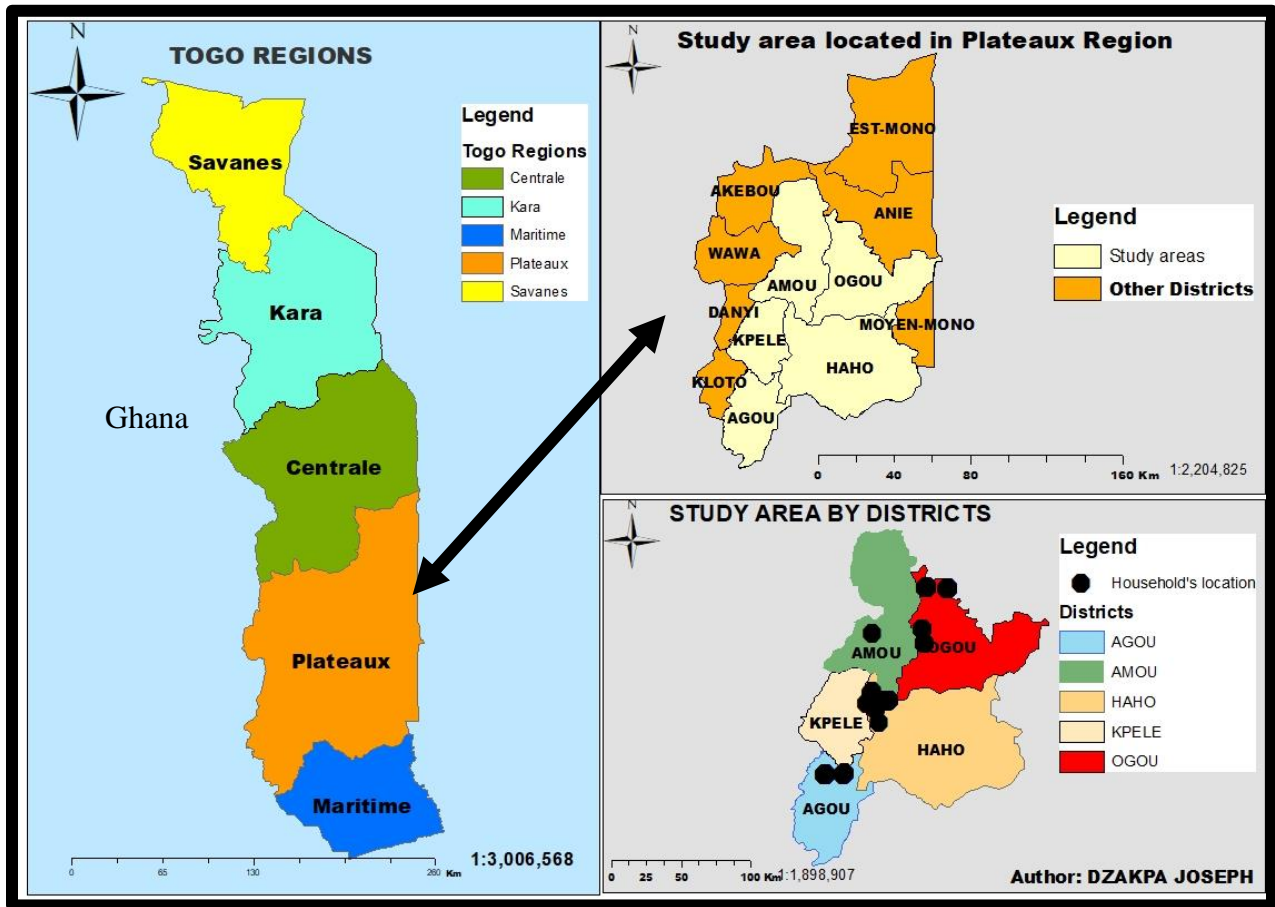


Figure 6: Map of Togo showing the study area

2.4.3.2. Sampling Procedure

A multi-stages sampling method was applied to collect cross-sectional data from 327 household heads in the Plateau regions of Togo. The data were collected in the month of November 2021. In the first stage, the Plateau region was selected, based on its high potential share of off-grid solar market size within the regions. For instance, Global Lightning, (2018) reported that this region is the most populous and have higher income levels for solar panel purchase. Truly, about 103,000 people in Plateau region are able to pay for Solar home system against 73,000 people in Maritime

region (Global Lightning, 2018). Moreover, this region also was the first place where the CIZO project was officially launched in 2018 by the government.

In the second stage, three districts (Agou, Haho, Ogou) were selected in the Plateau region of Togo. Ogou district was selected for being the main district in which CIZO project was first implemented. Agou and Haho districts were selected due their proximity to Ogou district. Eleven villages were randomly selected from the three districts in the third stage using a random number table. The villages have the same characteristics which are: the non-existence of grid or mini-grid solution for electricity access, the climate is favorable to agricultural practices, and in majority, households head are farmers.

The sample selected in each district and village is summarized in table (10).

Table 10: Sample selection

Districts	Villages	Number of selected Households by village	Number of selected Households by District	The proportion of total respondents	The proportion of total respondents District
Agou	Akplolo	24		7.34	
	Kati	51	75	15.60	22.94
Haho	Baya-cope	13		3.98	
	Haito	53		16.21	
	Kpegnon-Adja	51	124	15.60	37.92
	Saba-cope	6		1.83	
Ogou	Adougbela	32		9.79	
	Agbafro	13		3.98	
	Awagome	58	128	17.74	39.14
	Okpodjive	11		3.36	
	Sama-Tandjé	15		4.59	
Total	11	327	327	100.00	100.00

2.4.3.3. Data Collection

For the data collection, the study employed a structured questionnaire to collect information from rural household heads located in the study areas. The survey included information on household's type of energy use and its awareness of off-grid solar system in the area. Thus, the questionnaire was structured in three sections. The first section contained information on the respondent's socio demographics characteristics. Thus, the responded were asked questions relating to household size,

responder's gender, level of education, age, and its profession. In the second sections, the questionnaire was designed to obtain information about households' access to energy services. This section includes information on the type of energy use for lighting, the type of energy used for cooking, and the convenience and the safety of the type of the energy sources. The last section gathered information about respondents' awareness to climate change mitigation policies implemented by the government in the area. The questionnaire was drafted base on previous energy poverty analysis done by Gafa & Egbendewe, (2021). It was also developed by using "Kobo collect Toolbox", an on-line survey tool, and the data collection was conducted by visiting and a face-to-face interviewing of each responded.

In the validation process, two validation methods were used: the pilot test, and Kaiser-Meyer-Olkin (KMO) sampling size validation methods (Hair et al., 2010). In the pilot questionnaire tested process, a preliminary field visit was undertaken in two steps. The first step was undertaken near the off-grid solar market actors intervening in the supply of solar energy in rural area of Togo such as AT2ER, Bboxx-EDF Togo, Soleva, and Kya energy during the period 20 August to 03-September 2021. This step helped us to have critical points on the solar home system deployment in rural area, and we adapted the questionnaire to those points. The second steps however, consisted of a pretest of the questionnaire to assess the level of understanding of the enumerators after their training on how to survey respondents. Then, the pretest helped to pursue the respondents understanding on the clarity of the survey questionnaire, and we adjusted the questionnaire taking in to accounts the underling points raised by the pretesting of the questionnaire.

After all the questionnaires were collected, the second validation test was processed following Kaiser-Meyer-Olkin (KMO) test method. Indeed, KMO test method is used to measure for overall sampling adequacy. Hair et al., (2010) suggested that for sampling adequacy, the sample size should be 100 or larger and the sampling adequacy test following KMO test method should be greater than 0.6 (Gebreslassie, 2020). In the present study, the sampling size is 327 greater than 100, and the KMO test ran with SPSS software shows a KMO value of 0.729 greater than 0.6. Thus, the KMO test shows that the sample size is good and valid for the data analysis.

2.5. Empirical analysis

Descriptive statistic and cross-tabulation were first use to analyze respondent's characteristics between the districts. Secondly, quantitative method were also used to assess energy poverty, using one-dimensional as well as multidimensionality poverty measures. Alkire & Foster, (2011) multidimensional poverty measuring method were used for the MEPI construction, and physical energy demand-based approach was used for one-dimensional energy poverty assess. These methods allow us to know the poverty rate for each dimension and also between the gender gaps. Finally, logistic regressions were used to analyze the link between government policies implementation for energy poverty alleviation, socioeconomic characteristics of the household and MEPI in the rural areas.

2.5.1- Descriptive statistics

Across the three districts surveyed, 37 percent of respondents are reported as female household heads, and 63 percent respondents are Males. The figure2 shows that the female role as household head is relevant in Agou and Haho districts than Ogou districts. Respectively, around 47 percent household head in Agou, and 46 percent in Haho districts. In Ogou district, they represent 22 percent of household heads interviewed. Following Gafa & Egbendewe, (2021), this high share of women in households decision making is important for energy poverty alleviation in rural area. The survey results as presented in Table11 shows that nearly 85 percent of household heads are farmers, 12 percent are self-employed, and less than 3 percent of the respondents are formal workers. These show the predominance of agricultural activities in the study area and their dependency on climate condition as the agricultural system is rain-fed agriculture. This evidence has been also illustrated in graph 5, where Ogou district has the highest share of famer household's (92.2 percent), followed by Agou (81 percent), and about 80 percent in Haho district.

Table 11: Respondent's Gender and occupation

Occupation of respondents	Frequencies	Percentages (%)
Farmers	278	85.02
Trade and self employed	40	12.23
Formal workers	9	2.75
Female	121	37
Male	206	63
Observations	327	100.00

Concerning the energy access within the districts, it is observed that access to off-grid solar energy has considerably improved recently in the Togolese rural area. As reported in table 6, around 79 percent of survey respondents have access to solar domestic's systems for lighting, and the use of dry-cell battery lamp and kerosene lamp for lighting have considerably decreased respectively by 22 percent and 4 percent in the area. Within districts, the largest access has been registered in Haho (87 percent) and Agou (86 percent) districts, and 65 percent of household was reported to have access to SHS in Ogou district (see Graph6). In addition, a large access to SHS within the gender with high proportion for male-headed households (82 percent), and 72 percent for female-headed household is recorded. This high rate of access to solar home system shows that households in the plateau region are well aware of benefits of using renewable energy solution for lighting access. However, in contrast with the observation made in the context of developing countries so far, where access to off-grid solar is said to be lower due to the expensive price cost of solar panel, this study's finding underlying efforts achieved by some developing countries such as Togo in giving access to electricity in rural areas.

Moreover, the recent report made by Global Lightning, (2018) on off-grid solar market assessment in Togo particularly, observed a huge potential in the adoption of solar panels in the Plateau region (Global Lightning, 2018). Therefore, this successful improvement of off-grid could be attributed to the government's effort on solar home systems promotion for rural electricity access towards the countries (ECREEE & World Bank, 2019). In line with the findings of Aung et al., (2021), and Wassie & Adaramola, (2021), this study suggest that the adoption of solar home solution in Togo is steadily growing, and needs to be supported for its concrete impact on rural electrification.

Overall, government's action on rural electrification has boosted off-grid solar access of rural household in Plateau regions in Togo. Indeed, government supports rural electrification under CIZO project, and household that buy its solar system from this project benefit from a reduction borne by the government. However, its observed in figure 7 that there is a relatively low access to solar home systems under government project implemented in the districts. Prominently, 32 percent of survey respondents in rural areas of Plateau region benefited from this project. This low adoption of the solar home system proposed by the government can be associated to the price systems of the off-grid solar solution which is very expensive and cannot be afforded by several households. Moreover, a lack understanding of the solar systems proposed, its terms and

conditions, and also lack of after-sales maintenance and technical support system of the proposed solar systems, affected household choice option. These observations frame with the findings of Wassie & Adaramola, (2021) which underlines those factors as main challenges for solar home access.

In addition, Figure 8 shows the share of access to the solar home system across gender and energy sources. For access to SHS that government sponsored, it is observed that female-headed household (33 percent) is a little more likely to adopt the government sponsored system than male-headed household (30 percent). While the contrary is observed for SHS offers in the local Market (female 62 percent and male 68 percent). This find concurs with the results from Guta, (2018) for Ethiopian solar home system implementation.

Table 12: Descriptive statistics by energy sources

	Energy sources share per Districts (%)			Energy used (%)	Energy used (KgOE/month)	Energy used (KgOE/capita/month)
	Agou	Haho	Ogou	Region	Mean/Max	Mean/Max
Lighting energy						
Solar domestic lighting system	86.67	87.10	65.62	78.59		
Solar lamp dry-cell battery	21.33	25.81	12.5	19.57	6.68/256.77	1.30/28.29
Kerosene lamp	6.67	3.22	2.34	3.67		
Cooking energy						
Fuelwood	85.33	83.84	82.81	83.79		
Charcoal	68	47.58	46.87	51.98	5.82/18.85	2.45/33.94
LPG	2.67	0.81	0	0.91		
Energy facility						
TV/Radio	49.33	28.22	39.06	37.31		
Phone	90.67	78.22	72.65	78.90	11.75/256.57	2.29/32.59
Fan	26.67	6.45	10.15	12.54		
Solar energy source						
Bboxx_EDF	25.33	50.80	15.63	31.19		-
Solergie	5.33	0.81	0	1.52		
Local Market	66.67	49.19	81.25	65.75		
Sample size	75	124	128	327		327

NB: KgOE means Kilograms per Oil equivalents

Considering cooking dimension, it is observed that most of households remain using traditional energy sources such as fuelwood, charcoal, and crops residue in the regions for cooking. Table 12 shows that 84 percent of surveyed households are still using traditional energy for cooking, while less than one percent are using modern energy for cooking. This finding is consistent with the findings of Gafa & Egbendewe, (2021), and is explained by the area location with a great presence of woody traditional forests. This high dependences on traditional energy sources are also detrimental to climate change in terms of excessive use of forest resource, and air pollution in the countries. On average, household average total energy consumption per capita in a month, in kilograms per Oil equivalents is equal to 2.29kgOE.

2.5.2- One-dimensional energy poverty estimation results

Table 13 presents the empirical results of estimated energy poverty based on the physical energy threshold, the demand-based approach, and the energy expenditure-based approach. Different thresholds were used appropriately for each approach as the extreme poverty line. The overall income poverty rate is also reported for each district in the same table, and was calculated based on the World Bank extreme poverty line of \$1.90 per day (2011 PPP)⁴.

Focusing on the overall income poverty result, with the threshold of US\$57 per month, it is found that 98.47% of respondents live below the extreme income poverty line, but also not all of them are reported as energy non-poor. Thus, this result confirms that not all low-income households are energy poor (Gafa & Egbendewe, 2021). Across the districts, the income poverty rate remains very high. 97.33% in the Agou district, 98.38% in the Haho district and 99.21% in the Ogou district, are defined as income poor.

For the energy expenditure-based approach, a 10% threshold was used for physical energy access for lighting according to Nussbaumer et al., (2012), and a 5% threshold was used for energy expenditure for cooking according to the Energy Sector Management Assistance Program (ESMAP) (Bhatia & Angelou, 2015). It is observed that above the 10% threshold, 93.88% of respondents spend a significant portion of their income on energy for lighting, and face the problem of energy accessibility. In all districts, households in Agou and Haho districts are the most affected

⁴ The World Bank proposed US \$1.90 a day (2011 Parity of Purchase Price) per person, as an extreme poverty line under which a household is considered as income poor. This is equivalent to US \$57 a month per person.

by the problem of energy affordability. 98.66% and 96.77% in Agou and Haho respectively spent more than 10% of their income for lighting, whereas 88.28% are reported in Ogou. With regard to the problem of the cooking energy affordability, with the threshold of 5%, 92.96% of respondents are reported using more than 5% of their income for the purchase of cooking energy.

In regards to the physical energy threshold, the household total physical energy needs approach was estimated following Foster et al., (2000). Foster et al proposed 2,154 Kilowatt-hours per year as physical energy need by household to satisfy its basic needs. This threshold corresponds to 15.43 KgOE⁵, used in table 13. The result shows that, 82.87% of the respondent are energy poor. Across the district, 68% of Agou district household were declared as energy poor, and 82.03% in Ogou district, whereas the high rate was recorded in Haho district (87.09). Barnes et al., (2011) demand-based approach however considers household's per capita energy consumption to measure energy poverty. Under this framework, a threshold of 5.31KgOE per capita per month modern energy consumption is defined (Barnes et al., 2011).

Table 13: One-dimensional energy poverty estimates

Poverty line measurement approaches	Poverty line	Poverty estimation – Headcount ratio (%)			
		Agou	Haho	Ogou	Region
Income poverty					
General income poverty line	\$57	97.33	98.38	99.21	98.47
Energy poverty					
Expenditure-based energy poverty line lighting (10%)	10%	98.66	96.77	88.28	93.88
Expenditure-based energy poverty line Cooking (5%)	5%	97.33	96.77	86.00	92.96
Demand-based					
Demand-based approach (Barnes et al., 2011)	5.31 ^a	86.67	95.16	96.09	93.88
Household total physical energy needs (Foster et al., 2000)	15.43 ^b	68	87.09	82.03	82.87
Household total physical energy needs (Goldemberg et al., 1985)	32.1 ^b	92	95.96	99.21	96.33

⁵ Foster et al., (2000) proposed 2,125 kilowatt-hours per year (5.8 kilowatt-hours per day) this poverty line was calculated based on income extreme poverty line. As 1 kilowatt-hour = 0.086 KgOE, 15.43KgOE= (2,125/12) *(0.086)

Then, household with less than this threshold is declared as energy non-poor household. Following this approach, it is observed that, 93.88% of households in the plateau region, 86.67% in Agou district, 95.16% in Haho district, and 96.09% in Ogou district, are using less than 5.31kgOE per capita per month. Thus, it has resulted in a high energy poverty rate in the region, which can be explained by the relatively lower per capita energy consumption by rural household in Ogou, Haho and Agou districts.

2.5.3- Multidimensional energy poverty estimation results

As shown in table 8, the multidimensional energy poverty measures is estimated using the simple weighting method proposed by Sadath & Acharya, (2017), and Zhang et al., (2019). The MEPI is estimated with and without government intervention. To make a difference from previous multidimensional energy measures, this study specified the energy needs for each dimension such as lighting dimensions, cooking dimension, affordability issue, and energy facilities and convenience dimension. In addition, multidimensional energy poverty index was computed considering the subgroup and the gender gaps.

Thus, the results reported in table 8 shows that the MEPI estimation without government intervention indicates a higher energy poverty index and energy poverty incidence respectively 0.613 and 90.2% for rural households in Plateau region. While government intervention by subsidies off-grid solar system access lowers the energy poverty level and energy poverty incidence respectively 0.533 and 82.6% in the region. This result corroborates Gafa & Egbendewe, (2021) findings that shows that the MEPI level in rural Togo is around 0.626, and the energy poverty incidence is about 98.8%. The difference observes between MEPI estimation without government intervention using Sadath & Acharya, (2017), and Zhang et al., (2019) approaches and the one of Gafa & Egbendewe, (2021) approach is explained by the integration of energy facilities dimension such as the use of appliances (Radio, fan, and phone) in MEPI dimension. Notedly, the use of radio, phone and fan have increased with access to SHS in rural plateau region. In fact, access to phone is very important in solar home system deployment in rural areas. It is used as a means of payment of solar home system in PAY-AS-YOU-GO (PAYG) financing system (Adwek et al., 2020; Yadav et al., 2019).

It is observed also that without government intervention, the multidimensional energy poor households are deprived on 67.9% of the weighted deprivation in rural plateau region in Togo, while 64.6% with government intervention. Across the districts, the highest MEPI is recorded in Ogou district (0.635), whereas the lowest is recorded in Agou district (0.567). Moreover, about 97.6%, 94.7%, and 90.6% of household in Haho, Agou and Ogou districts respectively are declared as energy poor. For the gender gaps, female-headed household is reported more sensitive to energy poverty in the area. The MEPI estimated results with and without government intervention show respectively 0.572 and 0.661 for female-headed household and 0.510 and 0.585 for male-headed household. The results suggest that about 84.30% of household headed by females are multidimensional energy poor and this proportion of households are deprived on 67.80% of weighted deprivation in rural plateau region in Togo. 81.6% of male household heads however, are multidimensional energy poor and this proportion are also deprived on 65.35% of the weighted deprivation in the areas relatively lower than cases of households headed by females.

Globally, the contribution of each dimension as reported in table 8, shows a relatively low contribution of lighting dimension to energy poverty with and without government intervention in rural Plateau region in Togo (10.3% and 11.6%). Also, it is observed that without government intervention, energy affordability dimension was the highest contributors to the region's energy poverty (35.5%), while with government intervention, cooking energy dimension is reported the highest contributor to the energy poverty (30.7%). At the district level, Agou and Haho are found to be more affected by these two dimensions. Lighting dimensions' contribution to energy poverty is relatively high for households headed by females (12.9%) compared to Male-headed households (10.8%) with government intervention.

These results show that the support provided by the government for off-grid solar access in rural Togo highly contribute to reduce households' energy expenditure. This result corroborates Aung et al., (2021) findings in Malawi case study. However, the excessive use of traditional cooking energy (fuelwood, charcoal) remains a huge challenge for energy poverty alleviation in this region. These two dimensions (affordability and cooking energy) are relatively high for male-headed households than female-headed households meaning that female-headed households are likely to support the high cost of energy access for their energy needs due to their activities. This finding is in line with energy poverty situation in rural Senegal, and Benin examined by Gafa et al., (2022),

and Gafa & Egbendewe, (2021). Similar result has also found by Wagner et al., (2021). Finally, the energy facilities and convenience dimensions are not negligible in the energy poverty analysis in the area. These dimension account for 24.4% for energy poverty in the region. It affects more female-headed households (24.6%), than Male-headed households (24.3%).

Overall, this study suggests that efforts have been made in terms of lighting energy access in rural Togo with a support from the government for SHS access. However, household are still highly affected by energy affordability issues indicating the high cost of solar home system, and also household's low-income level in rural Togo. The use of traditional cooking energy is also part of the major contributors to the energy poverty in the region. Moreover, Female-headed households are relatively more affected by energy poverty contrasting with their high share in Solar Home access for lighting from government sponsored panel than Male-headed households. Similar findings are observed at district level, where Agou and Haho districts households are more likely to adopt government sponsored solar home systems, but more affected by energy affordability issues than households in Ogou district. Hence, more efforts are needed in terms of energy affordability and cooking energy dimensions as well as energy facilities and convenience dimensions for an overall energy poverty alleviation in the rural Plateau region in Togo.

Table 14: Multidimensional energy poverty indexes and contribution of each dimension

MEPI- Without Government intervention						
	Agou	Haho	Ogou	Male	Female	Regions
Intensity (A)	66.47%	66.09%	70.71%	66.25%	70.77%	67.9%
Headcount (H)	85.3%	93.5%	89.8%	88.3%	93.4%	90.2%
MEPI (H*A)	0.567	0.618	0.635	0.585	0.661	0.613
Contribution of each dimension (%)						
Lighting	8.3	6.7	14.7	9.6	11.3	10.3
Cooking	34.5	31.8	29.6	31.8	31	31.5
Affordability	37.3	37.5	32.8	36.1	34.7	35.5
Energy facilities and convenience	19.9	24.0	23	22.5	23.1	22.5
MEPI- With Government intervention						
Intensity (A)	64.20%	64.03%	70.71%	65.31%	67.80%	64.60%
Headcount (H)	81.3%	79.8%	85.9%	81.6%	84.30%	82.60%
MEPI(H*A)	0.522	0.551	0.561	0.510	0.572	0.533
Contribution of each dimension (%)						
Lighting	8.8	7.9	16.4	10.8	12.9	11.6
Cooking	35.7	33.2	31.9	33.6	32.6	33.2
Affordability	34.6	33.3	26.3	31.3	29.9	30.7
Energy facilities and convenience	20.8	25.6	25.4	24.3	24.6	24.4

2.5.4- Link between MEPI and climate change mitigation action: logit regression.

This section presents the estimation results of the logit regression models linking socioeconomic characteristics of household, government climate change mitigation policy, and energy poverty variables. Four endogenous variables of energy poverty indicators, taking the value “1” if households are energy poor in that dimension, and “0” otherwise, were considered. Those variables include the MEPI constructed following Sadath & Acharya, (2017), and Zhang et al., (2019) weighted approach, the unidimensional energy poverty approach following physical energy need approach of Foster et al., (2000), lighting energy poverty dimension, and energy expenditure based approach, whether to analyze factors contributing to energy poverty on those dimensions. Preliminary test for logistics regression model were performed. The average margin effect results are reported in table 9.

As shown in Table 9, the Wald test is statistically significant at the 1% level, indicating that overall, models are fit and the explanatory variables in the models are also adequate, even if the pseudo- R^2 are relatively low (51.4% for energy expenditure approach, and 20.2% for MEPI estimations, 19.9% for Lighting and 17.9% for physical energy need following Foster et al., (2000)). The models' performances were also tested using the performance of Receiver Operating Characteristic (ROC). ROC value reported in the table 9 shows that all the models estimated are optimal with a good score for the areas under the ROC curve. Respectively, the scores are 0.961 for energy expenditure based approach, 0.811 for MEPI approach, 0.803 for lighting dimension, and 0.791 for energy poverty estimation following Foster et al., (2000) physical energy needs' approach. These preliminary tests show that the models are suitable for analyzing the link between energy poverty, socio-economic characteristics of households and government climate change policy implemented in the rural area of the Plateau region of Togo.

Coming to the results, table 15 shows that the climate change mitigation policy implemented by the government has either positive or negative effects on energy poverty alleviation in rural Plateau region in Togo. For MEPI, lighting dimension and physical energy demand approach, the coefficients are negative and respectively -0.537, -3.307, and -1.451 suggesting that off-grid solar systems promoted by the government as a climate change mitigation policy, contribute to reduce the probability of household to be energy poor. The coefficients are statistically significant at 1% level, for lighting dimension, energy affordability dimension and physical energy demand

approach, but not statistically significant for the multidimensional energy poverty indicator. This results concord with González-Eguino, (2015) and Wassie & Adaramola, (2021).

However, a positive and statistically significant effect has been recorded for off-grid solar access in affordability dimension showing that it raised the probability of household to spend a larger share of their income in energy expenditures. The same impact is also observed for solar home systems purchased by households on the local market. Similar to Aung et al., (2021) and Diallo & Moussa, (2020), this finding indicates that modern energy solution for rural household remains too expensive despite government subsidies. Overall, these results suggest that off-grid solar solution generally meets energy access objective in lighting dimension and physical energy demand, but raises another challenge in energy affordability dimension.

The type of cooking energy used by a household in the region, highly contributes to the probability of being multidimensional energy poor, but reduces the probability of spending large share of household income on energy expenditure. As shown in table 9, the margin effect of the use of fuelwood and charcoal for cooking is statistically positively significant for MEPI, indicating the negative effect of using traditional energy for cooking on energy poverty alleviation in the region. Convenience, health and safety indicators have the same effect on the likelihood of being in fuel poverty in the region. For example, the use of traditional cooking fuels increases the risk that households will be exposed to indoor pollution throughout the cooking process. This can lead to another cost opportunity in terms of health expenditures, affecting household income. However, the availability of fuelwood in the region makes it more readily available at a lower price to households, reducing the likelihood that they will use a large portion of their income for cooking energy expenses. These results concord with the finding of Gafa et al., (2022) in Benin and Togo rural areas where households are likely to be energy poor in the areas where biomass energy abounds.

With respect to socioeconomic characteristics, female-headed households are likely to be more affected by energy poverty in lighting domain. This indicates that female-headed households make fewer decisions about adopting off-grid solar energy outside of government-funded SHS. This result concords with the finding of Gafa et al., (2022) in the case of Senegal, where female headship is associated with energy poverty. However, female-headed households are less affected in energy affordability dimension. The sign associated with the variable is negative and statistically

significant on the energy affordability dimension, which may be explained by the fact that women are more associated with the use of cooking energy that is available at low cost in the Plateau region. In addition, women's decision making regarding physical energy needs increases the likelihood that the household is energy poor. This can be attributed to women's activities, like trade (cooking for sale), which require greater use of cooking energy. This result is in line with, the observation made by (Guta, 2018a) in Ethiopia rural areas where women are found to be responsible for energy acquisition.

Furthermore, Table 15 also shows that the number of adults and the number of children in the household contribute to the reduction of energy poverty in the rural Plateau region. This is because adults over the age of eighteen (>18) participate in increasing household income by helping their parents with agricultural production. Household heads also make the decision to adopt SHS to support the education of children, those who attend primary and secondary school in the household. Similar to Gafa & Egbendewe, (2021) the education level of household heads has a significant impact on household energy poverty status, meaning that households with basic education have a better understanding of the challenges of climate change and its mitigation through renewable energy such as off-grid systems in remote areas where the main grid does not exist. This result is also consistent with that found by Guta, (2018) which studied a similar case in Ethiopia.

Finally, a high level of income is necessary for better adoption of climate mitigation policy and to reduce the probability of being in energy poverty in the region. As shown in Table 15, an increase in per capita household income reduces the probability of multidimensional energy poverty. This result is also consistent with the findings of Gafa & Egbendewe, (2021) in rural Senegal, as well as the reduced energy poverty situation in India found by Khandker et al., (2012).

Table 15: Logit regression estimates --Average marginal effects

Variables	MEPI approach	Lighting Dimension	Energy expenditure- based Approach	Physical Energy Need (Foster)
	Margins effects	Margins effects	Margins effects	Margins effects
Age of head	0.014 (0.300)	0.013 (0.266)	-0.0523* (0.037)	0.038* (0.013)
Number of adults	-0.263** (0.013)	-0.059 (0.549)	-0.342 (0.129)	-0.234** (0.042)
Number of children	-0.114 (0.288)	-0.023 (0.782)	-0.261 (0.140)	-0.249*** (0.006)
Head has formal education	-1.155** (0.016)	-0.375 (0.255)	-1.725** (0.022)	-0.972** (0.017)
Female head	-0.483 (0.180)	0.894*** (0.007)	-1.134 (0.155)	1.039** (0.012)
Household self- activities	0.059 (0.878)	-1.059*** (0.006)	0.477 (0.643)	-0.451 (0.256)
Indoor air pollution	0.674* (0.085)	0.989*** (0.005)	0.391 (0.663)	-0.119 (0.790)
Log income per capita	-1.016*** (0.000)	-0.246 (0.224)	-3.464*** (0.000)	-0.495** (0.025)
Convenience	0.517* (0.219)	0.031 (0.925)	0.507 (0.502)	0.486 (0.301)
Government energy policy	-0.537 (0.298)	-3.307*** (0.000)	7.427*** (0.000)	-1.451* (0.062)
Household SHS self- action	-0.553 (0.263)	-1.608*** (0.008)	4.201*** (0.000)	-1.983** (0.015)
Health and safety	1.532*** (0.000)	0.138 (0.673)	0.105 (0.882)	0.406 (0.269)
Log likelihood	-120.65	-136.053	-36.574	-122.899
Wald Chi2(14)	57.87*** (0.000)	47.92*** (0.000)	61.91*** (0.000)	56.83*** (0.000)
Pseudo-R ²	0.202	0.199	0.514	0.179
Lroc	0.811	0.803	0.961	0.791
Number of observations	327	327	327	327

NB: *** significant at 1% threshold, ** significant at 5% threshold, * significant at 10% threshold

2.6. Partial Conclusion

This study investigates the socioeconomic impact of climate change mitigation on energy poverty alleviation in West Africa, using a case study of off-grid solar access in rural Togo. It uses the energy poverty measurement approaches including the novel approach developed by Gafa & Egbendewe, (2021), as well as the approach proposed by Sadath & Acharya, (2017), and Zhang et al., (2019) to apprehend the level of energy poverty in rural Togo. Moreover, the margin effects are also computed to know the expected impact of government action for rural electrification and energy poverty alleviation in the area.

Overall, the results suggest that despite the progress on solar home system adoption in rural Togo (78.59%), the energy poverty level remains high and vary from 68% to 97%. MEPI for the region is 0.681, and female-headed households are more vulnerable to energy poverty than male-headed households. Access to government-sponsored off-grid solar systems is relatively low in the region (31%), with significant access for female-headed households, indicating the household's preference for solar panels available on the local market (65%). Energy affordability issues remain the most important factors of energy poverty in the rural Plateau region followed by the type of energy used for cooking (36.3%). The affordability issue can be attributed to the high cost associated with modern energy solutions in the region. Lighting dimensions contribution however is very low (9.7%), showing the reduction in lighting dimensions with the adoption of off-grid solar.

Furthermore, the logistic regression confirms the positive and statistically significant effect of government action for rural electrification and energy poverty alleviation on energy poverty alleviation through lighting energy access, while a negative and significant effect is observed for energy expenditure. But the government action is not statistically significant for energy poverty alleviation in all its dimension. The level of education of households and the per capita income of households are found to be positive and statistically significant for multidimensional energy poverty alleviation in the region. However, the use of fuelwood for cooking negatively affects energy poverty alleviation.

Based on these results, it is important to implement public policies that target the adoption of Off-grid solar systems not only for home lighting but also for economic activities development. This

could generate additional revenue that could be used to address affordability issues. Moreover, additional policies such as improved stoves, are needed to reduce household dependence on fuelwood for cooking. This will simultaneously reduce women's vulnerability to energy poverty in developing countries. It is important to integrate households sensitizing on the benefits of solar home system adoption. This could rise their awareness of the benefits of off-grid solar solution for energy poverty alleviation and for resilience to climate change. Insurance-based credit for solar home systems access could also help households to gain access to solar panels. This could constitute a research area for future studies.

3. Essay3: Farm households' preference for Solar Home System choice in rural area: Evidence from Plateau region in Togo.

3.1. Introduction

The lack of access to electricity is one of the major problems challenging human development in developing countries. It is detrimental to economic and social development of households (Aarakit et al., 2021; Guta, 2018a). This problem is becoming more and more worrisome for the whole world thus, the need for a joint action towards an eradication. The lack of access to electricity is even more worrisome in Sub-Saharan Africa where, about 621 million people lack access to electricity, representing three quarters of the global population without access to electricity (IEA, 2019). This number is expected to increase due to unprecedented population growth (Aarakit et al., 2021; Abdul-Salam & Phimister, 2016, 2019). Being aware of this situation, the United Nation has made as priority, the universal access to electricity for all by 2030 in the 2030 Agenda for Sustainable Development (Hyun et al., 2021; United Nations, 2018).

Promoting the access to electricity for all has to be combined with the increasing concerns of global warming and the urgent need to combat it (Hyun et al., 2021). In West Africa context, some technical, economic and financial constraints can also be highlighted as justification of modern energy adoption. The technical constraints include insufficient grid generation, poor maintenance of existing networks, and geographical barriers to grid extension. The economic and financial constraints are poor economics of electricity supply to sparsely populated and remotely located rural areas, government budget constraints, the inability of poor rural inhabitants to pay for the economic price of electricity grid among others as listed by Abdul-Salam & Phimister, (2019).

Meanwhile, access to clean and affordable electricity has been proved to be vital for human wellbeing, especially for farmers' households in rural and remote areas (Abdul-Salam & Phimister, 2019; Alam & Bhattacharyya, 2017; Grimm et al., 2017). It improves households' revenues, households' health and healthcare facilities, as well as households' education. However, modern energy adoption in rural is often related to the overall characteristics of the energy source, household behavioral and their expected satisfaction or utility from its adoption (Mankiw, 2020). This refers to the theory of consumer behavioral (Varian, 1992).

Therefore, the problem related to modern energy access in rural area could be analyzed from several perspectives. The first perspective is the problem of energy availability and or energy cost. This perspective implies that the decision of households to adopt modern energy system is made while considering the up-front cost of the energy source and its availability. Taylor, (1975) underlined this point in the sense where consumers or households maximize their electricity consumption under the constraint of electricity supply, which in turn depends on the firm's generation capacity and the type of tariffs it charges. The second perspective however, place the problem of energy access under the household behavior and the expected utility that they will derive from its adoption(Guta, 2018a; Schelly, 2014). This point was carried out by Lancaster consumer theory, in which household income level govern their choice making in regards to modern energy solution (Lancaster, 1966).

Despite the role of solar energy in rural and remote areas, its adoption in developing countries remains low and subject to certain market imperfections (Abdul-Salam & Phimister, 2019; Alam & Bhattacharyya, 2017; Hyun et al., 2021). However, Togo is making progress in providing electricity to its population by using solar energy solution. In 2019, approximately 52% of the population has access to electricity (World Bank, 2021), up from 45% in 2018 (Global Lightning, 2018). This progress is owed partly to the implementation of the universal access to electricity for all by 2030 in 2017 through the implementation of the CIZO initiative with a very large involvement of private actors. The CIZO project, meaning “lighting up” in local language, seeks to provide electricity to households in rural areas where livelihoods are predominantly based on small scale farming. Another reason why modern energy, such as off-grid solar systems, are provided to farmers is that they can be used as an alternative solution to adapt to climate variability (irregular rainfall) in the crop production process.

Accordingly, the CIZO project aims to raise rural electrification rates up to 45% by 2023 (ECREEE & World Bank, 2019). In this line, the Government is partnering with off-grid companies to offer Solar energy for rural customers. These efforts have notably contributed to the recent installation of one of the largest photo voltaic power plants in West Africa, in Blitta, a locality in the central region of Togo, 267km from Lomé. This power plant with an annual production capacity of 92.256Mwh, will serve Blitta populations and its surrounding areas such as Atakpame, Kara and Sokode. It will supply more than 158.333 households with clean energy.

Although the country has made this progress in the electricity provision, efforts are still needed to ensure universal access to electricity in rural areas. Notably, World Bank statistics show that the country recorded a decline in terms of access to electricity between 2018 and 2019. In fact, the electricity access rate in the rural area was 23.62% of the rural population in 2019 compared to 26.32% of the rural population that had access in 2018 (World Bank, 2021). This decline can be attributed, on one hand, to excessive population growth, and on the other hand, to the poor maintenance of the existing network as well as the individual panels installed. In addition, the economic and financial constraints of some rural households limit their ability to honor their commitment to pay the monthly panel fees. In this situation, some households have had their lights turned off, and others have had their solar installations removed.

It should also be noted that household income is mainly derived from agriculture, which is highly dependent on climate variability. Any choc from climate variability on their crops production system, has direct or indirect effects on their ability to pay for solar home system. Even if government provides subsidies for Solar Home System adoption, the choice of rural households based on their preferences is critical to the successful deployment of an off-grid solution for universal electricity access. Therefore, to identify rural farmers' preferences and their ability to pay for off-grid system is highly recommended for an efficient and sustainable deployment of off-grid solar solution for rural household electrification.

Available literature shows that the off-grid solar market is very promising in Togo with great potential in the southern regions where more households are able to pay for SHS (ECREEE & World Bank, 2019; Global Lightning, 2018). Market players such as Bboxx-EDF, Kya Energy, SOLEVA, ENERGA AFRIQUE Sarl, etc., offer different off-grid solar options at different prices for households. It is up to the household to make their choice based on their ability to afford the appropriate system corresponding to their preferences. However, what determine their choice remains unclear and the economic cost associate with their modern energy adoption remains unknown. Apart from a few non-empirical works attempting to access the off-grid solar market in Togo (ECREEE & World Bank, 2019; Global Lightning, 2018), there is a lack empirical studies exploring the choices and preferences of rural farm households in the adoption of solar home systems and the economic cost associate to their choices.

Some few studies explored solar energy adoption in Sub-Saharan Africa countries. For Instance, Elegbede et al., (2021) examined consumers' preferences on off-grid solar panels choices regarding the characteristics of solar technologies in Nigeria. They found that confidence in the quality of the product leads consumers preferences, and the respondents have high WTP for solar chargers with higher quality. But this study was conducted in areas where people have access to the electrical grid and are trying to switch from this source of electricity to solar photovoltaic energy due to unavailability of it. In fact, the authors indicate that the population of the area that is connected to the electricity network receives power for only 3 hours a day on average.

Entele, (2020) also studied the preferences of rural households for a different source of renewable electricity in Ethiopia and estimated the willingness to pay (WTP) of rural households for the energy service. The study highlighted the value consumers place on each source of electricity service and found that between the two sources of renewable electricity service, households preferred grid line to solar electricity service because of the high cost of solar PV. However, this study was conducted also in area where there exists solar PV electricity in addition to grid line, and it does not identify consumer preference for the off-grid solution where the grid line doesn't exist. In Kenya, another study conducted by Lay et al., (2013), also investigated factors that affect household choices of fuels and solar home system. The study highlighted household income and education level as some of the major factors affecting solar home system adoption. This study also failed to capture rural farming household choice making in regards to off-grid solar solutions that are available, especially in rural areas where grid connection is not evident (see also Gebreslassie, 2020; Hyun et al., 2021).

Apart from these empirical studies in Sub-Saharan African context, there is a lack of studies exploring the factors involved in the preference and choice making of rural households in the adoption of off-grid solar solution in rural Togo. However, knowing these factors could drive policy implementation for better deployment of off-grid solar system for energy poverty alleviation in rural area (Elegbede et al., 2021). This could also guide the market actors (investors and policy makers) in providing useful and appropriate solar panel that meet the household preferences.

Research questions

Hence, this study aims to fill the gap by answering this relevant question: what are the drivers of farm households' preferences for off-grid solar system adoption in rural Togo?

This main question can be divided in three specific questions as follows:

- What is the main solar panel solution preferred by the rural household in Togo?
- Does climate change awareness affect their decision making?
- What is their Willingness to Pay (WTP) for having the appropriate the off-grid solar System that match with their needs?

Objectives

This study aims to investigate factors that driver farmer's household preference off-grid solar choice in the Togolese rural areas where national grid solution is not evident. Given the fact that farmers' incomes depend highly on climate, whether climate change awareness impacts preferences and solar panel affordability in the rural area was explored. To do so, this study:

- Explores rural household preferences for off-grid solar panel;
- Determines factors that affect their decision making, and
- Estimates the economic cost (willingness to Pay) of modern energy adoption.

Hypothesis

In these regards, it is assumed that

- Farmers prefer climate smart solar pump than solar home system
- Climate change awareness is one of the main factors that affect rural farmers household preferences in Off-grid solar system choice making, and
- Rural farmers are willing to pay high price for having the solar panel that meet their need.

Contribution.

This essay contributes to providing empirical evidence of factors that govern preference and choice making of rural households in the adoption of off-grid solar systems in rural Togo. The novelty of the willingness to pay approach that is used in this study resides in the designing of the choice set. Different from choice method used in Elegbede et al., (2021), this study confronts two different types of Off-grid solar solutions, solar home system basically for lighting, and climate smart solar

solution for crops production. The interest is to provide successful policy recommendation that could be implemented for the successful achievement of the seventh global Sustainable Development Goal (SDG 7.1) which is “to ensure access to affordable, reliable and modern energy services for all by 2030” (UN, 2015). Furthermore, this research brings out, farmers basic needs in terms of modern energy services and their ability to afford it. Based on these findings, solar companies, renewable energy investors and government could make good decisions for SHS deployment to satisfy households basic needs to alleviate energy poverty in rural areas.

Plan

After presenting the introduction in section 1, the rest of this study is structured as follows. The following section (section 2) presents literature review of rural electrification in Togo. Firstly, this section presents the energy sector and off-grid solar market structure in Togo. Secondly, this section presents an empirical review of household choice making of SHS adoption. Section 3 presents data and methodological approach. In section 4, it is essentially the empirical analysis and discussion of findings. The final section (section 5) concludes the study with implication and suggestions for further studies.

3.2. Background on rural electrification context in Togo

This section presents an overview of the Togolese rural electrification with some related empirical reviews in support of solar home system adoption in rural area. It explores firstly, the socioeconomic situation of the country, followed by brief presentation of the energy sector highlighting government policy vision for rural electrification. Secondly, this section gives an overview of the country’s off-grid solar market structure. Finally, this section is closed by presenting the empirical review in support of rural household preferences and SHS choice making.

3.2.2. Overview of Togolese rural electrification context.

This subsection gives brief overview of socio-economic development of Togo and highlights the diverse rural electrification policies implemented by policymakers in Togo. The socio-economic development overview of Togo includes, the geographical localization of the country and an insight of economic and social development.

3.2.2.2. Socio-economic performance

The republic of Togo is a small country located in West Africa with an area of 56,790 km². It is bordered by Ghana to the west, Benin to the east, Burkina Faso to the north and the Atlantic Ocean to the south and located between latitudes 6° and 11°N and longitudes 0° and 2°E. In 2020, the country's population was over 8.2 million with a growing rate of 2.4% per year. Notably, nearly 60 percent of this population lives in rural areas, where access to basic services such as health, education, clean water and electricity is lacking. However, the country recorded the lowest economic growth since 2005 due to the Corona Virus (COVID-19) pandemic in 2020. In fact, the real GDP, which had grown by 5% in 2018 and 5.5% in 2019, grew only by 0.4% in 2020. The pandemic led to a fall in foreign direct investment, financial investment, private remittances, and slow global trade. In terms of contribution to economic growth by sector, the primary sector contributes 19.7% of GDP; the secondary sector, which is based on the cement industry, phosphate mining and beverages in particular, accounts for 13.9% of GDP, while services centered on trade, port, airport and banking activities contribute half of GDP (49.9%), with the remainder (16.5%) being taxes. The informal sector remains largely predominant, contributing more than 50% of the value added of the various sectors of the economy. Clinker (about 13% of export earnings), phosphates (10%) and cotton fiber are the three main export products (Kohnert, 2021).

Despite the prudent monetary policy that the country benefits from the West African and Economic Monetary Union (WAEMU), the inflation rate has doubled from 0.7% in 2019 to 1.6% in 2020, mainly due to supply disruptions. Moreover, the fiscal deficit increased sharply from 0.8% of GDP to 4.7% of GDP, as tax revenues fell and health spending increased as a result of government efforts to curb the situations of the pandemic. The current account deficit increased slightly from 2.2% of GDP in 2019 to 3.2% in 2020 (AfDB, 2021).

Notably, the recent report on human development index (HDI) in 2020 shows a progressive trend of Togo's HDI over the period 1990-2018. However, this progressive trend is not enough to put the country out of the low human development category. In fact, the country's HDI has progressed from 0.4 in 1990 to 0.51 for 2018, an increase of 26.6 % over the period (Kohnert, 2021; UNDP, 2020). This positioning it at 167 out of 189 countries. Despite this progress, there is a huge deterioration in terms of unequal distribution of the HDI dimension indices. Adjusting the value of HDI for inequality, the HDI falls to 0.350, a loss of 31.7 % (Agbodji et al., 2013; Kohnert, 2021;

UNDP, 2020). In addition, this disparity has also been shown in term of gender balance. The HDI value for female in Togo is 0.459 lower than the HDI value 0.561 for males, resulting in a Gender Development Index (GDI) value of 0.818.

Moreover, the poverty rate remained at a high level among the population. In 2018, Africa Development Bank reported that about 53.5 % of the population live below the poverty line in 2017. Considerably, the poverty rate decreased from 61.7 % in 2006, 58.7 % in 2011 to 53.5 % in 2017 (AfDB, 2018). In contrarious, inequalities continue to widen with the Gini index rising from 0.380 in 2015 to 0.427 in 2017 (AfDB, 2018, 2021). According to (Kohnert, 2021), this situation has very much worsened and around 80% of the population is now at risk of falling below the poverty line. On the sub-regional level, this situation is still very worrying, especially since, the rate of extreme poverty (49.2%) in Togo is two times higher than the poverty rate in Ghana (25.2 %) (AfDB, 2018). In the countryside, this situation is more alarming. Even though the rural poverty rate decreased from 73.4 % to 68.9 % between 2011 and 2015, energy poverty remains high in the Togolese rural area (57% in 2020) (World Bank, 2020). The northern and central region are pronounced to be the poorest areas of the country and the energy poverty in these areas is three times as high as in the South area (Kohnert, 2021).

Maintaining a sustained rate of economic growth and producing more goods and services to meet the needs of an ever-growing population (2.4% per year) are detrimental to the environmental sustainability. In fact, Togo faced a huge problem of environmental degradation and natural resource depletion due to its current economic growth system which is based on natural resources exploitations (phosphates, clinker, the cement industry...), outdated and neglected farming systems (soil and forest resource depletion), population growth pression and the global climate change (Kohnert, 2021). Even though the country has adopted several environmental laws and programs (Paris agreement in 2015, climate and clean Air Coalition in 2014, Kyoto protocol in 2009...), these are insufficient and poorly enforced. Recently, Global Forest Watch, (2020) reported that between 2001 and 2019, “Togo lost 55.9 kha of tree cover, equivalent to a 10% decrease in tree cover since 2000, and 11.3Mt of CO₂ emissions”. In the same period, the total area of humid primary forest decreased by 18%, and this reduction is not without consequences on the agricultural sector, the main activity of the rural population. Therefore, it remains necessary to ensure sustained and sustainable economic growth that meets the basic needs of its rural

population. This can be done by taking full control of the energy sector in both urban and rural areas.

Providing energy access to about 8.2 million of inhabitants is very challenging for the Togolese government. However, the country is improving its own energy production and reduce considerably its dependence on some neighboring countries: Ghana, Nigeria and Cote d'Ivoire for electricity supply. The electricity access has improved, from 17% in 2000 to 45% in 2018 (Global Lightning, 2018). In 2010, 95% of Togo's electricity was imported from Nigeria and Ghana through the interconnected networks of the Benin-Togo company (CEB). The national company in charge of electricity production and its distribution is Compagnie Energie Electrique du Togo (CEET). The strategy of CEET to give access to electricity is based on hydropower and fossil fuels sources. The electricity produced in 2017 is dominated by hydropower 69.1%, followed by petroleum products with a share of 24.7%. Other renewable energy sources such as solar, wind, etc., represents 6.2% of the total energy produced in 2017 (SIE, 2017). However, the dependence on neighboring countries to provide additional electricity to supply the growing energy demand of the home population could be affected negatively by their decision to reduce their energy exports. To reduce its dependence on neighboring countries, Togolese policymakers relies on the development of the off-grid energy market to electrify the rural areas of the country.

3.2.2.3. Historical overview of Togolese rural electrification

The Togolese rural electrification can be accessed in fifth dates. The first date underling the first action of Togolese government for rural electrification is 1992. The second date is about the implementation of "Pilot project of solar panel" in 1995. The third date is related to the Togolese government adhesion to ECOWAS strategy to increase modern energy in rural area in 2005. The fourth date concerns the Togolese first formally rural electrification action denominated "Rural Electrification Program" in 2012. The last date is the ongoing rural electrification started in 2017 named "CIZO project" which aims at increasing rural electrification from 6% to 40% by 2022 (AfDB, 2019).

Since 1992, the issue of rural electrification has been at the center of Togolese government projects. Indeed, the first action in favor of rural electrification was to extend grids to villages near the transmission lines, electrified some villages far from grids extensions with solar power, and undertaken some feasibility studies. The projects are funded in part with the government budget

and another part with grants or loans raised ECOWAS and the WAEMU. This project covered the period 1992-2011 and it is reported that a total of 167 villages were electrified out of 3592 identified representing rural electrification rate of 4% between the same period (Afo et al., 2013; Dorkenou, 2014).

The second action in favor of rural electrification was launched in 1995, where, two villages of the country benefitted from the government pilot project of rural electrification via solar panels. The two villages are Atalote, located in the northern part of Togo, about 71 km from Kara, in the Kara region and Gape-kpodji, located in the south of Togo, about 80 km from the capital Lomé, in Maritime region. Unfortunately, this pilot project was unsuccessful because of a shortage of funding from the government and the inability of local populations to take over the funding. In addition, the lack of competence in solar panel equipment maintenance contributed to the failure of the project experimentation (Afo et al., 2013).

In 2005, the country committed to the ECOWAS electrification program, which aimed at increasing access to modern energies in rural area in order to achieve the Millennium Development Goals (MDGs) by 2015 (ECOWAS, 2006). Through this project, the government realized several studies related to rural areas and the ways in which access to electricity contributes to their socio-economic development, their living conditions at home and with regard to health and education. The country benefitted also from the Islamic Bank of Development (IBD), an amount of \$200,000 to invest in a rural electrification feasibility study at the country level (Dorkenou, 2014).

Related to the first formal rural electrification program, the Togolese government benefitted a budget of \$15 million from the Indian Exim Bank for its first formally rural electrification action denominated “Rural Electrification Program” in 2012 (Afo et al., 2013; Dorkenou, 2014). This program allowed for the electrification of approximately 40 villages in its first phase. It is expected to be benefit for an additional target of 71 localities. This project improved the rural electrification rate to 7% in 2016.

The current rural electrification program was launched in 2017 in the perspective of sustainable development goal (SDG-7) and aims to give full access to electricity in rural area by 2030. In this line, the Togolese government raised financial support from the African Sustainable Energy Fund (SEFA), hosted by the African Development Bank (AfDB), a \$975,000 grant, to start the CIZO

project. This project is estimated to meet 50% of the electricity needs with off-grid solar power by 2030. In this line, the project covers the entire territory of Togo and is structured in five (05) components. Thus, the first component targets electrification of 300,000 households in off-grid areas through pay-as-you-go solar kits by the private sector. This will represent 40% of rural electrification by 2022 (AT2ER, 2019). The second component concerns an establishment of a national Pay-as-you-Go (Pay Go) platform for the management of solar kits. For competence building, the third component targets the creation of solar academies in charge of training and certifying local installers and technicians and deployment of a national distribution network. Component four consists of equipping small farms, electrifying health centers and equipping Village Water Supply (AEV in French) with solar energy as well as installing 10 mini-grids connected to the Pay Go platform using smart technologies. And the last component includes government support through implementation of subsidies for disadvantaged rural households (AT2ER, 2019).

As of today, several solar panels installations have been carried out for the benefit of the rural population, but the goal of achieving 40% rural electrification by 2022 is far from being reached. This study aims to propose an enabling framework that can contribute to the successful deployment of off-grid solar systems in rural area. The framework consists of identifying the preferences of farming households and the factors that explain their choices of solar systems. In addition, knowing the preferences and willingness to pay of farming households for off-grid systems would allow proper deployment of the fifth component of the CIZO project objectives, which is about government support through implementation of subsidies for disadvantaged rural households. The next subsection presents the off-grid solar market structure in Togo.

3.2.2.4. Off-grid solar market structure in Togo

In general, the term “energy market” or “electricity market” refers to the manner that the sector of energy production and its commercialization is organized, from institutional level to consumers’ level. Therefore, “off-grid solar market” designates the way electricity produced through individual solar panel is organized in whether to ensure a reliable supply of electricity to consumers. In this section, we analyze the Off-grid solar market structure in Togo, starting from institutional level to consumer’s level.

3.2.3. Institutional framework

The institutional framework on rural electrification in Togo has been enriched with the creation of three main institutions such as the Direction Générale d'Énergie (DGE), Electricity Sector Regulatory Authority (ARSE), Togolese Rural Electrification and Renewable Energy Agency (AT2ER). These institutions are in charge of giving electrification to the population and to regulate the energy sector.

3.2.3.1. General Direction of Energy (DGE)

The DGE's remit is to propose the elements of energy policy and development of the country, particularly in terms of research and development of renewable energies. It has to elaborate and implement the programs and investment projects defined in the energy sector. It elaborates and proposes legislation, regulations and standards related to energy.

3.2.3.2. Regulatory Authority of Electricity sector (ARSE)

The regulatory authority implements the regulatory activities of the electricity sub-sector and the drinking water and domestic wastewater sub-sector in accordance with the general policy of the Ministry of Health.

3.2.3.3. Togolese Agency for Rural Electrification and Renewable Energies (AT2ER)

Created by the presidential decree N°2016 - 064/PR of May 11, 2016, the Togolese Agency for Rural Electrification and Renewable Energies (AT2ER) is a public establishment, with financial autonomy. The agency is in charge of implementing the country's rural electrification policy and promoting and developing renewable energies. As a central actor dedicated to the development of renewable resources, AT2ER's ambition is to transform the country's natural energy potential into electrical energy for the development of rural localities. Thus, AT2ER has the dual responsibility of accelerating rural electrification and increasing the share of renewable energy in Togo's energy mix. From now on, any intervention with the aim of guaranteeing the supply of electricity to rural populations is ensured by the agency.

3.2.4. Private and rural actors in Off-grid solar market

Off-grid solar market in Togo includes private actors that propose solar solutions, and the local households that need solar systems for their energy needs.

3.2.4.2. Private actors

The private actors highly involved in Off-grid solar market development in rural Togo. They are the key actors in the deployment of this off-grid solution.

- BBoxx energy EDF
- Kya Energy
- Soleva

3.2.4.3. Rural consumers

Considered as the impact sector, rural consumers adopting off-grid solar system are expecting to have a better life in rural area as convenient as in cities. Notedly, rural electrification is expected to generate an additional income for rural household (Barnes, 2007). For example, lighting can help in ameliorating educational system, creating new business activities. Farmers can also increase their crop yields by adopting climate smart solar pump for water system irrigation. However, off-grid solar system adoption is considered very expensive to undertake and rural consumers ability to afford it is questionable.

3.3. Literature review

The purpose of this section is to highlight, the dual theoretical and empirical dynamics of farming household preferences for off-grid solar electricity demand analysis. In particular, it is a question of insisting on the theoretical developments of the analysis of the consumer demand theory on households' preferences and choice making of off-grid solar electricity in rural area. The empirical framework focuses on recent studies conducted for understanding the preferences of households in choosing their lighting source, especially in rural areas.

3.3.1. Theoretical framework of Off-grid solar adoption in rural areas

The adoption of solar energy in rural areas is often related to the overall characteristics of this energy source, the expected satisfaction or utility that the farming household will derive from it, and the ability of the household to afford it. In economics, this thinking refers to the theory of consumer behavior, in which individuals maximize their consumption under a set of constraints (Lancaster, 1966; Mankiw, 2020; Varian, 1992). Therefore, the electricity demand issue can be

analyzed from several perspectives. In the first perspective, the electricity demand is analyzed under the energy availability issue including supply and pricing system. In this sense, consumers maximize their electricity consumption under the constraint of electricity supply, which in turn depends on the firm's generation capacity and the type of tariffs it charges (Taylor, 1975). Lévy et al., (2014) insisted on this point and explained that individuals' electricity consumption is constrained by pricing policies and energy uses, regardless of technological innovations and their adoption by consumers. Thus, the decision of households to adopt a solar system is made while considering the up-front cost of off-grid solar adoption.

The second perspective however, analyzes the electricity demand under the household behavior and the expected utility that they will derive from its adoption. Notably, Schelly, (2014) highlight this issue, and claimed that households solar adoption decision repose not only on biophysical and economic structure but also highly influenced by a complex set of lifestyle choice, interplay of indicators of household conditions, and access to information (Guta, 2018a). Therefore, the households will not only make their decision based on income constraints but under all factors that can influence their decision. This point was carried out in Lancaster consumer theory (Lancaster, 1966).

This study is based on these two theoretical frameworks: the Lancaster consumer theory on the choice experiments and the energy ladder hypothesis in the context of consumer theory (Lancaster, 1966; Leach, 1992). The energy ladder hypothesis assumes that the income level of households plays an important role in their choice of the energy source. Indeed, households seek to improve their standard of living when their income increases. Thus, in terms of energy transition, households are shifting from the use of traditional energy sources (wood, kerosene, etc....) to modern energy sources: grid electricity or renewable sources (modern fuel, solar energy, wind, etc.) (Leach, 1992). This assumption is viewed as an extension of consumer economic theory, which states that "as income rise, consumers not only demand more goods, but also requested for a high quality of goods"(Lay et al., 2013). Therefore, the energy ladder hypothesis puts the energy price, as an important factor, determinant of the energy adoption by the household. This means that there exists a reference threshold over which household could not be able to afford energy for their basics need by considering their income level (Qureshi et al., 2017). As response, there is a

need of state policy incentives that could promote the energy access by reducing the high cost of its adoption (Crago & Chernyakhovskiy, 2014).

Moreover, the Lancaster consumer theory however, provides insight of consumers choice making based on the properties and characteristics of the good. In fact, this approach illustrates that “utility is derived from the properties and characteristics of a good, and it assumes the consumption of a good as an activity that produces an output that is a collection of characteristics” (Elegbede et al., 2021; Lancaster, 1966). This theory was used by several authors in the process of understanding how consumers makes choice to adopt new technologies (Egbedewe et al., 2010; Elegbede et al., 2021; Waldman et al., 2017). For instance, Elegbede et al., (2021) have used the choice experiment to evaluate how consumer will make choices between technologies that generate solar electricity in Nigeria. Waldman et al., (2017) also used this theoretical framework to assess how decision makers hypothetically make their choices in regards to new technologies adoption. By using consumer theory to assess household preferences and its choice making for new technologies adoption, the most important reason from an economic point of view is that the choice makers are rational, and they are willing to have the optimal satisfaction or utility from their choices (Mankiw, 2020). This mean that, farming household could maximize their utility, based on the assumption that they will always pick the most preferred solar panel that is affordable (Elegbede et al., 2021; Varian, 1992).

As solar panel is categorized as an environmental good, due to its environmentally-friendly characteristics in electricity generation without contributing to greenhouse gases emissions, such as carbon dioxide (CO₂) (Elegbede et al., 2021), valuing it in the perspective of households ability to afford it has to follow nonmarket good economic valuation. This economic value of the environmental-friendly goods is estimated based revealed or stated preferences of households. If the preference is revealed, the economic valuation uses three methods to monetized the environmentally-friendly goods, such as Hedonic Price Method, Travel-Cost Method, and Benefits Transfer Method. However, in the case where the preference is stated, the environmentally-friendly goods is valued in two folds, first, by using Contingent Valuation Method (CVM) (Davis, 1963; Hanley et al., 2001b), and second, by using the Choice Modelling Method (CMM) (Costanza et al., 1998; Hanley et al., 2001b; Shaw, 2004; Tietenberg & Lewis, 2014).

Theoretically, these methods lead to the conventional measures of social welfare as a result of price changes and refers to the compensating variation and equivalent variation (Hanemann, 1984, 1991). Compensating variation denote the maximum amount a household would be willing to pay (WTP) to benefit from the up cost of solar home system (environmentally-friendly goods). In order words, “the compensating variation is the amount of money it would take to compensate for price increase in order to make a consumer just as well off as she was before the price increase” (Tietenberg & Lewis, 2014). Equivalent variation however, designs the minimum amount that they would be willing to accept (WTA) for resigning from the usage of the good for the environmental purpose (Davis, 1963). It describes also “the amount of money it would take to make a consumer indifferent between the money and the price increase” (Tietenberg & Lewis, 2014).

In the stated preference formats, the contingent valuation (CV) method was one of the first direct survey approach used to estimate consumer preferences (Mitchell et al., 1989). This approach constructs a fictitious market or hypothetical market for environmental good trade. Based on a questionnaire designed, survey is conducted to elicit respondents’ preferences for environmental good by tracking their maximum willingness to pay (WTP) or minimum willingness to accept (WTA) for the quality improvement policy of the good (Hanley et al., 2001b; Kwak et al., 2013). For instance, the method was used to elucidate respondents WTP for residential water quality improvement in the Grand River watershed in the province of Ontario, Canada (Brox et al., 2003). Entele, (2020) also used contingent valuation method to measure the economic benefit of improved electricity service connection in rural Ethiopia. However, the CV method performances is conditioned by the use of professional interviewers and the familiarization of respondents with the good and services to be valued. Due to these associated cognitive burden and the exigence of the model, it was revealed dissatisfied (Hanley et al., 2001b).

Some growing approaches were proposed such as the dichotomous choice elicitation (Alberini et al., 1997; Arrow et al., 1993; Chilton, 2007) and choice modeling (Hanley et al., 2001b; Tietenberg & Lewis, 2014) as alternative method to value environmental goods with more precision. The dichotomous choice modeling is a form of CV method which provides incentives for truthful revelation of preferences and reduce cognitive task faced by respondents. It has been revealed to be good in measuring statistical efficiency and gained more attention after receiving the endorsement of the National Oceanic and Atmospheric Administration (NOAA) panel in 1993

(Arrow et al., 1993). But this model was criticized to not be the suited to deal with cases where changes are multidimensional (Hanley et al., 2001b).

Another promising models that value respondents' preferences for environmental good with less cognitive task, suited to deal whit cases where changes are multidimensional, is known as Choice Modeling (CM) method (Hanley et al., 2001b; Tietenberg & Lewis, 2014). This method was first developed by Louviere & Hensher, (1983), and aimed at modeling respondents preferences for goods by displaying the attributes of the goods. Respondents are called to rank the various alternatives, to rate them or to choose their most preferred according to the descriptions of the goods, their attributes and levels. Then, based on the price or cost as one of the attributes of the good, the WTP is indirectly calculated from respondents ranking, ratings or choices (Hanley et al., 2001b). CM alternative can be divided in four approaches. The first approach refers to, Choice Experiment (CE), in which respondents are called to choose between two or more alternatives their most preferred. In its process, a baseline alternative is designed and included in each choice set, corresponding to the status quo or "do nothing situation". This gives the possibility to estimate the respondent's economic welfare (Boxall et al., 1996; Hanley et al., 2001b; Louviere et al., 2000; Louviere & Hensher, 1983). The second approach is Contingent Ranking (CR). Here, the respondents are invited to rank a set of alternative options, focusing on a number of attributes and different levels across options. In the third approach, Contingent rating, a number of scenarios are presented to the respondents and they are asked to rate them individually on a semantic or numeric scale. The last CM alternative approach refers to Paired comparisons. In this approach, respondents have to choose their preferred alternative between a set of two choices and have to indicate the strength of their preference numerically of semantic scale (Hanley et al., 2001). Between these four alternative approaches, we give more attention to the Choice Experiment for this study for its consistency with utility maximization and demand theory.

3.3.2. Empirical framework of Off-grid solar adoption in rural areas

The off-grid solar adoption by rural households has obtained more attention in the recent literature. Empirically, several authors have investigated factors that shaped household solar system adoption decision in rural area (Elegbede et al., 2021; Entele, 2020; Guta, 2018; Hyun et al., 2021; Lay et al., 2013; Schelly, 2014). These factors are from environmental, economic and political side. This sub-section presents and discusses recent works which underling household solar system adoption

in rural area. The discussion aims to provide an overview of variables that can be taken into account when analyzing household preferences and adoption decisions.

From environmental perspective, scholars showed that population with highest environmental concerns have positive attitude in renewable energy solution adoption. Instance, (Ek, 2005) has investigated public and private consumers attitude on wind power electricity access in Sweden, and showed a positive attitude towards green winds power electricity for consumers that face environmental concerns. The study made evidence also on the decreases of consumers attitude towards green winds power electricity with age and income. However, the study failed to include other renewable energy sources, solar PV, mini-grid, which may affect consumers attitude for renewable electricity. In the same line, Hansla et al., (2008) investigated psychological attitudes of electricity consumers in Sweden, focusing on green electricity demand. The study confirmed a positive attitude and high willingness to pay for green electricity access for consumers valuing environmental cleanness. However, the study used an aggregate value for green electricity and failed to differentiate between the sources of renewable energy and their specific implication for consumer's attitude.

A similar study was carried out in United States by Borchers et al., (2007). The authors considered solar, wind, biomass and farm methane energy sources, and compared consumers preference and willingness to pay for these green energy sources. This study revealed that consumers are willing to pay for all the different sources of green electricity, but with a high preference for solar electricity compared to others renewable sources. However, this may not work in developing countries where alternative renewable sources of electricity are not available. In the South Korea, a study by Yoo & Kwak, (2009) emphasized on the significant willingness to pay for the green energy by consumers, due to their preferences towards environmental friendly sources of energy. Hence, it results that most of consumers' attitude on renewable energy choice are guided by environmental concerns. However, environmental concerns could not be the only aspect that boosted household preferences for green electricity.

Other scholars have investigated households' preference for off-grid solar access under consumers' socioeconomic profile. For example, Lay et al., (2013) analyzed factors that affect household choices of fuels including solar home system in Kenya, and found that household income and education levels significantly affects solar home system adoption in the areas. Ma et

al., (2015) highlighted that households are willing to pay for modern electricity generated from renewable sources, but the willingness to pay is less and this is impacted by consumers' socioeconomic profile and energy consumption pattern. The study reveals also that consumers have higher willingness to pay for electricity generated from wind, solar than that of biomass or hydropower. Contrary to Ma et al., (2015) results, Guta, (2018) pointed out that wealthy and educated households are more likely to adopt solar energy than the poorest one. In the same line, Entele, (2020) found that household income level, the level of education, age, location and amount of initial bid prices are important variables in determining the scale of households' willingness to pay for connection of electricity service. He explored households' preference for renewable source of electricity service connections and estimated potential willingness to pay for the services by considering solar PV electricity in addition to the grid-line in Ethiopia.

Modern energy access has been investigated as a way of strengthening the resilience of smallholder farmers to weather risks variability. For instance, Tesfaye et al., (2019) estimated the economic value of agricultural climate services for farmers' resilience to climate variability in Ethiopia. Using a generalized multinomial logit (G-MNL) model with choice modeling approach, the study found that smallholder farmers in Ethiopia are highly willing to pay high implicit price for agricultural climate services that strengthening their resilience to climate variability and risks. Also, the study highlighted the role of digital and ITC based solution, access to financial and market information on farmers decision-making. In the same line, Ali, (2021) analyzed Farm households' adoption of climate-smart practices in subsistence agriculture in Northern Togo. The study sheds light on socioeconomics factors that influence households' choice of climate-smart practices adaptation. Those factors include gender, household location, education level, family size, allocated labor, market access and financial facility (access to credit).

Moreover, studies also highlighted the government role in smallholders' farmers decision making for modern energy adoption. Notedly, Elegbede et al., (2021) showed that coupled with the quality of solar charger, government action in promoting solar home system for rural electrification are very relevant to farmers' decision making to adopting modern energy. Implicitly, government provide financial support to poor household for modern energy access.

However, these studies failed to associate the co-benefits of energy poverty reduction to the agricultural climate-smart services adoption. Indeed, considering West African countries situation

household respondent choose an alternative j that maximizes utility instead of alternative t can be expressed as follows:

$$P[(U_{ij} > U_{it}) \forall t \neq j] = P[(V_{it} - V_{ij}) > (\varepsilon_{it} - \varepsilon_{ij})] \dots \dots \dots (3.3)$$

Under the assumption that the errors terms are independently and identically distributed (IID), with an extreme-value (Weibull) distribution, the probability expression can be displayed as follows:

$$P(\varepsilon_{ij} \leq t = F(t) = \exp(-\exp(-t)) \dots \dots \dots (3.4)$$

From this distribution of the errors term, the estimated probability of the respondent choices can be expressed in terms of the logistic distribution as showed by McFadden, (1973).

$$P(U_{i1} > U_{i2}, \forall t \neq j) = \frac{\exp(\mu V_{it})}{\sum_j \exp(\mu V_{ij})} \dots \dots \dots (3.5)$$

Where, μ is a scale parameter inversely proportional to the standard deviation of the error distribution, and is assumed to be one. Once the model (3.5), known as the conditional Logit model, is well defined, it can be estimated using the likelihood procedures.

$$\log L = \sum_i^N \sum_{j=1}^J Y_{ij} \log \left[\frac{\exp(V_{it})}{\sum_{j=1}^J \exp(V_{ij})} \right] \dots \dots \dots (3.6)$$

Where, Y_{ij} is a binary variable coded 1 if the respondents choose the alternative option (t) and 0 otherwise.

3.4.2. Data survey

Based on literature, some attributes were selected for the choice modeling: solar system price, lighting, battery capacity, subsidies, use Tv and crops irrigation (Ali, 2021b; Ali et al., 2020; Elegbede et al., 2021; Entele, 2020). Two off-grid solar systems that could respond to households' energy needs in rural area such as Solar Home System (SHS) and Climate Smart Solar Pump (CSSP) were considered. With these two off-grid solar systems, two choice experiment was conducted. In the first-choice experiment, four attributes were associated to the SHS (Price, lighting, battery capacity and subsidies).

The attribute price is considered as one of the first motivation for household solar system choice. It is given to negatively affect farmers willingness to adopt modern energy due to the fact that compared to other source of energy, an expensive cost is associated to off-grid solar electricity (Elegbede et al., 2021). Information on solar system was collected from private actors operating in off-grid solar market in Togo. This information allows us to establish a range of three price systems for SHS and two price systems for CSSP in this present choice modeling (see table 10;11). The attributes lighting determines the number of times the Off-grid system can be used for. It informed the household on the average amount of time that they can use the technology daily time (Elegbede et al., 2021). We established three amount time of power system for SHS and two amount of time for CSSP, based on the information collected from households and market actors. The amount of wattage that households can get from off-grid solar panel can also be determinant in households choice making. It is determine by the attribute Battery (Elegbede et al., 2021). Lastly, the attribute subsidies underline government effort in promoting off-grid solar access in rural area. This attribute is presented as dummy variable indicating 1 if the SHS is sponsored by the government and 0 otherwise. These attributes are resumed in Tables 10.

In the second-choice experiment, the two off-grid solar system (SHS and CSSP) with fours attributes (Price, lighting, Tv, and crops irrigation), were combined and proposed to the respondents. Tv and Crops irrigation attributes are selected following (Ali, 2021b). The attribute Tv is a dummy variable indicating 1 if the Tv appliance can be used with the selected panel, and 0 otherwise. Also, the attribute crops irrigation is a dummy variable indicating 1 is the selected solar panel can be used for Irrigation practices, and 0 otherwise. Summary of this attributes is reported in Table11.

Following the existing reviews, a set of profiles were elaborated. SAS software was used to select an efficient orthogonal design with attributes and its various levels (Egbedewe-Mondzozo et al., 2010; Elegbede et al., 2021; Lancsar et Louviere, 2008). Using the four attributes with three, three, two, and two levels, the full factorial set of 36 combinations was obtained in the two choice experiments ($3^2 \times 2^2 = 36$). For each choice experiment, a total of 9 choices tasks were generated. These 9 choices scenarios were presented to the respondents, and they were asked to make their best choice.

Based on these materials, a household survey was conducted in three districts of Plateau region in Togo between September and November 2021. The sample of 327 household-heads were interviewed. The survey included information on household's characteristics, type of energy use, its awareness of off-grid solar systems, and its willingness to pay for off-grid solar systems. Thus, the questionnaire was structured in four sections. The first section contained information on the respondent's socio-demographics characteristics. Here, respondents were asked questions relating to household size, responder's gender, level of education, age, and their profession. In the second section, the questionnaire was designed to obtain information about households' access to energy services. This section includes information on the type of energy use for lighting, the type of energy use for cooking, and the convenience and the safety of the type of the energy sources. The third section gathered information about responded awareness of climate change mitigation policies implemented by the government in Togolese rural areas. The last section tackled household Willingness to pay for off-grid solution. In this part, respondents were exposed to the nine choices scenarios. Then, they were asked to express and make their optimal choices within the options listed.

Table 16: Attribute and Attribute levels in the first-choice experiment

N0	Attributes	Description	Attribute levels
1	Price	Upfront cost of solar panel	\$264; \$528; \$572
2	Lighting	Amount of time it can be used per day	5,7,10
3	Battery	capacity of solar panel	20; 50;
4	Subsidies	If the solar panel is sponsored by government	1; 0

Table 17: Attribute and Attribute levels in the second-choice experiment

N0	Attributes	Description	Attribute levels
1	Price	Upfront cost of solar panel	\$572; \$589; \$792
2	Lighting	Amount of time it can be used per day	10, 12, 24
3	Tv	Ability to use Tv with the solar package	0, 1
4	Crops irrigation	Crops irrigation capacity	0,1

3.4.3. Model specification

Following equation (3.1), the utility function of famer to select a given off-grid solar scenarios can be deployed as follow:

$$U(alt1) = \beta_1 Price + \beta_2 lighting + \beta_3 Power + \beta_4 Subsidy \dots \dots \dots (3.7)$$

$$U(alt2) = \beta_1 Price + \beta_2 lighting + \beta_3 TV + \beta_4 Cropsirrigation \dots \dots \dots (3.8)$$

$U(alt1)$ and $U(alt2)$ represent the utility derived from a given off-grid solar panel with its attributes. Price denotes the monthly cost of acquiring the off-grid solar solution and is a continuous variable. Also, lighting is a continuous variable indicating the amount of time (hour) that a household can use the off-grid solar solution for in a day time. Power is a continuous variable and represents the storage capacity of the battery associated to the off-grid solar technology. Subsidy is a dummy variable indicating 1 if the off-grid solar panel is sponsored by the government and 0 otherwise. TV is a dummy variable indicating 1 if the off-grid solar solution can be used for television appliance and 0 otherwise. Lastly, crops irrigation is a dummy variable and is equal to 1 if the off-grid solar system can be used for crops irrigation, and 0 otherwise.

In line with Kwak et al., (2016) modeling approach, this study also includes interactions between respondents socioeconomic characteristics and attribute. This aims to specify a model with observed heterogeneity.

Once equation 3.7 and 3.8 are estimated using the boosting conditional logit estimation method (H. Shi & Yin, 2018), the famers willingness to pay (WTP) for an improvement of his/her utility can be computed. Indeed, this WTP defined the monetary values or how much cost farmers are willing to give up in order to have the improvement of their utility. Following Hanley et al., (2001b), the WTP can be mathematically deployed as follow:

$$WTP = b_y^{-1} [\ln \sum_i \exp (V_i^1) - \ln \sum_i \exp (V_i^0)] \dots \dots \dots (3.9)$$

where V_i^0 , represents the utility of the initial state and V_i^1 represents the utility of the alternative state. b_y is the marginal utility of income and the attribute's cost. This WTP formulae can be simplified or measured as a ratio of coefficients.

$$WTP = -\frac{b_c}{b_y} \dots \dots \dots (3.10)$$

With b_c , the coefficient of any of the attributes. For instance, how much farmers are willing to pay for off-grid solar system for having lighting can be displayed as follow:

$$WTP(lighting) = -\frac{\partial U / \partial (lighting)}{\partial U / \partial (Price)} = -\frac{\beta_2}{\beta_1} \dots \dots \dots (3.11)$$

This equation is also known as the implicit prices.

3.5. Results and discussion

The descriptive statistic summarizing the data used in this study, attribute base specification, and the choice modeling results using conditional logit model are presented in this section.

3.5.1. Descriptive statistics

Table 18 provides summary statistics of respondents in the survey. It shows the average age of respondents is about 41 years, with a limited farms size of 2.63 hectares on the average. The data shows also that the majority of farmers in the study area have very low assets and earn less than \$87 (56250FCFA) per month which is about \$2.9 per day. The farmers’ average asset is \$10.32 (6642Fcf) per month, and ranges from less than \$1 to \$88 per month. Again, over 99% of farmers reported that their food crops were affected by weather variability over the past 5 years, while 73% of farmers also have lost their food crops in 2 recent past seasons (Table annex).

However, 65% of respondents acknowledged that they have heard about climate smart solar pump for crops irrigation but never experimented it. 87% reported that they have heard about solar home system because the first campaign on solar home system launched by the government was held in the region. On average, 68% of farmers in the survey have access to formal education. This relatively high rate of education access can explain the ability of farmers in the survey to understand the proposed packages well and make a rational choice according to their basic needs. It is also noted that less than 36% of farmers in the survey have benefited from solar home system launched in the region.

Table 18: Summary statistics

Variables	Unit	Mean	Standard Deviation	Min/Max
SHS price	FCFA	5800	4840.588	0/12250
Per day lighting time amount	Hour/day	4.88	3.84	0/10
SHS Battery capacity	Watt/hour	26.66	22.11	0/50
Government subsidies	Dummy	0.37	0.48	0/1
CSSP price	FCFA	7388.889	5362.958	0/12250
CSSP Battery capacity	Watt/hour	217.778	244.799	0/620
Crops irrigation	Dummy	0.44	0.49	0/1
Gender	Dummy	0.37	0.48	0/1
Age	Number of a year	41.61	13.05	19/82
Household size	Number	5.86	2.39	1/14
Farm size	Hectare	2.63	2.62	0/25
Household Monthly Asset	FCFA	6642.042	7535.469	379/56250
Have formal education	Dummy	0.68	0.46	0/1
Aware about SHS	Dummy	0.87	0.33	0/1
Aware about CSSP	Dummy	0.37	0.48	0/1
Yield reduction	Dummy	0.72	0.44	0/1

3.5.2. Farmers preferences for off-grid solar system

Table 19 and 20 report farmers' preferences for Solar Home System (SHS) and Climate Smart Solar Pump (CSSP) packages. The study found from the SHS packages proposed to the respondents that, about 87.67% of respondents are likely to have off-grid solar solution, while 12.33% of respondents said otherwise (Table 19). More explicitly, 29.56% of respondents expressed their desire to have Solar Home System Package 1 (Basic_bp50) which gives access to basically light, radio, Torch and phone charger. Whereas, about 38.53% expressed their desire for the Basic Plus option (Package 2), which makes it possible to use television too. And lastly, about 17.57%

expressed their desire for having the Basic Premium option (Package3), with the possibility of watching Canal plus channels (Table19).

This result shows that, despite farmers’ relatively low-income level, the majority of them in Plateau Region in Togo are willing to adopt modern energy solution in order to meet their basic energy needs and make a structural change in their home. These basic energy needs include: the access to lighting, ability to charge phone, and the use of household appliance such us radio or Tv for having information. In line with previous studies (Elegbede et al., 2021; Simpson et al., 2021), this finding confirms the willingness of rural households living in remote area to adopt modern energy solution for a structural change in their living condition. For this first-choice experiment, the Basic Plus package was the most preferred by the respondents in the study area.

Table 19: Type of Solar Home System package and Farmers preferences

Off-grid solar Packages	Price	% Of respondent
P1	4600	29.56
P2	9250	38.53
P3	12250	17.57
Status quo	0	12.33
Total of respondents	327	100.00

In the second-choice experiment, SHS and CSSP packages was proposed at the same time to the respondents. It comes out that close to the half of the respondents (49.75%) expressed their willingness to have Climate smart solar Pump against 30.38% for Solar Home System (Table20). However, about 19.78% of the respondents maintain the status quo in regards to the off-grid solar packages. It results that, most of farmers in the Plateau region in Togo have interest in climate smart solar Pump packages as an alternative solution to reduce climate change impact on their farming activities. CSSP serves for crops irrigation and helps in reducing weather risk effect, basically drought, on food crops system. This result is in line with the findings of Ali et al., (2020) and Ali, (2021) in the northern part of Togo, showing that farmers are likely to adopt innovative solution that can protect them from weather risks affecting their substantial agriculture system.

Table 20: Type of Climate Smart Solar Pump package and Farmers preferences

Off-grid solar Packages	Price	% Of respondent
P CSSP1	9000	29.56
PSHS	9250	30.38
P CSSP2	12000	20.29
Status quo	0	19.78
Total of respondents	327	100.00

3.5.3. Attribute-based specification

The attribute-based specification using boosting conditional logit model (H. Shi & Yin, 2018) result is reported in Table 21 and 22. This boosting conditional logit model controls the over-fitting of the model and gives consistent approximation of the utility function. Thus, Table 21 shows the result of the first-choice experiments (SHS) and Table 22 reports the result of the second-choice experiment (SHS+CSSP).

Overall, the models are statistically significant as well as the random parameters at 1% threshold level. Looking at the first-choice experiment attributes (Table 21), all the coefficients are statistically significant. The price attribute is negative, meaning that the SHS price negatively influences farmers' demand for off-grid solar packages. The higher the SHS price is, the less likely farmers will be willing to choose them. Similar result also is found in (Ali et al., 2020). However, it contrasts with the findings of Elegbede et al., (2021) in the context of Nigeria. Elegbede et al., (2021) found that the price attribute positively affects respondents' choice, highlighting that people associate price with quality of solar panel in their decision making. But their findings do not conform to the theory of choice experiment. The result of this study rather underlines the idea that farmers look carefully to their household financial asset in their decision making for off-grid solar system adoption.

The result shows also that the attribute lighting, indicating the amount of time that the SHS can last for lighting during the day time, and the attribute battery indicating the wattage capacity of solar panel, are likely to significantly and positively motivate farmers to choose off-grid solar solution. Also, offering financial support to farmers to access SHS significantly contributes to their choice for off-grid solar solution adoption. This result is also confirmed in the literature (Ali et al.,

2020; Giné & Yang, 2009; Üрге-Vorsatz & Tirado Herrero, 2012). Indeed, the financial support lowers the off-grid solar panel charge for household and help them to save money which can be used for another households needs. Following the odds ratio result, the amount of time that the SHS can last for lighting during the day time has the highest ratio (1.965) indicating that the attribute lighting highly contributes to farmers’ choice for solar home system adoption in rural Plateau region in Togo. This variable was not statistically significant in the study of Elegbede et al., (2021).

Table 21: Attribute-based specification result for the first-choice experiments.

Choice of alternatives	Model1		
	Odds Ratio	Coef	P> Z
Price	0.001	-9.896***	0.000
Lighting	1.965	0.675***	0.000
Battery	1.125	0.117***	0.000
Subsidies	1.933	0.659***	0.000
Pseudo R2		0.149	
Number of households		327	
Choice set per household		9	
Number of observations		2,943	
Wald-Statistics		322.05***	

NB: *** significant at 1% threshold, ** significant at 5% threshold, * significant at 10% threshold

From the second-choice experiment (Table22), the attributes: price and lighting are significant and have the same sign as in the first-choice experiments. This confirms that attribute price negatively affects farmers decision making in regards to off-grid solar system choice (SHS, CSSP), while attribute lighting positively motivate farmers to adopt it. The results of the attributes “Tv and crops irrigation” also are significant and positively motivate farmers to express their interest for both SHS and CSSP. In fact, ownership of Tv is seen as a channel of having access to climate change adaptation information and also a means of distraction for farmers. Ali, (2021) has reported its benefits in Northern Togo as contributing to farm households’ adoption of climate-smart practices in subsistence agriculture. This is also the case in rural Plateau region in Togo.

Irrigation practice is also highlighted as climate change adaptation practices in Northern Togo by Ali, (2021) and Gadédjisso-Tossou et al., (2018). The significance of the attribute “crop irrigation”

here means that this attribute highly contributes to farmers decision making to adopt CSSP solution in Plateau region, as they are experiencing a huge challenge of weather risk on their farming activities. For this second-choice experiment, the odds ratio is relatively high for attributes: lighting and Crops irrigation (Table22), indicating that these two attributes are very important in farmers decision making for off-grid solar solution adoption.

Table 22: Random parameter model result for second-choice experiments.

Choice of alternatives	Model2		
	Odds Ratio	Coeff	P> Z
Price	0.103	-2.271***	0.000
Lighting	15.27	2.726***	0.000
Tv	1.85	0.618***	0.000
Crops irrigation	11.94	2.480***	0.000
Pseudo R ²		0.072	
Number of households		327	
Choice set per household		09	
Number of observations		2,943	
Log pseudolikelihood		-1000.038	
Wald-Statistics		156.42***	

NB: *** significant at 1% threshold, ** significant at 5% threshold, * significant at 10% threshold

3.5.4. *Econometric results from conditional logit specification*

Following Kwak et al., (2016) novel approach that detect attribute by using covariate interaction, the study found that farmers socioeconomic characteristics contribute to explain respondents decision making for off-grid solar system adoption. For instance, in the first-choice experiment (Table23), it is shown that households headed by females are less likely to desire solar home system adoption considering the attribute: price level. This can be explained by the relatively low-income level of households headed by females, and also, their attachment to solar technology that could reduce their exposure to burden of energy collection. This result contrast with the findings of (Guta, 2018). For example, Guta, (2018) found in rural Ethiopia context that it is households headed by male that are less likely to adopt solar energy technology contrary to households headed by females. Moreover, previous study (Ma et al., 2015; Tesfaye et al., 2019) result associates the

positive interest of households headed by female to solar energy technology that could reduce their exposure to indoor air pollution and the burden of energy collection for cooking issues. As the proposed Solar Home System in this study is not related to cooking energy, it is rational that they express less interest regarding the price level.

The same observation is also made for the Ages of household heads which shows that, the more household-heads are younger, the more they are willing to have solar home systems. Younger farmers assume that in order to increase their income level to be able to afford the proposed solar system, they could expand their farming. Notably, farm size was found to positively contribute to solar home system choice making, implying that, the larger the farm size, the more the household asset will increase and the more the household-head will be willing to have the best solar home system with regards to the price level. This result is similar to that of Ali et al., (2020) and Guta, (2018)

Moreover, having formal education could also explain farmers' desire to adopt Solar Home System for lighting. For instance, from the result, formal educated farmers have a better understanding of the benefit of solar home system for energy services access such as lighting, use of phone charger, and Tv. They also associate high quality to the price level and will be willing to adopt solar home system with better SHS outcome services. Similar result was also found by Ali et al., (2020). Thus, this study confirms that access to education by farmers increase their understanding in modern energy solution adoption for the alleviation of climate change and energy poverty in rural Togo.

Furthermore, being aware of the different types of existing SHS on the market also positively affects households' decision making to adopt the best one. This result indicates that information is very significant in choosing solar home system. This result is similar to a study in Tanzania where off-grid solar awareness played an important role in youths' renewable energy adoption (Simpson et al., 2021).

Table 23: Econometric results of Solar Home System choice from conditional logit.

Choice of alternatives	Model1		
	Odds Ratio	Coeff	P> Z
Price	0.001	-11.216***	0.000
Lighting	2.141	0.761***	0.000
Battery	1.136	0.128***	0.000
Subsidies	2.138	0.760***	0.000
Respondents' characteristics			
Price*Gender	0.493	-0.707***	0.001
Price*Formal education	1.880	0.631***	0.003
Price*SHS Awareness	1.724	0.544**	0.041
Price*Household Age	0.973	-0.027***	0.000
Price*Household Size	1.070	0.068	0.133
Price*Farm Size	1.133	0.125***	0.001
Household asset	1810.526	7.501**	0.017
Pseudo R2		0.184	
Number of households		327	
Choice set per household		9	
Log pseudolikelihood		-880.252	
Number of observations		2,943	
Wald-Statistics		255.79***	

NB: *** significant at 1% threshold, ** significant at 5% threshold, * significant at 10% threshold

The second-choice experiment's results (Table24) also shows that formal education positively contributes to Climate Smart Solar Pump adoption in rural Plateau region in Togo. In addition, CSSP Awareness and the size of cultivated land highly contribute to solar home system adoption. This confirms that farmers that have access to education and CSSP information are more likely to adopt CSSP. Thus, education and information access are relevant in knowing the benefits that could result from crops irrigation technologies adoption. This generates benefits in terms of crops yield improvement and yield losses reducing.

Moreover, farmers with a large cultivated land are more likely to adopt both CSSP and Solar home system. As the farm size increase by one hectare, the odd ratio of off-grid solar adoption increases

by a factor of 1.15. This confirms that the larger farm size the more crop yields increase, which in turn positively influences farmers' revenue and their ability to afford off-grid solar systems. This result is similar to the finding of Guta, (2018).

Table 24: Econometric results of Climate Smart Solar Pump choice from conditional logit

Choice of alternatives	Model2		
	Odds Ratio	Coef	P> Z
Price	0.089	-2.419***	0.000
Lighting	18.68	2.927***	0.000
Tv	1.869	0.626***	0.000
Crops irrigation	1.435	0.361	0.491
Respondents' characteristics			
Crops irrigation* Gender	1.168	0.156	0.375
Crops irrigation* Formal education	3.643	0.185***	0.000
Crops irrigation* SHS Awareness	2.235	0.804***	0.000
Crops irrigation* Household Age	1.008	0.008	0.212
Crops irrigation* Household Size	1.000	0.001	0.995
Crops irrigation* Farm Size	1.155	0.144***	0.000
Crops irrigation* Crop yield	1.146	0.136	0.491
Household asset	1.00	0.001	0.282
Pseudo R2		0.126	
Number of households		327	
Choice set per household		09	
Number of observations		2,943	
Log pseudolikelihood		-944.282	
Wald-Statistics		219.26***	

NB: *** significant at 1% threshold, ** significant at 5% threshold, * significant at 10% threshold

3.5.5. Willingness to Pay (WTP) analysis

In this section, the economic value of off-grid solar adoption is determined. The discrete choice experiment method makes it possible to estimate the monetary value that respondents are willing to Pay or to Accept, in order to benefit from modern energy technologies. For instance, the

Willingness to Pay refers to the maximum amount that farmers would like to pay for adoption of off-grid solar system, while the Willingness to accept targets the minimum amount that individuals would like to receive in order to renounce the use of a specific environmental good (Hanley et al., 2001).

The WTP for Solar Home Systems in the first-choice experiment is relatively low (\$1.04/month for lighting) compared to the second-choice experiment result where both Solar Home System and Climate Smart Solar Pump packages were proposed (\$18.33/month for lighting) (Table25). This result shows that combining households’ energy access issues with other climate change risk management would enhance off-grid solar solution adoption in rural or remote areas. Similar result was found by Tesfaye et al., (2019); Ali et al., (2020) and Tadesse et al., (2015). As shown in Tesfaye et al., (2019) in rural Ethiopia, smallholder farmers are willing to pay high implicit price for participatory decision making in regards to agricultural climate services. In the Northern Togo, Ali et al., (2020) pointed out that a rational farmer preferred mostly the proposed package with the highest expected value. Using insurance products, Tadesse et al., (2015) revealed that interlinking weather index-based insurance package with other packages such as credit or safety net would increase farmers’ willingness to pay in Sub-Saharan Africa. Here, farmers may think that adopting CSSP packages insures them from weather risk and could increase income. They will then be able to pay high price for having solar home system with the highest expected utility.

With the combining packages (Table26), the economic cost of off-grid solar adoption by farmers for lighting is equal to \$18.33 per month (12004.9FCFA/month), while the economic value of CSSP adoption is equal to \$16.67 per month (10922.02FCFA/month). This confirms that farmers/respondents in this region are rational and express a high willingness to Pay for off-grid solar system that gives them the highest expected utility (Ali, 2021b; Ali et al., 2020).

Table 25: Willingness to pay in the first-choice experiment

Attribute	WTP	Standard error	Confidence intervals
Lighting	682.361	30.345	[622.887 741.836]
Battery	119.222	5.351	[108.734 129.71]
Subsidies	666.253	188.402	[296.991 1035.515]

Table 26: Willingness to pay for Climate Smart Solar Pump packages.

Attribute	WTP	Standard error	Confidence intervals (95%)
Lighting	12004.9	692.228	[10648.16 13361.64]
Tv	2721.882	505.311	[1731.49 3712.273]
Crops irrigation	10922.02	553.427	[9837.326 12006.72]

3.6. Partial Conclusion

Climate change and energy poverty challenges threaten farmers' living condition in developing countries. There is a need to adopt modern energy system that could reduce simultaneously these two threats. Off-grid solar systems such as Solar Home System and Climate Smart Solar Pump system, provide a promising framework for households in reducing both climate risk and energy poverty issues. However, the cost associated with its adoption by rural households cannot be overlooked. This study developed two experimental choice modeling approach to assess farmers' willingness to pay for off-grid solar system as renewable energy market base solution for climate change impact and energy poverty reduction in rural Togo. The first-choice experiment proposed Solar Home System for lighting while the second proposed a combination of Solar home system and Climate Smart Solar Pump for crops irrigation. This choice modeling approach were developed based on a cross-sectional data collected in a survey from 327 households in Plateau region in Togo.

Overall, the results indicate that a large proportion of respondents (87.67%) are willing to adopt Solar home system against energy poverty issues in the first-choice experiment. In the second-choice experiment, the results indicate that a total of 80.13% of respondents are willing to adopt off-grid solar solution. Specifically, 30.38% of respondents express their interest for Solar Home system while about half of the respondent (49.75%) opt for Climate Smart Solar Pump system. Also, the results showed that the willingness to pay in the first-choice experiment is relatively low (\$1.04/month for lighting) comparatively to the willingness to pay in the second-choice experiment (\$18.33/month for lighting). These results indicate that farmers are subject to both energy poverty and weather risk challenges, and they are willing to adopt SHS and CSSP solution that could reduce both weather risk and energy poverty challenges. Meanwhile, the proposed modern energy

solution that combine households' energy access issues with other climate change risk management would enhance farmers willingness to pay for it in rural or remote areas.

Moreover, the results show also that education and information access positively contribute to off-grid solar system deployment in this region, while off-grid solar price system decrease farmers' willingness to adopt modern energy technologies. The results again, indicate that, as part of factors that explain farmers' interest to off-grid solar system, attention should be given to the head of households' gender, age and the cultivated land. For instance, the larger the farm size the more farmers are willing to adopt off-grid solar solution. Also, households headed by relatively younger people are more likely to opt for off-grid solar solution. Households headed by females however, are less likely to opt for the proposed modern energy solution in this study. This imply that the modern energy solution for both energy poverty and climate risk management have to integrate female energy needs in terms of energy for cooking.

Furthermore, government's assistance in providing financial support for modern energy adoption motivates farmers to adopt off-grid solar systems. This support reduces off-grid solar adoption cost making it comparatively affordable for the rural households. Overall, there is a need to offer Off-grid solar system that integrate farmers' basic need in terms of weather risk management and energy poverty reduction. There is also a need to educate and provide off-grid solar information to households in rural areas. These could help them in understanding better the benefits of modern energy technologies adoption. Therefore, proposed modern energy technologies that incorporate weather risk management and energy poverty reduction in lighting and cooking dimension is recommended to the stakeholders intervening in off-grid solar market in developing countries. Government policy makers could also refer to these findings in orders to ameliorate their policy intervention for household financial support and off-grid solar information access. Future research could assess the financial system of off-grid solar deployment to determine the role of digital finance system on rural household modern energy access. Such research could take into account Pay-As-You-Go system developed in rural Togo and other developing countries.

General conclusion

There is increasing concern about climate change and energy poverty challenges in developing countries. These two concerns have considerable impact on human living condition in West African countries. For instance, climatic variability and change impact could be observed through its effect on agricultural sector. Indeed, agricultural sector is the main sector that driver's economic growth in West Africa region and constitute the principal activity of more than 70% of the region's population. The sector relies on climate condition and is called rainfed agricultural. Thus, any change in climate condition directly have multiple impact on human livelihood. Moreover, energy poverty situation is characterized by a critical lack of access to energy services such as electricity, modern energy for lighting, cooking. Its situation in West Africa region is becoming increasingly warison as more than 70% of the world population living without access to energy service are located in this region. Even if there is a great potential of natural resource that can be used to generate energy, its affordability, safety and efficiency also remain other challenges in rural West Africa. Therefore, finding an alternative solution that can address climate change and energy poverty issues in West Africa becomes a big priority for policymakers and economists worldwide.

The use of renewable energy has been widely explored recently for being a key strategy in combating climate change and energy poverty in low-income countries. It includes energy generation from biomass, hydropower, solar, and wind. However, high cost is associated with its adoption in rural areas. This study therefore has investigated this fundamental question: what is the trade-off between climate change and renewable energy generation in West Africa?

This study thus, aimed to explore the trade-off between climatic change and modern energy services access in West Africa. Specifically, it first assesses the role of renewable energy consumption and domestic investment in climate-economy relationship in West. With particular attention given to agricultural added value to the economy as proxy to economic growth. Panel Error Correction Model is used to determine short and long-run causal relationship between variables based on Breusch & Pagan, (1980) inter-individual dependency test, second-generation panel unit root tests and Westerlund cointegration methods. Data were collected from 12 West Africa from 1990 to 2019.

In second, the study investigates the socioeconomic impact of climate change mitigation on energy poverty alleviation in West Africa, using a case study of off-grid solar access in rural Togo. It uses

the energy poverty measurement approaches including the novel approach developed by Gafa & Egbendewe, (2021), as well as the approach proposed by Sadath & Acharya, (2017), and Zhang et al., (2019) to apprehend the level of energy poverty in rural Togo. Moreover, the margin effects are also computed to know the expected impact of government action for rural electrification and energy poverty alleviation in the area. The study used household survey from 327 households in Plateau region in Togo.

And third, it develops two experimental choice modeling approach to assess farmers' willingness to pay for off-grid solar system as renewable energy market base solution for climate smart agricultural development and energy poverty reduction in rural Togo. The first-choice experiment proposed Solar Home System for lighting while the second proposed a combination of Solar home system and Climate Smart Solar Pump for crops irrigation or lighting. This choice modeling approach were developed based on a cross-sectional data collected in a survey from 327 households in Plateau region in Togo.

Findings show for the first objective that there is negative relationship between climatic change and agricultural contribution to the economy in West Africa region. Any change in temperature has in short and long-run negative causal relationship with agricultural development. Also, the findings show that renewable energy consumption has short and long-run positive causal impact on climatic change and agricultural development in West Africa. Moreover, domestic investment has short-run positive causal relationship with agricultural development while negative causal effect is observed for climatic change.

For the second objective, the results suggest that despite the progress made in adoption of solar home systems in the Plateau region of Togo (78.59%), the level of energy poverty remains high and ranges from 68% to 97%. Multidimensional energy poverty estimation reveals that the high level of energy poverty is largely caused by expenditure-based energy poverty (affordability) and the type of energy used for cooking. Also, female-headed households are more vulnerable to energy poverty than male-headed households. Furthermore, government action on rural electrification and energy poverty reduction, household assets, and household education level are likewise among the main drivers of household energy poverty. On the other hand, a negative and significant effect is observed on energy expenditures.

Finally, results for third objective indicate that a large proportion of respondents (87.67%) are willing to adopt Solar home system against energy poverty issues in the first-choice experiment. In the second-choice experiment, the results indicate that a total of 80.13% of respondents are willing to adopt off-grid solar solution. Specifically, 30.38% of respondents express their interest for Solar Home system while about half of the respondent (49.75%) opt for Climate Smart Solar Pump system. Also, the results showed that the willingness to pay in the first-choice experiment is relatively low (\$1.04/month for lighting) comparatively to the willingness to pay in the second-choice experiment (\$18.33/month for lighting). These results indicate that farmers are subject to both energy poverty and weather risk challenges, and they are willing to adopt SHS and CSSP solution that could reduce both weather risk and energy poverty challenges. Meanwhile, the proposed modern energy solution that combine households' energy access issues with other climate change risk management would enhance farmers willingness to pay for it in rural or remote areas.

Based on these results, the study confirms the first hypothesis that renewable energy positively contributes to reduce climate change impact on West African economy. The second assumption is also confirmed showing that off-grid solar system could be the channel by which policymakers could use for climate change and energy poverty alleviation in rural West Africa. However, effort is needed in controlling modern energy access cost. Finally, the third hypothesis is also confirmed showing that weather risk challenges awareness highly contributes in enhancing farmers willingness to pay for modern energy solution in rural areas.

Overall, the study recommend that policies should target renewable energy technologies implementations and domestic investment for agricultural development as West Africa economic response to climate change. Trade policy also has to encourage local transformation of agricultural goods based on renewable and clean technologies. This should avoid the exportation of more agricultural commodities as raw material and create additional added-value to the economy. Public policies also should target the adoption of Off-grid solar systems not only for home lighting but also for economic activities development. This could generate additional revenue that could be used to address energy affordability issues. Moreover, additional policies such as improved stoves, are needed to reduce household dependence on fuelwood for cooking. Finally, there is a need to offer Off-grid solar system that integrate farmers' basic need (crops irrigation), that could be used

in terms of weather risk management and energy poverty reduction. Provide off-grid solar information to households in rural areas is also required.

Lastly, this study has some limitations. In the first place, the study of climate-economy relationships in West African countries misses the role of monetary policies. Secondly, the work analyzing modern energy access in rural Togo fails to capture the role of digital financing mechanisms in energy transition in developing countries. These could be improved by assessing the role of digital energy transition in energy poverty alleviation in rural communities. Therefore, future research could focus on assessing the impact of climate change on monetary policies in the West African Economic and Monetary Union. This could constitute an effective research area for future research to better understand the monetary union's economic response to climate change.

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Annex.

Annex1: Material for essay1

```
. xtreg AgriValue Renc FBCF Opnes Temp Rainfall, fe
Fixed-effects (within) regression      Number of obs   =       360
Group variable: Code                  Number of groups =       12

R-squared:                             Obs per group:
  Within = 0.1527                      min =          30
  Between = 0.3074                      avg =          30.0
  Overall = 0.2593                      max =          30

corr(u_i, Xb) = 0.2347                  F(5,343)       =       12.36
                                          Prob > F        =       0.0000
```

AgriValue	Coefficient	Std. err.	t	P> t	[95% conf. interval]	
Renc	.2391535	.0388483	6.16	0.000	.1627426	.3155644
FBCF	.0241394	.0443986	0.54	0.587	-.0631884	.1114672
Opnes	.0266584	.0461432	0.58	0.564	-.0641009	.1174178
Temp	-.8867964	.9400254	-0.94	0.346	-2.735736	.9621435
Rainfall	.0001809	.0023209	0.08	0.938	-.0043842	.0047459
_cons	11.28069	5.124681	2.20	0.028	1.200934	21.36045
sigma_u	9.1163617					
sigma_e	5.0122663					
rho	.76787755	(fraction of variance due to u_i)				

F test that all u_i=0: F(11, 343) = 72.60 Prob > F = 0.0000

```
. testparm AgriValue Renc FBCF Opnes Temp Rainfall
```

```
( 1) Renc = 0
( 2) FBCF = 0
( 3) Opnes = 0
( 4) Temp = 0
( 5) Rainfall = 0

F( 5, 343) = 12.36
Prob > F = 0.0000
```

```
. xtreg Renc AgriValue FBCF Opnes Temp Rainfall, fe
Fixed-effects (within) regression      Number of obs   =       360
Group variable: Code                  Number of groups =       12

R-squared:                             Obs per group:
  Within = 0.3831                      min =          30
  Between = 0.1016                      avg =          30.0
  Overall = 0.1842                      max =          30

corr(u_i, Xb) = -0.0213                 F(5,343)       =       42.60
                                          Prob > F        =       0.0000
```

Renc	Coefficient	Std. err.	t	P> t	[95% conf. interval]	
AgriValue	.41603	.0675803	6.16	0.000	.2831061	.5489539
FBCF	-.1300144	.058162	-2.24	0.026	-.2444136	-.0156153
Opnes	-.1711978	.0601839	-2.84	0.005	-.2895737	-.052822
Temp	-10.5569	1.102839	-9.57	0.000	-12.72608	-8.387721
Rainfall	-.0078247	.0030319	-2.58	0.010	-.0137881	-.0018613
_cons	88.83894	4.829227	18.40	0.000	79.34031	98.33756
sigma_u	12.586373					
sigma_e	6.6108612					
rho	.78377484	(fraction of variance due to u_i)				

F test that all u_i=0: F(11, 343) = 67.17 Prob > F = 0.0000

```
. testparm Renc AgriValue FBCF Opnes Temp Rainfall
```

```
( 1) AgriValue = 0
( 2) FBCF = 0
( 3) Opnes = 0
( 4) Temp = 0
( 5) Rainfall = 0

F( 5, 343) = 42.60
Prob > F = 0.0000
```

```
. xtreg Temp Opnes Renc AgriValue FBCF Rainfall, fe
```

```
Fixed-effects (within) regression      Number of obs   =      360
Group variable: Code                  Number of groups =      12

R-squared:                            Obs per group:
  Within = 0.2666                      min =          30
  Between = 0.1811                     avg =          30.0
  Overall = 0.1474                      max =          30

corr(u_i, Xb) = -0.7560                F(5,343)       =      24.94
                                        Prob > F        =      0.0000
```

	Temp	Coefficient	Std. err.	t	P> t	[95% conf. interval]	
	Opnes	.0007141	.002648	0.27	0.788	-.0044943	.0059225
	Renc	-.0199705	.0020862	-9.57	0.000	-.024074	-.0158671
	AgriValue	-.0029183	.0030934	-0.94	0.346	-.0090028	.0031662
	FBCF	-.0016469	.0025465	-0.65	0.518	-.0066556	.0033618
	Rainfall	-.0000587	.0001331	-0.44	0.660	-.0003205	.0002031
	_cons	2.629511	.2597819	10.12	0.000	2.118545	3.140477
	sigma_u	.27206938					
	sigma_e	.28753109					
	rho	.47239117	(fraction of variance due to u_i)				

```
F test that all u_i=0: F(11, 343) = 10.81          Prob > F = 0.0000
```

```
. testparm Temp Opnes Renc AgriValue FBCF Rainfall
```

```
( 1) Opnes = 0
( 2) Renc = 0
( 3) AgriValue = 0
( 4) FBCF = 0
( 5) Rainfall = 0

F( 5, 343) = 24.94
Prob > F = 0.0000
```

```
. reg AgriValue Renc FBCF Opnes Temp Rainfall,
```

Source	SS	df	MS	Number of obs	=	360
Model	17939.051	5	3587.81019	F(5, 354)	=	44.28
Residual	28680.2325	354	81.017606	Prob > F	=	0.0000
				R-squared	=	0.3848
				Adj R-squared	=	0.3761
Total	46619.2835	359	129.858728	Root MSE	=	9.001

AgriValue	Coefficient	Std. err.	t	P> t	[95% conf. interval]	
Renc	.356537	.0368022	9.69	0.000	.2841586	.4289155
FBCF	-.2647446	.0656764	-4.03	0.000	-.3939095	-.1355797
Opnes	.152123	.0596108	2.55	0.011	.0348872	.2693589
Temp	1.751744	1.453636	1.21	0.229	-1.107103	4.610592
Rainfall	.0050458	.0008993	5.61	0.000	.0032771	.0068145
_cons	-4.189104	4.180219	-1.00	0.317	-12.41029	4.032082

```
. vif
```

Variable	VIF	1/VIF
Renc	1.38	0.725720
Temp	1.19	0.842002
Rainfall	1.18	0.845928
Opnes	1.11	0.899025
FBCF	1.07	0.931737
Mean VIF	1.19	


```

. xtreg Renc AgriValue FBCF Temp Opnes Rainfall, re

Random-effects GLS regression           Number of obs   =       360
Group variable: Code                   Number of groups =       12

R-squared:                             Obs per group:
  Within   = 0.3818                      min       =       30
  Between  = 0.2355                      avg       =      30.0
  Overall  = 0.2686                      max       =       30

corr(u_i, X) = 0 (assumed)              Wald chi2(5)    =      214.76
                                          Prob > chi2     =      0.0000

```

	Renc	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
	AgriValue	.4329853	.0662947	6.53	0.000	.3030501	.5629205
	FBCF	-.1250116	.0580647	-2.15	0.031	-.2388164	-.0112069
	Temp	-10.59717	1.102056	-9.62	0.000	-12.75716	-8.437183
	Opnes	-.1746846	.0599117	-2.92	0.004	-.2921094	-.0572598
	Rainfall	-.005399	.0027085	-1.99	0.046	-.0107074	-.0000905
	_cons	85.39209	5.554571	15.37	0.000	74.50533	96.27885
	sigma_u	11.628232					
	sigma_e	6.6108612					
	rho	.75573628	(fraction of variance due to u_i)				

```

. xttest0

Breusch and Pagan Lagrangian multiplier test for random effects

```

```

Renc[Code,t] = Xb + u[Code] + e[Code,t]

Estimated results:

```

	Var	SD = sqrt(Var)
Renc	229.5981	15.1525
e	43.70349	6.610861
u	135.2158	11.62823

```

Test: Var(u) = 0
      chibar2(01) = 1924.26
      Prob > chibar2 = 0.0000

```

```

. xtreg FBCF Renc AgriValue Temp Opnes Rainfall, re

Random-effects GLS regression           Number of obs   =       360
Group variable: Code                   Number of groups =       12

R-squared:                             Obs per group:
  Within   = 0.1334                      min       =       30
  Between  = 0.0013                      avg       =      30.0
  Overall  = 0.0464                      max       =       30

corr(u_i, X) = 0 (assumed)              Wald chi2(5)    =      46.99
                                          Prob > chi2     =      0.0000

```

	FBCF	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
	Renc	-.0635507	.0452869	-1.40	0.161	-.1523114	.0252101
	AgriValue	-.0095854	.0598603	-0.16	0.873	-.1269095	.1077388
	Temp	-.4372425	1.12498	-0.39	0.698	-2.642164	1.767679
	Opnes	.3117589	.0519355	6.00	0.000	.2099671	.4135507
	Rainfall	-.002204	.0016565	-1.33	0.183	-.0054507	.0010427
	_cons	17.81602	4.721192	3.77	0.000	8.562651	27.06938
	sigma_u	3.6892546					
	sigma_e	6.0929937					
	rho	.26826753	(fraction of variance due to u_i)				

```

. xttest0

Breusch and Pagan Lagrangian multiplier test for random effects

```

```

FBCF[Code,t] = Xb + u[Code] + e[Code,t]

Estimated results:

```

	Var	SD = sqrt(Var)
FBCF	56.15309	7.493536
e	37.12457	6.092994
u	13.6106	3.689255

```

Test: Var(u) = 0
      chibar2(01) = 191.64
      Prob > chibar2 = 0.0000

```

. ***xtcips - Pesaran Panel Unit Root Test in the Presence of Cross-section
 . *Dependence, Pesaran (2007)
 . *****level
 . xtcips AgriValue, maxlags(2) bglags(1) trend

Pesaran Panel Unit Root Test with cross-sectional and first difference mean included for AgriValue
 Deterministics chosen: constant & trend

Dynamics: lags criterion decision General to Particular based on F joint test

H0 (homogeneous non-stationary): $b_i = 0$ for all i

CIPS = -2.392 N,T = (12,30)

	10%	5%	1%
Critical values at	-2.6	-2.7	-2.89

. xtcips Renc, maxlags(2) bglags(1) trend

Pesaran Panel Unit Root Test with cross-sectional and first difference mean included for Renc
 Deterministics chosen: constant & trend

Dynamics: lags criterion decision General to Particular based on F joint test

H0 (homogeneous non-stationary): $b_i = 0$ for all i

CIPS = -2.033 N,T = (12,30)

	10%	5%	1%
Critical values at	-2.6	-2.7	-2.89

. xtcips FBCF, maxlags(2) bglags(1) trend

Pesaran Panel Unit Root Test with cross-sectional and first difference mean included for FBCF
 Deterministics chosen: constant & trend

Dynamics: lags criterion decision General to Particular based on F joint test

H0 (homogeneous non-stationary): $b_i = 0$ for all i

CIPS = -2.544 N,T = (12,30)

	10%	5%	1%
Critical values at	-2.6	-2.7	-2.89

. xtcips Opnes, maxlags(2) bglags(1) trend

Pesaran Panel Unit Root Test with cross-sectional and first difference mean included for Opnes
 Deterministics chosen: constant & trend

Dynamics: lags criterion decision General to Particular based on F joint test

Individual t_i were truncated during the aggregation process

H0 (homogeneous non-stationary): $b_i = 0$ for all i

CIPS* = -3.281 N,T = (12,30)

	10%	5%	1%
Critical values at	-2.59	-2.69	-2.88

. xtcips Rainfall, maxlags(2) bglags(1) trend

Pesaran Panel Unit Root Test with cross-sectional and first difference mean included for Rainfall
 Deterministics chosen: constant & trend

Dynamics: lags criterion decision General to Particular based on F joint test

Individual t_i were truncated during the aggregation process

H0 (homogeneous non-stationary): $b_i = 0$ for all i

CIPS* = -5.167 N,T = (12,30)

	10%	5%	1%
Critical values at	-2.59	-2.69	-2.88

. xtcips Temp, maxlags(2) bglags(1) trend

Pesaran Panel Unit Root Test with cross-sectional and first difference mean included for Temp
 Deterministics chosen: constant & trend

Dynamics: lags criterion decision General to Particular based on F joint test

H0 (homogeneous non-stationary): $b_i = 0$ for all i

CIPS = -4.851 N,T = (12,30)

	10%	5%	1%
Critical values at	-2.6	-2.7	-2.89

```

. *****first difference*****
.
. xtcips D.Agrivalue, maxlags(2) bglags(1) trend
Pesaran Panel Unit Root Test with cross-sectional and first difference mean included for D.Agrivalue
Deterministics chosen: constant & trend

Dynamics: lags criterion decision General to Particular based on F joint test
Individual ti were truncated during the aggregation process

H0 (homogeneous non-stationary): bi = 0 for all i
CIPS* = -5.421 N,T = (12,29)

```

	10%	5%	1%
Critical values at	-2.59	-2.69	-2.88

```

. xtcips D.Renc, maxlags(2) bglags(1) trend
Pesaran Panel Unit Root Test with cross-sectional and first difference mean included for D.Renc
Deterministics chosen: constant & trend

Dynamics: lags criterion decision General to Particular based on F joint test
Individual ti were truncated during the aggregation process

H0 (homogeneous non-stationary): bi = 0 for all i
CIPS* = -5.047 N,T = (12,29)

```

	10%	5%	1%
Critical values at	-2.59	-2.69	-2.88

```

. xtcips D.FBCF, maxlags(2) bglags(1) trend
Pesaran Panel Unit Root Test with cross-sectional and first difference mean included for D.FBCF
Deterministics chosen: constant & trend

Dynamics: lags criterion decision General to Particular based on F joint test
Individual ti were truncated during the aggregation process

H0 (homogeneous non-stationary): bi = 0 for all i
CIPS* = -5.225 N,T = (12,29)

```

	10%	5%	1%
Critical values at	-2.59	-2.69	-2.88

```

. xtcips D.Opnes, maxlags(2) bglags(1) trend
Pesaran Panel Unit Root Test with cross-sectional and first difference mean included for D.Opnes
Deterministics chosen: constant & trend

Dynamics: lags criterion decision General to Particular based on F joint test
Individual ti were truncated during the aggregation process

H0 (homogeneous non-stationary): bi = 0 for all i
CIPS* = -5.518 N,T = (12,29)

```

	10%	5%	1%
Critical values at	-2.59	-2.69	-2.88

```

. xtcips D.Rainfall, maxlags(2) bglags(1) trend
Pesaran Panel Unit Root Test with cross-sectional and first difference mean included for D.Rainfall
Deterministics chosen: constant & trend

Dynamics: lags criterion decision General to Particular based on F joint test
Individual ti were truncated during the aggregation process

H0 (homogeneous non-stationary): bi = 0 for all i
CIPS* = -6.293 N,T = (12,29)

```

	10%	5%	1%
Critical values at	-2.59	-2.69	-2.88

```

. *****Cointegration test*****
.
. *****Pedroni test*****
.
. xtointttest pedroni AgriValue Renc FBCF Opnes Temp Rainfall, demean

```

Pedroni test for cointegration

```

H0: No cointegration          Number of panels      =    12
Ha: All panels are cointegrated Number of periods     =    29

```

```

Cointegrating vector: Panel specific
Panel means:          Included          Kernel:              Bartlett
Time trend:           Not included      Lags:                3.00 (Newey-West)
AR parameter:         Panel specific     Augmented lags:     1

```

Cross-sectional means removed

	Statistic	p-value
Modified Phillips-Perron t	2.1488	0.0158
Phillips-Perron t	-1.3856	0.0829
Augmented Dickey-Fuller t	-0.7217	0.2353

```

. *****Kao test*****
.
. xtointttest kao AgriValue Renc FBCF Opnes Temp Rainfall, demean

```

Kao test for cointegration

```

H0: No cointegration          Number of panels      =    12
Ha: All panels are cointegrated Number of periods     =    28

```

```

Cointegrating vector: Same
Panel means:          Included          Kernel:              Bartlett
Time trend:           Not included      Lags:                3.00 (Newey-West)
AR parameter:         Same              Augmented lags:     1

```

Cross-sectional means removed

	Statistic	p-value
Modified Dickey-Fuller t	0.9008	0.1838
Dickey-Fuller t	0.5346	0.2965
Augmented Dickey-Fuller t	0.2223	0.4120
Unadjusted modified Dickey-Fuller t	-4.0887	0.0000
Unadjusted Dickey-Fuller t	-2.8051	0.0025

```

. *****westerlund*****
.
. xtointttest westerlund AgriValue Renc FBCF Opnes Temp Rainfall, demean

```

Westerlund test for cointegration

```

H0: No cointegration          Number of panels      =    12
Ha: Some panels are cointegrated Number of periods     =    30

```

```

Cointegrating vector: Panel specific
Panel means:          Included
Time trend:           Not included
AR parameter:         Panel specific

```

Cross-sectional means removed

	Statistic	p-value
Variance ratio	3.2386	0.0006

```
. *****Granger ECM causality test*****
.
. xtwest AgriValue Renc, westerlund constant trend lags(0 1) leads(0 1) lrwindow(1)
```

Calculating Westerlund ECM panel cointegration tests.....

Results for H0: no cointegration
 With 12 series and 1 covariate
 Average AIC selected lag length: .8300000000000001
 Average AIC selected lead length: .33

Statistic	Value	Z-value	P-value
Gt	-3.131	-3.344	0.000
Ga	-17.219	-2.771	0.003
Pt	-9.601	-2.658	0.004
Pa	-13.222	-2.475	0.007

```
. xtwest AgriValue FBCF, westerlund constant trend lags(0 1) leads(0 1) lrwindow(1)
```

Calculating Westerlund ECM panel cointegration tests.....

Results for H0: no cointegration
 With 12 series and 1 covariate
 Average AIC selected lag length: .67
 Average AIC selected lead length: .25

Statistic	Value	Z-value	P-value
Gt	-3.274	-3.959	0.000
Ga	-16.796	-2.551	0.005
Pt	-9.403	-2.427	0.008
Pa	-12.493	-2.053	0.020

```
. xtwest AgriValue Opnes, westerlund constant trend lags(0 1) leads(0 1) lrwindow(1)
```

Calculating Westerlund ECM panel cointegration tests.....

Results for H0: no cointegration
 With 12 series and 1 covariate
 Average AIC selected lag length: .75
 Average AIC selected lead length: .33

Statistic	Value	Z-value	P-value
Gt	-3.519	-5.014	0.000
Ga	-19.639	-4.032	0.000
Pt	-10.109	-3.250	0.001
Pa	-13.681	-2.742	0.003

. xtwest AgriValue Temp, westerlund constant trend lags(0 1) leads(0 1) lrwindow(1)

Calculating Westerlund ECM panel cointegration tests.....

Results for H0: no cointegration
With 12 series and 1 covariate
Average AIC selected lag length: .75
Average AIC selected lead length: .25

Statistic	Value	Z-value	P-value
Gt	-2.843	-2.102	0.018
Ga	-14.327	-1.265	0.103
Pt	-8.779	-1.700	0.045
Pa	-11.155	-1.277	0.101

. xtwest Temp Renc, westerlund constant trend lags(0 1) leads(0 1) lrwindow(1)

Calculating Westerlund ECM panel cointegration tests.....

Results for H0: no cointegration
With 12 series and 1 covariate
Average AIC selected lag length: .67
Average AIC selected lead length: .17

Statistic	Value	Z-value	P-value
Gt	-4.903	-10.986	0.000
Ga	-32.957	-10.967	0.000
Pt	-17.637	-12.018	0.000
Pa	-29.065	-11.663	0.000

```

. *****Estimation du model PECM*****
.
. *****Estimation with change in temperature lineare*****
. xtpmg d.Agrivalue d.Renc d.FBCF d.Opnes d.Temp d.Rainfall, lr(1.Agrivalue Renc FBCF Opnes Temp Rainfall)
> ec(ec) replace dfe

```

Dynamic Fixed Effects Regression: Estimated Error Correction Form
(Estimate results saved as DFE)

	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
ec						
Renc	.0415592	.1336137	0.31	0.756	-.2203189	.3034373
FBCF	.0053889	.1466205	0.04	0.971	-.281982	.2927598
Opnes	-.1144012	.1600241	-0.71	0.475	-.4280427	.1992402
Temp	-5.499777	3.628724	-1.52	0.130	-12.61195	1.612391
Rainfall	-.0003288	.0107915	-0.03	0.976	-.0214799	.0208222
SR						
ec	-.2083421	.0357018	-5.84	0.000	-.2783164	-.1383678
Renc						
D1.	.1206843	.0688159	1.75	0.079	-.0141923	.255561
FBCF						
D1.	-.1556286	.0430687	-3.61	0.000	-.2400417	-.0712155
Opnes						
D1.	.0898781	.0422793	2.13	0.034	.0070121	.172744
Temp						
D1.	1.799435	.6519491	2.76	0.006	.5216381	3.077232
Rainfall						
D1.	.0017598	.0014907	1.18	0.238	-.0011619	.0046815
_cons	7.175763	4.143599	1.73	0.083	-.945541	15.29707

```

. xtpmg d.Agrivalue d.Renc d.FBCF d.Opnes d.Temp d.Rainfall, lr(1.Agrivalue Renc FBCF Opnes Temp Rainfall)
> ec(ec) replace pmg

```

```

Iteration 0: log likelihood = -781.09597 (not concave)
Iteration 1: log likelihood = -779.00243 (not concave)
Iteration 2: log likelihood = -776.18472 (not concave)
Iteration 3: log likelihood = -771.91695
Iteration 4: log likelihood = -771.76973
Iteration 5: log likelihood = -770.76315
Iteration 6: log likelihood = -770.69205
Iteration 7: log likelihood = -770.69119
Iteration 8: log likelihood = -770.69119

```

Pooled Mean Group Regression
(Estimate results saved as pmg)

```

Panel Variable (i): Code          Number of obs   =      348
Time Variable (t): Year          Number of groups =       12
                                Obs per group: min =       29
                                avg   =      29.0
                                max   =       29
                                Log Likelihood = -770.6912

```

D.Agrivalue	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
ec						
Renc	.4719866	.0882308	5.35	0.000	.2990574	.6449157
FBCF	-.0811403	.0938041	-0.86	0.387	-.2649929	.1027123
Opnes	.22649	.1014313	2.23	0.026	.0276882	.4252918
Temp	-7.094988	2.859562	-2.48	0.013	-12.69963	-1.490348
Rainfall	.0155077	.0098527	1.57	0.115	-.0038032	.0348186
SR						
ec	-.1936887	.0566462	-3.42	0.001	-.3047133	-.0826642
Renc						
D1.	-.1311959	.1905557	-0.69	0.491	-.5046783	.2422864
FBCF						
D1.	-.2680364	.0844416	-3.17	0.002	-.433539	-.1025339
Opnes						
D1.	.1038936	.0682535	1.52	0.128	-.0298808	.237668
Temp						
D1.	2.412601	.6184902	3.90	0.000	1.200382	3.624819
Rainfall						
D1.	.0003151	.0012902	0.24	0.807	-.0022136	.0028439
_cons	-4.732806	1.383362	-3.42	0.001	-7.444145	-2.021467

```

. hausman DFE pmg, sigmamore

```

	Coefficients		(b-B) Difference	sqrt(diag(V_b-V_B)) Std. err.
	(b) DFE	(B) pmg		
Renc	.0415592	.4719866	-.4304274	.2140614
FBCF	.0053889	-.0811403	.0865292	.2361199
Opnes	-.1144012	.22649	-.3408912	.2580798
Temp	-5.499777	-7.094988	1.59521	5.600179
Rainfall	-.0003288	.0155077	-.0158366	.0158939

b = Consistent under H0 and Ha; obtained from xtpmg.
B = Inconsistent under Ha, efficient under H0; obtained from xtpmg.

Test of H0: Difference in coefficients not systematic

```

chi2(5) = (b-B)'[(V_b-V_B)^(-1)](b-B)
        = 8.82
Prob > chi2 = 0.1163

```

```
. xtpmg d.Agrivalue d.Renc d.FBCF d.Opnes d.Temp d.Rainfall, lr(1.Agrivalue Renc FBCF Opnes Temp Rainfall)
> ec(ec) replace pmg
```

```
Iteration 0: log likelihood = -781.09597 (not concave)
Iteration 1: log likelihood = -779.00243 (not concave)
Iteration 2: log likelihood = -776.18472 (not concave)
Iteration 3: log likelihood = -771.91695
Iteration 4: log likelihood = -771.76973
Iteration 5: log likelihood = -770.76315
Iteration 6: log likelihood = -770.69205
Iteration 7: log likelihood = -770.69119
Iteration 8: log likelihood = -770.69119
```

Pooled Mean Group Regression
(Estimate results saved as pmg)

```
Panel Variable (i): Code           Number of obs   =       348
Time Variable (t): Year           Number of groups =        12
                                   Obs per group: min =         29
                                   avg =       29.0
                                   max =         29

                                   Log Likelihood    = -770.6912
```

D.Agrivalue	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
ec						
Renc	.4719866	.0882308	5.35	0.000	.2990574	.6449157
FBCF	-.0811403	.0938041	-0.86	0.387	-.2649929	.1027123
Opnes	.22649	.1014313	2.23	0.026	.0276882	.4252918
Temp	-7.094988	2.859562	-2.48	0.013	-12.69963	-1.490348
Rainfall	.0155077	.0098527	1.57	0.115	-.0038032	.0348186
SR						
ec	-.1936887	.0566462	-3.42	0.001	-.3047133	-.0826642
Renc D1.	-.1311959	.1905557	-0.69	0.491	-.5046783	.2422864
FBCF D1.	-.2680364	.0844416	-3.17	0.002	-.433539	-.1025339
Opnes D1.	.1038936	.0682535	1.52	0.128	-.0298808	.237668
Temp D1.	2.412601	.6184902	3.90	0.000	1.200382	3.624819
Rainfall D1.	.0003151	.0012902	0.24	0.807	-.0022136	.0028439
_cons	-4.732806	1.383362	-3.42	0.001	-7.444145	-2.021467

```
. xtpmg d.Renc d.Agrivalue d.FBCF d.Opnes d.Rainfall d.Temp, lr(1.Renc Agrivalue FBCF Opnes Rainfall Temp)
> ec(ec) replace pmg
```

```
Iteration 0: log likelihood = -698.59061 (not concave)
Iteration 1: log likelihood = -687.49063 (not concave)
Iteration 2: log likelihood = -686.41486 (not concave)
Iteration 3: log likelihood = -685.68321
Iteration 4: log likelihood = -685.21029
Iteration 5: log likelihood = -685.18917
Iteration 6: log likelihood = -685.18914
```

Pooled Mean Group Regression
(Estimate results saved as pmg)

```
Panel Variable (i): Code           Number of obs   =    348
Time Variable (t): Year           Number of groups =    12
                                   Obs per group: min =    29
                                   avg   =    29.0
                                   max   =    29
```

Log Likelihood = -685.1891

D.Renc	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
ec						
Agrivalue	.9244884	.2049529	4.51	0.000	.5227881	1.326189
FBCF	.4771216	.2193299	2.18	0.030	.047243	.9070003
Opnes	-.4079463	.1456394	-2.80	0.005	-.6933942	-.1224984
Rainfall	.0135383	.0119262	1.14	0.256	-.0098367	.0369133
Temp	-20.25647	3.989095	-5.08	0.000	-28.07495	-12.43799
SR						
ec	-.0994839	.0263339	-3.78	0.000	-.1510973	-.0478704
Agrivalue						
D1.	-.0731515	.0571212	-1.28	0.200	-.185107	.0388041
FBCF						
D1.	-.0536758	.055817	-0.96	0.336	-.1630752	.0557236
Opnes						
D1.	-.047802	.0545411	-0.88	0.381	-.1547005	.0590965
Rainfall						
D1.	.0008049	.0011784	0.68	0.495	-.0015046	.0031145
Temp						
D1.	1.345393	.440846	3.05	0.002	.4813513	2.209436
_cons	4.779152	1.467547	3.26	0.001	1.902812	7.655493

```
. xtpmg d.FBCF d.Renc d.AgriVar d.Opnes d.Rainfall d.Temp, lr(1.FBCF Renc AgriVar Opnes Rainfall Temp)
> ec(ect) replace pmg
```

```
Iteration 0: log likelihood = -787.92806 (not concave)
Iteration 1: log likelihood = -783.40655 (not concave)
Iteration 2: log likelihood = -783.32978
Iteration 3: log likelihood = -782.68889
Iteration 4: log likelihood = -782.67223
Iteration 5: log likelihood = -782.67217
```

Pooled Mean Group Regression
(Estimate results saved as pmg)

```
Panel Variable (i): Code          Number of obs   =    348
Time Variable (t): Year          Number of groups =    12
                                Obs per group: min =    29
                                avg   =    29.0
                                max   =    29
```

Log Likelihood = -782.6722

D.FBCF	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
ect						
Renc	.3034354	.1214321	2.50	0.012	.065433	.5414379
AgriVar	-.2108822	.1086069	-1.94	0.052	-.4237479	.0019834
Opnes	.5211247	.0850243	6.13	0.000	.3544801	.6877692
Rainfall	.0152524	.0069238	2.20	0.028	.001682	.0288229
Temp	3.941846	1.978133	1.99	0.046	.0647772	7.818915
SR						
ect	-.2571808	.0756993	-3.40	0.001	-.4055486	-.1088129
Renc D1.	-.0792914	.1328207	-0.60	0.551	-.3396153	.1810324
AgriVar D1.	-.1346046	.0665074	-2.02	0.043	-.2649568	-.0042525
Opnes D1.	.239564	.0705969	3.39	0.001	.1011966	.3779314
Rainfall D1.	-.0014179	.0010842	-1.31	0.191	-.0035429	.0007072
Temp D1.	1.01721	.5655465	1.80	0.072	-.091241	2.125661
_cons	-10.87794	3.8076	-2.86	0.004	-18.3407	-3.415187

```
. xtpmg d.Opnes d.FBCF d.Renc d.AgriVarue d.Rainfall d.Temp, lr(1.Opnes FBCF Renc AgriVarue Rainfall Temp)
> ec(ect) replace pmg
```

```
Iteration 0: log likelihood = -842.88797 (not concave)
Iteration 1: log likelihood = -835.56117
Iteration 2: log likelihood = -834.03451
Iteration 3: log likelihood = -833.94017
Iteration 4: log likelihood = -833.93989
Iteration 5: log likelihood = -833.93989
```

Pooled Mean Group Regression
(Estimate results saved as pmg)

```
Panel Variable (i): Code           Number of obs   =       348
Time Variable (t): Year           Number of groups =        12
                                   Obs per group: min =         29
                                   avg =          29.0
                                   max =          29
```

Log Likelihood = -833.9399

D.Opnes	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
ect						
FBCF	.0794479	.0613558	1.29	0.195	-.0408074	.1997031
Renc	.0617923	.0872737	0.71	0.479	-.1092611	.2328457
AgriVarue	.2165244	.1069262	2.02	0.043	.0069528	.426096
Rainfall	.0079374	.0055746	1.42	0.154	-.0029887	.0188634
Temp	3.098329	1.964751	1.58	0.115	-.7525124	6.949171
SR						
ect	-.3032615	.0686423	-4.42	0.000	-.437798	-.168725
FBCF D1.	.3646628	.1003451	3.63	0.000	.1679901	.5613356
Renc D1.	-.3259165	.1451621	-2.25	0.025	-.6104291	-.0414039
AgriVarue D1.	.0264937	.0684337	0.39	0.699	-.1076339	.1606213
Rainfall D1.	-.0012508	.0013772	-0.91	0.364	-.0039501	.0014485
Temp D1.	-1.920476	.4838664	-3.97	0.000	-2.868837	-.9721153
_cons	.2544479	.8895075	0.29	0.775	-1.488955	1.997851

```
. xtpmg d.Rainfall d.Opnes d.FBCF d.Renc d.AgriVarue d.Temp, lr(1.Rainfall Opnes FBCF Renc AgriVarue Temp)
> ec(ect) replace pmg
```

```
Iteration 0: log likelihood = -2128.5407 (not concave)
Iteration 1: log likelihood = -2100.5724 (not concave)
Iteration 2: log likelihood = -2054.2393 (not concave)
Iteration 3: log likelihood = -2037.6287
Iteration 4: log likelihood = -2034.8632
Iteration 5: log likelihood = -2034.8547
Iteration 6: log likelihood = -2034.8547
```

Pooled Mean Group Regression
(Estimate results saved as pmg)

```
Panel Variable (i): Code           Number of obs   =   348
Time Variable (t): Year           Number of groups =   12
                                   Obs per group: min =   29
                                   avg   =   29.0
                                   max   =   29
```

Log Likelihood = -2034.855

D.Rainfall	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
ect						
Opnes	-.1227947	.8871747	-0.14	0.890	-1.861625	1.616036
FBCF	1.159953	.6432398	1.80	0.071	-.1007739	2.42068
Renc	-1.834126	.7583821	-2.42	0.016	-3.320528	-.3477245
AgriVarue	.2853422	.9419655	0.30	0.762	-1.560876	2.131561
Temp	21.65157	13.64269	1.59	0.113	-5.087615	48.39075
SR						
ect	-1.071414	.0680085	-15.75	0.000	-1.204708	-.9381201
Opnes D1.	4.604044	1.691591	2.72	0.006	1.288587	7.919502
FBCF D1.	1.801118	3.403887	0.53	0.597	-4.870378	8.472614
Renc D1.	6.536792	3.320397	1.97	0.049	.0289342	13.04465
AgriVarue D1.	6.513039	4.314893	1.51	0.131	-1.943996	14.97007
Temp D1.	-76.29833	17.57468	-4.34	0.000	-110.7441	-41.85258
_cons	1469.156	238.8853	6.15	0.000	1000.95	1937.363

```
. xtmg d.Temp d.Rainfall d.Opnes d.FBCF d.Renc d.AgriVar, lr(1.Temp Rainfall Opnes FBCF Renc AgriVar)
> ec(ect) replace pmg
```

```
Iteration 0: log likelihood = -7.5915533 (not concave)
Iteration 1: log likelihood = 3.4660575 (not concave)
Iteration 2: log likelihood = 13.303305
Iteration 3: log likelihood = 20.155484 (not concave)
Iteration 4: log likelihood = 20.87987
Iteration 5: log likelihood = 26.359998
Iteration 6: log likelihood = 28.026732
Iteration 7: log likelihood = 28.583465
Iteration 8: log likelihood = 28.590155
Iteration 9: log likelihood = 28.590161
Iteration 10: log likelihood = 28.590161
```

Pooled Mean Group Regression
(Estimate results saved as pmg)

```
Panel Variable (i): Code          Number of obs   =      348
Time Variable (t): Year          Number of groups =      12
                                Obs per group: min =      29
                                avg =      29.0
                                max =      29
                                Log Likelihood = 28.59016
```

	D.Temp	Coefficient	Std. err.	z	P> z	[95% conf. interval]
ect						
	Rainfall	-.000877	.0002335	-3.76	0.000	-.0013346 -.0004193
	Opnes	-.0007298	.0034765	-0.21	0.834	-.0075436 .0060841
	FBCF	.0010953	.0039747	0.28	0.783	-.006695 .0088855
	Renc	-.0267255	.0027148	-9.84	0.000	-.0320464 -.0214045
	AgriVar	.0124011	.0037244	3.33	0.001	.0051014 .0197008
SR						
	ect	-.6784656	.0942573	-7.20	0.000	-.8632066 -.4937246
	Rainfall					
	D1.	.0002377	.0001189	2.00	0.046	4.58e-06 .0004708
	Opnes					
	D1.	-.0087988	.0073104	-1.20	0.229	-.0231269 .0055294
	FBCF					
	D1.	.0203793	.0085336	2.39	0.017	.0036537 .0371049
	Renc					
	D1.	.0185763	.0109746	1.69	0.091	-.0029336 .0400862
	AgriVar					
	D1.	.0071814	.0052555	1.37	0.172	-.0031192 .017482
	_cons	2.459727	.3335567	7.37	0.000	1.805968 3.113487

Annex2: Materiel and figures for essay2

Proportion estimation

Number of obs = 327

	Proportion	Std. err.	Logit [95% conf. interval]	
SHS				
No	.2140673	.0226827	.1728145	.2620479
Yes	.7859327	.0226827	.7379521	.8271855
SolarLamp				
No	.8042813	.0219405	.7575088	.8438914
Yes	.1957187	.0219405	.1561086	.2424912
Kerosenewick				
No	.9633028	.0103974	.9363773	.9790877
Yes	.0366972	.0103974	.0209123	.0636227
h_dryblamp				
No	.7767584	.023028	.7282226	.8187834
Yes	.2232416	.023028	.1812166	.2717774
SHS_Kitssolaire				
No	.5840979	.0272561	.5296885	.636532
Yes	.4159021	.0272561	.363468	.4703115
BBOXXTogo				
No	.6880734	.0256194	.6355964	.7361306
Yes	.3119266	.0256194	.2638694	.3644036
SOLEVA				
No	.9969419	.0030534	.9784715	.9995725
Yes	.0030581	.0030534	.0004275	.0215285
Solergie				
No	.9847095	.0067856	.9636845	.9936423
Yes	.0152905	.0067856	.0063577	.0363155
Marchélocal				
No	.3425076	.0262426	.29289	.3958256
Yes	.6574924	.0262426	.6041744	.70711
Don_Etat				
No	.9449541	.0126123	.9141949	.9651077
Yes	.0550459	.0126123	.0348923	.0858051
Use_Radio_TV_Computer				
No	.6269113	.0267445	.5729853	.677856
Yes	.3730887	.0267445	.322144	.4270147
Charge_phone				
No	.2110092	.0225638	.1700209	.2587977
Yes	.7889908	.0225638	.7412023	.8299791
Use_Fan				
No	.8746177	.0183127	.8339521	.9064415
Yes	.1253823	.0183127	.0935585	.1660479
Cooking_wood				
No	.1620795	.0203794	.1258632	.206258
Yes	.8379205	.0203794	.793742	.8741368
cooking_chacoal				
No	.4801223	.0276282	.4262164	.5344951
Yes	.5198777	.0276282	.4655049	.5737836
cooking_LPG				
No	.9908257	.0052724	.9718344	.9970505
Yes	.0091743	.0052724	.0029495	.0281656
Subsidice				
No	.6636086	.0261279	.6104397	.7129333
Yes	.3363914	.0261279	.2870667	.3895603

. summarize LED_KgOE LperCED_KgOE CED_KgOE CperCED_KgOE TED_KgOE TperCED_KgOE

Variable	Obs	Mean	Std. dev.	Min	Max
LED_KgOE	327	6.681033	17.56617	0	256.7734
LperCED_KgOE	327	1.300709	2.973743	0	28.28947
CED_KgOE	327	5.819384	4.047644	1.885965	18.85965
CperCED_KgOE	327	1.152027	.9677993	.1571637	6.28655
TED_KgOE	327	12.50042	18.2744	1.885965	262.4313
TperCED_KgOE	327	2.452736	3.395178	.194883	33.94737

. summarize TEEG TEEGe Ratio_TEEGincome TED_KgOEG pcTED_KgOEG TperCED_KgOE TED_KgOE

Variable	Obs	Mean	Std. dev.	Min	Max
TEEG	327	97528.86	278152	0	4058488
TEEGe	327	148.6818	424.04	0	6187.125
Ratio_TEEG~e	327	.3449299	.9032718	0	12
TED_KgOEG	327	11.7567	17.90147	1.855368	256.5657
pcTED_KgOEG	327	2.294703	3.284436	.1917213	32.59262
TperCED_KgOE	327	2.452736	3.395178	.194883	33.94737
TED_KgOE	327	12.50042	18.2744	1.885965	262.4313

- MEPI without government intervention.

Summary of mpi indicators

Indicator	Type	Weight	Deprived
Domain 1			
DepSHS	Binary	.13	21.407 %
Kerosenewick	Binary	.06	3.670 %
DeprSlarki	Binary	.06	58.410 %
Domain 2			
DepLPG	Binary	.13	99.083 %
Cooking_wood	Binary	.06	83.792 %
cooking_chacoal	Binary	.06	51.988 %
Domain 3			
TEEIR	Binary	.13	93.884 %
RTEEC	Binary	.12	92.966 %
Domain 4			
DepRadio	Binary	.05	62.691 %
Depphone	Binary	.05	21.101 %
DepFan	Binary	.05	87.462 %
Depricdu	Binary	.05	90.520 %
Acci_saft	Binary	.05	33.333 %

Deprived: Percentage of individuals whose indicator values are below the threshold.

Main results

N = 327

	Coefficient	Std. err.	[95% conf. interval]	
Main	H	0.902	0.016	0.870 0.934
	M0	0.613	0.012	0.589 0.637
Additional	A	0.679	0.006	0.668 0.691

Note: Adjusted Multidimensional Headcount

M0 = H*A

Indicator	M0
domain 1	
DepSHS	0.045
Kerosenewick	0.004
DeprSlarki	0.054
domain 2	
DepLPG	0.191
Cooking_wood	0.078
cooking_chacoal	0.046
domain 3	
TEEIR	0.185
RTEEC	0.171
domain 4	
DepRadio	0.050
Depphone	0.017
DepFan	0.067
Depricdu	0.067
Acci_saft	0.026
Total	1.000

Contribution of each indicator (%)

Domain	M0
domain 1	0.103
domain 2	0.315
domain 3	0.355
domain 4	0.227
Total	1.000

Contribution of each domain (%)

Type `ereturn list` to see the list of saved results and more information on the estimation sample.

Decomposition by subgroups

MPI by: hprefect

	Agou	Haho	Ogou	Total
H	0.853	0.935	0.898	0.902
M0	0.567	0.618	0.635	0.613
pop share	0.229	0.379	0.391	1.000

Indices by subgroup (absolute)

	Agou	Haho	Ogou	Total
H	0.217	0.393	0.390	1.000
M0	0.212	0.383	0.405	1.000

Contribution of subgroups to indices (%)

	Agou	Haho	Ogou	Total
M0				
DepSHS	0.031	0.027	0.070	0.045
Kerosenewick	0.007	0.003	0.002	0.004
DeprSlarki	0.045	0.037	0.075	0.054
DepLPG	0.196	0.197	0.184	0.191
Cooking_wood	0.086	0.079	0.072	0.078
cooking_chacoal	0.063	0.042	0.040	0.046
TEEIR	0.196	0.195	0.170	0.185
RTEEC	0.178	0.180	0.158	0.171
DepRadio	0.043	0.056	0.047	0.050
Depphone	0.008	0.016	0.022	0.017
DepFan	0.062	0.073	0.065	0.067
Depricdu	0.072	0.072	0.059	0.067
Acci_saft	0.013	0.022	0.037	0.026
Total	1.000	1.000	1.000	1.000

Contribution of each indicator (%)

	Agou	Haho	Ogou	Total
M0				
domain 1	0.083	0.067	0.147	0.103
domain 2	0.345	0.318	0.296	0.315
domain 3	0.373	0.375	0.328	0.355
domain 4	0.199	0.240	0.230	0.227
Total	1.000	1.000	1.000	1.000

Contribution of each domain (%)

Type `ereturn list` to see the list of saved results and more information on the estimation sample.

Decomposition by subgroups

MPI by: hhsex

	Homme	Femme	Total
H	0.883	0.934	0.902
M0	0.585	0.661	0.613
pop share	0.630	0.370	1.000

Indices by subgroup (absolute)

	Homme	Femme	Total
H	0.617	0.383	1.000
M0	0.601	0.399	1.000

Contribution of subgroups to indices (%)

	Homme	Femme	Total
M0			
DepSHS	0.039	0.055	0.045
Kerosenewick	0.002	0.006	0.004
DeprSlarki	0.055	0.052	0.054
DepLPG	0.196	0.184	0.191
Cooking_wood	0.080	0.074	0.078
cooking_chacoal	0.042	0.052	0.046
TEEIR	0.189	0.179	0.185
RTEEC	0.172	0.168	0.171
DepRadio	0.046	0.055	0.050
Depphone	0.016	0.017	0.017
DepFan	0.068	0.066	0.067
Depricdu	0.068	0.066	0.067
Acci_soft	0.026	0.026	0.026
Total	1.000	1.000	1.000

Contribution of each indicator (%)

	Homme	Femme	Total
M0			
domain 1	0.096	0.113	0.103
domain 2	0.318	0.310	0.315
domain 3	0.361	0.347	0.355
domain 4	0.225	0.231	0.227
Total	1.000	1.000	1.000

Contribution of each domain (%)

- MEPI with government intervention.

Summary of mpi indicators

Indicator	Type	Weight	Deprived
Domain 1			
DepSHS	Binary	.13	21.407 %
Kerosenewick	Binary	.06	3.670 %
DeprSlarki	Binary	.06	58.410 %
Domain 2			
DepLPG	Binary	.13	99.083 %
Cooking_wood	Binary	.06	83.792 %
cooking_chacoal	Binary	.06	51.988 %
Domain 3			
TEEGD	Binary	.13	58.716 %
RTEEC	Binary	.12	92.966 %
Domain 4			
DepRadio	Binary	.05	62.691 %
Depphone	Binary	.05	21.101 %
DepFan	Binary	.05	87.462 %
Depricdu	Binary	.05	90.520 %
Acci_saft	Binary	.05	33.333 %

Deprived: Percentage of individuals whose indicator values are below the threshold.

Main results

N = 327

		Coefficient	Std. err.	[95% conf. interval]	
Main	H	0.826	0.021	0.785	0.867
	M0	0.533	0.014	0.505	0.561
Additional	A	0.646	0.006	0.634	0.657

Note: Adjusted Multidimensional Headcount

M0 = H*A

Indicator	M0
domain 1	
DepSHS	0.052
Kerosenewick	0.004
DeprSlarki	0.060
domain 2	
DepLPG	0.201
Cooking_wood	0.081
cooking_chacoal	0.050
domain 3	
TEEGD	0.128
RTEEC	0.179
domain 4	
DepRadio	0.054
Depphone	0.019
DepFan	0.071
Depricdu	0.071
Acci_saft	0.029
Total	1.000

Contribution of each indicator (%)

Domain	M0
domain 1	0.116
domain 2	0.332
domain 3	0.307
domain 4	0.244
Total	1.000

Contribution of each domain (%)

Decomposition by subgroups

MPI by: hprefect

	Agou	Haho	Ogou	Total
H	0.813	0.798	0.859	0.826
M0	0.522	0.511	0.561	0.533
pop share	0.229	0.379	0.391	1.000

Indices by subgroup (absolute)

	Agou	Haho	Ogou	Total
H	0.226	0.367	0.407	1.000
M0	0.225	0.364	0.412	1.000

Contribution of subgroups to indices (%)

	Agou	Haho	Ogou	Total
M0				
DepSHS	0.033	0.033	0.080	0.052
Kerosenewick	0.008	0.004	0.003	0.004
DeprSlarki	0.047	0.043	0.082	0.060
DepLPG	0.202	0.203	0.199	0.201
Cooking_wood	0.089	0.080	0.077	0.081
cooking_chacoal	0.066	0.049	0.043	0.050
TEEGD	0.163	0.148	0.092	0.128
RTEEC	0.184	0.186	0.171	0.179
DepRadio	0.045	0.060	0.054	0.054
Depphone	0.009	0.020	0.024	0.019
DepFan	0.066	0.076	0.070	0.071
Depricdu	0.075	0.074	0.065	0.071
Acci_saft	0.013	0.026	0.041	0.029
Total	1.000	1.000	1.000	1.000

Contribution of each indicator (%)

	Agou	Haho	Ogou	Total
M0				
domain 1	0.088	0.079	0.164	0.116
domain 2	0.357	0.332	0.319	0.332
domain 3	0.346	0.333	0.263	0.307
domain 4	0.208	0.256	0.254	0.244
Total	1.000	1.000	1.000	1.000

Contribution of each domain (%)

Decomposition by subgroups

MPI by: hhsex

	Homme	Femme	Total
H	0.816	0.843	0.826
M0	0.510	0.572	0.533
pop share	0.630	0.370	1.000

Indices by subgroup (absolute)

	Homme	Femme	Total
H	0.622	0.378	1.000
M0	0.603	0.397	1.000

Contribution of subgroups to indices (%)

	Homme	Femme	Total
M0			
DepSHS	0.045	0.064	0.052
Kerosenewick	0.002	0.007	0.004
DeprSlarki	0.061	0.058	0.060
DepLPG	0.208	0.192	0.201
Cooking_wood	0.083	0.076	0.081
cooking_chacoal	0.045	0.058	0.050
TEEGD	0.131	0.124	0.128
RTEEC	0.182	0.175	0.179
DepRadio	0.051	0.058	0.054
Depphone	0.019	0.020	0.019
DepFan	0.072	0.071	0.071
Depricdu	0.072	0.069	0.071
Acci_saft	0.029	0.029	0.029
Total	1.000	1.000	1.000

Contribution of each indicator (%)

	Homme	Femme	Total
M0			
domain 1	0.108	0.129	0.116
domain 2	0.336	0.326	0.332
domain 3	0.313	0.299	0.307
domain 4	0.243	0.246	0.244
Total	1.000	1.000	1.000

Contribution of each domain (%)

- Multicollinearity test

. vif

Variable	VIF	1/VIF
Subsidice	2.99	0.334848
Marchélocal	2.98	0.335355
lpchincome	1.35	0.740137
hhsexe	1.29	0.776635
hh_Age	1.27	0.784559
nadulth	1.27	0.788038
nbchild	1.19	0.842047
hhindep	1.18	0.844761
hhformedu	1.18	0.848984
hhfarmer	1.17	0.854005
Cooking_wood	1.17	0.858226
CL_Danslacour	1.16	0.858595
hhformworker	1.11	0.904618
Lconve	1.10	0.907035
Acci_saft	1.10	0.912173
Mean VIF	1.43	

- Logistic regression

Logistic regression

Number of obs = 327

LR chi2(15) = 61.27

Prob > chi2 = 0.0000

Pseudo R2 = 0.2025

Log likelihood = -120.65617

MEPIGi	Odds ratio	Std. err.	z	P> z	[95% conf. interval]
hh_Age	1.014469	.0150167	0.97	0.332	.98546 1.044333
hhsexe	.6165702	.2376173	-1.25	0.210	.2896954 1.312271
nadulth	.7683774	.0873055	-2.32	0.020	.6149762 .9600433
nbchild	.8925734	.0923047	-1.10	0.272	.7288156 1.093126
hhformworker	2.646452	2.343416	1.10	0.272	.466585 15.01057
hhfarmer	1.585605	.8641713	0.85	0.398	.5448555 4.614331
hhindep	1.060395	.4171341	0.15	0.881	.4904847 2.292504
hhformedu	.3150489	.1441064	-2.53	0.012	.1285376 .772193
lpchincome	.3621289	.089186	-4.12	0.000	.2234741 .5868122
Cooking_wood	1.962168	.8085058	1.64	0.102	.8749856 4.400189
CL_Danslacour	1.734257	.6174704	1.55	0.122	.8630759 3.484801
Subsidice	.5842463	.3272904	-0.96	0.337	.1948764 1.751591
Lconve	1.677652	.6629535	1.31	0.190	.7732761 3.639729
Marchélocal	.5751453	.3284117	-0.97	0.333	.1878175 1.761242
Acci_saft	4.625601	2.135058	3.32	0.001	1.87187 11.43038
_cons	80.82679	179.8803	1.97	0.048	1.030869 6337.343

Note: _cons estimates baseline odds.

. margins, dydx(*)

Average marginal effects
Model VCE: OIM

Number of obs = 327

Expression: Pr(MEPIGi), predict()

dy/dx wrt: hh_Age hhsexe nadulth nbchild hhformworker hhfarmer hhindep hhformedu lpchincome Cooking_wood
CL_Danslacour Subsidice Lconve Marchélocal Acci_saft

	Delta-method				[95% conf. interval]	
	dy/dx	std. err.	z	P> z		
hh_Age	.001645	.0016915	0.97	0.331	-.0016702	.0049602
hhsexe	-.0553745	.0438074	-1.26	0.206	-.1412354	.0304865
nadulth	-.0301701	.0127314	-2.37	0.018	-.0551232	-.005217
nbchild	-.0130135	.0117895	-1.10	0.270	-.0361205	.0100935
hhformworker	.1114421	.1009157	1.10	0.269	-.086349	.3092332
hhfarmer	.0527846	.0621478	0.85	0.396	-.0690228	.174592
hhindep	.006715	.0450481	0.15	0.882	-.0815777	.0950076
hhformedu	-.1322606	.0513568	-2.58	0.010	-.2329181	-.0316032
lpchincome	-.1163128	.0259486	-4.48	0.000	-.1671711	-.0654544
Cooking_wood	.0771845	.0465808	1.66	0.098	-.0141121	.1684812
CL_Danslacour	.0630461	.0403792	1.56	0.118	-.0160958	.1421879
Subsidice	-.0615407	.0637205	-0.97	0.334	-.1864306	.0633492
Lconve	.0592462	.0450035	1.32	0.188	-.0289591	.1474515
Marchélocal	-.0633385	.0649693	-0.97	0.330	-.1906759	.063999
Acci_saft	.1753822	.051057	3.44	0.001	.0753123	.2754521

```
. logit MEPIi hh_Age hhsexex nadulth nbchild hhformworker hhfarmer hhindep hhformedu lpchincome Cooking_wood
> CL_Danslacour Subsidice Lconve Marchélocal Acci_saft, vce(robust)
```

```
Iteration 0: log pseudolikelihood = -104.7557
Iteration 1: log pseudolikelihood = -85.141419
Iteration 2: log pseudolikelihood = -73.56699
Iteration 3: log pseudolikelihood = -72.711619
Iteration 4: log pseudolikelihood = -72.702891
Iteration 5: log pseudolikelihood = -72.702886
```

```
Logistic regression                                Number of obs =    327
                                                    Wald chi2(15) =  55.95
                                                    Prob > chi2    = 0.0000
Log pseudolikelihood = -72.702886                Pseudo R2      = 0.3060
```

MEPIi	Robust		z	P> z	[95% conf. interval]	
	Coefficient	std. err.				
hh_Age	.0200169	.0203269	0.98	0.325	-.0198231	.0598569
hhsexex	-.2389661	.5002814	-0.48	0.633	-1.2195	.7415674
nadulth	-.1536968	.1230812	-1.25	0.212	-.3949315	.087538
nbchild	-.1636158	.1304222	-1.25	0.210	-.4192385	.092007
hhformworker	.0873482	.8095072	0.11	0.914	-1.499257	1.673953
hhfarmer	-.3076918	.6653411	-0.46	0.644	-1.611736	.9963527
hhindep	.3063983	.4848108	0.63	0.527	-.6438135	1.25661
hhformedu	-1.779678	.749142	-2.38	0.018	-3.247969	-.3113865
lpchincome	-1.134735	.3954046	-2.87	0.004	-1.909713	-.3597559
Cooking_wood	1.960175	.4413391	4.44	0.000	1.095166	2.825184
CL_Danslacour	.7096633	.4718139	1.50	0.133	-.215075	1.634402
Subsidice	.311719	.8502221	0.37	0.714	-1.354686	1.978124
Lconve	.8561606	.4710723	1.82	0.069	-.0671241	1.779445
Marchélocal	-1.104626	.8788889	-1.26	0.209	-2.827217	.617964
Acci_saft	1.521876	.6463312	2.35	0.019	.2550902	2.788662
_cons	4.173678	3.158898	1.32	0.186	-2.017649	10.36501

```
. lroc
```

```
Logistic model for MEPIi
```

```
Number of observations =    327
Area under ROC curve   =  0.8797
```

```
. xi: logistic PLight hh_Age hhsexo nadulth nbchild hhfarmer hhindep hhformedu lpchincome Cooking_wood CL_
> Danslacour Subsidice Lconve Marchélocal Acci_saft
```

```
Logistic regression                               Number of obs =   327
                                                  LR chi2(14)   =  67.51
                                                  Prob > chi2   =  0.0000
Log likelihood = -136.05387                       Pseudo R2    =  0.1988
```

PLight	Odds ratio	Std. err.	z	P> z	[95% conf. interval]	
hh_Age	1.013357	.0132226	1.02	0.309	.9877694	1.039607
hhsexo	2.445904	.867269	2.52	0.012	1.220731	4.900705
nadulth	.9424777	.0940899	-0.59	0.553	.7749855	1.146169
nbchild	.9771891	.0887477	-0.25	0.799	.8178488	1.167574
hhfarmer	1.776338	1.010144	1.01	0.312	.582741	5.414713
hhindep	.3464844	.1518246	-2.42	0.016	.1467908	.81784
hhformedu	.6868152	.2339331	-1.10	0.270	.3523027	1.338948
lpchincome	.7815899	.1629449	-1.18	0.237	.5194234	1.176079
Cooking_wood	.5423718	.2400738	-1.38	0.167	.2277843	1.291428
CL_Danslacour	2.689326	.9587112	2.78	0.006	1.337213	5.408616
Subsidice	.0366365	.0256997	-4.71	0.000	.0092643	.1448817
Lconve	1.03195	.3775189	0.09	0.931	.5038058	2.113753
Marchélocal	.2001573	.1172482	-2.75	0.006	.0634972	.6309404
Acci_saft	1.14851	.3694897	0.43	0.667	.6113544	2.157629
_cons	1.835267	3.7278	0.30	0.765	.0342559	98.32466

Note: _cons estimates baseline odds.

```
. margins, dydx(*)
```

```
Average marginal effects                               Number of obs = 327
Model VCE: OIM
```

```
Expression: Pr(PLight), predict()
dy/dx wrt: hh_Age hhsexo nadulth nbchild hhfarmer hhindep hhformedu lpchincome Cooking_wood
           CL_Danslacour Subsidice Lconve Marchélocal Acci_saft
```

	Delta-method				
	dy/dx	std. err.	z	P> z	[95% conf. interval]
hh_Age	.001774	.0017341	1.02	0.306	-.0016249 .0051728
hhsexo	.1195833	.0457228	2.62	0.009	.0299683 .2091983
nadulth	-.0079208	.0133162	-0.59	0.552	-.0340201 .0181785
nbchild	-.0030851	.0121378	-0.25	0.799	-.0268747 .0207044
hhfarmer	.0768179	.0756013	1.02	0.310	-.071358 .2249937
hhindep	-.1417111	.0569409	-2.49	0.013	-.2533131 -.030109
hhformedu	-.0502298	.045252	-1.11	0.267	-.138922 .0384624
lpchincome	-.032947	.0276882	-1.19	0.234	-.0872148 .0213208
Cooking_wood	-.0817982	.0585677	-1.40	0.163	-.1965889 .0329925
CL_Danslacour	.1322682	.045915	2.88	0.004	.0422765 .22226
Subsidice	-.4421073	.0836543	-5.28	0.000	-.6060667 -.278148
Lconve	.0042049	.0489118	0.09	0.931	-.0916604 .1000702
Marchélocal	-.2150769	.0745689	-2.88	0.004	-.3612293 -.0689244
Acci_saft	.0185129	.0429677	0.43	0.667	-.0657023 .102728

```
. logit PLight hh_Age hhsexo nadulth nbchild hhfarmer hhindep hhformedu lpchincome Cooking_wood CL_Danslac
> our Subsidice Lconve Marchélocal Acci_saft, vce(robust)
```

```
Iteration 0: log pseudolikelihood = -169.80976
Iteration 1: log pseudolikelihood = -139.97945
Iteration 2: log pseudolikelihood = -136.13077
Iteration 3: log pseudolikelihood = -136.05388
Iteration 4: log pseudolikelihood = -136.05387
```

```
Logistic regression                                Number of obs =    327
                                                    Wald chi2(14) =  47.92
                                                    Prob > chi2    = 0.0000
Log pseudolikelihood = -136.05387                Pseudo R2      = 0.1988
```

PLight	Robust		z	P> z	[95% conf. interval]	
	Coefficient	std. err.				
hh_Age	.0132682	.0119277	1.11	0.266	-.0101097	.0366461
hhsexo	.8944146	.3297748	2.71	0.007	.2480679	1.540761
nadulth	-.059243	.0987471	-0.60	0.549	-.2527838	.1342978
nbchild	-.0230751	.0834241	-0.28	0.782	-.1865834	.1404332
hhfarmer	.5745538	.5609075	1.02	0.306	-.5248047	1.673912
hhindep	-1.059918	.3885548	-2.73	0.006	-1.821471	-.2983641
hhformedu	-.37569	.3302338	-1.14	0.255	-1.022936	.2715563
lpchincome	-.246425	.2028417	-1.21	0.224	-.6439875	.1511374
Cooking_wood	-.6118036	.3965218	-1.54	0.123	-1.388972	.1653648
CL_Danslacour	.9892906	.3491717	2.83	0.005	.3049266	1.673655
Subsidice	-3.30671	.7156644	-4.62	0.000	-4.709386	-1.904033
Lconve	.0314503	.3320471	0.09	0.925	-.61935	.6822506
Marchélocal	-1.608652	.6071034	-2.65	0.008	-2.798553	-.4187508
Acci_saft	.1384658	.3276257	0.42	0.673	-.5036688	.7806004
_cons	.6071899	1.85753	0.33	0.744	-3.033503	4.247882

```
. lroc
```

```
Logistic model for PLight
```

```
Number of observations =    327
Area under ROC curve   =  0.8026
```

```
. xi: logistic PEEExpbaseG hh_Age hhsexex nadulth nbchild hhfarmer hhindep hhformedu lpchincome Cooking_woo
> d CL_Danslacour Subsidice Lconve Marchélocal Acci_saft
```

```
Logistic regression                               Number of obs =   327
                                                    LR chi2(14)   =   77.37
                                                    Prob > chi2   =   0.0000
Log likelihood = -36.574561                       Pseudo R2    =   0.5140
```

PEExpbaseG	Odds ratio	Std. err.	z	P> z	[95% conf. interval]	
hh_Age	.9490534	.0273251	-1.82	0.069	.8969803	1.004149
hhsexex	.321814	.2725524	-1.34	0.181	.0611928	1.692424
nadulth	.7102958	.1527528	-1.59	0.112	.4659978	1.082666
nbchild	.7700809	.1707558	-1.18	0.239	.4986468	1.189268
hhfarmer	.4254599	.5694704	-0.64	0.523	.0308703	5.863765
hhindep	1.611839	1.498563	0.51	0.608	.2605793	9.970185
hhformedu	.178129	.1721488	-1.79	0.074	.0267985	1.184021
lpchincome	.0312861	.026128	-4.15	0.000	.0060882	.1607743
Cooking_wood	1.479233	1.252019	0.46	0.644	.2815672	7.771256
CL_Danslacour	.18773	.169533	-1.85	0.064	.0319772	1.102115
Subsidice	1680.523	3563.031	3.50	0.000	26.34719	107190.1
Lconve	1.660757	1.600637	0.53	0.599	.2511415	10.98231
Marchélocal	66.74084	74.04248	3.79	0.000	7.586933	587.1068
Acci_saft	1.111184	.7999276	0.15	0.884	.2710295	4.555703
_cons	1.10e+09	6.80e+09	3.37	0.001	6063.81	2.00e+14

Note: _cons estimates baseline odds.
Note: 0 failures and 1 success completely determined.

```
. margins, dydx(*)
```

```
Average marginal effects                               Number of obs = 327
Model VCE: OIM
```

```
Expression: Pr(PEExpbaseG), predict()
dy/dx wrt: hh_Age hhsexex nadulth nbchild hhfarmer hhindep hhformedu lpchincome Cooking_wood
           CL_Danslacour Subsidice Lconve Marchélocal Acci_saft
```

	Delta-method		z	P> z	[95% conf. interval]	
	dy/dx	std. err.				
hh_Age	-.0017193	.0009474	-1.81	0.070	-.0035761	.0001375
hhsexex	-.0372783	.027505	-1.36	0.175	-.091187	.0166305
nadulth	-.0112472	.0067739	-1.66	0.097	-.0245238	.0020293
nbchild	-.0085901	.0072669	-1.18	0.237	-.022833	.0056527
hhfarmer	-.0280984	.0436915	-0.64	0.520	-.1137322	.0575354
hhindep	.0156959	.0304605	0.52	0.606	-.0440056	.0753975
hhformedu	-.0567254	.0314568	-1.80	0.071	-.1183796	.0049288
lpchincome	-.113914	.0242755	-4.69	0.000	-.161493	-.066335
Cooking_wood	.0128731	.0277296	0.46	0.642	-.0414758	.0672221
CL_Danslacour	-.0549993	.0291568	-1.89	0.059	-.1121457	.002147
Subsidice	.2441921	.0646959	3.77	0.000	.1173904	.3709938
Lconve	.0166789	.0316496	0.53	0.598	-.0453532	.0787111
Marchélocal	.1381211	.030788	4.49	0.000	.0777778	.1984645
Acci_saft	.0034664	.0236852	0.15	0.884	-.0429557	.0498885

```
. logit PEEExpbaseG hh_Age hhsexe nadulth nbchild hhfarmer hhindep hhformedu lpchincome Cooking_wood CL_Dan
> slacour Subsidice Lconve Marchélocal Acci_saft, vce(robust)
```

```
Iteration 0: log pseudolikelihood = -75.260072
Iteration 1: log pseudolikelihood = -55.300074
Iteration 2: log pseudolikelihood = -40.199766
Iteration 3: log pseudolikelihood = -36.909035
Iteration 4: log pseudolikelihood = -36.579185
Iteration 5: log pseudolikelihood = -36.574562
Iteration 6: log pseudolikelihood = -36.574561
```

```
Logistic regression                                Number of obs =    327
                                                    Wald chi2(14) =   61.91
                                                    Prob > chi2    =  0.0000
Log pseudolikelihood = -36.574561                Pseudo R2      =  0.5140
```

PEExpbaseG	Robust		z	P> z	[95% conf. interval]	
	Coefficient	std. err.				
hh_Age	-.0522903	.0250548	-2.09	0.037	-.1013968	-.0031837
hhsexe	-1.133782	.7964508	-1.42	0.155	-2.694797	.4272331
nadulth	-.3420738	.2251713	-1.52	0.129	-.7834015	.0992538
nbchild	-.2612597	.1768264	-1.48	0.140	-.6078332	.0853137
hhfarmer	-.8545847	.9459952	-0.90	0.366	-2.708701	.9995319
hhindep	.4773755	1.030498	0.46	0.643	-1.542363	2.497114
hhformedu	-1.725247	.7522938	-2.29	0.022	-3.199716	-.2507784
lpchincome	-3.464581	.6411902	-5.40	0.000	-4.721291	-2.207871
Cooking_wood	.3915238	.8988637	0.44	0.663	-1.370217	2.153264
CL_Danslacour	-1.672751	1.033977	-1.62	0.106	-3.699309	.3538077
Subsidice	7.42686	1.383271	5.37	0.000	4.715699	10.13802
Lconve	.5072735	.7550013	0.67	0.502	-.9725018	1.987049
Marchélocal	4.200817	.9459271	4.44	0.000	2.346834	6.0548
Acci_saft	.1054262	.7105699	0.15	0.882	-1.287265	1.498118
_cons	20.8188	4.718387	4.41	0.000	11.57093	30.06667

Note: 0 failures and 1 success completely determined.

```
. lroc
```

```
Logistic model for PEEExpbaseG
```

```
Number of observations =    327
Area under ROC curve   =   0.9609
```

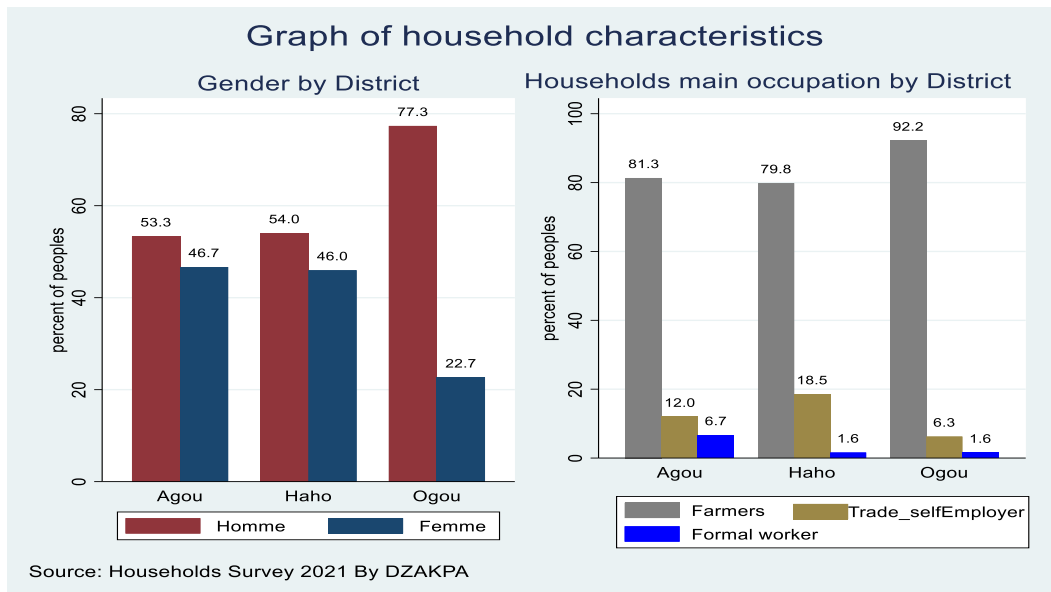


Figure 7: Household characteristics (gender and main occupation by districts)

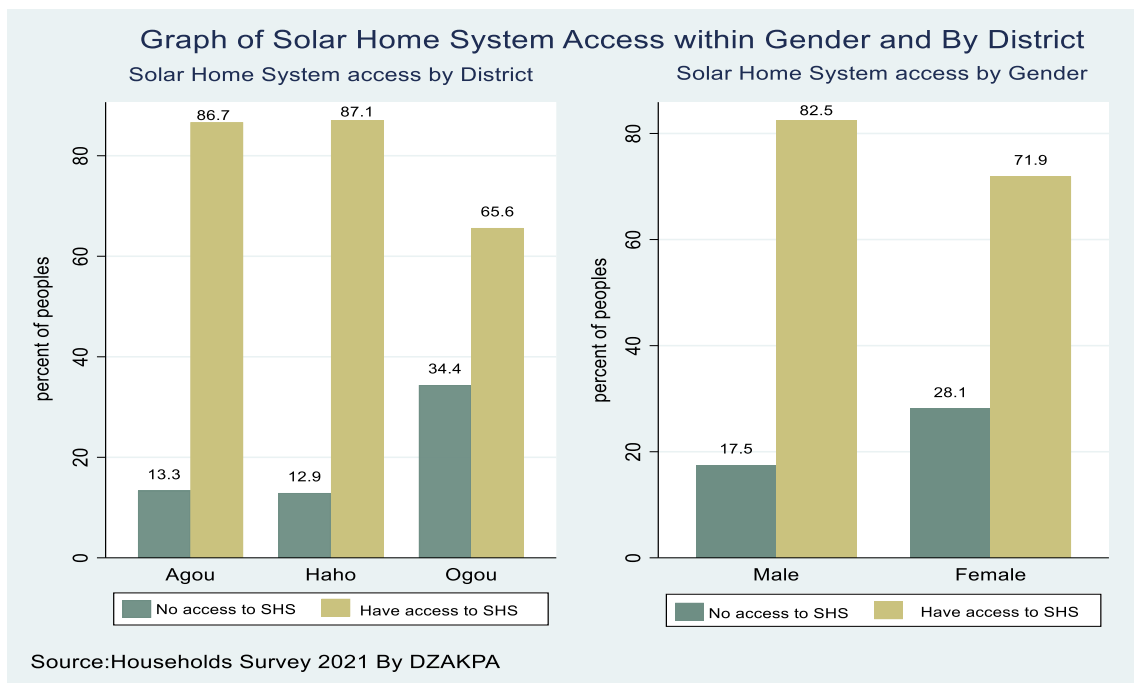


Figure 8: Solar Home access by District and by Gender

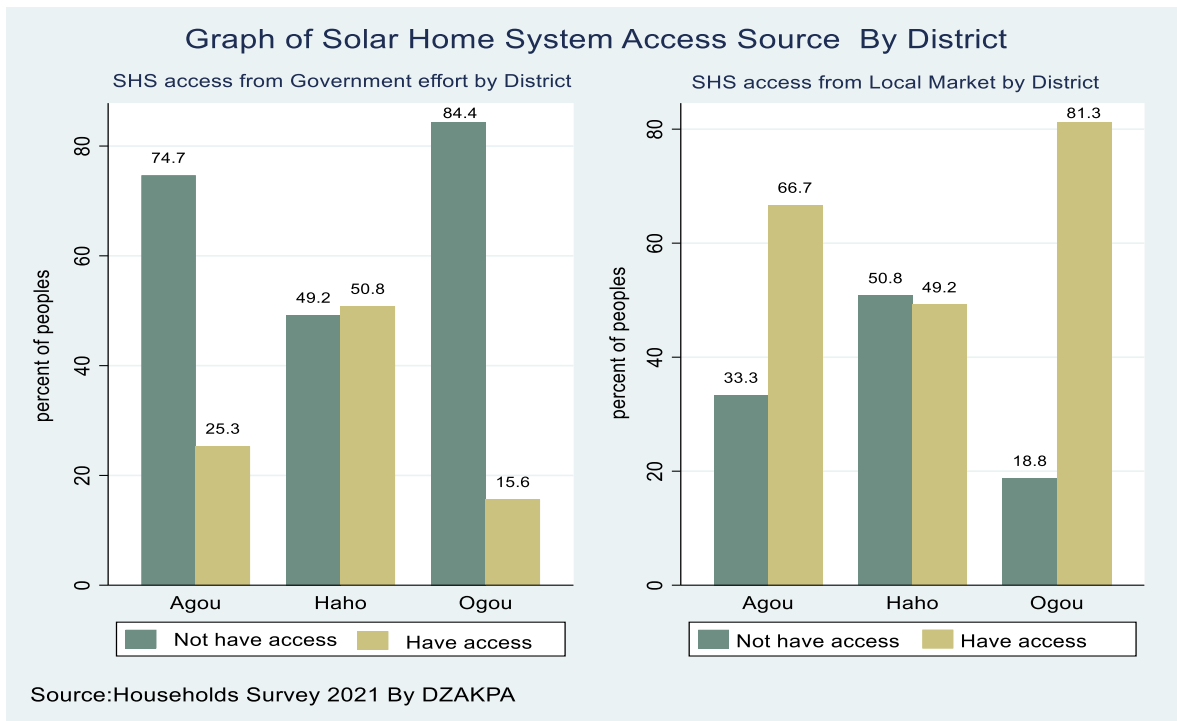


Figure 9: Household preference between Government SHS and Local Market SHS

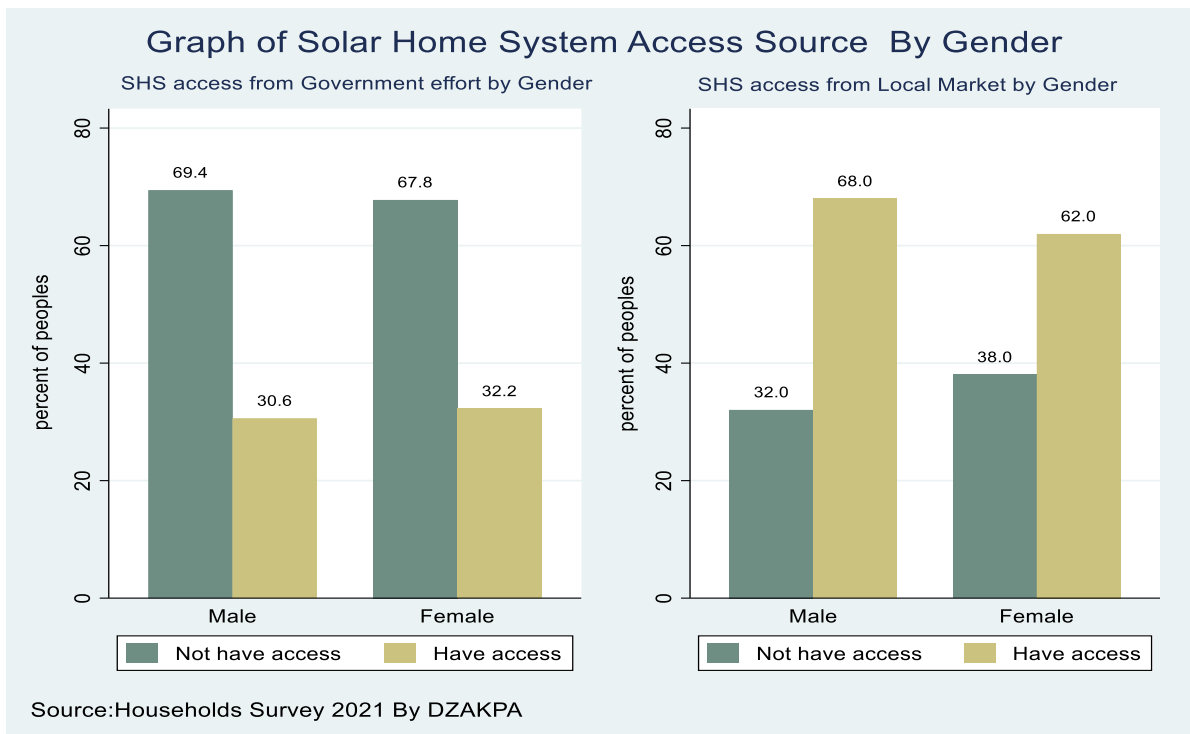


Figure 10: Gender preferences of Solar sources

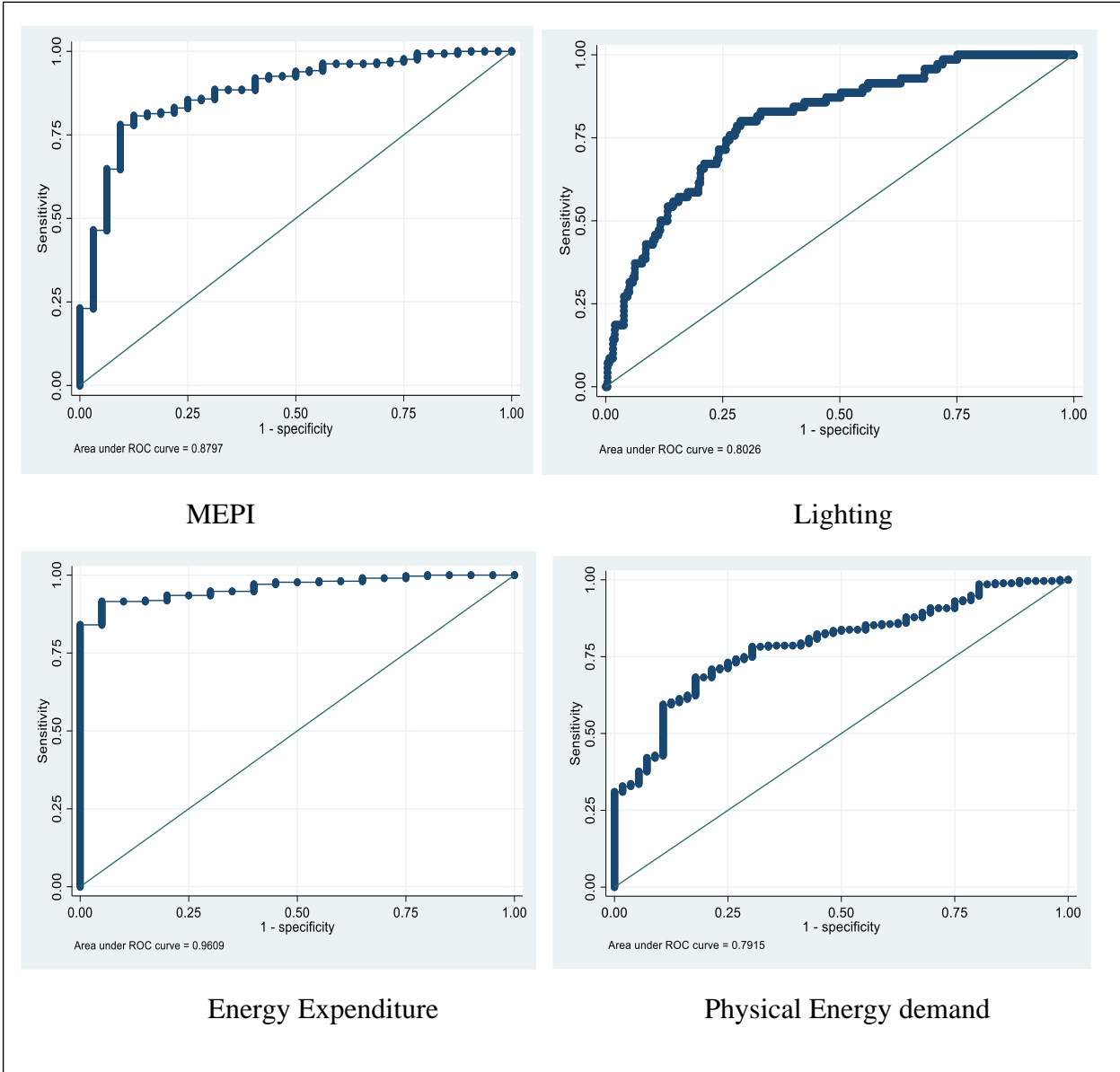


Figure 11: Receiver Operating Characteristic (ROC)

Annex3: Materials and graphic for Essay3

- Descriptive statistic of household level Data.

Variable	Description	Mean	Std. Dev.	Min./Max.
hhAge	Age of the household head	41.61	13.07	19/82
Hsize	Number of people living in the Household	5.85	2.40	1/14
Hhsex	Household's head gender (1 = female, 0 = male)	0.37	0.48	0/1
Hhformedu	Household head has basic education (1 = Yes, 0 = No)	0.68	0.46	0/1
Nbadult	Number of adults in the household	3.17	1.65	0/10
Nbchild	Number of children under 18 in the household	2.82	1.77	0/9
Nchpedu	Number of children in primary school	1.72	1.57	0/9
Nchsedu	Number of children in secondary school	0.97	1.27	0/6
Hhformwork	Household has a job with formal contract (1= Yes, 0 = No)	0.06	0.23	0/1
Hhfarm	Farmer farmer's household (1 = Yes, 0 = No)	0.89	0.31	0/1
Hhindp	Household's head is an independent worker (1 = Yes, 0 = No)	0.26	0.44	0/1
Htotincome	Household total income in a year in euro	588.98	522.32	76.2/5334
Htotexp	Household total energy expenditure in a year in euro	303.038	443.0124	45.72/6361.92
Pchincome	Per capita household income in a year in euro	121.848	138.346	6.92/1028.7
Pctexp	Per capita household total energy expenditures in a year in euro	59.45	82.30	4.72/822.96
Hhawgpe	Household's head aware about of government energy policy effectiveness (1 = Yes, 0 = No)	0.795	0.404	0/1
hhawSHS	Household's head aware about Solare Home Systems (1 = Yes, 0 = No)	0.87	0.335	0/1
Hhawcizopeff	Household's head aware about CIZO project effectiveness (1 = Yes, 0 = No)	0.85	0.35	0/1
Hmep	Household Multidimensional Energy Poor (1 = Yes, 0 = No)	0.90	0.29	0/1
Hshs	Household access to solar home system (1 = Yes, 0 = No)	0.78	0.41	0/1

. pcorr Prices1 Ligth1 Baterry1 sub , star(0.05) bonferroni

	Prices1	Ligth1	Baterry1	sub
Prices1	1.0000			
Ligth1	0.9876*	1.0000		
Baterry1	0.9781*	0.9503*	1.0000	
sub	0.4150*	0.4099*	0.4059*	1.0000

```
. ////////////////////////////////////////////////// Willingness to Pay//////////////////////////////////////
>
. clogit Choice1 Prices1 Ligth1 Baterry1 sub, group(choice_set_id)
note: multiple positive outcomes within groups encountered.
```

```
Iteration 0: log likelihood = -936.20483
Iteration 1: log likelihood = -918.13709
Iteration 2: log likelihood = -917.22546
Iteration 3: log likelihood = -917.2239
Iteration 4: log likelihood = -917.2239
```

```
Conditional (fixed-effects) logistic regression      Number of obs = 2,943
LR chi2(4) = 322.05
Prob > chi2 = 0.0000
Pseudo R2 = 0.1493
Log likelihood = -917.2239
```

Choice1	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
Prices1	-9.896513	.8040225	-12.31	0.000	-11.47237	-8.320658
Ligth1	.6752998	.0683907	9.87	0.000	.5412564	.8093431
Baterry1	.1179884	.0085742	13.76	0.000	.1011834	.1347935
sub	.6593578	.1893637	3.48	0.000	.2882117	1.030504

```
. clogit, or
```

```
Conditional (fixed-effects) logistic regression      Number of obs = 2,943
LR chi2(4) = 322.05
Prob > chi2 = 0.0000
Pseudo R2 = 0.1493
Log likelihood = -917.2239
```

Choice1	Odds ratio	Std. err.	z	P> z	[95% conf. interval]	
Prices1	.0000503	.0000405	-12.31	0.000	.0000104	.0002434
Ligth1	1.964622	.1343619	9.87	0.000	1.718164	2.246432
Baterry1	1.125231	.0096479	13.76	0.000	1.10648	1.1443
sub	1.93355	.3661443	3.48	0.000	1.33404	2.802478

```
. nlcom (_b[Ligth1])/- (_b[Prices1])
      _nl_1: (_b[Ligth1])/- (_b[Prices1])
```

Choice1	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
_nl_1	.0682361	.0030345	22.49	0.000	.0622887	.0741836

```
. nlcom (_b[Baterry1])/- (_b[Prices1])
      _nl_1: (_b[Baterry1])/- (_b[Prices1])
```

Choice1	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
_nl_1	.0119222	.0005351	22.28	0.000	.0108734	.012971

```
. nlcom (_b[sub])/- (_b[Prices1])
      _nl_1: (_b[sub])/- (_b[Prices1])
```

Choice1	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
_nl_1	.0666253	.0188402	3.54	0.000	.0296991	.1035515

```
. ////////////////////////////////////////////////// Willingness to Pay//////////////////////////////////////
>
. clogit Choice1 Prices1 Ligth1 Baterry1 sub, group(choice_set_id)
note: multiple positive outcomes within groups encountered.
```

```
Iteration 0: log likelihood = -936.20483
Iteration 1: log likelihood = -918.13709
Iteration 2: log likelihood = -917.22546
Iteration 3: log likelihood = -917.2239
Iteration 4: log likelihood = -917.2239
```

```
Conditional (fixed-effects) logistic regression      Number of obs = 2,943
                                                    LR chi2(4)      = 322.05
                                                    Prob > chi2     = 0.0000
                                                    Pseudo R2      = 0.1493

Log likelihood = -917.2239
```

Choice1	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
Prices1	-9.896513	.8040225	-12.31	0.000	-11.47237	-8.320658
Ligth1	.6752998	.0683907	9.87	0.000	.5412564	.8093431
Baterry1	.1179884	.0085742	13.76	0.000	.1011834	.1347935
sub	.6593578	.1893637	3.48	0.000	.2882117	1.030504

```
. clogit, or
```

```
Conditional (fixed-effects) logistic regression      Number of obs = 2,943
                                                    LR chi2(4)      = 322.05
                                                    Prob > chi2     = 0.0000
                                                    Pseudo R2      = 0.1493

Log likelihood = -917.2239
```

Choice1	Odds ratio	Std. err.	z	P> z	[95% conf. interval]	
Prices1	.0000503	.0000405	-12.31	0.000	.0000104	.0002434
Ligth1	1.964622	.1343619	9.87	0.000	1.718164	2.246432
Baterry1	1.125231	.0096479	13.76	0.000	1.10648	1.1443
sub	1.93355	.3661443	3.48	0.000	1.33404	2.802478

```
. nlcom (_b[Ligth1])/- (_b[Prices1])
      _nl_1: (_b[Ligth1])/- (_b[Prices1])
```

Choice1	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
_nl_1	.0682361	.0030345	22.49	0.000	.0622887	.0741836

```
. nlcom (_b[Baterry1])/- (_b[Prices1])
      _nl_1: (_b[Baterry1])/- (_b[Prices1])
```

Choice1	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
_nl_1	.0119222	.0005351	22.28	0.000	.0108734	.012971

```
. nlcom (_b[sub])/- (_b[Prices1])
      _nl_1: (_b[sub])/- (_b[Prices1])
```

Choice1	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
_nl_1	.0666253	.0188402	3.54	0.000	.0296991	.1035515

```
. ////////////////////////////////////////////////// Probability in change of choice option if the price varies////////////////////////////////////
>
. nlcom (exp(_b[Prices1 ]*0.4600) - exp(_b[Prices1 ]*0.9000))/(exp(_b[Prices1 ]*0.9000) + exp(_b[Prices1
> ]*0.4600))
```

```
      _nl_1: (exp(_b[Prices1 ]*0.4600) - exp(_b[Prices1 ]*0.9000))/(exp(_b[Prices1 ]*0.9000) + exp(_b[P
> rices1]*0.4600))
```

Choice1	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
_nl_1	.9746274	.0088622	109.98	0.000	.9572578	.991997

```
.
. nlcom (exp(_b[Prices1 ]*0.4600) - exp(_b[Prices1 ]*1.2250))/(exp(_b[Prices1 ]*1.2250) + exp(_b[Prices1
> ]*0.4600))
```

```
      _nl_1: (exp(_b[Prices1 ]*0.4600) - exp(_b[Prices1 ]*1.2250))/(exp(_b[Prices1 ]*1.2250) + exp(_b[P
> rices1]*0.4600))
```

Choice1	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
_nl_1	.99897	.0006332	1577.62	0.000	.9977289	1.000211

```
.
. nlcom (exp(_b[Prices1 ]*0.9000) - exp(_b[Prices1 ]*1.2250))/(exp(_b[Prices1 ]*1.2250) + exp(_b[Prices1
> ]*0.9000))
```

```
      _nl_1: (exp(_b[Prices1 ]*0.9000) - exp(_b[Prices1 ]*1.2250))/(exp(_b[Prices1 ]*1.2250) + exp(_b[P
> rices1]*0.9000))
```

Choice1	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
_nl_1	.9228911	.0193723	47.64	0.000	.8849222	.9608601

```
.
.
. nlcom (exp(_b[Prices1]*0.4600+_b[sub]) - exp(_b[Prices1]*0.4600))/(exp(_b[Prices1]*0.4600) + exp(_b[Pr
> ices1]*0.4600+_b[sub]))
```

```
      _nl_1: (exp(_b[Prices1]*0.4600+_b[sub]) - exp(_b[Prices1]*0.4600))/(exp(_b[Prices1]*0.4600) + exp
> (_b[Prices1]*0.4600+_b[sub]))
```

Choice1	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
_nl_1	.3182322	.0850933	3.74	0.000	.1514525	.485012

```
. //////////////////////////////////////////////////Probability for making choice between the choices option presented//
>
. predict prob
(option pc1 assumed; probability of success given one success within group)
```

```
. sum prob
```

Variable	Obs	Mean	Std. dev.	Min	Max
prob	2,943	.3329935	.1854724	.0380587	.6252819

```
. list choice_id Choice1 Prices1 Ligth1 Baterry1 sub prob in 1/3, nodisplay
```

	cho~e_id	Choice1	Prices1	Ligth1	Baterry1	sub	prob
1.	1	0	.46	5	20	.46	.3290561
2.	1	1	.925	7	50	.925	.5965739
3.	1	0	0	0	0	0	.07437

```
. list choice_id Choice1 Prices1 Ligth1 Baterry1 sub prob in 4/6, nodisplay
```

	cho~e_id	Choice1	Prices1	Ligth1	Baterry1	sub	prob
4.	1	0	.925	7	50	.925	.6252819
5.	1	1	1.225	10	50	1.225	.2967694
6.	1	0	0	0	0	0	.0779488

```
. list choice_id Choice1 Prices1 Ligth1 Baterry1 sub prob in 7/9, nodisplay
```

	cho~e_id	Choice1	Prices1	Ligth1	Baterry1	sub	prob
7.	1	0	.46	5	20	.46	.4792753
8.	1	1	1.225	10	50	1.225	.4124037
9.	1	0	0	0	0	0	.108321

```
. xi: clogit Choice1 Prices1 Ligth1 Baterry1 sub PriGend Priedu Prihhawshs PrihhAge Prihsize Prifarmsize Pc
> hincm, group(choice_set_id)
note: multiple positive outcomes within groups encountered.
```

```
Iteration 0: log likelihood = -914.11476
Iteration 1: log likelihood = -882.42167
Iteration 2: log likelihood = -880.44796
Iteration 3: log likelihood = -880.25302
Iteration 4: log likelihood = -880.25265
Iteration 5: log likelihood = -880.25265
```

```
Conditional (fixed-effects) logistic regression      Number of obs = 2,943
LR chi2(11) = 395.99
Prob > chi2 = 0.0000
Pseudo R2 = 0.1836
Log likelihood = -880.25265
```

Choice1	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
Prices1	-11.21634	.9680328	-11.59	0.000	-13.11365	-9.319028
Ligth1	.761279	.0715619	10.64	0.000	.6210203	.9015378
Baterry1	.1280276	.0089686	14.28	0.000	.1104496	.1456057
sub	.7600221	.2022277	3.76	0.000	.3636631	1.156381
PriGend	-.7069342	.198883	-3.55	0.000	-1.096738	-.3171306
Priedu	.6313606	.1994354	3.17	0.002	.2404743	1.022247
Prihhawshs	.5445851	.263386	2.07	0.039	.028358	1.060812
PrihhAge	-.0270156	.0074888	-3.61	0.000	-.0416933	-.0123379
Prihsize	.0678775	.0406845	1.67	0.095	-.0118626	.1476175
Prifarmsize	.1250481	.0402782	3.10	0.002	.0461044	.2039918
Pchincom	7.501372	6.173644	1.22	0.224	-4.598748	19.60149

```
. margins, dydx(*)
```

```
Average marginal effects      Number of obs = 2,943
Model VCE: OIM
```

```
Expression: Pr(Choice1|fixed effect is 0), predict(pu0)
dy/dx wrt: Prices1 Ligth1 Baterry1 sub PriGend Priedu Prihhawshs PrihhAge Prihsize Prifarmsize Pchincom
```

	Delta-method				
	dy/dx	std. err.	z	P> z	[95% conf. interval]
Prices1	-.4620993	.4502019	-1.03	0.305	-1.344479 .4202801
Ligth1	.0313638	.0305189	1.03	0.304	-.0284521 .0911797
Baterry1	.0052746	.0051441	1.03	0.305	-.0048076 .0153568
sub	.031312	.0314806	0.99	0.320	-.0303889 .0930128
PriGend	-.0291248	.029839	-0.98	0.329	-.0876083 .0293586
Priedu	.0260113	.0266971	0.97	0.330	-.0263142 .0783367
Prihhawshs	.0224362	.0241792	0.93	0.353	-.0249541 .0698266
PrihhAge	-.001113	.0011196	-0.99	0.320	-.0033074 .0010813
Prihsize	.0027965	.0031431	0.89	0.374	-.0033639 .0089568
Prifarmsize	.0051518	.0053204	0.97	0.333	-.005276 .0155797
Pchincom	.3090473	.0479657	6.44	0.000	.2150363 .4030584

```
. clogit Choice1 Prices1 Ligth1 Baterry1 sub PriGend Priedu Prihhawshs PrihhAge Prihsize Prifarmsize Pchin
> com, group(choice_set_id) vce(robust)
note: multiple positive outcomes within groups encountered.
```

```
Iteration 0: log pseudolikelihood = -914.11476
Iteration 1: log pseudolikelihood = -882.42167
Iteration 2: log pseudolikelihood = -880.44796
Iteration 3: log pseudolikelihood = -880.25302
Iteration 4: log pseudolikelihood = -880.25265
Iteration 5: log pseudolikelihood = -880.25265
```

```
Conditional (fixed-effects) logistic regression      Number of obs = 2,943
Wald chi2(11) = 255.79
Prob > chi2 = 0.0000
Pseudo R2 = 0.1836
Log pseudolikelihood = -880.25265
```

(Std. err. adjusted for clustering on choice_set_id)

Choice1	Coefficient	Robust std. err.	z	P> z	[95% conf. interval]	
Prices1	-11.21634	.9949296	-11.27	0.000	-13.16636	-9.266311
Ligth1	.761279	.0728299	10.45	0.000	.6185351	.904023
Baterry1	.1280276	.0089213	14.35	0.000	.1105423	.145513
sub	.7600221	.2145899	3.54	0.000	.3394336	1.180611
PriGend	-.7069342	.2074916	-3.41	0.001	-1.11361	-.3002581
Priedu	.6313606	.209057	3.02	0.003	.2216164	1.041105
Prihhawshs	.5445851	.2659481	2.05	0.041	.0233363	1.065834
PrihhAge	-.0270156	.0076261	-3.54	0.000	-.0419625	-.0120686
Prihsize	.0678775	.0452294	1.50	0.133	-.0207706	.1565255
Prifarmsize	.1250481	.0374608	3.34	0.001	.0516262	.19847
Pchincom	7.501372	3.13798	2.39	0.017	1.351045	13.6517

```
. clogit, or
```

```
Conditional (fixed-effects) logistic regression      Number of obs = 2,943
Wald chi2(11) = 255.79
Prob > chi2 = 0.0000
Pseudo R2 = 0.1836
Log pseudolikelihood = -880.25265
```

(Std. err. adjusted for clustering on choice_set_id)

Choice1	Odds ratio	Robust std. err.	z	P> z	[95% conf. interval]	
Prices1	.0000135	.0000134	-11.27	0.000	1.91e-06	.0000946
Ligth1	2.141013	.1559298	10.45	0.000	1.856207	2.469518
Baterry1	1.136584	.0101398	14.35	0.000	1.116884	1.156633
sub	2.138324	.4588627	3.54	0.000	1.404152	3.256362
PriGend	.4931538	.1023253	-3.41	0.001	.3283713	.740627
Priedu	1.880167	.393062	3.02	0.003	1.248093	2.832344
Prihhawshs	1.723893	.4584661	2.05	0.041	1.023611	2.903259
PrihhAge	.9733461	.0074229	-3.54	0.000	.9589057	.9880039
Prihsize	1.070234	.0484061	1.50	0.133	.9794437	1.169441
Prifarmsize	1.133203	.0424507	3.34	0.001	1.052982	1.219535
Pchincom	1810.526	5681.393	2.39	0.017	3.861457	848903

- Second choice modeling.

Variable	Obs	Mean	Std. dev.	Min	Max
choice2	2,943	.3333333	.4714846	0	1
Prices2	2,943	.6722222	.4881979	0	1.2
Ligth2	2,943	.2222222	.4158104	0	1
Battery2	2,943	217.7778	244.799	0	620
cropsirg	2,943	.4444444	.4969884	0	1
PriGende	2,943	.2487428	.4399606	0	1.2
Prieduc	2,943	.4604825	.510686	0	1.2
PriAwardsps	2,943	.4481482	.5092582	0	1.2
PrihhAg	2,943	27.97431	23.02926	0	98.4
Prihsiz	2,943	3.940826	3.484968	0	16.8
Prifarmsiz	2,943	1.766279	2.528953	0	30
Priyeilredu	2,943	.4851512	.5126397	0	1.2
Pripchincom	2,943	.4463625	.7049733	0	6.75
cropsirgeduc	2,943	.3044512	.4602528	0	1
cropsirgAw~s	2,943	.2962963	.4567009	0	1
cropsirgfa~z	2,943	1.167788	2.182729	0	25
cropsirgGen	2,943	.164458	.3707537	0	1
cropsirghh~e	2,943	18.49541	22.43833	0	82
cropsirghs~e	2,943	2.605505	3.321898	0	14

. pwcorr choice2 Prices2 Ligth2 Tv cropsirg, star(0.05) bonferroni

	choice2	Prices2	Ligth2	Tv	cropsirg
choice2	1.0000				
Prices2	0.1713*	1.0000			
Ligth2	0.1387*	0.2768*	1.0000		
Tv	0.1712*	0.7037*	0.0598*	1.0000	
cropsirg	0.0769*	0.6922*	-0.4781*	0.5500*	1.0000

```
. ////////////////////////////////////////////////// Willingness to Pay//////////////////////////////////////
>
. clogit choice2 Prices2 Ligth2 Tv cropsing, group(choice_set_id)
note: multiple positive outcomes within groups encountered.
```

```
Iteration 0: log likelihood = -1011.4818
Iteration 1: log likelihood = -1000.1286
Iteration 2: log likelihood = -1000.0384
Iteration 3: log likelihood = -1000.0384
```

```
Conditional (fixed-effects) logistic regression      Number of obs = 2,943
LR chi2(4) = 156.42
Prob > chi2 = 0.0000
Pseudo R2 = 0.0725
Log likelihood = -1000.0384
```

choice2	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
Prices2	-2.270891	.3612997	-6.29	0.000	-2.979026	-1.562757
Ligth2	2.726183	.335069	8.14	0.000	2.069459	3.382906
Tv	.6181099	.1011713	6.11	0.000	.4198177	.8164021
cropsing	2.480273	.3628365	6.84	0.000	1.769126	3.191419

```
. clogit, or
```

```
Conditional (fixed-effects) logistic regression      Number of obs = 2,943
LR chi2(4) = 156.42
Prob > chi2 = 0.0000
Pseudo R2 = 0.0725
Log likelihood = -1000.0384
```

choice2	Odds ratio	Std. err.	z	P> z	[95% conf. interval]	
Prices2	.1032201	.0372934	-6.29	0.000	.0508423	.2095576
Ligth2	15.27447	5.118	8.14	0.000	7.92054	29.45624
Tv	1.855418	.1877151	6.11	0.000	1.521684	2.262345
cropsing	11.94452	4.333909	6.84	0.000	5.865727	24.32293

```
. nlcom (_b[Ligth2])/- (_b[Prices2])
      _nl_1: (_b[Ligth2])/- (_b[Prices2])
```

choice2	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
_nl_1	1.20049	.0692228	17.34	0.000	1.064816	1.336164

```
. nlcom (_b[Tv])/- (_b[Prices2])
      _nl_1: (_b[Tv])/- (_b[Prices2])
```

choice2	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
_nl_1	.2721882	.0505311	5.39	0.000	.173149	.3712274

```
. nlcom (_b[cropsing])/- (_b[Prices2])
      _nl_1: (_b[cropsing])/- (_b[Prices2])
```

choice2	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
_nl_1	1.092202	.0553427	19.74	0.000	.9837326	1.200672

```
. /////////////// Probability in change of choice option if the price varies/////////////////
>
. nlcom (exp(_b[Prices2 ]*0.9) - exp(_b[Prices2 ]*1.2000))/(exp(_b[Prices2 ]*1.2000) + exp(_b[Prices2]*0.9)
> )
```

```
      _nl_1: (exp(_b[Prices2 ]*0.9) - exp(_b[Prices2 ]*1.2000))/(exp(_b[Prices2 ]*1.2000) + exp(_b[Prices2
> ]*0.9))
```

choice2	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
_nl_1	.328043	.0483629	6.78	0.000	.2332534	.4228326

```
. nlcom (exp(_b[Prices2 ]*0.9) - exp(_b[Prices2 ]*1.2250))/(exp(_b[Prices2]*1.2250) + exp(_b[Prices2]*0.9))
      _nl_1: (exp(_b[Prices2 ]*0.9) - exp(_b[Prices2 ]*1.2250))/(exp(_b[Prices2]*1.2250) + exp(_b[Prices2
> ]*0.9))
```

choice2	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
_nl_1	.3531341	.0513897	6.87	0.000	.2524121	.4538561

```
. nlcom (exp(_b[Prices2 ]*1.2) - exp(_b[Prices2 ]*1.2250))/(exp(_b[Prices2]*1.2250) + exp(_b[Prices2]*1.2))
      _nl_1: (exp(_b[Prices2 ]*1.2) - exp(_b[Prices2 ]*1.2250))/(exp(_b[Prices2]*1.2250) + exp(_b[Prices2
> ]*1.2))
```

choice2	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
_nl_1	.0283785	.0045126	6.29	0.000	.019534	.0372231

```
. nlcom (exp(_b[Prices2]*0.9+_b[cropsing]) - exp(_b[Prices2]*0.9))/(exp(_b[Prices2]*0.9) + exp(_b[Prices2]*
> 0.9+_b[cropsing]))
```

```
      _nl_1: (exp(_b[Prices2]*0.9+_b[cropsing]) - exp(_b[Prices2]*0.9))/(exp(_b[Prices2]*0.9) + exp(_b[Pri
> ces2]*0.9+_b[cropsing]))
```

choice2	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
_nl_1	.8454945	.0517294	16.34	0.000	.7441067	.9468823

```
. predict prob
(option p1 assumed; probability of success given one success within group)
```

```
. sum prob
```

Variable	Obs	Mean	Std. dev.	Min	Max
prob	2,943	.3329935	.1344249	.0857546	.5857914

```
. list choice_id choice2 Prices2 Ligth2 Battery2 crosirg prob in 1/3, nodisplay
```

	cho~e_id	choice2	Prices2	Ligth2	Battery2	crosirg	prob
1.	1	0	.925	1	50	0	.3256676
2.	1	1	.9	0	310	1	.5001209
3.	1	0	0	0	0	0	.1742114

```
. list choice_id choice2 Prices2 Ligth2 Battery2 crosirg prob in 4/6, nodisplay
```

	cho~e_id	choice2	Prices2	Ligth2	Battery2	crosirg	prob
4.	1	0	.925	1	50	0	.5857914
5.	1	0	1.2	0	620	1	.2453189
6.	1	1	0	0	0	0	.1688897

```
. list choice_id choice2 Prices2 Ligth2 Battery2 crosirg prob in 7/9, nodisplay
```

	cho~e_id	choice2	Prices2	Ligth2	Battery2	crosirg	prob
7.	1	1	.9	0	310	1	.3868309
8.	1	0	1.2	0	620	1	.3631551
9.	1	0	0	0	0	0	.250014

```
. xi: clogit choice2 Prices2 Ligth2 Tv crosirg crosirgeduc crosirgAwardsps crosirgfarmsiz crosirgyeilre
> du crosirgGen crosirghhAge crosirghsize Pchincom, group(choice_set_id)
note: multiple positive outcomes within groups encountered.
```

```
Iteration 0: log likelihood = -957.26486
Iteration 1: log likelihood = -942.33914
Iteration 2: log likelihood = -942.28251
Iteration 3: log likelihood = -942.2825
```

```
Conditional (fixed-effects) logistic regression      Number of obs = 2,943
LR chi2(12) = 271.93
Prob > chi2 = 0.0000
Pseudo R2 = 0.1261
Log likelihood = -942.2825
```

choice2	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
Prices2	-2.419518	.3751315	-6.45	0.000	-3.154762	-1.684273
Ligth2	2.927573	.3469782	8.44	0.000	2.247508	3.607638
Tv	.6256638	.1044137	5.99	0.000	.4210167	.8303109
crosirg	.3612453	.5150716	0.70	0.483	-.6482765	1.370767
crosirgeduc	1.292849	.1699412	7.61	0.000	.9597704	1.625928
crosirgAwardsps	.8040656	.1591404	5.05	0.000	.4921562	1.115975
crosirgfarmsiz	.1445772	.0332985	4.34	0.000	.0793134	.209841
crosirgyeilre	.1365707	.164851	0.83	0.407	-.1865313	.4596727
crosirgGen	.1557781	.1634763	0.95	0.341	-.1646295	.4761857
crosirghhAge	.0080794	.0060534	1.33	0.182	-.0037851	.0199439
crosirghsize	.0002159	.0331703	0.01	0.995	-.0647967	.0652285
Pchincom	3.576793	6.291436	0.57	0.570	-8.754195	15.90778

. margins, dydx(*)

Average marginal effects
Model VCE: OIM

Number of obs = 2,943

Expression: Pr(choice2|fixed effect is 0), predict(pu0)

dy/dx wrt: Prices2 Ligth2 Tv cropsirg cropsirgeduc cropsirgAwardsps cropsirgfarmsiz cropsirgyeilredu
cropsirgGen cropsirghhAge cropsirghsize Pchincom

	Delta-method		z	P> z	[95% conf. interval]	
	dy/dx	std. err.				
Prices2	-.2464723	.3176174	-0.78	0.438	-.868991	.3760464
Ligth2	.2982271	.3825043	0.78	0.436	-.4514676	1.047922
Tv	.0637353	.0823188	0.77	0.439	-.0976065	.2250772
cropsirg	.0367995	.0703562	0.52	0.601	-.1010963	.1746952
cropsirgeduc	.1317004	.1693815	0.78	0.437	-.2002812	.463682
cropsirgAwardsps	.0819088	.1060633	0.77	0.440	-.1259713	.289789
cropsirgfarmsiz	.0147278	.0191919	0.77	0.443	-.0228875	.0523432
cropsirgyeilredu	.0139122	.0241503	0.58	0.565	-.0334214	.0612459
cropsirgGen	.0158689	.0256977	0.62	0.537	-.0344976	.0662353
cropsirghhAge	.000823	.0012308	0.67	0.504	-.0015892	.0032353
cropsirghsize	.000022	.0033781	0.01	0.995	-.006599	.006643
Pchincom	.364362	.1758555	2.07	0.038	.0196917	.7090324

. clogit choice2 Prices2 Ligth2 Tv cropsirg cropsirgyeilredu cropsirgeduc cropsirgAwardsps cropsirgfarmsiz c
> cropsirgGen cropsirghhAge cropsirghsize Pchincom, group(choice_set_id) vce(robust)
note: multiple positive outcomes within groups encountered.

Iteration 0: log pseudolikelihood = -957.26486
Iteration 1: log pseudolikelihood = -942.33914
Iteration 2: log pseudolikelihood = -942.28251
Iteration 3: log pseudolikelihood = -942.2825

Conditional (fixed-effects) logistic regression

Number of obs = 2,943

Wald chi2(12) = 219.26

Prob > chi2 = 0.0000

Pseudo R2 = 0.1261

Log pseudolikelihood = -942.2825

(Std. err. adjusted for clustering on choice_set_id)

choice2	Robust		z	P> z	[95% conf. interval]	
	Coefficient	std. err.				
Prices2	-2.419518	.3800416	-6.37	0.000	-3.164386	-1.67465
Ligth2	2.927573	.3345987	8.75	0.000	2.271772	3.583374
Tv	.6256638	.1066352	5.87	0.000	.4166625	.834665
cropsirg	.3612453	.524253	0.69	0.491	-.6662718	1.388762
cropsirgyeilredu	.1365707	.1831824	0.75	0.456	-.2224602	.4956016
cropsirgeduc	1.292849	.1845767	7.00	0.000	.9310852	1.654613
cropsirgAwardsps	.8040656	.1752506	4.59	0.000	.4605807	1.147551
cropsirgfarmsiz	.1445772	.0409229	3.53	0.000	.0643697	.2247846
cropsirgGen	.1557781	.1754908	0.89	0.375	-.1881775	.4997338
cropsirghhAge	.0080794	.0064751	1.25	0.212	-.0046117	.0207704
cropsirghsize	.0002159	.0362072	0.01	0.995	-.0707488	.0711806
Pchincom	3.576793	3.132999	1.14	0.254	-2.563773	9.717359

. clogit, or

```
Conditional (fixed-effects) logistic regression      Number of obs = 2,943
                                                    Wald chi2(12) = 219.26
                                                    Prob > chi2   = 0.0000
Log pseudolikelihood = -942.2825                  Pseudo R2    = 0.1261
```

(Std. err. adjusted for clustering on choice_set_id)

choice2	Odds ratio	Robust std. err.	z	P> z	[95% conf. interval]	
Prices2	.0889645	.0338102	-6.37	0.000	.0422401	.1873738
Ligth2	18.68223	6.251052	8.75	0.000	9.696564	35.9948
Tv	1.869486	.1993531	5.87	0.000	1.516891	2.304042
cropsirg	1.435115	.7523636	0.69	0.491	.5136199	4.009884
cropsirgyeilredu	1.146336	.2099886	0.75	0.456	.8005469	1.641485
cropsirgeduc	3.643151	.672441	7.00	0.000	2.537261	5.231054
cropsirgAwarsps	2.234608	.3916164	4.59	0.000	1.584994	3.150467
cropsirgfarmsiz	1.155551	.0472885	3.53	0.000	1.066487	1.252053
cropsirgGen	1.168567	.2050728	0.89	0.375	.8284676	1.648282
cropsirghhAge	1.008112	.0065277	1.25	0.212	.995399	1.020988
cropsirghsize	1.000216	.036215	0.01	0.995	.9316959	1.073775
Pchincom	35.75867	112.0319	1.14	0.254	.0770136	16603.33

```
. clogit choice2 Prices2 Ligth2 Tv cropsirg PriGende Prieduc PriAwarsps PrihhAg cropsirgeduc cropsirgAwarsp
> s cropsirgfarmsiz cropsirgGen cropsirghhAge cropsirghsize Prihsiz Prifarmsiz Priyeilredu Pripchincom, gro
> up(choice_set_id) vce(robust)
note: multiple positive outcomes within groups encountered.
```

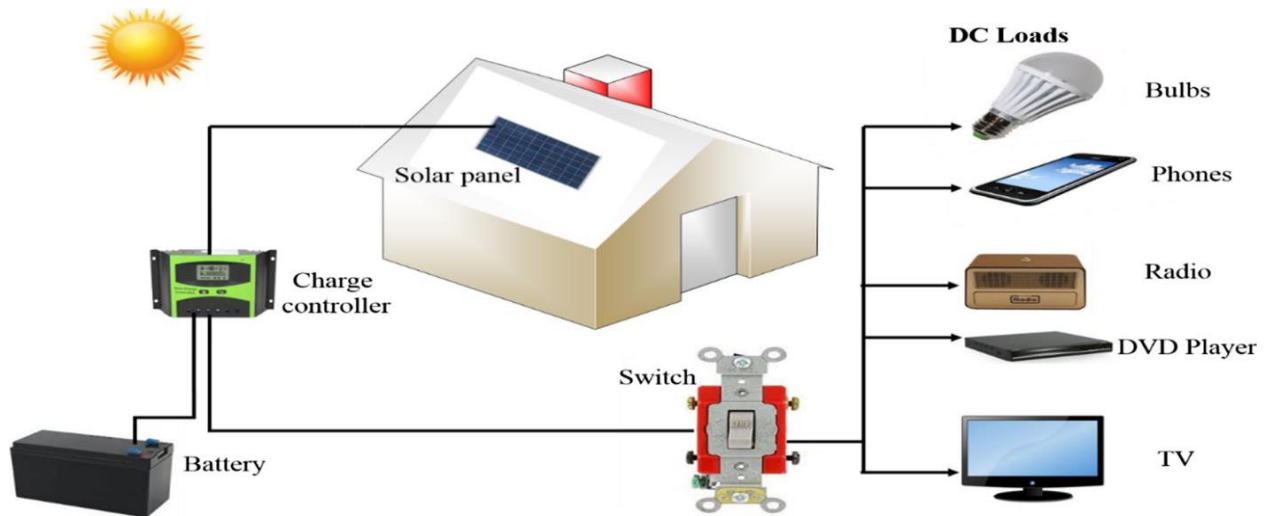
```
Iteration 0: log pseudolikelihood = -951.11815
Iteration 1: log pseudolikelihood = -934.51294
Iteration 2: log pseudolikelihood = -933.8063
Iteration 3: log pseudolikelihood = -933.80553
Iteration 4: log pseudolikelihood = -933.80553
```

```
Conditional (fixed-effects) logistic regression      Number of obs = 2,943
                                                    Wald chi2(18) = 245.29
                                                    Prob > chi2   = 0.0000
Log pseudolikelihood = -933.80553                  Pseudo R2    = 0.1340
```

(Std. err. adjusted for clustering on choice_set_id)

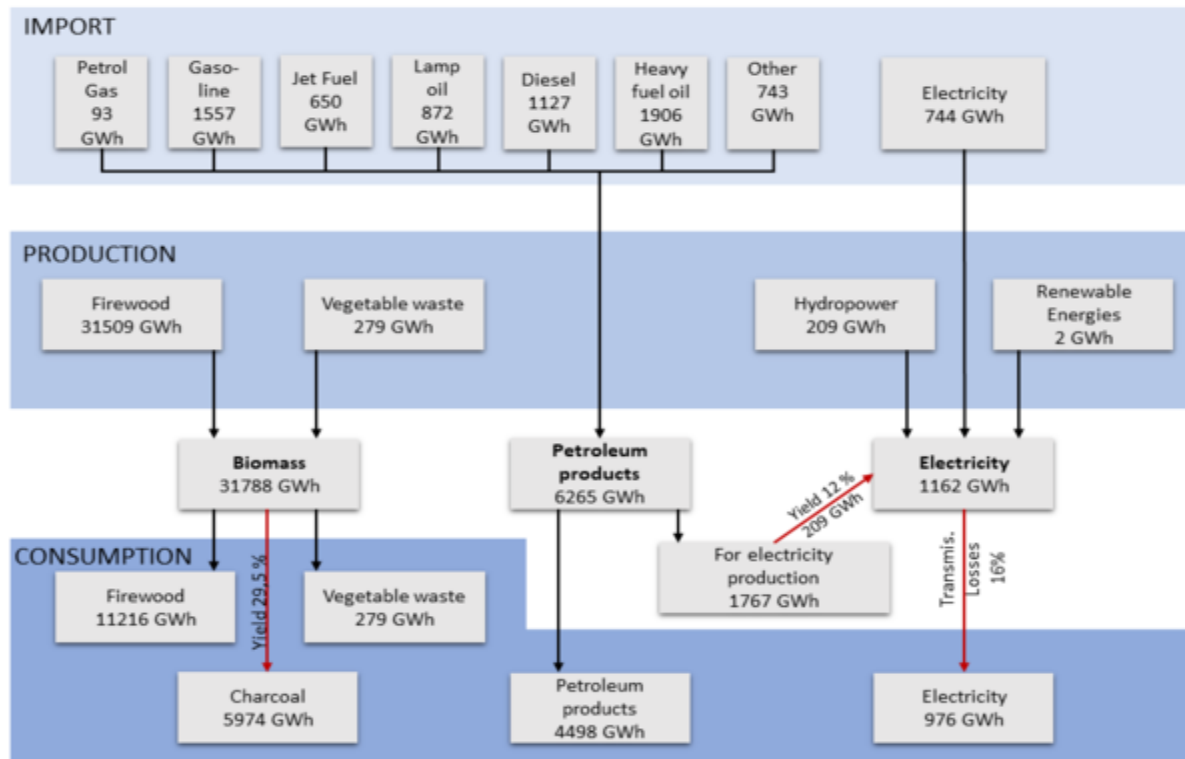
choice2	Coefficient	Robust std. err.	z	P> z	[95% conf. interval]	
Prices2	-1.391214	.6410276	-2.17	0.030	-2.647605	-.1348225
Ligth2	2.881101	.3419552	8.43	0.000	2.210881	3.55132
Tv	.6654665	.1129533	5.89	0.000	.444082	.8868509
cropsirg	-.2622322	.6366999	-0.41	0.680	-1.510141	.9856766
PriGende	.0038591	.2317904	0.02	0.987	-.4504418	.45816
Prieduc	-.4663572	.2287096	-2.04	0.041	-.9146198	-.0180945
PriAwarsps	-.6888523	.2165259	-3.18	0.001	-1.113235	-.2644693
PrihhAg	-.0092979	.0085125	-1.09	0.275	-.0259822	.0073863
cropsirgeduc	1.609343	.2494316	6.45	0.000	1.120466	2.09822
cropsirgAwarsps	1.232285	.2343348	5.26	0.000	.7729968	1.691573
cropsirgfarmsiz	.1856888	.0619464	3.00	0.003	.0642762	.3071014
cropsirgGen	.1429309	.2360199	0.61	0.545	-.3196595	.6055213
cropsirghhAge	.0143778	.008667	1.66	0.097	-.0026093	.0313649
cropsirghsize	-.0310882	.048981	-0.63	0.526	-.1270892	.0649127
Prihsiz	.041467	.0512339	0.81	0.418	-.0589495	.1418836
Prifarmsiz	-.0630825	.0592926	-1.06	0.287	-.1792939	.053129
Priyeilredu	.0827901	.1774528	0.47	0.641	-.2650111	.4305913
Pripchincom	-.0646958	.1140922	-0.57	0.571	-.2883124	.1589208

- Off-grid solar system



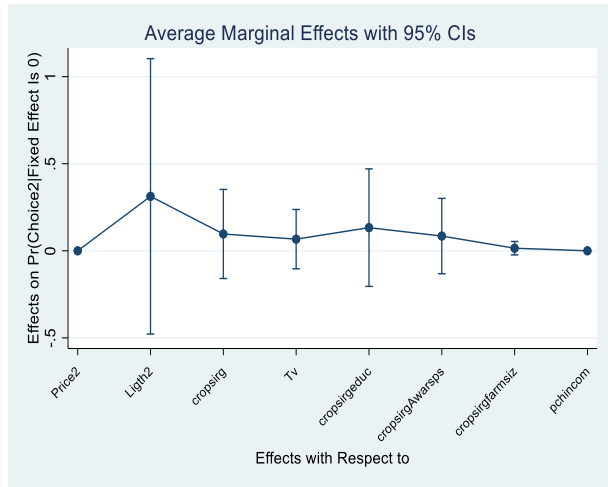
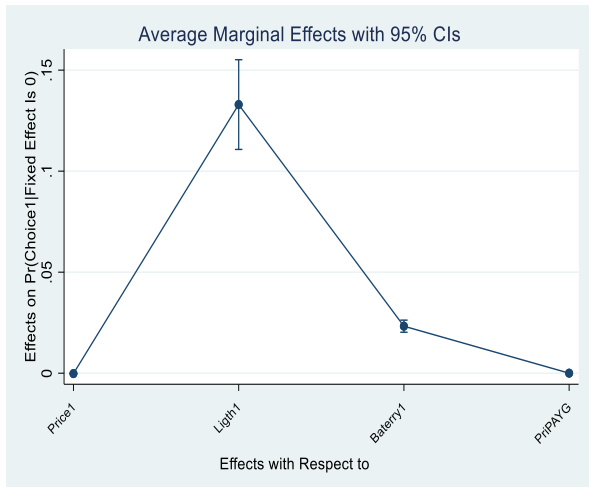
Source : (Adwek et al., 2020)

- Energy structure in Togo



Source : SIE, (2017)

- Marginal effect of attribute participation to Farmers willingness to pay for off-grid solar system



B.2	Agent de vérification/Superviseur...../ _/ _/	
SECTION 2 : CARACTERISTIQUES SOCIODEMOGRAPHIQUES		
Identification du ménage, du répondant, du chef de ménage		
A	Identification du ménage	
A.1	Nombre total de personnes dans le ménage/ _/ _/
A.2	Composition : nombre d'adulte(s) Homme (+18ans)/ _/ _/
	Nombre d'adulte(s) Femme/ _/ _/
A.3	Composition : nombre d'enfant(s) Garçon(s) (Ayant moins de 18 ans) ?/ _/ _/
	Fille(s)/ _/ _/
B	Identification du répondant	
B.1	Nom et Prénoms	
B.3	Téléphone	
		/ _/ _/ _/ _/ _/ _/ _/
B.4	Age	
	/ _/ _/
B.5	Sexe	
		1= Homme 2= Femme

C	Identification du chef de ménage	
C.1	Etes-vous le chef du ménage ? (Si oui passer à la questions C.11.)	1- Oui
		2- Non
C.2	(Si Non pour C.1) Qui est le chef du ménage (Nom et Prénoms)
C.3	Téléphone	
C.4	Age	
C.5	Sexe	
		1= Homme 2= Femme

C.6	Quel est son niveau d'éducation ?	1- Aucun
		2- Primaire
		3- Secondaire
		4- Universitaire
		5- Formation professionnelle
		6- Autre,
C.7	Quelle est sa situation professionnelle actuelle ?	1- Salarie
		2- Agriculteur/Élevage
		3- Commerçant
		4- Fonctionnaire
		5- Ménagère
		6- Autre,
C.8	Quelle est sa situation dans son travail ?	1- Employeur
		2- Indépendant
		3- Salarie
		4- Stagiaire
		5- Apprenti
		6- Autre.....
C.9	Quelle est sa moyenne d'heure de travail par jour/semaine ?	1-par jour...../ __/ __/ 2-par semaine...../ __/ __/
C.10	Quel est votre lien avec le chef de ménage ?	1-Epoux
		2-Epouse
		3-Parent
		4-Autre.....
C.11	Quels sont les principales sources de revenus du ménage ?	1- Agriculture
		2- Commerce
		3- Salaire
		4- Rente
		5- Transfer d'argent

		6- Autre...../...../
C.12	Si Agriculture, quels sont les différents types de cultures que vous pratiquez ? et combien d'unité produisez-vous annuellement (Tone/ sac/ unité de mesure locale)	1-Mais...../...../
		2-Riz...../...../
		3-Igname...../...../
		4-Rente (cacao, café, coton,) /____/
		5-Autre..... /..... /
C.13	Combien d'unité avez-vous vendu à la fin des récoltes/...../
C.14	Combien coûte l'unité vendue sur le marché local ?Fcfa
C.15	A combien estimez-vous le niveau de revenu du ménage ?Fcfa

SECTION 3 : CONSOMMATION DES SERVICES ENERGETIQUES

N*	Questions	Option de réponses
D	Principale source d'électricité	
D.1	Quelle(s) est/sont les sources d'électricité dans le ménage. <i>(Plusieurs réponses sont possibles)</i>	1-Réseau électrique
		2-Mini-réseau local
		3-Installation solaire individuelle
		4-Groupe électrogène
		5-Batterie rechargeable
		6-Pile non rechargeable
		7-Autre...../...../
		1-Réseau électrique
		2-Mini-réseau local
		3-Installation solaire individuelle

N*	Questions	Option de réponses
E	Principale source et foyers de cuisson des aliments	
E.1	Quelle est la principale source d'énergie de cuisson dans le ménage ? (Une seule réponse possible)	1-Bois
		2-Charbon de bois
		3-Copeaux et sciure de bois
		4-Gaz de pétrole liquéfié (LPG)
		5-Electricite
		6-Energie Solaire
		7-Residue Agricole
		8-Autre.....
E.1.a	Quelle est la quantité moyenne mensuelle consommée de cette source (Kg, kWh, L) ?
E.1.b	Combien de temps passez vous à collecter cette source d'énergie de cuisson ?	
E.1.c	Quelles sont les autres sources de cuisson dans le ménage. (Plusieurs réponses possible)	1-Bois
		2-Charbon de bois
		3-Copeaux et sciure de bois
		4-Gaz de pétrole liquéfié (LPG)
		5-Electricite
		6-Energie Solaire
		7-Residue Agricole
		8-Autre.....
E.1.d		

	Quelles sont les quantités mensuelles (Kg, kWh, L) consommées de ces autres sources de cuisson ?	
E.2	Pourquoi Vous utilisez cette source d'énergies (principale) de cuisson ?	1-Disponible
		2-Moins chère
		3-Facile d'approvisionnement
		4-Autre.....
E.3	Quel est le principal foyer de cuisson dans le ménage	1-Foyer à trois pierres
		2-Foyer traditionnel en céramique
		3-Foyer cloporte
		4-Foyer amélioré à bois
		5-Foyer à gaz traditionnel
		6-Foyer à gaz amélioré (Mivo...)
		7-Cuisiniere électrique
		8-Autre
E.4	Pourquoi vous préférez utiliser ce foyer de cuisson ?	1-Disponible
		2-Moins chère
		3-Facile d'approvisionnement
		4-Donne un meilleur résultat (gout)
		5-Plus économique
		6-Rapidité de la cuisson
		7-Facile à utiliser
		8-Pollue moins
		9-Autre.....

E.5	Quelle est votre dépense mensuelle d'approvisionnement de votre principale source de cuisson FCFA
E.6	Combien d'heures passez-vous par semaine à la collecte de bois ou à l'approvisionnement en énergie ?Heures
E.7	Où se trouve le foyer de cuisson ?	1-Exterieur
		2-Cuisine (pièce fermée)
		3-Salle commune
		4-Espace clos
		5-Espace ouvert
E.8	Combien de temps en moyenne par jour vous passez à faire la cuisson ?Heure
F Santé		
F.1	Combien de membres du ménage sont tombé malade au cours du dernier mois ?	-----/_/_/_/_/
F.2	Se plaignent-ils des problèmes respiratoires ?	1-Oui 2-Non
F.3	Combien de membres du ménage se plaignent de problèmes de respirations ?	-----/_/_/_/_/
F.4	Combien de membres du ménage se plaignent de problèmes de vue, cataracte ?	-----/_/_/_/_/
F.5	Combien de membres du ménage se plaignent de problèmes de cancer ?	-----/_/_/_/_/
F.6	Quels membres du ménage présentent ces problèmes de santé ?	1- Femme
		2- Enfants
		3- Homme

		4- Femmes et enfants
		5- Femmes et homme
		6- Enfants et hommes
		7- Femmes, enfants et hommes
F.7	Quels accidents avez-vous déjà enregistré dans l'usage de vos foyers ?	1- Brulures
		2- Incendies
		3- Autre
		4- Brulures et incendies
		5- Aucun accident
F.8	Quels membres du ménage en étaient victimes ?	1- Femme
		2- Enfants
		3- Homme
		4- Femmes et enfants
		5- Femmes et homme
		6- Enfants et hommes
		7- Femmes, enfants et hommes

SECTION 4 : Politique d'atténuations du changement climatique et de promotion des énergies renouvelables		
G	Aide ou Subvention pour l'accès au service énergétique moderne	
G.1	Quelles sont les ressources énergétiques naturelles disponibles dans votre milieu?	1-Solaire
		2-Lac/Cours d'eau /Rivière / Fleuve
		3-Bois
		4-Residus agricoles
		5-Autre.....
G.2	Avez-vous été consulté par le passé, au nom du gouvernement, pour la prise en	1- Oui
		2- Non

	compte de vos besoins énergétiques dans un projet /programme / loi nationale?	3- Ne sait pas
G.3	Votre localité a-t-elle bénéficié depuis les cinq (5) dernières années d'un projet d'électrification rurale ? <i>(Si non passer à la question H.1)</i>	1- Oui 2- Non
G.4	Si oui quel type de projet d'électrification avez-vous bénéficié ?	1- Réseau électrique
		2- Mini-réseau local
		3- Kits solaires
		4- Panneau Solaire
		5- Autre.....
G.5	A combien estimer vous les aides ou subventions que vous avez reçu de l'Etat pour le projet dont vous êtes bénéficié ?Fcfa
H	Information sur le changement climatique	
H.1	Avez déjà entendu parler du changement climatique ?	1-Oui 2- Non
H.2	Où avez-vous déjà écouté parler du changement climatique ?	1-Radio
		2-Télévision
		3-Sensibilisation
		4-Ecole
		5-Autre
H.3	En examinant la régularité des pluies ces 20 dernières années (2000-2021), avez-vous remarqué un changement dans la régularité des pluies ?	1-Oui 2- Non
H.4	Si Oui, a-t-elle augmentée ou diminuée ?	1-Augmentée 2- Diminuée

H.5	Avez-vous constaté un arrêt de la pluie en pleine saison des cultures pendant la dernière campagne ?	1-Oui Non	2-
H.6	Si oui, combien de jours sans pluie ?	/___/___/___/	
H.7	Durant ces jours sans pluie, quelles actions avez-vous entrepris au niveau des plantations pour éviter une baisse de vos rendements ?	_____ _____ _____	
H.8	En examinant la Température (chaleur) ces 20 dernières années (2000-2021), fait-il de plus en plus chaud dans les habitations Pendant la journée ? Pendant la nuit ?	1-Oui Non	2-
		1-Oui	2-Non
H.9	Comment arrivez-vous à vous maintenir à une température normale au niveau des habitations ?	1-Ventilateur 2-Climatisation 3-Autre (s)_____	
H.10	Avez-vous observé une sécheresse durant la dernière campagne agricole ?	1-Oui Non	2-
H.11	A-t-elle affecté vos cultures ?	1-Perte de culture 2-Reduction des rendements 3-Autre(s)	
H.12	Durant ces jours sans pluie, quelles actions avez-vous entrepris au niveau des champs pour éviter une baisse de vos rendements ?	1-Irrigation 2-Rien 3-Autre	
H.14	Savez-vous que le fait de couper plus d'arbre pour la cuisson est l'une des causes de la rareté des pluies ?	1-Oui Non	2-
H.15	Pensez-vous que le fait d'utiliser l'énergie solaire et les foyers améliorés sont-ils solution pour lutter contre le changement climatique ?	1-Oui 2-Non	

I	Consentement à payer pour avoir accès aux services énergétiques	
I.1	Avez-vous déjà attendu parler des systèmes solaires hors réseaux ?	1- Oui 2- Non
I.2	Savez-vous que les systèmes solaires hors réseaux peuvent vous permettre d'avoir accès aux services énergétiques (électricité) ?	1- Oui 2- Non
I.3	Avez-vous déjà attendu parler des Pompes solaires ?	1- Oui 2- Non
I.4	De cette liste d'offre de systèmes solaires, lequel préféreriez-vous le plus selon vos besoins et revenus financiers ?	1- Ezo Plus bPower50 (Torche, chargeur, 5 lampes, radio). Frais mensuel=4.600Fcfa, prix à crédit= 169.299Fcfa sur 3 ans ; prix cash = 150.000Fcfa 2- Ezo Tv bPower50 (Torche, chargeur, 5 lampes, radio + TV). Frais mensuel : 9.250; prix à crédit= 339.374; prix comptant=300.000Fcfa 3- Ezo Tv avec Canal+ (Torche, chargeur, 5 lampes, radio + TV+ Canal+). Frais mensuel : 12.250Fcfa ; prix à crédit= 450000Fcfa 4- Aucune
I.5	Si Ezo Plus bPower50	1- Payer au comptant = 150000Fcfa 2- Payer à crédit sur 3 ans avec paiement mensuel de 4.600Fcfa = 169.299Fcfa
I.6	Si Ezo Tv bPower50	1- Payer au cash = 300.000Fcfa 2- Payer à crédit sur 3 ans avec paiement mensuel de 9.250Fcfa = 339.374Fcfa

I.7	Si Ezo Tv avec Canal+	<p>1- Payer Cash = 300.000Fcfa</p> <p>2- Payer à crédit sur 3 ans avec paiement mensuel de 12.250Fcfa et 300Fcfa pour abonnement Canal+ après les 3ans</p>
I.8	De cette liste d'offre de Pompe solaires pour les besoins en eau, lequel préférez-vous le plus selon vos besoins d'irrigation et vos revenus agricole ?	<p>1- Pompi (1 panneau solaire de 310W ; Permet d'irriguer demi-Hectare par Jour) Frais mensuel=9.000F, prix à crédit= 335.000F sur 3 ans ; prix comptant= 250.000Fcfa</p> <p>2- Pompi plus (2panneau solaire de 310W ; Permet d'irriguer un Hectare par Jour) Frais mensuel=12.000F, prix à crédit= 450.000F sur 3 ans ; prix comptant = 325.000Fcfa</p> <p>3- Aucune</p>
I.9	Si Pompi	<p>1- Payer Cash = 250.000Fcfa</p> <p>2- Payer à crédit sur 3 ans avec un paiement mensuel de 9.000Fcfa = 335.000Fcfa</p>
I.10	Pompi plus	<p>1- Payer Cash = 325.000Fcfa</p> <p>2- Payer à crédit sur 3 ans avec un paiement mensuel de 12.000Fcfa = 450.000Fcfa</p>

Benefits	Basic_bp50	Basic plus	No interest
Monthly Price	4.600FCFA	9.250FCFA	
Have light, Radio, Phone charger, Torch	Yes	Yes	
TV without Canal Plus for having access to information	No	Yes	
TV with Canal Plus for having access to information	No	No	

Benefits	Basic plus	Basic Premium	No interest
Monthly Price	9.250FCFA	12250FCFA	
Have light, Radio, Phone charger, Torch	Yes	Yes	
TV without Canal Plus for having access to information	Yes	Yes	
TV with Canal Plus for having access to information	No	Yes	

Benefits	Basic_bp50	Basic Premium	No interest
Monthly Price	4.600FCFA	12250FCFA	
Have light, Radio, Phone charger, Torch	Yes	Yes	
TV without Canal Plus for having access to information	No	Yes	
TV with Canal Plus for having access to information	No	Yes	

Benefits	Basic Premium	Climate smart Pump Plus	No interest
Monthly Price	12250FCFA	12.000FCFA	
Have light, Radio, Phone charger, Torch	Yes	No	
TV without Canal Plus for having access to information	Yes	No	
TV with Canal Plus for having access to information	Yes	No	

Improve crop production and farmers revenues through farm irrigation	No	Yes	
--	----	-----	--

Benefits	Climate smart Pump	Climate smart Pump Plus	No interest
Monthly Price	9.000FCFA	12.000FCFA	Neither
Have light, Radio, Phone charger, Torch	No	No	
TV without Canal Plus for having access to information	No	No	
TV with Canal Plus for having access to information	No	No	
Improve crop production and farmers revenues through farm irrigation (0.5hectare per day)	Yes	Yes	
Improve crop production and farmers revenues through farm irrigation (1 hectare per day)	No	Yes	

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