THE HETEROGENEOUS IMPACTS OF ENERGY TYPE AND METERING SYSTEMS ON HOUSEHOLD WELFARE: INSIGHTS FROM GHANA AND SOUTH AFRICA

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THESIS ABSTRACT

This thesis addresses the multifaceted challenges associated with energy delivery and usage in emerging economies, focusing on their impacts on household welfare. It examines the differential effects of electricity and other primary energy sources on household enterprise income in Ghana, highlighting the significant role of energy inputs in enterprise development. Additionally, the study investigates the relationship between prepaid electricity metering and food insecurity in South Africa, revealing how prepayment systems can exacerbate hunger due to their advance payment requirement. Furthermore, the research explores the link between prepaid electricity metering and energy poverty, showing that such systems can increase the likelihood of households becoming energy-poor and resorting to unclean energy sources. Through comprehensive empirical analyses presented in three substantive papers in Chapters Two to Four, this thesis provides critical insights into the policy implications of the Heterogeneous Impacts of Energy Type and Metering Systems on Household Welfare, advocating for targeted government interventions to alleviate food and energy poverty and promote sustainable energy use. Chapter Two presents productive electricity use by non-farm enterprises in Ghana.

Energy inputs such as electricity and fuel are essential drivers of enterprise development. The research employs the Ghana Living Standard Survey (GLSS7) data to examine the importance of electricity usage on household enterprise income. This study further shows the relevance of fuel expenditure and other firm characteristics in the enterprise production process. The Lewbel IV method was the main estimation approach used in the study, with the standard Instrumental Variable (IV) results providing a foundational estimation. Both methods showed positive effects of electricity and fuel expenditure on enterprise performance. However, the test for differences between the coefficients of electricity and fuel remained insignificant, highlighting that both energy inputs are equally important. The

choice between them should consider other external factors. Furthermore, heterogeneity results based on firm size, type, location, and gender revealed specific differences when considering particular inputs, but these differential impacts were statistically insignificant. Our results have significant policy implications and advance the need for enhanced government electricity programs. Additionally, the government electricity expansion program should be target-specific if the goal is to facilitate household welfare through the productive use of electricity and promote modern fuel supply to improve household enterprise income in Ghana. This chapter's academic contribution includes decomposing the composite energy input in a household enterprise income model into electricity and other primary sources of energy (referred to as fuel) to explore energy's differential and heterogeneous impacts on household enterprise income.

Chapter Three discusses food insecurity, a long-time issue in South Africa, with over 12% (7.26 million) of its population suffering from hunger. Food insecurity in South Africa can be attributed to multiple factors, including income, employment, and access to food. However, prepayment systems could also explain food insecurity in the country as they require households to pay in advance, potentially reducing savings. This research investigates the differential impact of electricity prepayment systems and competing policy instruments on food insecurity. Applying robust techniques such as propensity score matching to the General Household Survey 2020 from South Africa, the findings show that households that use prepaid electricity meters have a higher probability of experiencing hunger. Specifically, using prepaid meters increases hunger in families and among adults and children by 3.9%, 4.7%, and 4.4%, respectively. However, hunger marginally decreases when households receive social interventions with prepaid meters. The study further observed multiple burdens of chronic diseases mediating the relationship between using prepaid electricity meters and hunger. Therefore, the policy implications of the results suggest reviewing prepaid metering and subsidy schemes for low-income households. Additionally, the study suggests that providing food assistance programs or subsidies may prove vital in directly addressing hunger in these vulnerable households. This chapter makes a significant academic contribution by pioneering the empirical regression analysis of the heterogeneous relationship between, among other factors, the use of prepaid electricity metering and food insecurity.

Chapter Four investigates the relationship between energy poverty and prepayment systems. Energy poverty is a major global issue and has implications for the welfare of individuals and society. The main drivers and barometers in measuring this phenomenon have varied across specific indicators and country-specific case studies. An often underexplained cause is the payment systems constraining electricity consumption in multiple fuel uses, resulting in fuel switching. We use the General Household Survey data of South Africa to explain the impact of prepaid payment systems on energy poverty. Applying fractional probit regression and other robustness methods, the results show that using prepaid meters increases energy poverty between 0.03 and 0.06 percentage points. Using Propensity Score Matching (PSM) to address endogeneity and enable impact analysis through quasi-experimental methods, the study found that households using prepaid meters had a 3.35% higher likelihood of being energy-poor than those using postpaid meters. The study further revealed that households become energy-deprived by switching to unclean energy sources for cooking and heating when given prepaid meters. Specifically, prepaid meters increased biomass for cooking by 5.7%, space heating by 10.9%, and room heating by 4.3%. The results also showed that vulnerable groups or poor South Africans suffer most from energy poverty using prepaid meters. Joint use of prepaid meters and Free Basic Electricity (FBE) could reduce energy poverty. Additionally, the study highlights that the combination of the Reconstruction and Development Programme

(RDP) housing scheme with prepaid meters is an effective pro-poor policy in reducing energy poverty. The study's policy implications suggest increased energy subsidies and targeted policy interventions to mitigate energy poverty. This chapter makes a significant academic contribution by pioneering the empirical regression analysis of the heterogeneous relationship between, among other factors, the use of prepaid electricity metering and energy poverty.

This study emphasises the imperative for governments to prioritize cleaner energy investments, particularly in electricity, due to its comparable impact on fuel energy but with enhanced environmental sustainability. By highlighting the lack of a significant difference in the effect of electricity and fuel energy, the research underscores the ecological advantages of electricity, urging a shift away from environmentally unfriendly fuel reliance. Additionally, the study makes a novel contribution by extending the known link between payment systems and food insecurity to electricity payment systems, shedding light on an overlooked aspect in the existing literature. Furthermore, it reveals the potential impact of payment systems on food insecurity and advocates for a comprehensive approach that addresses this economic issue for adults and children, considering safeguards not previously explored in policy solutions. The exploration of the role of prepayment technology in explaining energy poverty adds another layer to the study's contributions. Moreover, the emphasis on housing policy and energy subsidies emerges as a significant revelation, serving as a policy guide for Sub-Saharan countries and developing states aiming to enhance household welfare through well-structured policies and clean energy development, aligning with the global campaign against climate change mitigation.

DECLARATION OF OWN WORK

I, **Isaac Kwamena Nunoo**, declare that this thesis is my own unaided work, both in concept and execution and that apart from the normal guidance from my supervisor, I have received no assistance except where appropriately acknowledged in the text. I further declare that neither the substance nor any part of this thesis has been in the past, or is being, or is to be submitted for a degree at this University, or any other university.

Signature of Student

Signed by candidate

July 2023

PLAGIARISM DECLARATION

I, **Isaac Kwamena Nunoo**, declare that this thesis has been submitted to Turnitin (or equivalent similarity and originality checking software). I confirm that my supervisor has seen my report and any concerns revealed by such have been resolved with my supervisor.

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July 2023

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DEDICATION

I dedicate this thesis to my beloved parent Mr Kweku Nunoo and Madam Hannah Gyebi, and all my loved ones.

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LIST OF ACRONYMS/ABBREVIATIONS

ATE	Average Treatment Effect
CS	Community Survey
FAO	Food and Agriculture Organization
FBE	Free Basic Electricity
FBE	Free Basic Electricity
FIVIMS	Food Insecurity and Vulnerability Information and Mapping System
GHS	General Household Survey
GLSS7	Ghana Living Standard Survey
IES	Income and Expenditure Survey
ISIC	International Standard Industrial Classification
IV	Instrumental Variable
LFS	Labour Force Survey
LS	Least Square
MEPI	Multidimensional Energy Poverty Index
MS	Master Sample
NFCS	National Food Consumption Survey
NIDS	National Income Data Survey
PUE	Productive Use of Energy
RCT	Randomized Control Trial
RDP	Reconstruction for Development Programme
SASAS	South African Social Attitudes Survey
SDGs	Sustainable Development Goals
WDI	World Development Indicator

CHAPTER ONE: INTRODUCTION

1.1 Introduction to Thesis

Energy is an indispensable input in a country's sustainable development and an essential requirement for human development (Muawya & Walter, 2012; Ouedraogo, 2013). Energy used unproductively or inefficiently derails the benefit of energy access to the household. Productive and efficient energy use are two separate concepts, though often used interchangeably. However, both are closely linked and can potentially explain household welfare. Productive energy use requires households to use it for activities that generate income (Terrapon-Pfaff et al., 2018); in comparison, efficient energy use necessitates households to minimise wastage. When households use energy to engage in commercial activities that generate revenue, they become self-sufficient, lower poverty, and can pay for energy used. Simultaneously, households minimising inefficiency in energy consumption ensure reduced payments, leading to savings. Therefore, advocating for both productive and efficient energy use is a strategic approach to enhancing household welfare (Terrapon-Pfaff et al., 2018). This dual focus addresses the intertwined goals of economic empowerment through income generation and financial prudence through cost-effective energy management, contributing holistically to overall household well-being. However, the ability of households to utilise energy productively or efficiently is influenced by various factors, including the available energy quantity, alternative fuels, income levels, and payment structures. Consequently, the diverse energy mix accessible to households and income constraints, driven by income and payment systems, often result in trade-offs between different energy inputs, modern versus traditional, clean versus unclean, and even among competing for household necessities such as food and others. These intricate trade-offs and consequences constitute a comprehensive domain, which will be thoroughly explored in three substantive papers. The statement of the problem for this research emphasises the tradeoffs faced by households concerning electricity versus fuel energy, as well as the allocation of resources between food and electricity consumption. Additionally, it examines the choice between clean and unclean forms of energy, highlighting how household decisions are influenced by affordability within the constraints of limited income. These choices often involve sacrificing other essential needs, leading to either improved welfare or adverse consequences for households. The overarching research question guiding this doctoral thesis is: "How do energy utilisation patterns, particularly in the context of productive use and payment systems, impact household welfare, with a focus on developing countries?" This research question encapsulates the core focus of the thesis, aiming to delve into the intricate interplay between energy consumption behaviours, payment structures, policy initiatives and their collective influence on household welfare outcomes. By answering this broader research problem in three separate substantive papers, the thesis endeavours to contribute to a deeper understanding of the multifaceted challenges surrounding clean, modern energy usage and their implications for socioeconomic well-being in diverse household settings.

Transitioning to modern energy sources is critical to achieving SDG7 and promoting sustainable development. The use of modern energy is believed to be safe compared to the cheaper traditional energy sources that have health consequences and contribute to global climate change issues (Ouedraogo, 2013). Energy access is relevant, but what energy is used for is what generates income and improves the livelihoods of poor households in developing countries. In addition to energy use, the study answers which type of energy drives enterprise performance better. Based on this background, paper one will focus on productive electricity use among non-farm enterprises. However, an alternative energy source, such as fuel, used commonly in addition to electricity in enterprise growth, has yet to receive more consideration. Hence, we begin the research by exploring electricity and fuel energy, which have more importance to enterprise development. Governments will be motivated to enhance electrification and electricity usage if electricity drives enterprise development better. Besides, will the combination of energy use differ by different enterprise groups or sizes? When answered, evidence on the differential impact between electricity and fuel energy aligns with the productive use of energy discussion earlier.

On the other hand, energy efficiency focuses on a household using energy only when needed (Jaffe & Stavins, 1994). Given the high population growth rate and the slower investment in the energy sector in most developing countries, energy efficiency becomes an important tool to ensure a relatively stable supply to meet growing demands. Even high investment in energy without a corresponding investment in energy efficiency measures affects both the state goals of fastening energy access for all and, more importantly, impoverishes the already poor household. To this end, most developing countries had to implement measures and policies to enhance energy efficiency. These measures include a ban on inefficient appliances and prepayment technologies (Jaffe & Stavins, 1994). The latter has gained much attention since it can affect key welfare indicators such as hunger and energy poverty. With the same notion of Productive Energy Use, Energy Efficiency could potentially explain household welfare by improving their income, reducing food insecurity, or preventing energy poverty.

A postpaid payment system functions as a form of credit assistance, allowing individuals to defer payment to a later date. This setup enables individuals to work, accumulate savings, and subsequently meet their financial obligations for electricity usage. In contrast, the prepaid payment system lacks this form of credit assistance, requiring users to make upfront payments without the option for deferred payments. The prepayment technologies allow consumers to determine the amount of electricity they require and are to pay upfront (Jack & Smith, 2016a). The absence of credit assistance in prepaid systems may impact the financial dynamics of households, influencing their ability to manage and prioritise expenses, as explored in subsequent sections of this thesis. In households experiencing financial constraints where credit assistance is eliminated, and upfront payment is required, individuals often face a dilemma: either forego electricity usage or allocate the available income towards both electricity and essential food needs. This decision-making process, driven by the payment structure for electricity delivery, becomes a focal point in this thesis, mainly explored in Paper Two. Additionally, certain households heavily depend on electricity for cooking and refrigeration. Prioritising food over electricity would result in a lack of energy for cooking or reliance on unclean fuel sources. Conversely, prioritizing electricity over food would mean that perishable items cannot be preserved in refrigerators, leading to potential food spoilage and food poisoning risks. Both scenarios significantly impact overall food consumption, providing a compelling avenue for investigation in this thesis, particularly in Paper Two. Examining the diverse groups within households and understanding the sacrifices made to maintain insufficient food consumption will contribute to a nuanced comprehension of the issue. This investigation holds relevance for both academic inquiry and policy considerations.As we delve into the transition from postpaid to prepaid systems, it becomes evident that this shift may introduce trade-offs among essential household needs, such as allocating resources between electricity and necessities like food. Moreover, a potential trade-off emerges between cleaner energy sources, exemplified by electricity, and less clean alternatives like biomass. Prepaid meters elevate the perceived cost of electricity (though the tariff remains consistent), subsequently impacting household welfare and resulting in a decline in energy consumption (Jack & Smith, 2016a). Households faced with reduced electricity usage may resort to cheaper yet unclean energy sources, constituting a condition defined in this study as energy poverty – the tendency to rely on unclean forms of energy for household activities. Households typically draw from multiple energy sources, including electricity, charcoal, candles, paraffin, firewood, natural gas, and others, for various needs such as lighting, cooking, and heating. Constraints imposed by prepaid payment systems and household income may lead to a shift away from electricity reliance, mainly if savings are not readily available for upfront payments. Consequently, households may predominantly utilise electricity for lighting while turning to biomass sources for cooking and heating, as the fuel stacking theory elucidated. The research not only explores the possibility of this phenomenon but also delves into several policy initiatives that could potentially influence household decisions regarding energy consumption. One noteworthy initiative is the Free Basic Electricity (FBE) subsidy, designed to provide a minimum amount of electricity for free, potentially encouraging households to maintain their reliance on electricity. Additionally, various policies, such as the government-assisted Reconstruction and Development Programme (RDP) housing, aim to construct dwellings for low-income families with quality structural features, energy-efficient appliances, standardised metering systems, and adherence to building codes. Enhanced structural features and energy-efficient appliances reduce electricity costs, fostering increased electricity consumption for household activities and mitigating energy poverty. Investigating how policies can address energy poverty within the context of payment systems constitutes the focal point of Paper Three.

In summary, this thesis explores the intricate relationship between energy utilisation and household welfare, recognising the pivotal roles of both productive energy use and energy efficiency. The research aims to elucidate their impacts on economic empowerment and financial prudence within households by advocating for a dual focus. The transition from postpaid to prepaid payment systems unveils potential trade-offs between essential needs such as electricity and food and cleaner and less clean energy sources like biomass.

These dynamics underscore the importance of understanding how payment structures influence energy consumption patterns and household welfare. Moreover, the thesis delves into policy initiatives to promote modern energy usage over traditional sources, highlighting the significance of energy access in driving income generation and improving livelihoods, particularly in developing countries. Through comprehensive examination and analysis, this research offers insights into effective policy interventions for addressing energy poverty and enhancing household well-being in diverse socio-economic contexts.

1.2 Research Objectives

Energy access should be affordable, reliable, and sustainable for all individuals to achieve Sustainable Development Goals (SDGs). To this end, energy is one relevant requirement for welfare enhancement as it's helpful in all aspects of human life notably, education (SGD 4), Health (SDG 3), Zero hunger (SDG 2), and poverty reduction through the promotion of affordable and clean energy (SDGs 1 and 7).

The research generally investigates energy usage and how electricity metering impacts household welfare in the developing nations of Ghana and South Africa. Specifically, the research aims will;

- ❖ Examine productive electricity use in a non-farm enterprise.
- ❖ Explores the possibility of experiencing hunger or household food insecurity considering prepayment electricity systems.
- ❖ Conduct a comprehensive assessment to analyse the influence of implementing prepaid metering and the effectiveness of compensating policy interventions on household energy poverty.

1.3 Relevance of the Thesis

This thesis makes significant contributions to both academic research and policy by exploring the multifaceted impacts of energy use on household welfare. Academically, the research decomposes household energy input into electricity and other fuels to assess their distinct effects on enterprise income. It also extends theoretical frameworks to link prepaid electricity metering with household food and energy budgets, offering new insights into food insecurity and energy poverty. The thesis pioneers' empirical analyses of how prepaid metering influences these issues, revealing important differential and heterogeneous relationships. From a policy perspective, the thesis provides critical insights into the complex effects of energy delivery and usage on household welfare in emerging economies. It highlights the potential challenges of promoting productive electricity use driven by climate change motivations and uncovers previously unknown implications of electricity metering systems for government programs targeting food insecurity and energy poverty. Additionally, the research emphasises the importance of housing policy and energy subsidies in enhancing household welfare and supporting clean energy development.

The first paper provides a compelling rationale for government investment in electricity expansion despite the availability of alternative energy sources. Through a meticulous analysis of the differential impacts of electricity and fuel energy on non-farm activities, the paper highlights the pivotal role of income generation for households in repaying investments in the electricity sector. By addressing the critical gap in acknowledging the multifaceted role of various energy sources beyond mere economic considerations, the study advocates for the adoption of modern, cleaner energy solutions. This not only facilitates income generation for households but also holds promise for broader improvements in welfare, extending beyond financial aspects to encompass environmental sustainability and other socio-economic factors. Furthermore, it is imperative to prioritise a higher proportion and utilisation of cleaner energy within household energy mixes for both individual and environmental health, transcending the allure of cheaper fuels. The potential difference in profitability between diverse energy inputs may not outweigh the broader benefits of adopting cleaner energy solutions. Therefore, emphasising the importance of transitioning towards cleaner energy sources becomes paramount, not only for economic prosperity but also for sustainable development and the well-being of both individuals and the environment.

In addition, a critical gap in the literature persists regarding the acknowledgement of fuel energy's pivotal role in household commercial activities. This paper endeavours to fill this void by emphasising the necessity of incorporating modern fuel energy sources, including gas, diesel and traditional fuels such as wood, charcoal and kerosene, into governmental initiatives to foster entrepreneurial endeavours within households. By doing so, the study aims to address a fundamental question: which energy source holds greater significance in augmenting household profitability? Furthermore, this research makes a substantial contribution by meticulously examining the varying impacts of competing energy sources across distinct enterprise types, encompassing manufacturing, wholesale/retail, service, and food processing sectors. Through this comprehensive analysis, the paper offers invaluable insights into optimising energy utilisation strategies tailored to diverse business contexts, thereby enriching scholarly discourse and informing policy frameworks to bolster household economic empowerment. The research study's second objective is to significantly contribute to the existing literature on the causes of food insecurity at the household level. The scope of household food insecurity is restricted to concentrate specifically on the issue of hunger. The second paper explicitly investigates the impact of prepaid metering technologies on household welfare, particularly concerning hunger. While previous literature has identified income constraints and unemployment as contributing factors to food insecurity, payment mechanisms that affect household income and expenditure patterns, such as prepaid meters, are essential instruments that must be considered. This study highlights the relevance of subsidies in mitigating the adverse effects of food insecurity, particularly hunger. Moreover, the paper identifies chronicity as a significant transmission channel that elucidates the link between prepayment electricity systems and food insecurity among South African households. This study also brings to light the possibility of electricity prepayment systems to explain food insecurity. It highlights the need to explore other payment mechanisms, such as credit cards and other transmission mechanisms that have yet to be explored. By addressing these issues, policymakers and academics can develop comprehensive solutions to achieve SDG goal 2, which aims to eradicate hunger and food insecurity, especially at the household level. The study's findings are crucial to developing policies and strategies to combat food insecurity and improve household welfare, making it highly relevant to ongoing research.

The third objective of this study is to investigate the effects of electricity prepayment and the moderation effects of competing policy instruments on energy poverty and fuel stacking. The research makes a valuable contribution to energy poverty studies by utilising more sophisticated and comprehensive measures to assess the phenomenon. Specifically, the study proposes a multidimensional energy poverty measure based on several indicators of energy deprivation, including cooking, lighting, space and water heating, household entertainment appliances, walling structures, and telecommunication, which is uncommon in the existing literature on energy poverty. The study also sheds light on the fuel stacking theory, providing a deeper understanding of the factors contributing to energy poverty. The fuel stacking theory is a valuable theoretical framework for understanding the energy consumption patterns of households experiencing energy poverty. It proposes that households prioritise more accessible fuels over more expensive and cleaner alternatives due to financial constraints and limited access to modern energy sources. This often results in households relying on multiple energy sources, negatively impacting their health, income, and the environment. The theory is supported by empirical evidence from various studies across different regions and has guided policy interventions to improve access to affordable and clean energy for households in energy poverty. Therefore, the fuel stacking theory is a significant contribution to the research on energy poverty and has practical implications for policy and practice.

Furthermore, the paper reveals that prepayment electricity systems significantly impact energy poverty, as households often use biomass for cooking and heating instead of electricity. This finding contributes to the discourse on clean cooking energy, highlighting how electricity prepayment drives poor households to use unclean energy sources. Lastly, the study demonstrates the significance of energy subsidies, such as Free Basic Electricity for lifeline consumers, in alleviating energy poverty. The importance of such subsidies underscores the need for governments to explore additional energy subsidies to address energy poverty and achieve Sustainable Development Goal 7 of a clean energy transition at both the household and national levels. Throughout all three papers, the focus on either productive electricity use or the associated payment structures underscores the importance of transitioning towards cleaner and modern forms of energy. The research justifies government investment in the electricity sector by highlighting the potential for electricity to generate income within households, particularly through productive use. This investment facilitates economic empowerment and enables households to afford electricity payments, thus aiding in the sustainability of the energy infrastructure. Moreover, advocating for policies that promote increased electricity usage amidst the energy mix is a crucial strategy for reducing household reliance on biomass, which has detrimental environmental effects and contributes to climate change. By emphasizing the significance of energy in employment generation and environmental preservation, this research advocates for a holistic approach towards sustainable energy development and household welfare. Finally, the study provides a guide to understanding and addressing specific issues of household welfare using micro-level data from Ghana and South Africa.

1.5 Organization of the Study

The rest of the paper is organised as follows: the next chapter presents the productive use of electricity with a focus on Ghana and explains the importance of fuel energy in enterprise development. Chapters Three and Four focus on South Africa and explain the impact of prepayment systems on food insecurity (hunger) and energy poverty, respectively. They outline the methodological procedure used in the research with their results of the estimations, and the last chapter concludes.

CHAPTER TWO

2 The Impact of Energy Type on Household Non-farm Enterprise Income in Ghana.

Abstract

Energy inputs such as electricity and fuel are essential drivers of enterprise development. It is believed that energy used productively can increase individual income, thereby enabling them to afford energy services and ultimately improving household welfare and socio-economic development. However, the debate over which competing energy inputs exert a more substantial influence on enterprise performance and whether a significant difference exists in their impact on income remains inconclusive. The research employs the Ghana Living Standard Survey (GLSS7) data to examine the importance of electricity usage on household enterprise income. This study further shows the relevance of fuel expenditure and other firm characteristics in the enterprise production process. The Lewbel IV method was the main estimation approach used in the study, with the standard Instrumental Variable (IV) results providing a foundational estimation. Both methods showed positive effects of electricity and fuel expenditure on enterprise performance. However, the test for differences between the coefficients of electricity and fuel remained insignificant, highlighting that both energy inputs are equally important. The choice between them should consider other external factors. Furthermore, heterogeneity results based on firm size, type, location, and gender revealed specific differences when considering particular inputs, but these differential impacts were statistically insignificant. Our results have significant policy implications, advocating for an enhanced government "electricity for all" program and targeted expansion initiatives. The findings underscore the importance of promoting modern fuel supply to augment household enterprise income in Ghana. The research thereby contributes valuable insights to inform policy decisions and facilitate more effective utilisation of energy resources for economic development. This chapter's academic contribution includes decomposing the composite energy input in a household enterprise income model into electricity and other primary sources of energy (referred to as fuel) to explore energy's differential and heterogeneous impacts on household enterprise income.

2.1 INTRODUCTION

Energy is a crucial driver of economic growth at the macro and micro levels that can drive an enterprise's productivity. Energy is diverse, and there can be other types that can enhance productivity more than others, given their availability for use or cost expenditure. The assumption that switching to modern energy sources drives enterprise performance better than traditional energy sources remains to be settled. Extant literature supports the claim that modern energy sources such as electricity improve enterprise performance (Tybout, 2000; Maleko, 2005; Prasad & Dieden, 2007). However, others provided contradicting evidence to this claim (Grimm et al., 2013; Neelsen & Peters, 2011). This same idea discussed by some researchers provided findings on electricity access in enterprise types and sizes. According to Rud (2012), electricity provision increases manufacturing output. Surprisingly, results from a few studies suggest that electricity access does not drive the performance or income of small enterprises (Kooijman-van Dijk, 2012; Grimm et al., 2013). Building upon the existing discourse surrounding the impact of diverse energy on enterprise productivity, this study seeks to address the practical problem of identifying the most effective energy sources for driving enterprise performance. Despite assertions in the literature regarding the superiority of modern energy sources, such as electricity, over traditional alternatives, contradictory evidence exists.

Another important aspect of productive energy use that remains relevant in recent discussion is the different energy sources used by women and men and the amount of energy consumed in urban and rural locations. The social roles assigned to men and women result in different energy choices and the kind of economic activity pursued. Women are most disadvantaged regarding access to modern energy, such as electricity. The subgroup effects tend to affect the type of enterprise activity women engage in, given the energy sources available. In addition, rural communities are believed to be energy-poor due to low income and the ability to pay for energy services. The World Development Indicators (WDI) 2020 statistics on Ghana show that about 95% of urban communities have access to electricity compared to 74% in rural areas. When access to clean cooking and technologies is considered, about 35% are urban compared to 9% rural. This trend of energy access tends to affect the enterprise activities undertaken or pursued in a different location.

The prevailing literature often neglects to acknowledge the multifaceted impact of various energy sources on enterprise development. Consequently, the ongoing discourse regarding the differential effects of modern versus traditional energy sources on enterprise performance remains inconclusive, particularly when considering the diverse spectrum of enterprise types, sizes, and socio-economic factors such as gender and location. This research aims to fill this gap by empirically examining the nuanced differences in enterprise performance attributable to different energy sources, specifically focusing on electricity and fuel energy. By considering a range of enterprise groups and sizes, the study seeks to elucidate which energy sources are most conducive to driving their respective activities effectively. Furthermore, the research endeavours to shed light on the distributional implications of different energy sources, considering socio-economic dimensions such as gender and location. This analysis acknowledges that production processes' electricity and fuel energy inputs often function as substitutes or complements. Notably, the latter's predominance is underscored by the adverse effects of frequent electricity outages on enterprise profitability and the subsequent income generated for households in contexts like Ghana. Moreover, amidst the debate surrounding the justification for investment in electricity infrastructure, considerations must be made regarding the ability of poorer households to afford electricity. Here, productive electricity use emerges as a crucial factor, as it justifies government investment and underscores the imperative for environmentally friendly energy utilization. By facilitating income generation within households and alleviating poverty, productive electricity use is a compelling rationale for prioritizing investments in electricity infrastructure. The imperative for environmentally friendly energy usage is also advanced, aligning with broader sustainability goals and mitigating adverse environmental impacts associated with traditional energy sources.

The impact of electricity access and outages on enterprise performance has been extensively studied in the literature. However, less attention has been given to the utilisation and expenditure of alternative energy sources such as fuel, which can also be modern or traditional. In the context of Ghana, a trend analysis of electricity access and fuel usage vis-a-vis industrial growth between 2007-2020 reveals an upward trend in both energy access and usage. Despite this, the industrial growth rate has been unstable, as depicted in

1.

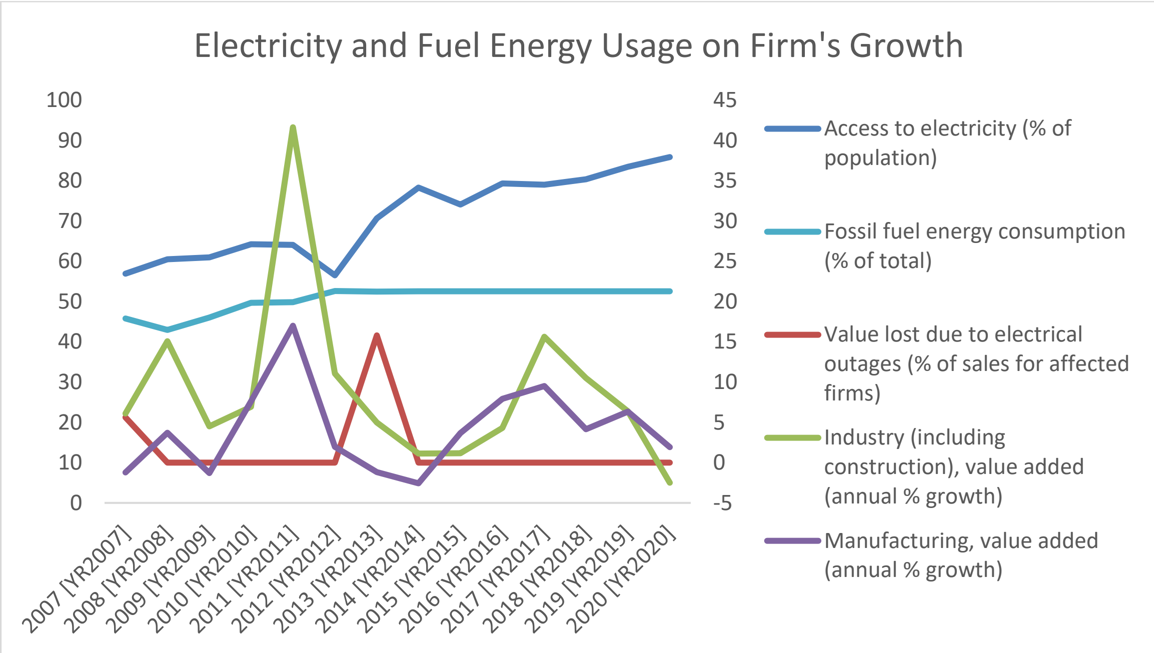

Figure 1: Trend in electricity access, fuel consumption, industrial growth, and value lost to electrical outages.
Source: World Development Indicators (WDI), 2007-2020.

Notably, industrial growth declined from 2011 to 2015, when the country experienced severe power outages. The decline was further supported by the percentage value lost from sales by firms in 2013. During the same period, fuel consumption remained relatively stable, but it was not a driving factor for industrial growth. However, the decline in industrial growth could have been worse if not for fuel energy consumption. Thus, it is crucial to consider diverse energy usage instead of just access, as it directly links to the firm's performance. Furthermore, the amount spent on energy (energy usage), whether electricity or fuel energy, plays a significant role in the performance of non-farm enterprises.

This paper study investigates the impact of diverse energy consumption on the household's enterprise income. Using the Ghana Living Standard Survey (GLSS 7) microdata, we provided evidence of the importance of electricity expenditure to firms' growth. The study used the Standard IV and Lewbel econometric approaches to estimate our findings. The model also accounted for fuel energy expenditure showing greater importance to electricity expenditure. This research contributes to the growing literature on Productive Use of Energy (PUE), emphasizing usage availability and expenditure decisions and the importance of other energy sources, such as fuel used by firms.

Furthermore, this research contributes to the literature on household welfare through the productive use of energy, especially by minority groups such as women and rural communities. Finally, this study provides evidence of other essential control variables affecting household enterprise income and profits.

The rest of the paper is organised as follows. Section 2.2 provides the empirical literature on existing findings and a conceptual framework, while Section 2.3 describes the data, measurement of variables and econometric approaches. Finally, sections 2.4 and 2.5 present the results and conclusion, respectively.

2.2 LITERATURE REVIEW

Electricity usage can have both direct and indirect impacts on enterprise income. The direct impact of electricity usage on enterprise income is related to the cost of electricity. In contrast, the indirect impact is related to the changes in productivity and efficiency resulting from electricity use.

2.2.1 Theoretical model

Production Theory: Cobb-Douglas Model

Grounded in the foundational principles of microeconomic production theory, this study adopts a classical approach as delineated by Varian (2014) in examining the nexus between energy inputs and the productivity of non-farm enterprises. Employing the well-established Cobb-Douglas production function framework, the research posits that the output (Q) of a firm is a function of labour (L), capital (K), and energy inputs (E), with the respective contributions of these inputs to output encapsulated by their output elasticities (α, β, γ). This model underscores the pivotal role of energy inputs, specifically electricity and fuel, in bolstering the efficiency and productivity of production processes, which, in turn, could precipitate an augmentation in enterprise output. Through the empirical estimation of this production function utilizing GLSS 7 data on non-farm enterprises in Ghana, the study endeavours to elucidate the empirical relationship between energy inputs and firm performance. The insights gleaned from this analysis are anticipated to have significant implications for the formulation of energy policies and the development of support structures for non-farm enterprises.

Neoclassical profit maximisation

The neoclassical profit-maximising model frequently employed in microeconomics is at the core of theoretical underpinnings explaining the link between energy inputs (specifically electricity and fuels) and enterprise performance. Rooted in the premise that firms strive to maximise profits through optimal production and pricing decisions, this model integrates vital components such as the firm's production function (Arnold, 1985). This function delineates the correlation between inputs, encompassing labour and capital, and the resultant output. Within this framework, firms endeavour to identify the optimal combination of inputs to minimise costs and maximise output concurrently. Moreover, the model considers the market structure and product demand crucial in determining the optimal selling price for the firm's output. Within the neoclassical economic paradigm, profit maximisation manifests when a firm produces at a level where marginal cost equals marginal revenue (Brueckner, 2013). This fundamental model provides a theoretical scaffold for scrutinising how firms navigate decision-making processes to maximise profit within competitive markets, forming the theoretical foundation to comprehend the intricate relationship between energy inputs and enterprise performance. Within this theoretical model, the decision-making process predominantly revolves around crucial factors such as pricing, efficiency, and selecting renewable energy inputs to optimise profits or outputs (Appiah, 2022).

Aligned with the production and profit models outlined in the framework, the production function highlights how energy quantity affects firm output, while energy input prices influence profit outcomes. Both models illustrate how energy input, whether through prices or quantity, impacts firm income performance. Now, we turn our attention to the empirical literature that underscores the importance of these factors, emphasizing the necessity of considering energy input expenditures, as evidenced by previous studies in this area.

2.2.2 Empirical Literature

Numerous studies have examined the impact of electricity usage on enterprise profit or income. We begin the empirical literature on findings of electricity cost on enterprise income. Electricity pricing has a significant impact on enterprise profit or income. A study by Xu et al. (2022) established electricity as one of the principal energy sources, and increased energy pricing deteriorates firms' profitability and productivity. Similarly, a study by Lee and Yu (2019) found that increased electricity consumption affects firms' energy costs, especially for larger manufacturing firms in Korea. A recent study by Li et al. (2022) and Bijnens et al. (2022) found that electricity pricing tends to have negative cost-effectiveness, affecting employment outcomes. The impact of electricity pricing on enterprise profit or income has been widely studied in Sub-Saharan Africa, including Ghana. However, many studies have focused on the broader impacts of electricity access and reliability rather than specifically on the impacts on enterprise profit or income. The high cost of electricity is a major challenge for enterprises in Ghana, and it can negatively impact their profitability (Hussain et al., 2022). Electricity access benefits small and medium enterprises in Ghana, as revealed in the works of Owusu et al. (2022). The existing evidence indicates that electricity usage is crucial for firm development, but high pricing negatively impacts firm profits. Therefore, we hypothesized that increased expenditure on electricity would lead to improvements in firm income.

Several studies have demonstrated the importance of alternative fuels in enterprise performance. Owusu et al. (2022) recommended exploring alternative energy sources due to high electricity prices. Ayakwah and Mohammed (2014) found that fuel price adjustment had a negative impact on the profitability of SMEs, with fuel costs accounting for a significant proportion of their operating expenses. Exploring the relevance of alternative energy sources is an essential element that must be considered in modern studies. Once again, we hypothesise that fuel energy usage improves enterprise income.

The key question revolves around comparing the relative importance of two competing energy sources in increasing firm income to enhance welfare. Addressing this, Abresse (2017) compared the impact of electricity and coal costs on firm performance in India. Higher electricity costs led firms to shift towards less electricity-intensive production processes, reduce machine intensity, and experience lower output and productivity growth rates. However, determining whether there is a significant difference between the preference for using electricity or fuel energy remains a crucial question. Therefore, we hypothesize that there will be a significant disparity in the utilization of electricity versus fuel energy.

The existing literature on energy consumption and firm growth highlights the importance of both electricity and fuel input usage. However, a more granular examination considering various types of enterprises, their production capacities, and the types of machines they employ may reveal varying preferences for a specific energy source or a higher reliance on others. Small and Medium Enterprises (SMEs) are an important segment of Ghana's economy, accounting for a significant share of employment and income. Several studies have found that SMEs in Ghana face challenges in accessing reliable electricity, which affects their productivity, profitability, and competitiveness. For example, a study by Owusu et al. (2022) found that inadequate and unreliable electricity supply leads to reliance on alternative energy sources, significantly reducing the profit margins of SMEs in Ghana. The study focused on SMEs in urban areas, which should be extended to rural areas. Gender dynamics also play a significant role in the impacts of electricity usage on enterprise profit or income in Ghana. Women-owned SMEs face additional challenges in accessing reliable electricity, which affects their productivity, profitability, and competitiveness (Pueyo & Maestre, 2019; Pueyo et al., 2020). Location dynamics also play a significant role in the impacts of electricity usage on enterprise profit or income in Ghana. Rural enterprises face more challenges accessing reliable electricity than urban enterprises, affecting their productivity, profitability, and competitiveness (Kuada, 2022). The evidence concerning the type and size of enterprises, gender dynamics, and location considerations further underscores the socioeconomic and geographical effects of the diverse energy types' impact on firm profitability or productivity. Therefore, we will ascertain that different sizes and types of enterprises, as well as gender and location, will employ different energy consumption patterns, and the resulting impact will vary across diverse groups.

The empirical review emphasizes the importance of electricity usage for firm development, suggesting that increased expenditure on electricity could enhance firm income. Additionally, it underscores the significance of exploring alternative energy sources, particularly fuel energy, to improve enterprise income. The examination of different enterprise types, production capacities, and energy consumption patterns reveals potential disparities in energy source preferences. SMEs in Ghana face challenges accessing reliable electricity, particularly in urban areas, impacting profitability. Gender dynamics and location further complicate the issue, as women-owned SMEs and rural enterprises encounter additional obstacles in electricity access. In essence, the findings underscore the significance of diverse energy inputs for enterprises, yet the optimal choice to drive income remains uncertain, especially across different demographic groups. Suppose no significant difference is found among energy sources. In that case, it prompts further consideration of external factors to guide government policy towards selecting the most beneficial options for enhancing welfare and promoting environmentally friendly energy sources.

2.2.3 The Relationship between Energy Consumption and Enterprise Performance

Energy consumption plays a crucial role in the prosperity of households as it drives the growth of businesses, thereby generating income and wealth for individuals (Owusu et al., 2022). Various relevant inputs are employed for effective enterprise production, including material and human resources, production equipment, and the availability and utilization of diverse energy inputs. Energy inputs constitute a vital component in business operations, and firms face critical decisions regarding selecting energy sources based on factors such as cost-effectiveness, availability, and reliability. Opting for an expensive energy input would result in increased production costs, thus negatively impacting enterprise profitability (Nie & Yang, 2016). Similarly, if the energy source is insufficient, firms cannot sustain continuous production, leading to reduced output and further affecting profitability. However, it is crucial to note that firms operating with complete cost recovery mechanisms, such as monopolies, can pass the augmented production costs to consumers. This ability to transfer costs allows them to sustain higher profitability even when opting for expensive energy input, such as renewables, which may have a higher initial cost but promise long-term benefits for households. In this context, the enterprise's strategic positioning within the market, especially concerning cost recovery and consumer pricing dynamics, plays a pivotal role in determining the viability and impact of choosing a more expensive yet sustainable energy source. Furthermore, several other factors influence the choice of energy input in the production process, including the nature of the business, the energy requirements of machinery and equipment, and the external costs associated with acquiring energy inputs.

Diverse types of enterprises necessitate different energy sources, and in some cases, multiple energy sources are utilized, mainly when one is scarce or unavailable, regardless of cost implications. Industries involved in manufacturing, for instance, require sophisticated equipment predominantly powered by electricity. In such cases, increased expenditure on fuel, such as diesel, to operate machinery during periods of intermittent electricity supply has resulted in diminished profits and, in some instances, business collapse in Ghana. Households typically require power for a limited number of hours compared to enterprises, which demand more energy to operate their businesses for extended hours (Zerriffi, 2011). Consequently, a firm, on average, consumes more energy than an individual household (Su, 2018; Nejat et al., 2015). This disparity in energy consumption patterns highlights the diverse needs and usage intensity between residential and commercial entities. Understanding these variations is crucial for developing energy policies and strategies that cater to the specific requirements of both households and different enterprise groups, ensuring a balanced and efficient distribution of resources in the broader energy landscape. It is worth noting that the choice of energy sources varies significantly depending on the type of enterprise, machinery used, and operational expenses. Different enterprise groups may have distinct energy consumption patterns and preferences based on their specific industry requirements and operational dynamics. Large industrial and manufacturing entities predominantly depend on grid electricity, complemented by natural gas and renewable sources. Conversely, small businesses and meal preparation enterprise groups frequently opt for more economical fuel options during production for cost-effectiveness. Understanding the energy sources preferred by various enterprise groups is paramount for effectively contextualising our study's results. In Ghana, where fuels like gas, wood, and charcoal are relatively less expensive, enterprises engaged in cooking and trading often rely on these alternatives.

Considering the external costs associated with accessing and utilizing diverse energy inputs is also crucial for firms when selecting between different options. Electricity, readily available in homes and businesses, does not entail additional travel costs for access and utilization by enterprises. Additionally, electricity is considered a cleaner form of energy, posing fewer health risks to communities than the carbon emissions associated with using cheap and polluting fuels like kerosene, wood, and charcoal. In this study, the term "fuel energy sources" encompasses all energy sources other than electricity. This includes modern forms such as gas and diesel, as well as traditional fuels such as kerosene, wood and charcoal. The mounting advocacy for heightened electricity consumption in businesses and transportation systems stems from the understanding that even contemporary fuels like diesel emit greater carbon emissions and contribute to heightened environmental pollution when compared to electricity. Moreover, increased reliance on wood and charcoal leads to deforestation, disrupting ecological balance, depleting water resources, and consequently jeopardising human survival and business communities.

The consumption of modern energy sources, particularly electricity, directly impacts enterprise income and is primarily endogenous (Adjei-Mantey & Adusah-Poku, 2021). The magnitude of electricity consumption by an enterprise is contingent upon a multitude of interrelated factors inherent within the system. Notably, past electricity consumption patterns and the proportion of income allocated to individuals play pivotal roles. For instance, the historical expenditure on electricity directly influences the quantity of electricity a firm procures, subsequently impacting the enterprise's financial performance. Suppose the individual responsible for business decisions directly benefits from the proportion of income allocated to operational costs. In that case, they will strategically influence their expenditure on electricity within the business. This is because any effects on electricity usage will ultimately impact their income percentage. Therefore, the individual has a vested interest in optimizing energy consumption and cost-efficiency to maintain a favourable balance between income and expenses. Individuals can effectively manage their operational costs and preserve their income share by making informed decisions regarding energy usage, such as adopting energy-saving practices or exploring alternative energy sources.

In addition to the diverse energy consumption, firm or household characteristics can also affect enterprise income. These characteristics, such as the years of operation, capital source, enterprise difficulty, working hours, income belonging, training, and location, can significantly influence the determination of enterprise income. Enterprises with a long operational history, extended working hours, and prioritised training are well-positioned to benefit from positive production externalities, increased production capacity, and improved entrepreneurial skills. These factors create a conducive environment for higher profitability and sustained business success. On the other hand, credit constraints and the difficulties enterprises face in obtaining loans, exacerbated by high interest rates, significantly impact business operations. These constraints limit the availability of capital and hinder investment, expansion, and innovation. The burden of high-interest payments further reduces profitability, making it harder for businesses to thrive and grow. Addressing these challenges, such as through improved access to credit, favourable loan terms, or government support programs, can help alleviate the financial strain enterprises face and foster a more conducive environment for their success.

A Conceptual framework showing how diverse energy affects Enterprise Income

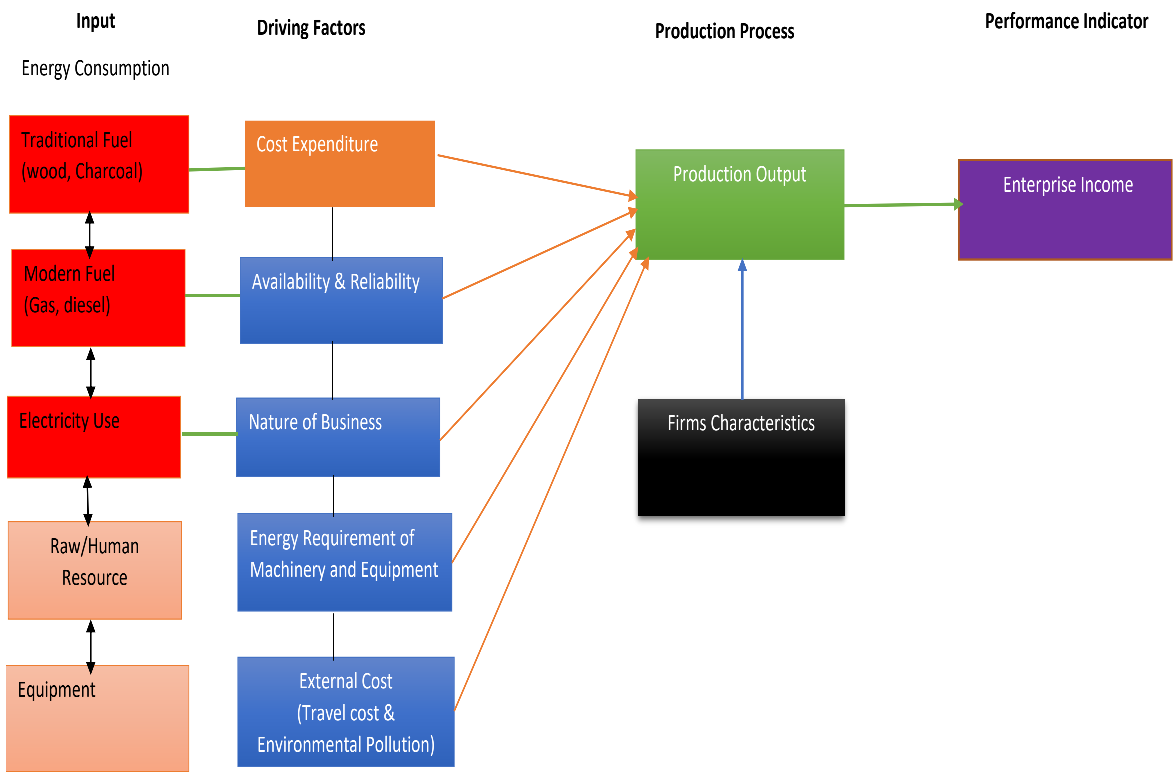

Figure 2: Conceptual Framework of Diverse Energy and Enterprise Income

To this end, the complex relationship between energy consumption, individual and firm characteristics, and enterprise income is well-represented in the diagram above (Figure 2). Both modern and traditional energy sources directly impact enterprise income, and various factors can influence this relationship. Further studies on the subject could provide deeper insights and help to understand the intricate relationship between energy consumption and enterprise income.

2.2.4 Brief Description of Ghana’s Nonfarm Enterprise Activity

The nonfarm sector in Ghana has gained importance over the past few decades and has significantly contributed to employment and income generation. According to the Ghana Statistical Service (GSS), the nonfarm sector accounted for 57.8% of total employment in 2020, with a growth rate of 8.7% from 2019. In 2019, the sector contributed 64.1% to Ghana's Gross Domestic Product (GDP) (*Ghana Statistical Service (GSS)*, 2022). Nonfarm enterprises in Ghana can be classified into formal and informal types, accounting for about 80% of total nonfarm employment. The Ghana Living Standards Survey (GLSS7) revealed that most nonfarm enterprises in Ghana are small, with fewer than five employees. Micro/small enterprises (less than five employees) account for 92% of all nonfarm enterprises in Ghana. Medium-scale enterprises (5-19 employees) account for 6.4% (GSS, 2020). The main types of nonfarm enterprises in Ghana include trading, manufacturing, services, and preparation and sale of meals. Trading is the most dominant type, accounting for about 35% of all nonfarm enterprises, while manufacturing accounts for about 11%. Services, which include transport, storage, communication, and finance, account for about 34% of all nonfarm enterprises in Ghana (GLSS, 2017). In summation, Ghana's nonfarm sector plays a crucial role in employment and income generation, with the informal sector being the largest employer. The majority of nonfarm enterprises are small, and trading is the most dominant type. These findings are based on data from the Ghana Statistical Service and the Ghana Living Standards Survey.

2.3 METHODOLOGY

This section presents data, description, and measurement of variables used. It also outlines the econometric strategy used in the research.

2.3.1 Data Description and Measurement of Variables

The study used the Ghana Living Standard Survey 2017 (GLSS7) data, which contains information about 6961 enterprises. GLSS 7, the latest survey, was conducted by the Ghana Statistical Service (GSS) in 2016/2017. The survey data on the non-farm enterprise in the GLSS 7 follows the International Standard Industrial Classification (ISIC) and can be further grouped under broad categories for manufacturing and construction activities, services, wholesale or retail trade, and food and beverage processing. Data collected provided adequate information on enterprise characteristics, profit, output, and expenditures, including input used, such as electricity and fuel energy, and socio-economic variables, such as gender and location.

The study used income mainly from enterprise activities to capture the firm's productive use of energy (PUE). Enterprise income was proxied by payment that goes to the household. An increase suggests improved firms' performances for the enterprise and improved welfare for the household. Electricity usage was measured by the amount spent on electricity, the same as fuel usage. The amount spent on electricity and fuel by the enterprise was logged. The study further examined enterprise income by type, size, and the influence of electricity or fuel energy. This study's types of enterprise groups are manufacturing, wholesale/retail, services, and food preparation.

Considering the predominant prevalence of micro and small-sized enterprises, we categorize them based on employment levels, distinguishing those with no employees, those with one employee, two to five employees, and those employing more than five individuals. Enterprises without employees typically operate as self-owned and self-managed businesses, whereas other entrepreneurs require additional workers' assistance to support and facilitate their business activities. In addition, the study controlled for other firm attributes important in explaining enterprise profit or income to the household. These included years of operation, the number of employees, credit source, difficulty in establishing the business, whether officially registered, operating account period, working hours, income belonging, location (urban/rural), and regional distribution of these enterprises. The study used two main instruments for the decision to spend and the amount spent on electricity in addressing the endogeneity problem. The instruments used were the electricity expenditure in the past and the income percentage that accrues to an individual.

2.3.2 Econometric Model

Our study primarily examines the link between electricity and fuel energy on non-farm enterprise income to the household. This research analysed the relationship between the productive use of energy and enterprise performance using a model that captures electricity and fuel energy usage and other essential variables. The estimating equation is specified as follows.

$$Y_i = B_o + B_1 Electricity_i + B_2 Fuel_i + \theta_i X_i' + e_i \dots\dots\dots\dots\dots (1)$$

Where Y_i is the outcome or dependent variable which focuses on household income from engaging in a non-farm enterprise, $electricity_i$ is the interest indicator variable for the amount of electricity spent within a year, $Fuel_i$ represents the amount an enterprise spends on fuel within a year, and X_i' represents explanatory variables controlled for on the dependent variable as discussed earlier, and e_i the error term, which is under the assumption of being independent and normally distributed.

The LS regression with robust standard errors regression is used to examine the effects of electricity usage availability on firms' profit or income outcome. However, a simple regression of the explanatory variables on enterprise performance may yield a biased and inconsistent estimate due to the potential endogeneity of the amount of electricity spent. Given that similar works of Abeberese (2017), Rao (2013), and Rud (2012) suggest endogeneity with electricity provision. Therefore, a systematic examination is conducted to determine the endogeneity of electricity usage. If the endogeneity test yields positive results, it indicates that the ordinary least squares (OLS) regression results may be subject to bias and inconsistency. Consequently, estimates derived from instrumental variable (IV) techniques will constitute the foundational estimates. Additionally, the Lewbel method will be employed to address potential endogeneity concerns, thereby yielding results that are both more reliable and accurate.

This study addresses the endogeneity issue by identifying instrumental variables, specifically using instruments such as past expenditure on electricity and the percentage of income allocated to individuals. It is observed that the annual amount expended on electricity is likely to be influenced by the prior expenditure. Furthermore, the impact of electricity expenditure on enterprise performance is contingent upon the percentage of income directed towards individual stakeholders. Individuals possess a vested interest in the quantity of electricity consumed as it directly affects their income derived from enterprise activities. Consequently, this vested interest significantly influences their decision-making regarding allocating financial resources towards electricity consumption, subsequently impacting enterprise performance.

Therefore, we use the past electricity amount spent and the percentage of enterprise share that goes to an individual as instruments for electricity consumed in an IV regression. The essence of the IV approach is to ensure that estimates are consistent and unbiased. It is imperative to fulfil the identification strategy while ensuring that the instrument is not associated with the outcome variable but rather with the potential endogenous variable, which is the expenditure on electricity. Past expenditures on electricity are likely to be exogenous to the current energy use behaviour and income outcomes. The decision to invest in energy inputs, driven by prior electricity expenditures, is likely independent of current energy use patterns. This temporal distinction helps establish relevance and validity for the instrumental variable. Furthermore, the external validity criteria are satisfied as the instrumental variables align with real-world scenarios. While influencing the amount of electricity consumed, past expenditures on electricity do not alter the different impacts of energy input but rather enhance the productive use of the energy resource. This aligns with the broader goal of the study, which is to understand the effect of cleaner energy on profits and incomes. This satisfies the exclusion restriction in instrumental variable regression. The system of equations is specified as follows.

$$Y_i = B_o + B_1 Electric_i + B_2 Fuel_i + \theta_i X_i' + e_i \ldots \ldots \ldots \ldots \ldots (2)$$

$$Electric_i = a_o + a_1 lamtelec_i + a_2 percentincome_i + a_3 Fuel_i + \vartheta_i X_i' + e_i \ldots \ldots (3)$$

Where $lamtelec_i$ and $percentincome_i$ represent electricity, the amount spent in the past, and the percentage income to the individual are the instruments in the IV regression. Equation 2 is the outcome equation and B_1 is the coefficient of interest. The study logged all valued monetary variables.

One primary objective of this study is to investigate the presence of a significant disparity between various energy inputs, specifically electricity and fuel. To achieve this, we conducted a linear test of coefficients between the parameter estimates and formulated a hypothesis as follows:

$$H_0 = B_1 - B_2 = 0 \ldots \ldots \ldots (4a)$$

$$H_1 = B_1 - B_2 \neq 0 \ldots \ldots \ldots (4b)$$

Equation 4a presents the null hypothesis, which posits that there is no significant difference between electricity and fuel energy inputs. We evaluate this hypothesis against the alternative, which suggests that a significant difference exists between the two. If the null hypothesis is accepted, it implies that both types of energy inputs are influential. Therefore, the choice between them should consider additional external benefits such as environmental friendliness and human health, besides enhancing income generation through enterprise activities. On the contrary, if the alternative hypothesis is accepted, it warrants further justification for government investment in other energy sources, particularly if significant income growth through enterprise businesses is desired.2.3.3 Diagnostic Test

The study reports the under-identification, weak identification, overidentification, and endogeneity test for the baseline IV model. The under-identification test checks whether the equation is identified; the excluded instruments are relevant. The null hypothesis is that the equation is under-identified; hence, rejecting the null implies the model is identified. Testing for weak identification checks whether the excluded instruments are weak. It reports the Cragg-Donald Wald F Statistics and compares them with the critical values of Stock and Yogo (2005). To ensure consistency, we report robust standard errors to the presence of heteroskedasticity; hence the i.i.d assumption is invoked. Given the robust Standard Errors (SE), inferences from the Kleibegen_Paap Statistic F statistics other than Cragg-Donald Wald F Statistics are drawn. The Sargen-Hansen test checks the overidentification test for the joint null hypothesis that the instruments are valid. Hence, accepting null implies that excluded instruments are uncorrelated with error, and a rejection doubts their validity. Finally, an endogeneity test was done to ascertain whether the specified endogenous regressor is exogenous. Accepting the null based on the reported chi-square implies no endogeneity problem and that the OLS estimates are consistent and unbiased.

2.3.4 Lewbel Estimation

Standard instrumental variable (IV) estimation often faces criticism due to the reliance on external instruments. To ensure that our estimates are efficient and reliable, and that endogeneity is adequately addressed—thereby satisfying internal validity and the exogeneity restriction—a more sophisticated IV estimation method, such as the Lewbel approach, is utilized. The Lewbel estimation technique addresses the exclusion criterion in instrumental variable (IV) estimation by utilizing heteroscedasticity in the error terms to identify internal instruments. This method circumvents the need for traditional, external instruments, which may not satisfy the exogeneity condition. By exploiting the variation in the error structure, the Lewbel approach generates inherently exogenous instruments, thereby fulfilling the exogeneity condition and strengthening the validity of the IV estimation (Lewbel, 2012). The principal strength inherent in incorporating Lewbel's method lies in its capacity to augment the validity and reliability of the instrumental variable approach. In scenarios where the baseline model encounters challenges or constraints, Lewbel's method is a crucial mechanism for reinforcing the evidence by providing an additional layer of scrutiny. This assumes greater significance should the initially selected instruments fail to satisfy the criteria of validity and exclusion. While the instruments chosen in the baseline model are theoretically grounded and intended to mitigate endogeneity concerns, Lewbel's method is a prudent safeguard against potential instrument-related issues. Supplementing external instruments also enables Sargan-Hansen tests of orthogonality conditions or overidentifying restrictions, which are not possible with exact identification by external instruments alone. This study used the latter by supporting external instruments with internally generated instruments to give more efficient and reliable estimates. By using this distinct set of instruments, Lewbel’s method enriches the analytical framework and ensures a more reliable analysis. Consequently, this thesis prioritizes Lewbel’s estimation method for inferential analysis, emphasizing its superiority over standard IV estimation and reinforcing the reliability of the findings.

2.4 RESULTS AND DISCUSSION

Table 1 provides a summary of descriptive statistics of the variables used. After the data generating and cleaning process, about 5569 balanced data on enterprises were left for analysis. Thus, the summary statistics report the mean and standard deviation of variables used in the estimation. Table 2 reports the LS results from estimating equation (1) with enterprise income to household outcomes of interest. The enterprise income used represents the amount that goes to the household.

Table 1: Summary Statistics and measurement of Variables (GLSS-7)

Variable	Measurement/Description	Mean	Standard Deviation
Lentamt_hh	Enterprise income for the household (logged)	3.448	1.344
Electricity	Electricity expenditure in a year (logged)	0.876	2.169
Fuel Energy	Fuel energy expenditure in a year (logged)	0.161	0.368
Years of operation	Years of operation	7.834	8.011
Main Capital Source	Main Source of Capital for enterprise (household savings)		
2.Bank/micro/loan	Equals 1 if received Bank/micro/loan and 0 if otherwise	0.231	0.422
3.External Support	Equals 1 if received external support and 0 if otherwise	0.031	0.175
Training	Equals 1 if received training and 0 if otherwise	0.077	0.265
Income belong	Equals 1 if income entirely belongs to the person responsible and 0 if otherwise	0.963	0.187
Registered	Equals 1 if the enterprise is registered and 0 if otherwise	0.012	0.131
Enterprise Difficulty	Enterprise Difficulty (No difficulty)		
2.Capital/credit	Equals 1 if the difficulty faced by the enterprise is capital/credit and 0 if otherwise	0.564	0.496
3.Technical	Equals 1 if the difficulty faced by the enterprise is technical and 0 if otherwise	0.02	0.138
4.Governmnet_Regulation	Equals 1 if the difficulty faced by the enterprise is government regulations and 0 if otherwise	0.007	0.082
5.Others	Equals 1 if the enterprise faces the other difficulties and 0 if otherwise	0.016	0.124
Number of employed	Number of employed	1.152	2.780
Operating account	Operating account (Daily)		
2.Weekly	Equals 1 if the operating account is weekly and 0 if otherwise	0.494	0.50
3.Fortnightly	Equals 1 if the operating account is fourth night and 0 if otherwise	0.107	0.309
4.Monthly	Equals 1 if the operating account is monthly and 0 if otherwise	0.216	0.411
5.Quarterly	Equals 1 if the operating account is quarterly and 0 if otherwise	0.026	0.158

6.Yearly	Equals 1 if the operating account is yearly and 0 if otherwise	0.017	0.128
Workhours	Hours of works	7.949	1.847
Location	Equals 1 if urban and 2 if rural	1.467	0.499
Region	Region (Western)		
2.Central	Equals 1 if Central region and 0 if otherwise	0.118	0.322
3.GreaterAccra	Equals 1 if Greater Accra region and 0 if otherwise	0.128	0.334
4.Volta	Equals 1 if Volta region and 0 if otherwise	0.136	0.344
5.Eastern	Equals 1 if Eastern region and 0 if otherwise	0.108	0.310
6.Ashanti	Equals 1 if Ashanti region and 0 if otherwise	0.109	0.311
7.Brong Ahafo	Equals 1 if Brong-Ahafo region and 0 if otherwise	0.075	0.263
8.Northern	Equals 1 if the Northern region and 0 if otherwise	0.087	0.281
9.Upper East	Equals 1 if Upper East region and 0 if otherwise	0.097	0.296
10.Upper West	Equals 1 if Upper East region and 0 if otherwise	0.062	0.241
Instruments			
Previous Electricity expenditure	Previous Electricity expenditure	0.156	0.755
Percent income	Percentage of income	3.923	0.418

Source: Ghana Living Standard Survey (GLSS 7).

2.4.1 Effects of Electricity and Fuel Energy on household enterprise Income

The present study investigates the impact of varied energy consumption on a firm's (Enterprise's) income. Table 2 displays the results of the ordinary least squares (OLS) and instrumental variable (IV) regressions conducted in this study. The first column presents the OLS regression outcomes, indicating the relationship between all variables and enterprise income, along with a linear differential test assessing the disparity between electricity and fuel coefficients (D(energy)). Following this, column 2 exhibits the IV results for the entire sample, including their respective differential impacts. Additionally, column 3 provides a comprehensive regression analysis, integrating all pertinent control variables and utilizing Lewbel estimation for robustness checks. This comprehensive approach allows for evaluating the distinct contributions of electricity and fuel energy towards enhancing enterprise income.

Table 2: Effects on Household Enterprise Income – OLS, IV and Lewbel

VARIABLES	OLS Lentamt_hh	Standard IV Lentamt_hh	Lewbel-IV Lentamt_hh
Electricity	0.055***	0.078***	0.075***
	(0.008)	(0.016)	(0.013)
Fuel Energy	0.081***	0.080***	0.081***
	(0.010)	(0.010)	(0.010)
Years of operation	0.015***	0.015***	0.015***
	(0.002)	(0.002)	(0.002)
Main Capital source (Savings)			
2.Bank/micro/loan	-0.093**	-0.093**	-0.093**
	(0.039)	(0.039)	(0.039)
3.External Support	-0.069	-0.073	-0.072
	(0.090)	(0.089)	(0.089)
1.Training	0.166**	0.148**	0.151**
	(0.067)	(0.068)	(0.068)
1.incomebelong	-0.415***	-0.413***	-0.414***
	(0.092)	(0.092)	(0.092)
1.Registered	0.647***	0.602***	0.609***
	(0.168)	(0.170)	(0.170)
Enterprise Difficulty (No difficulty)			
2.Capital/credit	0.111***	0.105***	0.106***
	(0.035)	(0.035)	(0.035)
3.Technical	0.522***	0.521***	0.521***
	(0.121)	(0.121)	(0.121)
4.Governmnet_Regulation	0.689**	0.694**	0.693**
	(0.285)	(0.285)	(0.286)
5.Others	0.055	0.026	0.031
	(0.146)	(0.148)	(0.147)
Number of employed	0.039***	0.037***	0.038***
	(0.009)	(0.009)	(0.009)
Operating account (Daily)			
2.Weekly	0.151***	0.144***	0.145***
	(0.047)	(0.047)	(0.047)
3.Fortnightly	0.381***	0.376***	0.377***
	(0.063)	(0.063)	(0.063)
4.Monthly	0.740***	0.736***	0.736***
	(0.056)	(0.056)	(0.056)
5.Quarterly	1.008***	1.011***	1.011***
	(0.131)	(0.131)	(0.132)
6.Yearly	1.709***	1.721***	1.719***
	(0.198)	(0.197)	(0.198)
Workhours	0.033***	0.031***	0.031***
	(0.008)	(0.009)	(0.009)
Location (Urban)			

2.Rural	-0.118***	-0.107***	-0.108***
	(0.034)	(0.035)	(0.034)
Region (Western)			
2.Central	-0.353***	-0.357***	-0.356***
	(0.082)	(0.082)	(0.082)
3.GreaterAccra	-0.229***	-0.238***	-0.237***
	(0.080)	(0.080)	(0.081)
4.Volta	-0.260***	-0.253***	-0.254***
	(0.077)	(0.077)	(0.077)
5.Eastern	-0.176**	-0.174**	-0.175**
	(0.080)	(0.080)	(0.080)
6.Ashanti	-0.148*	-0.148*	-0.148*
	(0.086)	(0.086)	(0.087)
7.Brong Ahafo	-0.219**	-0.219**	-0.219**
	(0.088)	(0.088)	(0.088)
8.Northern	-0.976***	-0.969***	-0.970***
	(0.087)	(0.087)	(0.088)
9.Upper East	-1.052***	-1.044***	-1.045***
	(0.078)	(0.078)	(0.078)
10.Upper West	-1.028***	-1.025***	-1.026***
	(0.091)	(0.091)	(0.091)
Constant	3.380***	3.384***	3.383***
	(0.140)	(0.139)	(0.140)
D(Energy)	-0.026**	-0.002	-0.006
	(0.013)	(0.019)	(0.016)
Observations	5,569	5,569	5,569
R-squared	0.234	0.233	0.233

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Author's estimate

The study findings reveal that both electricity and fuel expenditure positively influence enterprise income, with statistically significant effects observed at a 1% alpha level in the initial baseline regression (Column 1). Specifically, the coefficient for electricity expenditure indicates a positive effect of approximately 0.055 on enterprise income. Moreover, the results indicate that fuel energy expenditure yields a larger positive coefficient compared to electricity expenses when controlling for other explanatory variables. The calculated differential impact between electricity and fuel energy is -0.026%, signifying a statistically significant difference at a 5% conventional level. This implies that fuel energy expenditure has a more significant impact on enterprise income compared to electricity usage. However, given the potential endogeneity issues surrounding electricity use, these results require further testing to ensure unbiased and consistent estimates.

Table 3: Endogeneity Test Results

Variable	Durban Score Chi2(1)	Wu-Hausman test Statistics	Endogeneity results
lelec_amt	3.57449 (p = 0.0587)	3.55688 (p = 0.0594)	Endogenous

Source: Author's estimate

Table 3 displays the findings of an endogeneity assessment for the "lelec_amt" variable, which represents electricity expenses. The Durban score chi-square and Wu-Hausman test statistics are shown in the table, which are utilised to detect endogeneity in a regression model. The Durban score chi-square statistic examines the null hypothesis of no autocorrelation in the regression model errors. In this study, the Durban score chi-square statistic is 3.57449, with a p-value of 0.0587. The evidence indicates some autocorrelation in the errors, and the null hypothesis is rejected at 10% conventional levels of statistical significance. The Wu-Hausman test statistic is another test for endogeneity that compares the coefficients obtained via ordinary least squares (OLS) regression with those obtained through instrumental variables (IV) regression (Kock, 2022). The null hypothesis of the Wu-Hausman test is that the OLS estimates are unbiased and consistent, while the alternative hypothesis is that they are biased due to endogeneity (Patrick, 2021). This study's Wu-Hausman test statistic is 3.55688, with an associated p-value of 0.0594. Since the p-value is less than 0.1, the null hypothesis is rejected, and it is concluded that the OLS estimates are biased and inconsistent. Given the conclusive results of the Durban score and Wu-Hausman tests, it can be concluded that electricity is endogenous. This evidence implies that the variable correlates with the error term or other independent variables in the model, which may result in biased coefficient estimates. The findings in Table 3 suggest that additional techniques, such as instrumental variables regression, may be necessary to address endogeneity and obtain unbiased coefficient estimates. We, therefore, re-estimate our previous regression using the Instrumental Variable (IV) methodology.

Given the endogeneity results reported in Table 3, Table 2 presents the standard IV and Lewbel estimation. Instrumental Variable (IV) estimation must satisfy two main assumptions. First and foremost, the identified instruments must be correlated with the potential endogenous variable, electricity, in this study. Secondly, the covariance between instruments and the error term must be zero. Satisfying these conditions implies that the IV results are consistent and reliable. The study used two identified instruments believed to be related to electricity. They are the amount of electricity spent previously and the percentage of income from the owner.

The IV estimates suggest that electricity usage increases enterprise income by 0.078% at a 1% significant level. Regarding fuel energy, the point estimates imply enterprise income increases by 0.08% at a 1% significant level. Though the electricity coefficient increases after addressing endogeneity, the fuel energy coefficient is slightly higher, suggesting it is essential for firm performance. The test of the differential impact between the diverse energy was insignificant, implying no significant difference between electricity and fuel energy on enterprise income. These findings advance the argument for the importance of energy or other infrastructure to enterprise growth.

2.4.2 Diagnostic Results: Validity of Instruments

To ascertain whether IV results provide consistent and reliable estimates and, more importantly, whether the instruments are valid. The diagnostics test results are presented in Table 4. These diagnostics tests reported under-identification, weak identification, overidentification, and endogeneity for the primary Standard IV estimation. The Under-identification and weak identification test results for IV regression reject the null hypothesis and conclude that the instruments are identified and not weak, respectively. The overidentification estimation tests the null hypothesis that instruments are jointly valid. The study accepted the results for the overidentification; the instruments are jointly valid. Finally, the null of exogeneity was rejected at a 5% significance level, confirming that the electricity usage is endogenous and should draw inference from IV estimates. The results confirm the previous endogeneity test that electricity is indeed endogenous and show that the chosen instruments are valid, indicating that the IV results are consistent and unbiased.

Table 4: Diagnostics Results for Standard IV Regression

Postestimation results	***IV regression 1***	
Underidentification test	Kleibergen-Paaprk LM statistic: 245.541	Chi-sq(2) P-val = 0.0000***
Weak identification test	(Cragg-Donald Wald F statistic): 1091.391 (Kleibergen-Paaprk Wald F statistic): 2361.684	Stock-Yogo weak ID test critical values: 10% maximal IV size 19.93 15% maximal IV size 11.59 20% maximal IV size 8.75 25% maximal IV size 7.25
overidentification test	Hansen J statistic: 0.946	Chi-sq(1) P-val = 0.3308
Endogeneity test	2.933	Chi-sq(1) P-val = 0.0868*

This study assesses the reliability of our findings, employing a more dependable method, especially considering the potential weakness of our instruments. In this section, we test the robustness of the IV estimates by undertaking a different IV regression model using Lewbel's method. The Lewbel IV estimation provides supplementary instruments to improve the efficiency of the IV estimates, given that our instruments may be considered less relevant though valid. The results from the Lewbel methodology, where IV uses heteroscedasticity-based instruments in addition to our earlier instruments, settle the debate on which energy use improves enterprise performance. The Lewbel instrumental variable (IV) regression analysis results are presented in Table 2, column 3, revealing both electricity and fuel usage increase enterprise income by 0.075% and 0.081%, respectively. This result is consistent with the findings of the standard IV analysis presented in column 2 of the same table. Furthermore, the differential impact between the diverse energy sources was insignificant in both the Lewbel and standard IV analyses. Hence, the Lewbel results align with the consistent and unbiased estimates produced by the standard IV analysis.

2.4.4 Distributional effects of electricity and fuel energy on Enterprise income.

The results presented earlier indicate that fuel energy drives enterprise income better than electricity, but this difference is insignificant to various estimation techniques. We now examine if the effects of diverse energy input vary across different enterprise types and sizes. Given that diverse energy sources drive enterprise income differently will depend on what energy is used for in various sectors. The choice of energy input will depend on the enterprise's activities and production size. The choice of energy input in enterprise development also varies across socio-economic groups. The role played by gender, given the different uses of energy and availability of energy consumption in other locations, cannot be overlooked. We first report the Lewbel IV results for enterprise types, their sizes, and then the socioeconomic dimensions of gender and location.

2.4.4.1 Enterprise Type

This research further examined the importance of diverse energy by considering different enterprise types, such as manufacturing, wholesale/retail trade, services, and meal preparation. The sub-sample reports the effects of varying energy inputs on Manufacturing, Wholesale/retail, Services, and Meal enterprises in Table 5, Column 1, Column 2, Column 3, and Column 4, respectively.

Table 4: Effects on Enterprise Income by Types- IV(Lewbel Estimation)

	Manufacture	Wholesale/retail	Services	Meal

VARIABLES	Lentamt_hh	Lentamt_hh	Lentamt_hh	Lentamt_hh
Electricity	0.063***	0.094***	0.036	0.044
	(0.024)	(0.020)	(0.022)	(0.039)
Fuel Energy	0.081***	0.127***	0.054***	0.024
	(0.022)	(0.024)	(0.014)	(0.032)
Covariates	Yes	Yes	Yes	Yes
Constant	3.503***	2.991***	4.194***	3.269***
	(0.317)	(0.216)	(0.301)	(0.384)
D(Energy)	-0.018	-0.033	-0.017	0.020
	(0.033)	(0.032)	(0.024)	(0.050)
Observations	1,071	2,489	1,206	803
R-squared	0.263	0.198	0.272	0.234

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Author's estimate

Our analysis of the entire sample indicates that fuel energy usage has a more significant impact on enterprise profit than electricity, albeit with no significant difference in their respective impacts. However, our investigation of sub-samples, as displayed in Table 5, yields additional insights. In the manufacturing sub-sample, electricity usage leads to a 0.063% increase in enterprise income, while fuel energy usage results in a 0.081% boost in revenue, both of which are statistically significant at a 1% alpha level. Interestingly, contrary to our expectation, fuel energy usage yielded a higher coefficient compared to electricity. This unexpected finding suggests that manufacturing activities, which heavily rely on equipment or electric machines, may actually favour using fuel energy over electricity. The nature of the equipment and production processes in this sector appears to indicate that fuel energy usage tends to be more profitable for enterprises than electricity. Among the wholesale/retail and service industries, fuel energy usage is the key driver of enterprise income. In the Wholesale and Retail sub-industry, electricity usage has a significant coefficient of approximately 0.094%, whereas fuel usage has a coefficient of roughly 0.127%, both of which are statistically significant. The service sub-sector, however, only displays a significant relationship with fuel energy usage, with a more significant coefficient on enterprise income. Finally, our analysis of meal preparation and sales enterprises reveals no relationship between energy use and enterprise income. Despite observing different coefficients for electricity and fuel energy usage in our analysis, we found no statistically significant differences in these coefficients across all columns, which is consistent with our results for the full sample. These findings underscore the importance of both energy inputs, as we found no evidence to suggest that one energy source is substantially more beneficial to enterprises than the other.

2.4.4.2 Enterprise Size

The dataset employed in this study exhibits a substantial imbalance. Approximately 96% of the observations represent micro/small-scale enterprises employing 0-5 individuals, while the remaining enterprises employ 6-120 people. Therefore, a direct comparison of micro/small-scale and medium- or large-scale enterprises would need to understand the research issues comprehensively. Therefore, we reclassified the small-scale category based on the number of people employed by the enterprises. The reclassifications include enterprises with no employees (sole proprietorship), employing a single individual, and employing 2-5 individuals. The enterprises employ six or more individuals, which we categorise as "others." The findings from this reclassification are presented in Table 6.

Table 5: The effects on enterprise income by Size of Industry- IV(Lewbel Estimation)

	Small			**Others**
VARIABLES	0 employed	1 employed	2-5 employed	
Electricity	0.072***	0.072***	0.073***	0.042
	(0.018)	(0.022)	(0.026)	(0.054)
Fuel Energy	0.083***	0.108***	0.046**	0.065**
	(0.015)	(0.018)	(0.018)	(0.032)
Covariates	Yes	Yes	Yes	Yes
Constant	3.484***	3.273***	3.131***	4.332***
	(0.261)	(0.241)	(0.305)	(0.880)
D(Energy)	-0.012	-0.036	0.027	-0.023
	(0.024)	(0.029)	(0.031)	(0.061)
Observations	2347	2057	1031	134
R-squared	0.247	0.198	0.260	0.454

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Author's estimate

Table 6 presents the results of the enterprise subgroups' analysis, including the various scales of production and the significance of energy input. Columns 1-4 report the estimates for the different enterprise size categories and the corresponding differential impact of energy input. The analysis reveals no notable findings when comparing the different scales of firms. The results of enterprises that employ no individuals indicate that electricity and fuel energy inputs improve the firms' income by 0.072% and 0.083%, respectively, at a conventional level of 1%. However, the difference in impact between these energy sources was not statistically significant. At a significant level of 1%, electricity and fuel energy inputs increase enterprise income by coefficients of 0.072% and 0.108%, respectively. For businesses employing between 2-5 people, Column 3 reports higher coefficients for electricity input. Specifically, electricity and fuel expenses had 0.073% and 0.046% effects on enterprise income, respectively. The income generated from the enterprise to household suggests that both energy inputs are essential, but no significant difference was observed between the two sources. In Column 4 of Table 6, fuel energy appears to be larger enterprises' most crucial energy input. At a significant level of 5%, using fuel energy is positively associated with a coefficient of 0.065% on enterprise income. The spending on energy input reports highly significant coefficients for the Lewbel estimation of enterprise income for the categorised small-scale industries. Nevertheless, the difference in impact between the two energy sources remained insignificant across all levels of categorised enterprise sizes.

2.4.5 Heterogeneity analysis: Gender and location

The impact of electricity and fuel energy on enterprise performance may also differ by gender and location. It is established in the literature that women and men have different energy use, given the cultural role assigned to both genders. This notion is also the same when it comes to the ownership structure of enterprises. Therefore, female-owned enterprise energy use will be different from male-owned enterprises. The results are presented in Table 7.

Table 7: The effects on enterprise income by gender and location- IV(Lewbel Estimation)

	Male	Female	Urban	Rural
	1	2	3	4
VARIABLES	Lentamt_hh	Lentamt_hh	Lentamt_hh	Lentamt_hh
Electricity	0.070***	0.075***	0.083***	0.061**
	(0.017)	(0.018)	(0.016)	(0.026)
Fuel Energy	0.073***	0.077***	0.052***	0.107***
	(0.011)	(0.021)	(0.013)	(0.014)
Covariates	Yes	Yes	Yes	Yes
Constant	3.528***	3.167***	3.396***	3.098***
	(0.185)	(0.212)	(0.203)	(0.188)
D(Energy)	-0.003	-0.002	0.031	-0.046
	(0.020)	(0.027)	(0.021)	(0.029)
Observations	3,101	2,448	2,972	2,597
R-squared	0.255	0.2015	0.220	0.236

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Author’s estimate

The result in Table 7 Column 1 revealed that with male-owned enterprises, electricity and fuel energy increased the firm's income by 0.070% and 0.073%, respectively, at a 1 % significance level. Both male-owned and female-owned enterprises exhibit higher coefficients for fuel input compared to electricity input. Electricity use results in about a 0.075% increase in enterprise profit, while fuel only increases it by 0.077%, significant at 1%. There is no denying that urban communities are more energy-resourced than rural areas, especially when it comes to electricity access. Therefore, we expect that enterprise income using electricity should be higher. Consistent with our expectation, urban enterprise profit increases by 0.083% when using electricity compared to 0.052% when using fuel. Fuel energy drives enterprise development in rural areas, as shown in Table 7, Column 2. However, the impact difference between the two energy sources was insignificant for all levels of business categorised by gender and location differences.

2.4.7 Covariates

The study controlled for some firm-level characteristics to assess the accuracy of enterprise performances. Years of Operation appear significant and positive at a 1% significant level in the IV estimates. The findings imply that more years of enterprise operation increases household income, consistent with the findings of (Fafchamps & Quinn, 2018; Ahinful et al., 2023). Enterprise source of funds such as bank loans reduces firms' income for households compared to enterprises funded from households' savings. Ackah and Vuvor (2011) reported similar findings that businesses in Ghana funded through personal savings had higher profit margins than those that relied on external funding sources, including bank loans. The high cost of borrowing from loans reduces the profit of enterprises. Most research findings have reported financial constraints on enterprise development (Kusi et al., 2019; Oppong et al., 2014; Grimm et al., 2013). This finding emphasises that savings other than loans are more important for the firm's growth. Third, an observed pattern for registered firms is that more people employed, more working hours, and receiving training increases enterprise income amount for households and profit levels. This finding supports basic economic intuition that more people are employed, and more work hours improve performance, hence income and profit. The relationship between the number of people employed, working hours, and business performance is complex. It depends on various factors, such as the type of industry, the skill level of workers, and the efficiency of the production process. The works of Mahmood and Rosli (2013) confirm that higher employment levels and more working hours were associated with higher enterprise profitability. Receiving training gives household entrepreneurial and managerial skills in expanding enterprise activities, making it more profitable. As evident in previous studies (Oppong et al., 2014; Mahmood & Rosli, 2013; Garcia, 2005; Aragón-Sánchez et al., 2003; Zinger et al., 2001) have reported positive effects of training on business performance. However, it's important to note that the effectiveness of training may depend on various factors, such as the type and quality of training, the skill level of workers, and the enterprise's organisational culture. The period of accounting by the firm has also shown to be significant and positive with a higher magnitude in ascending order to enterprise income or profit. This is because the accounting period determines when revenue and expenses are recorded, which can affect the reported income for the period (Oppong et al., 2014).

Income belonging to an individual reduces the firm's revenue. Nyanzu and Adarkwah (2016) also found a negative effect of sole proprietorship on the profits of SMEs in Ghana. The regional distribution variables were significant and negative on enterprise income compared to the Western Region in the IV estimates in Table 4. A careful examination of the estimates shows an average constant term of about 3 and an R-square ranging around 23%. R-squared values in survey research are often lower than in experimental research, and values ranging around 23% are not uncommon. Results and direction from these estimates seem consistent in both the IV and robust Lewbel results.

2.4.8 Discussion

This section discusses the potential reasons explaining the results obtained in this study. The results first reported the complete sample estimate, followed by the sub-sample and the socio-economic dimensions. We commence our discussion by underscoring the significance of both electricity and fuel energy. Despite this acknowledgement, it is notable that fuel energy tends to exhibit higher coefficients in many instances. We subsequently examined if a significant difference between electricity and fuel energy coefficients exists. Furthermore, we examine the justification for considering additional factors in supporting policies promoting clean, modern energy and addressing environmental concerns.

The baseline and IV results emphasise the importance of electricity and fuel energy, though the fuel energy coefficient was higher in most estimations. However, it is important to note that the benefits of each energy source depend on various factors, such as the specific enterprise's energy needs, location, and the efficiency of the energy conversion process. Fuel energy is readily available and cheaper than electricity, which is believed to be more expensive and unstable in supply. Fuel energy often has a lower cost per unit of energy compared to electricity. For example, a study by the US Energy Information Administration (2020) found that in 2019, the average price of natural gas for industrial use was $3.18 per thousand cubic feet, while the average price of electricity for industrial use was 6.89 cents per kilowatt-hour. This lower cost can translate to significant savings for enterprises that rely heavily on energy. The cost of electricity per hour in most Sub-Saharan African countries is comparatively higher than that of the United States. As Blimpo and Cosgrove-Davies (2019) reported, the hourly cost of electricity in Liberia is four times greater than that of the United States. According to Adom et al. (2018), there has been a significant increase in Ghana's electricity prices between 2000 and 2013, with the current rates being more than six times higher than the average price recorded between 1990 and 2000. This has resulted in Ghana having one of the highest electricity tariffs in Africa.

In contrast, Ghana's fuel energy cost is relatively lower (Agyekum & Nutakor, 2020), especially for enterprises that can access domestic fuel sources such as biomass, charcoal, and diesel. Fuel energy is also more reliable in Ghana, as the country's electricity grid is often plagued by frequent power outages and supply interruptions, which can significantly disrupt business operations. Ghana has had a series of and continues to experience both planned and unplanned power outages. Such unreliable energy input may not drive the profit of the enterprise as expected. Another possible reason for the electricity lacking behind fuel energy is whether the amount consumed is enough for the supposed enterprise development. An enterprise that relies on electricity requires a substantial amount to continue the business. Hence, when electricity is in short or interrupted supply, it will affect the expected profit of enterprises. Fuel energy, in particular, has been identified as a vital resource for business development and income generation through enterprise activities (King et al., 2012). Recognising this, the Ghanaian government has implemented policies to promote fuel energy use for industrial purposes, including tax exemptions and other incentives for enterprises that invest in renewable energy and energy efficiency measures. These policies have helped improve the cost-effectiveness of fuel energy for Ghanaian businesses, especially those in rural areas with limited access to grid electricity (Asumadu-Sarkodie & Owusu, 2016; Apeaning & Thollander, 2013). Such initiatives could significantly impact household income and poverty reduction, particularly in rural areas with prevalent energy poverty. The findings also support the assertion that electricity usage increases household enterprise income (see works of Rao, 2013; Gibson & Olivia, 2010). The effects of electricity on income in the household counter the findings that underscore the importance of electricity usage to enterprises' development (Grimm et al., 2013; Neelsen & Peters, 2011).

The central aim of this paper extends beyond acknowledging the relevance of competing energy inputs; it endeavours to discern whether the differences in coefficients denote the superiority of one energy source over the other, warranting prioritization. While it is expected to observe that fuel energy often yields higher coefficients than electricity in various estimations, our study embarked on an empirical examination to ascertain the differential impact between the utilization of electricity and fuel. Surprisingly, our findings indicate that the differential impact between electricity and fuel energy on enterprise income lacks statistical significance. This outcome resonates with our initial expectation, further advocating for increased government investment in modern, cleaner energy sources such as electricity (Andrews & Johnson, 2016). The insignificance of the coefficient difference indicates that both inputs are significant. However, when factors like environmental impact are considered, electricity is preferred and recognized as a cleaner form of energy input. The widespread use of fuel energy, with its detrimental effects on the environment and climate change, presents compelling grounds for government intervention to promote the expansion of electricity infrastructure—a more modern and environmentally friendly alternative essential for human survival (Andrews & Johnson, 2016).

Moreover, additional arguments supporting investment in electricity include its potential for productive use, enabling households to repay initial investments and facilitating government recoupment. Furthermore, the employment opportunities generated by productive electricity usage contribute to economic development. Compared to households reliant on unclean fuel energy, those utilizing electricity are less susceptible to pollution-related health problems, thereby reducing healthcare costs and enhancing overall well-being. Furthermore, it is possible to choose from diverse energy sources to promote the interests of household businesses, taking into account the negligible differences in impact and evaluating the external or environmental costs. Although fuel energy is readily available and inexpensive, it incurs higher environmental costs (Abbasi & Abbasi, 2010). Traditional fuels such as wood and charcoal are acquired through the depletion of trees, which negatively impacts human survival. Likewise, modern fuels like diesel significantly contribute to carbon dioxide emissions (Amid et al., 2020). In addition, unlike electricity, which is readily accessible and connected within households for immediate use, obtaining fuel energy requires travel, resulting in additional costs for businesses (Bapna et al., 2002). Apart from the negative externalities associated with fuel energy consumption, there is a gradual increase in fuel prices due to reductions in fuel subsidies. Cooke et al. (2016) discovered that reducing certain fuel subsidies in Ghana has led to adverse welfare implications, including those for businesses. Consequently, electricity emerges as a cleaner and more modern form of energy with lower negative externalities for households and businesses, making it essential for enterprise development.

The underlying economic theory of input production and profit maximization further reinforces firms' choices among complementary and substitute inputs to maximize profits. Various factors, including input prices, production technology, and output characteristics, significantly influence input selection within enterprises. Therefore, firms make input choices based on their production requirements and market conditions. The study by Du et al. (2021) provides empirical evidence to support the input substitution theory in the context of inter-energy use in enterprises through energy savings. The finding that the differential impact on enterprise income between electricity and fuel energy is insignificant suggests that firms make energy input choices based on their production requirements and market conditions rather than the type of energy input.

The differential impact between fuel energy and electricity being insignificant in the whole sample needed further interrogation on whether the impact will be the same for sub-sample and socio-economic groups. The results from the enterprise sub-sample showed similar findings. These results affirmed Adu et al. (2018) assertion that electricity expansion increases the likelihood of enterprise development. The activities of the manufacturing sector are made possible by electricity expansion. Contrary to our expectations, increasing electricity access was anticipated to favour manufacturing types of enterprises over others. However, the fuel energy coefficient was unexpectedly higher, aligning with the findings of Peng et al. (2019), who showed more vital fuel consumption for manufacturing firms in China. However, they also found that the impact of energy consumption on productivity varied depending on the industry, with some industries showing a stronger preference for electricity over fuel. A similar finding was observed among enterprises with 2-5 employees; yet again, fuel energy was better for firms with 0 and 1 employees in small-scale enterprises. Again, this stresses the importance of electricity (Adu et al., 2018) and fuel to enterprise development. The medium and large enterprise results favoured fuel energy and could be explained by the earlier reasons for electricity costs and power outages.

Regarding the socio-economic dimension, such as gender and location, we report similar findings. While the differential impact between the two energy inputs was found to be insignificant, it is notable that both energy inputs exhibited significance, with fuel energy reporting higher coefficients for both male and female-owned enterprises. However, this observation holds only qualitatively, as the linear test of difference continues to yield insignificant results, suggesting a preference for more environmentally friendly and modern energy sources. Women and energy discussions show that modern energy is essential to welfare enhancement (Asibey et al., 2021). Empowering women through expansion in enterprise activities requires more electricity access. The social role assigned to both genders suggests different energy usage as women undertake most self-employed entrepreneurship activities while men engage in skilled-driven activities (Asibey et al., 2021). The results for the enterprise location suggest that electricity is a more important driver of urban firms than rural firms. Urban communities are energy-rich and, more importantly, have advanced electricity expansion than rural areas, which are energy-poor (Kankam & Boon, 2009). This finding confirms the works of Surya et al. (2021) on the importance of electricity in urban communities and the role of undertaking economic activities. However, there was no significant difference between electricity and fuel energy in the income of enterprises to the household.

Overall, this study's findings suggest that the impact of energy use on firm performance may vary depending on the specific context, such as the type of enterprise, the industry, and the availability and cost of different energy sources. For example, in some cases, electricity may be a more relevant driver of enterprise income, while fuel may be more important in others. However, the results also suggest that firms make input choices based on their production requirements and market conditions rather than the type of energy input. Finally, when taking into account the external and environmental costs associated with fuel-based energy, the results provide a compelling argument for promoting the utilisation of electricity to foster business enterprises while contributing to the global fight against environmental degradation, greenhouse gas emissions, and climate change.

2.5 CONCLUSION

Drawing on the Ghana Standard Living Survey (GLSS 7) non-farm enterprise survey, this paper analysed the effects of electricity expenditure on household income. Our study underscores the importance of both electricity and fuel energy in driving enterprise performance. Despite the common observation of higher coefficients for fuel energy in various estimations, our empirical examination reveals a statistically insignificant difference between the impacts of electricity and fuel energy on enterprise income. Similar research works believe electricity is an endogenous variable. In addressing the endogeneity issues surrounding electricity use, the research showed that firms' performance in terms of income responds positively and significantly. The study provided evidence for electricity and fuel usage by considering the enterprise types and sizes to inform specific policy directions and suggestions. Although we observed some differences among the diverse energy inputs across different types and sizes of enterprises, this disparity did not reach statistical significance, indicating the importance of both inputs. Therefore, we must consider other factors to emphasize the choice of energy. Considering external, environmental, and health considerations, government investment in electricity is justified and would encourage productive use.

Additionally, this study explored the socioeconomic aspects of enterprise activities, focusing on gender and location. The individual coefficient analysis highlighted that electricity was undoubtedly the preferred energy input for urban businesses, while fuel showed higher coefficients for both male and female-owned enterprises. However, fuel remained the dominant energy source for rural enterprises. The primary objective of this study was to assess the significance of disparities in the utilization of electricity and fuel, which we determined to be statistically insignificant. This prompts us to question the practical implications of this finding.

One significant implication is the need for nuanced energy policy interventions. While both electricity and fuel energy are vital, their relevance varies depending on factors such as enterprise type, industry, and location. Understanding these nuances is crucial for policymakers to design targeted interventions catering to enterprises' diverse energy needs. Furthermore, our findings highlight the economic and environmental implications of energy choices. While fuel energy may be cheaper and more reliable in specific contexts, it comes with significant environmental costs such as pollution and deforestation.

In contrast, despite its higher costs and occasional supply challenges, electricity offers a cleaner and more sustainable alternative. Our study underscores the importance of government investment in electricity expansion, as it drives enterprise performance and reduces unemployment through household engagement in productive activities. Governments can stimulate economic growth by expanding electricity access, particularly in energy-intensive industries like manufacturing, while creating employment opportunities. Moreover, our findings suggest that households' increased income from enterprise activities enables them to afford electricity, making government investment financially viable in the long term. Overall, prioritizing electricity infrastructure can foster sustainable economic development, benefiting households and the broader economy.

Additionally, our study sheds light on the socioeconomic dimensions of energy usage, particularly concerning gender and location. These insights underscore the need for targeted interventions to address energy access disparities and promote inclusive economic development. Furthermore, with the series of post-estimation tests on the validity of instruments used by Lewbel IV methodology, the findings are robust, implying unbiased and consistent estimates.

In summary, the findings of our study suggest that the impact of energy use on firm performance is contingent on various contextual factors such as the type of enterprise, the industry, the availability, the unit cost, and, more importantly, the external cost of different energy sources. Our study provides compelling evidence supporting government investment in electricity expansion as a catalyst for economic growth, employment generation, and poverty reduction. Governments can lay the foundation for sustainable and inclusive development by prioritising electricity infrastructure development, benefiting both households and the broader economy. Nevertheless, our study also underscores the importance of recognising that firms make input choices based on their unique production requirements and market conditions rather than the type of energy input. Thus, the results of our study provide important insights into the complexities surrounding the impact of energy use on firm performance and have implications for policy and practice aimed at promoting sustainable and inclusive economic development.

CHAPTER THREE

3. The Impact of Electricity Prepayment Metering Systems on Food Insecurity (Hunger) among South African Households

Abstract

Food insecurity has been a long-time issue in South Africa, with over 12% (7.26 million) of its population suffering from hunger. Food insecurity in South Africa can be attributed to multiple factors, including income, employment, and access to food. However, prepayment systems could also explain food insecurity in the country as it requires households to pay in advance, potentially leading to a reduction in saving money. This research investigates the differential impact of electricity prepayment systems and competing policy instruments on food insecurity. Applying robust techniques such as the propensity score matching to the General Household Survey 2020 from South Africa, the findings show that households that use prepaid electricity meters have a higher probability of experiencing hunger. Specifically, we find that using prepaid meters increases hunger in families and among adults and children by 3.9%, 4.7%, and 4.4%, respectively. However, hunger marginally decreases when households receive social interventions with prepaid meters. The study further observed multiple burdens of chronic diseases to mediate the relationship between using prepaid electricity meters and hunger. Therefore, the policy implications of the results suggest reviewing prepaid metering and subsidy schemes for poor-income households. Also, the study suggests that providing food assistance programs or subsidies may prove vital in directly addressing hunger in these vulnerable households.

3.1 BACKGROUND

Food insecurity or hunger has been a global crisis over the past decades due to economic downturns, poverty, rising inequalities, conflicts, hazards, climate change, and most recently COVID-19 pandemic. Statistics from the World Bank indicate that two out of five people are food insecure due to their inability to afford healthy diets. According to the 2021 report of the Food and Agriculture Organization (FAO) on the state of food security and nutrition in the world, over 928 million people in 2020 faced severe levels of food insecurity, with about 282 million living in sub-Saharan Africa. Moreover, about 30% of African and Asian women aged 15–49 years were anaemic due to food insecurity compared to about 15% of their counterparts in Europe and North America. Studies (Trudell et al., 2021**;** Collins, 2009) have shown that food insecurity negatively affects people, including children, as their later life outcomes are related to poor health. For instance, food insecurity is associated with severe levels of depression, the multiple burdens of chronic conditions like obesity and diabetes in adults, and suicidal ideation among adolescents (Trudell et al., 2021). This finding has been observed to hamper children's physical, cognitive, and social-emotional development (Hines et al., 2021; Ke & Ford-Jones, 2015). These issues reveal the challenge food insecurity presents to achieving the United Nations' Sustainable Development Goal (SDG) 2 by 2030, especially with the advent of the COVID-19 pandemic, hence a call for action on urgent ways for its eradication.

Many studies have reported findings on the causes and solutions to hunger. However, these scholarships have mostly been fixated on environmental issues (climate, land, and agriculture), conflicts, and social structure (family size and income levels) and need to pay more attention to the behavioural concepts of self-control and impulsiveness. The literature suggests that individuals who lack self-control and are impulsive tend to have negative consequences since they cannot control their expenditures. With post payment systems noted to capture this behaviour, it is worth examining how these systems affect household food-related issues. Thus, some literature argues that impulsive consumers pay little attention to their consumption and hence make spontaneous purchases of luxury goods, limiting their income spent on food. These studies usually propose prepayment methods to help curb this behaviour. These prepayment systems ensure efficiency and an increase in revenue mobilisation on the part of service producers and are now becoming popular, especially in developing economies (Tewari & Shah, 2003).

Nevertheless, given the limited income of poorer and low-income households in emerging economies, these prepayment systems are sometimes argued to constrain their consumption of food (O'Sullivan et al., 2011), among other basic needs (Jack & Smith, 2015). Thus, under the assumption of fixed income, services such as electricity paid under the prepayment system will mean lesser income for food, among other household needs. Hence, empirical studies are needed on the implications of such payment schemes on food insecurity.

Nevertheless, the few studies that examined the impact of these prepayment schemes on other welfare indicators (Ruiters, 2009; Casarin & Nicollier, 2011; Makonese et al., 2012; Jack & Smith, 2016) fail to account for channels through which this effect occurs. Neglecting these channels or mechanisms biases the estimates and affects the conclusion's generalization (Lin & Okyere, 2021a; MacKinnon et al., 2012). Furthermore, it is worth noting that the government and other donor agencies have introduced several support schemes and grants to low-income households to address income deficits that directly or indirectly affect hunger (Masekameni et al., 2018; Gilbert, 2004). However, the interventions' ability to supplement the household's income, specifically those using these prepayment schemes for essential services such as electricity and water, remains missing in the food security literature. Hence, analysing these interventions' role in addressing food insecurity amidst the prepayment scheme is necessary. Based on the above, we focus on electricity prepaid systems' role in explaining household food insecurity or hunger and how interventions such as subsidies moderate this effect. Thus, our present study seeks to answer the following questions: (1) Does using prepaid electricity meters affect hunger among households in the nine provinces of South Africa? If it does, (2) what are the channels through which this occurs? and (3) do subsidy schemes moderate the effect between prepaid electricity meter usage and hunger?

Our study, therefore, makes the following contributions to the literature. First, we contribute to the literature on food insecurity or hunger causes by considering prepayment schemes' impact. Unlike prior studies that have observed poverty (lack of purchasing power and resources), ecological damage, drought, land litigation, and Wars, among others, to affect hunger, we add to the literature by empirically examining the role prepayment schemes (as exemplified by prepaid electricity meters) play in explaining household hunger. Secondly, the research adds evidence to scholarship on self-control and impulsiveness (Pirog & Roberts, 2007; Hofmann et al., 2009; Runnemark et al., 2015). While previous studies on self-control and impulsiveness mainly employed credit and debit cards to examine this behaviour among consumers, we use the postpaid/credit and prepaid electricity meters to study this phenomenon.

Furthermore, we add to the literature on how prepaid electricity meters affect the welfare outcomes of the users. This is because extant literature remains inconclusive. For instance, some studies have observed the usage of prepaid electricity meters to significantly lower electricity consumption and improve customer service and satisfaction (Mwangi, 2017; O'Sullivan et al., 2014; Tewari & Shah, 2003). In contrast, others have also argued that prepaid meters present some difficulties for poorer households as they rely on biomass for cooking and heating due to the fear of disconnection (O'Sullivan et al., 2016; O'Sullivan et al., 2013; Colton, 2000). Hence, examining the implication of prepaid meters on food insecurity will add an extra dimension of analysis and possibly help clarify their overall impact. The discussion surrounding the influence of prepaid meters on the allocation of household resources between essential needs such as food and electricity and its potential impact on food insecurity may vary across different contexts and demographic groups, particularly those with specific family considerations such as households with children and adults. Therefore, conducting heterogeneity analysis will contribute to a nuanced understanding of these variations, thereby informing policy considerations tailored to distinct groups, by identifying which groups are most affected by these dynamics. In addition, we contribute to the empirical literature by conducting a mediation analysis by examining channels through which electricity prepayment systems affect hunger. Furthermore, we investigate how interventions in the form of subsidies moderate the effect between these associations. We finally contribute to the literature by adopting a micro dataset from a developing country. This is against the backdrop that studies on the implication of prepayment meters in developing economies remain limited (Jack & Smith, 2020; Mbohwa et al., 2019a)**.** The study by Jack and Smith (2020) used data limited to Cape Town. Hence, we employed a nationwide household survey from South Africa.

The rest of the paper is organised as follows: the next section presents a literature review and explains why the focus is on South Africa and the status of the prepaid deployment. Section 3 outlines the methodological procedure used in this research. Section 4 presents the results of the estimations, and the last section concludes.

3.2 LITERATURE REVIEW

3.2.1 Why South Africa?

Electricity is vital in enhancing several essential domains, such as education, employment, health, and food security. Despite this, the linkage between electricity accessibility and food insecurity is not straightforward and has received limited attention in scholarly literature. This paper utilises World Development Indicators (WDI) data from South Africa to investigate the relationship between access to electricity and food insecurity. Notably, the WDI data reveals a considerable increase in food production from 2019 to 2020, while the population growth rate declined during the same period. This phenomenon should imply a potential decrease in food insecurity. However, despite such trends, food insecurity continued to rise from 18.2% to 19% from 2019 to 2020. Intriguingly, access to electricity decreased slightly during this time, from 85% to 84.38%, coinciding with a rise in food insecurity. This correlation raises the possibility that any reduction in electricity access might exacerbate food insecurity. Moreover, implementing a prepaid metering system might lead to lower electricity consumption (Jack & Smith, 2020a) and thus link with food insecurity or hunger among households.

The consumption of electricity has evolved over the years due to the need for efficiency and ever-changing consumer demands. The organisation in charge of producing and distributing electricity in South Africa, Eskom, was one of the largest electricity generators in the world in the late 1980s. However, it had only 120,000 customers and mainly used the billed accounts (Tewari & Shah, 2003). By 1988, Eskom undertook a revolutionary "electricity for all" strategy that led to a significant customer base. With the growing customer base, many problems were associated with the standard billing account, such as personnel and management processing this account. In addition, some communities had no infrastructure to reach, and customers had no bank account, permanent jobs, or postal address, among others. Therefore, Eskom initiated the first inquiry to purchase 10000 prepayment meters in 1989. Having identified new specifications of prepayment systems, the old ones were replaced with time. By 1993 and 2000, the total number of prepayment meters manufactured increased to 200,000 and 300,000 per annum, respectively. As a result, Eskom had installed about 3.2 million prepaid meters by 2000 in South Africa (Tewari & Shah, 2003). In recent times, Eskom, as of 31st March 2020, had about a 6.7million direct customers, with 6.5 million residential customers compared to 5.6 million customers in 2017. The 31st of March 2021 report by Eskom shows sales to about 6.86 million customers, and about 6.72 million were residential customers.

The benefits of a prepayment system to the service provider (ESKOM) are enormous. Revenue has improved significantly; Eskom made a net profit of R9.2 billion after tax from R139 billion in revenue in 6 months from April 2021 to September 2021. Within the same period, there were further R10 billion reductions in debt. Aside from the increased tariffs and electricity demand, the prepayment system was a faster revenue recovery means. In addition, ESKOM has introduced smart prepaid split systems to improve its services and reduce electricity theft and fraud.

Despite the significant revenue, Eskom ended the financial year with a net loss. There has been resistance to prepaid meters in some township areas in South Africa. The opposition of poorer households to the switch from postpaid to prepaid metres can be attributed to the financial difficulties that arise from this transition (Makonese et al., 2012a). In some areas, the installation of prepaid meters was forced on the consumers (Malzbender & Kamoto, 2005), coupled with other challenges resulting in increased electricity theft (Mujuzi, 2020). These challenges notwithstanding, the ability to control electricity consumption using prepaid meters has been embraced by many consumers. South Africa is now one of the world's leading countries with a high prepayment metering technology rate. Also, it serves as a pacesetter for other countries to adopt the South African standards (Jack & Smith, 2015).

3.2.2 Theoretical Model: Income Redistribution Theory and Food Insecurity

This study integrates models of income redistribution based on the research of Plotnick & Winters (1985), which propose that households redistribute their income between two interdependent preferences. Following this theoretical model of household income redistribution, the study posits that such redistribution will occur between the presence of electricity and food, both essential needs and that the payment for electricity will affect household income, necessitating redistribution between these competing needs. The model posits payment systems, such as prepaid and postpaid methods, as pivotal factors influencing household income allocation and subsequent food security. Prepaid systems may restrict cash flow, impacting food purchasing power (Barriga-Cabanillas & Lybbert, 2021), while postpaid methods or subsidies could facilitate income redistribution, potentially enhancing food security. Food insecurity, arising from financial constraints

(Caselli & Battini, 1997; Heymans et al., 2014), is influenced by payment systems' impact on household budget allocation. Thus, prepaid systems may exacerbate food insecurity by limiting funds for food purchases, whereas postpaid methods or subsidies may mitigate it by increasing disposable income for food expenditure (Nababan, 2018). This model underscores the significance of income redistribution in addressing food insecurity and emphasizes the role of payment systems in shaping household food access. Understanding this relationship can inform targeted policies to promote equitable food resource access and enhance overall food security outcomes.

3.2.3 Framework on the Effect of payment systems on food insecurity

Although limited studies exist on payment systems and household food insecurity, only some scholarships have taken a swipe at this nexus. Shonchoy and Kurosaki (2014) provided evidence of credit prepayment for food consumption using a Randomized Control Trial (RCT) in Bangladesh. They found no positive evidence of prepayment flexibility on immediate food consumption. Their study further established that microcredit borrowers were more food secure than non-borrowers. Czura et al. (2011) proved how prepayment flexibility smoothens food consumption among Bangladeshi farmers by adopting a randomised experiment. Fuentealba et al. (2021) found that automatic bill payments increase household debt burden as they cause welfare losses. Although these studies establish linkages between prepayment schemes and food consumption, rigorous evaluation of the impact of prepaid electricity metering systems on food deprivation needs is lacking in the literature. O’Sullivan et al. (2014) examine electricity prepayment meter use on New Zealand household energy behaviour. Their study highlighted how electricity prepayment metering could reduce disadvantages and capture potential benefits. They identified households experiencing severe hardship to take extreme measures to restrict their energy use. This is because prepayment metering comes at a higher cost when compared to other metering systems (O'Sullivan et al., 2011).

Studies on prepaid metering in South Africa also report significant effects on vulnerable households (Mbohwa et al., 2019a). Mbohwa et al. (2019) examined how prepaid electricity metering affects low- and high-income households in Soweto, South Africa. They concluded that prepayment metering helps the service producer (Eskom) but poses a challenge for low-income consumers. Unsurprisingly, there have been reports of rejection of prepaid meters among poor South African households (Kambule et al., 2018; Makonese et al., 2012). The use of prepaid meters and the frequent purchase of electricity by poor consumers make it difficult to smoothen income (Jack & Smith, 2016). The requirement of prepayment for electricity entails initial expenses that diminish the amount of household income designated for sustenance, leading to a rise in food insecurity (O'Sullivan et al., 2014b). Though no direct link has been provided on the association between the usage of prepaid electricity meters and hunger, we hypothesise that patrons of electricity prepaid meters will experience higher levels of hunger or food insecurity:

H1: Using prepaid electricity meters positively correlates with food insecurity.

Although using prepaid electricity meters can directly affect food insecurity, it will likely influence it indirectly. Hence, we explore these mechanisms by concentrating on their effects on household expenditure and chronicity. Chronicity pertains to a persistent and recurring health condition (Kapfhammer, 2022). When an individual is affected by multiple chronic diseases, they are described as having a "burden of diseases." This leads to managing and coping with multiple chronic conditions simultaneously, which can significantly affect the individual's quality of life and daily functioning.

Unlike prepaid meters, post-paid meters enable consumers to defer payment for energy services, allowing them to allocate funds towards immediate necessities such as food.

Given a fixed income and electricity as households' primary energy source for cooking and heating, users of prepaid meters are obliged to pay before using electricity. In theory, making payments immediately before the consumption of services impacts income levels and expenditures related to other services (Arifovic et al., 2017; Hayashi & Klee, 2003). Empirical evidence by Quercia et al. (2012) observed lower income associated with prepayment users. Similarly, Colton (2000) reported that prepayment systems such as prepaid utility meters tend to reduce household expenditure. This reduction in household expenditure has been observed to render household food insecure. Akpalu and Okyere (2022) found that households in Ghanaian fishing communities experience a reduction in their protein intake as their income reduces.

Similarly, Arndt et al. (2020) observed a reduction in household income during the Covid 19 as the measures of curbing the pandemic affected poorer households, making them food insecure. Therefore, it is not surprising that the Keynesian theory of consumption indicates how lower income levels affect household food consumption. Based on this, we argue that using prepaid meters reduces household income and expenditure on food, increasing food insecurity.

The prepayment system reduces the household’s income (Mbohwa et al., 2019a; Wagner & Wiegand, 2018) and is also associated with chronicity or the multiple burdens of chronic conditions. Not paying ahead means no electricity for cooking, and sleeping in heat and darkness causes sleeplessness, anxiety, stress, and health issues (Wells et al., 1990)**.** This exacerbates the burden of contracting chronic conditions such as obesity, mental illness, and diabetes. According to Burlinson et al. (2022), households using prepaid electricity are likelier to eat fewer fruits and vegetables to stay healthy. This translates into chronic conditions such as asthma, respiratory infections, and cardiovascular disease. The researchers attribute this to the fact that households may be unable to afford to top up their electricity supply regularly, leading to extended periods without electricity for cooking, heating, and lighting. This can lead to sleeplessness, anxiety, stress, and other health issues. Using the socioeconomic panel data, for instance, Lin and Okyere (2020) asserted that the inability of a household to meet their energy needs as a result of payment issues increases depression among Ghanaians. Churchill et al. (2020) reported similar results for Kenya. The research revealed that individuals who encountered difficulties in accessing electricity owing to payment-related concerns exhibited a higher likelihood of experiencing symptoms associated with depression and anxiety. Their findings suggest the possibility of energy poverty leading to a range of negative consequences, including reduced social interaction, limited access to information and entertainment, and decreased productivity, which can all contribute to poor mental health outcomes. In Australia, Prakash and Munyanyi (2021) found the burden of not having energy due to payment issues to increase obesity. Following Hajat and Stein (2018), living with multiple chronic conditions increases household expenditure on healthcare as the inability to meet this need promotes premature mortality. Hence, people living with these conditions spend a lot on their healthcare, reducing their food expenditure and making them food insecure. Garcia et al. (2018) found adults with hypertension, arthritis, and diabetes to be food insecure. A similar conclusion was made by Adams et al. (2017). Based on this, we hypothesise that using prepaid meters increases one’s chances of having multiple chronic conditions, increasing their chances of being food insecure:

H2: Chronicity mediates the relationship between the usage of prepaid electricity meters and food insecurity.

Most low- and poor-income households often struggle to save due to the instantaneous electricity payments they make (Karásek & Pojar, 2018). Governments in the developed or developing world try to implement assistance programs to smoothen their consumption.

Governments often implement various interventions to ensure people meet their basic energy requirements. These interventions mostly come in the form of direct and indirect funds and liabilities transfers (budget outlays), forgone government revenue (reduced tax rates and tax exemptions), and income or price support schemes via market mechanisms (including non-enforcement) (Bridle et al., 2022). Following the permanent income hypothesis, an improvement in the households' economic status via these interventions increases their consumption, thereby improving food security (Adua, 2010; Wilson & Dowlatabadi, 2007). For example, the works of Arndt et al. (2020) establish transfer payments insulated income of poor households improving food security in South Africa. Other studies argue that social protection programs increase household food consumption or reduce hunger (Hidrobo et al., 2018; Devereux, 2016). Therefore, we propose that these interventions will smoothen the consumption of these prepaid users and reduce their food insecurity:

H3: Interventions negatively moderate the relationship between the usage of prepaid electricity meters and food insecurity.

This study focuses on the issue of food insecurity within households in South Africa, characterised by the presence of hunger. This research explores the causal pathway linking prepayment systems to food insecurity by examining the hypotheses. Additionally, it considers various socio-economic factors such as education, age, salary, marital status, household size, location, and regional indicators, which may also influence food insecurity. A schematic diagram illustrating the mechanism leading to hunger is depicted in Figure 3. It is observed that payment schemes, such as prepaid electricity meters, impact household income and expenditure patterns. Households utilising prepaid meters face credit constraints on their income, leading to a tradeoff between electricity consumption and food consumption. Prepayment for electricity necessitates upfront expenditures, which reduces the available household income allocated for food, resulting in increased hunger. This relationship is illustrated by the red arrow in Figure 3, indicating a direct link between prepaid meters to hunger.

In contrast, a postpaid system provides the option to pay for electricity at a later time, eliminating the tradeoff between food and electricity consumption and allowing households to allocate enough of their current income towards food expenses. The causal pathway diagram also indicates the potential indirect influence of electricity prepayment systems on household food insecurity through the mediating role of chronic diseases (chronicity). Prepaid meters are associated with stress and anxiety behaviours, which contribute to the occurrence of chronic conditions. Household spending on such diseases further strains their income, forcing a tradeoff between health expenditures and food consumption. Increased health expenditures limit the available budget for adequate food, resulting in hunger, as depicted in the lower panel of Figure 3. In addition to the mediation analysis, this study aims to examine how various pro-poor subsidies can alleviate the impact of prepayment systems on food insecurity among South African households. The moderating effects of pro-poor policies interact with prepaid meters, as supplementary household expenditure can reduce the tradeoff between food, electricity, and health expenditures. This implies that if subsidies supplement household income, the tradeoff between electricity consumption and food or health expenditures can be minimised, as the additional income enables households to afford basic necessities without compromising other essential needs. This concept is illustrated in the upper panel of Figure 3. The findings of this research underscore that households utilising prepaid electricity meters face a higher likelihood of experiencing hunger.

This study identifies the mediating role of chronic diseases and the moderating role of subsidies in the relationship between prepayment systems and food insecurity, emphasising the significance of considering the broader socio-economic context when addressing food insecurity in South Africa. The research provides valuable policy implications, recommending a review of prepaid metering and subsidy schemes for low-income households to tackle the issue of food insecurity effectively. A pictorial representation of this framework has been presented in Figure 3.

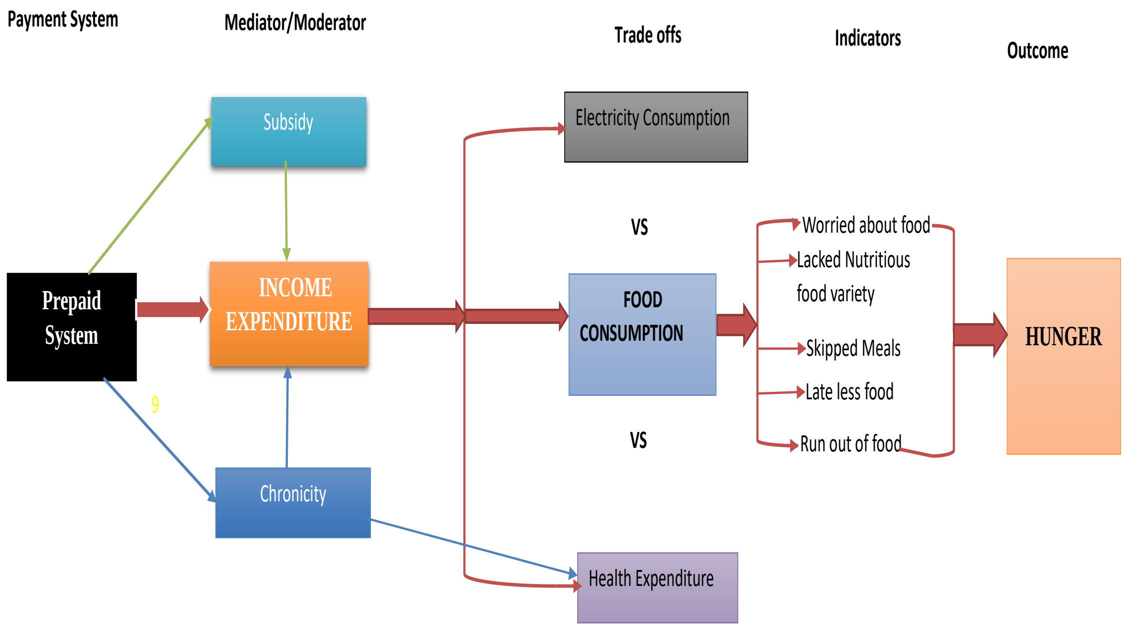

Figure 3: A Causal Pathways to understanding prepayment systems and Hunger
Sourced: **Author's construct**

3.3 METHODOLOGY

3.3.1 Data

The sample for this study leverages the General Household Survey 2020 in South Africa. The General Household Survey (GHS) has national coverage that provides the living circumstances of South African households, including education, health, social development, housing, access to services and facilities, agriculture, food security, energy, and prepaid and postpaid metered consumers. We draw on the sample from the latest round of surveys released in 2020, which uses the Master Sample (MS) frame developed in 2013 as a general-purpose sampling frame for all household-based surveys. This survey reported 19649 households; about 76% used prepaid meters, 11% used conventional (Postpaid) meters, and the rest used other sources or no electricity. Therefore, we construct a sample focusing on only these two-meter types of households, with 1 for prepaid users and 0 for postpaid users.

3.3.2 Measurements of Key Variables

Food Insecurity (Hunger)

We used the household hunger scale using the General Household Survey (GHS) to measure food insecurity. Other food security measurement surveys used in South Africa include National Food Consumption Survey (NFCS), Food Insecurity and Vulnerability Information and Mapping System (FIVIMS), the Income and Expenditure Survey (IES), Community Survey (CS), the South African Social Attitudes Survey (SASAS) and Labour Force Survey (LFS) (De Cock et al., 2013). The GHS survey asked whether households worried about food, lacked nutritious food variety, skipped meals, ate less, or ran out of food. Respondents who responded in affirmative coded as 1 and deemed food insecure. The data also provided information on food insecurity for adults (adult hunger) and children (child hunger) within the households.

Independent variables

Metering Systems

The GHS survey provided information on the household's source of electricity. The various categories of the main source of electricity include In-house conventional meters, In-house prepaid meters, connected to other sources, generators, home solar panels, and others. However, the research considered only two categories of electricity sources: in-house conventional and prepaid meters. The study recorded 0 for the conventional postpaid and 1 for the prepaid metering system.

Mediator

Chronicity

This study identifies 16 chronic conditions in capturing the chronic health status of respondents. This chronicity measure is a 16-item questionnaire about whether an individual has had such situations in the most recent period. The chronic health question was a dummy, 1 if the individual suffered and 0 otherwise, and the 16 diseases included asthma, diabetes, cancer, HIV, Blood pressure, arthritis, stroke, heart attack, TB, mental health issues, epileptic, meningitis, pneumonia, bronchitis, osteoporosis, and malaria. We adopted the Alkire and Foster (2011) multidimensional framework (hereafter referred to as AF) in measuring the multiple burdens of chronic conditions. The AF can capture the severity, intensity, and incidence of the multiple burdens of chronic diseases over a set of chronic conditions. A major advantage of this framework is its applicability to an ordinal or binary dataset (Fauzi et al., 2022; Dhongde, 2017). This is a two-step methodology that involves identification and aggregation. Thus, it identifies respondents who suffered from any chronic condition based on a defined cut-off and summarises them into a score through weighing and summation. In the GHS dataset, all conditions are captured as a binary variable, where 1 represents individuals with chronic conditions and 0 otherwise. Although there are no prescribed weights for each NCB under the AF methodology, we assigned an equal weight of 1/16 to all the conditions. The chronicity score estimated using the AF framework involves ratios or proportions that range from 0 to 1, where 1 signifies an individual with all sixteen chronic conditions and 0 otherwise. Hence, the higher the score, the higher the burden of multiple chronic conditions.

Covariates

Other control variables available in the dataset include the age of the household head, education, salary, marital status, household size, metropolitan areas, and provinces. Table 8 provides a summary description of the variables and how they were measured.

Table 8: Summary variable Description/Measurement

Variable	Measurement/Description	Mean	Standard Deviation
Hunger	Equals 1 if the household suffers from hunger and 0 if otherwise	0.112	0.316
Adult hunger	Equals 1 if the adult household suffers from hunger and 0 if otherwise	0.161	0.368
Child hunger	Equals 1 if children suffer from hunger and 0 if otherwise	0.15	0.357
Prepaid	Equals 1 if the household uses a prepaid electricity meter and 0 if postpaid	0.873	0.333
Education	The highest education level of household head	1.702	0.949
Head age	Age of household head	49.34	15.66
Marital stats	Marital status of household head	3.569	2.196
Household size	Household size	3.511	2.355
Ln (Salary)	Log of household salary	8.382	1.176
Metropolitan areas	Equals 1 if the household is in a metropolitan area and 0 if otherwise	1.612	0.687
Provinces	Province of residence	5.352	2.511
Chronicity	The score of multiple burdens of diseases	0.032	0.051
Housing subsidy	Equals 1 if a Housing subsidy was received and 0 if otherwise	0.223	0.46
State dwelling houses (RDP)	Equals 1 if State dwelling houses (RDP) were received and 0 if otherwise	0.204	0.403
Free Basic Electricity (FBE)	Equals 1 if Free Basic Electricity (FBE) was received and 0 if otherwise	0.232	0.422

Source: GHS (2022)

3.3.3 Empirical Model

Evaluating the effects of prepaid meters on household food insecurity, we formulate a basic multiple regression as follows;

$$FH_i = \alpha_o + \beta_1 Prepaid\_meter_i + \sum_i \psi_i X_i + \varepsilon_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where FH_i represents food hunger for households i, $Prepaid\_meter$ represents the payment systems which in this research is considered a dummy variable 1 using prepaid and 0 postpaid. α and ε_i represent the constant and error term in the model. The covariates are defined by X_i and ψ its coefficients. The slope parameter B captures the average effects of prepaid meters on hunger.

Given that the outcome variable (hunger) is binary, we use the Probit estimation technique for the baseline estimation. The Probit model fits for a binary dependent variable, as it assumes the probability of a positive result is determined by the standard normal cumulative distribution function. Furthermore, probit estimation allows using robust standard errors, as done for this research. By doing so, the results from the Probit model are consistent and efficient.

3.3.4 Impact Analysis (Average Treatment Effects)

Probit models primarily establish associations and do not ascertain causal inferences. However, our methodology incorporates a framework that considers potential endogeneity concerns and facilitates causal inferences. Prepaid metering can introduce endogeneity because consumer behaviour and food consumption patterns may influence the decision to adopt prepaid meters, affecting the observed outcomes. Customers who are more inclined to manage their energy consumption might also be more conscious about their food choices, potentially leading to biased estimates if not properly addressed. Neglecting endogeneity may result in partiality and incongruous parameter evaluations, causing the outcomes to be untrustworthy and possibly deceptive. We address potential endogeneity bias by using the propensity score matching technique. Endogeneity mainly concerns causality, omission bias, or measurement errors. The potential impact of a low control group in the sample should be carefully considered despite including significant covariates as a control in the study. Academic research may utilise household datasets with limited control groups, provided that appropriate methods address potential issues such as endogeneity, selection bias, and measurement error. Justification for using such datasets must also be properly established (Deaton, 1997; Wooldridge, 2002; Cameron & Trivedi, 2010).

Propensity score matching (PSM) can examine the actual effect of prepaid meters on hunger by its methodology. PSM can still be useful for estimating treatment effects even with household datasets with a low control group. However, it is important to consider the potential limitations of using a low control group and to ensure that the methodological assumptions underlying PSM are met. One potential limitation of using a low control group is that it may be more challenging to balance the treatment and control groups on observable characteristics, especially if the treatment group is large relative to the control group. This can lead to biased estimates of the treatment effect. However, PSM effectively reduces bias even when the control group is small (Dehejia & Wahba, 2002; Rosenbaum & Rubin, 1985). Another potential limitation of using a low control group is that it may be more challenging to assess the sensitivity of the treatment effect estimates to unobserved confounding variables (Rosenbaum & Rubin, 1985b). PSM relies on observable characteristics to create a matched control group, and unobserved confounders may still exist in the treatment group. However, sensitivity analyses can be used to assess the potential impact of unobserved confounders on the treatment effect estimates (Stuart, 2010).

According to Guo and Fraser (2014), it is crucial to guarantee the adequate balance of observable covariates between the treatment and control groups when executing PSM. It is imperative to refrain from comparing fundamentally incomparable entities (Caliendo & Kopeinig, 2008). To this end, a crucial measure involves assessing the extent of overlap and common support between the treatment and comparison groups. The literature proposes various methods for assessing whether the matching process has achieved balance in the distribution of pertinent variables between the control and treatment groups. One such method is the standardised bias (SB) proposed by Rosenbaum and Rubin (1985), which is a suitable measure for evaluating the degree of separation in marginal distributions of the co-variables. The utilisation of this methodology is a prevalent practice in numerous evaluation studies, as evidenced by the works of Lechner (1999), Sianesi (2004) and Caliendo et al. (2008). According to Austin (2011), in the context of propensity score matching (PSM), the letter "B" denotes the standardised difference between the treatment and control groups concerning a specific covariate or observed characteristic. The standardised difference is a metric that quantifies the extent of asymmetry between the treatment and control cohorts with respect to a particular covariate, represented as a percentage. A potential issue with the SB methodology is the lack of a definitive criterion for evaluating the efficacy of the matching process, despite the fact that a B value below a prescribed threshold following matching is generally deemed acceptable in most empirical investigations. As per Austin (2011) findings, in cases where B exceeds 25%, there is a notable difference of over 25% of a standard deviation between the treatment and control groups concerning the covariate. The observed degree of imbalance is commonly regarded as significant, indicating that there may be dissimilarities between the treatment and control groups with respect to the covariate in question. According to Austin (2011), the conventional approach strives to achieve a uniform discrepancy of no more than 10% or 20% across all covariates between the treatment and control cohorts. According to Guo and Fraser (2014), in cases where a specific covariate exceeds a threshold of 25%, it may be imperative to either incorporate an adjustment for that covariate in the outcome analysis or eliminate it from the matching process. The PSMATCH2 and PSTEST functions, available in the Stata software package, were employed to evaluate the credibility of Propensity Score Matching (PSM) estimates and ensure the establishment of a covariate balance. These methods offer a foundation for advocating the utilisation of propensity score matching (PSM) in survey data, even when the control group is limited.

After establishing a balance test property, the subsequent step involves estimating the average treatment effect (ATE) using the propensity score matching (PSM) approach if the balance test is satisfied. We estimate the average treatment effect of using a prepaid payments system on hunger as follows;

Hence, the difference in the mean estimator is given as

$$\tau = E(Y|t = 1) - E(Y|t = 0) \dots\dots\dots\dots\dots\dots\dots\dots\dots.(6)$$

$$\tau = ATT = E[Y(1) - Y(0)|W = 1] \dots\dots\dots\dots\dots..(7)$$

$$\tau = ATT = E[Y(1), p(\varpi) - Y(0), p(\varpi)|W = 1] \dots\dots\dots\dots\dots..(8)$$

Equation 6 This equation represents the Average Treatment Effect (ATE). It compares the expected outcomes (E(Y)) between the treated group (t=1) and the control group (t=0). The ATE gives the average difference in outcomes between the treated and untreated groups.

Equation 7 represents the Average Treatment Effect on the Treated (ATT). It focuses on individuals who received the treatment (denoted as W=1). E[Y(1)-Y(0) | W=1] calculates the average difference in outcomes for those who received the treatment. Equation 8 introduces the propensity score directly into the calculation, emphasising the importance of matching treated and untreated individuals based on their propensity scores. The average treatment effect (ATE) shown in equation 8 will include the impact of individuals in the population who may not have received treatment (Heckman, 1997). In this study, we emphasise evaluating the average treatment effects for the treated (ATT) in equation 8. The study utilises the nearest-neighbour (NN) matching in propensity score matching (PSM) due to its ability to minimise the bias arising from the potential confounding factors (Austin & Stuart, 2017; Bai, 2011). Additionally, the inverse probability weighting (IPW) and regression adjustment (RA) approaches were employed as robustness checks to validate the results obtained from the NN matching method. We have utilised these complementary methods to guarantee the reliability and robustness of our estimated results.

3.3.5 Mediating and Moderation Analysis

The relationship between payment systems and food insecurity can be direct or indirect. Therefore, it is essential to ensure the robustness of estimates by reporting their indirect effect as well. Accordingly, we conduct a mediation analysis to explain the indirect impact of a complementary variable on food hunger. Mediation analysis is a statistical technique investigating how a specific independent variable influences a dependent variable. Mediation analysis aims to determine whether the relationship between the independent variable and the dependent variable is direct or indirect, and if it is indirect, to identify the mediating variable(s) that explain the relationship. Mediation analysis strengthens economic theories and practises, enabling evidence-based economic decision-making. Mediation analysis estimates the link between the Independent Variable and the mediating variable before assessing the mediator-dependent variable relationship. Mediation analysis concludes with the mediating effect, which measures the indirect influence of the independent variable on the dependent variable through the mediator.

In this study, we identified chronicity as a mediating variable explaining the effects of prepaid payment systems on food hunger. We will use two methods of mediation analysis based on their procedures. The first method is adopted from Baron and Kenny's (1986) approach, which Iacobucci et al. (2007) adjusted. The second approach is that of Zhao et al. (2010) to ensure the robustness of estimates. The following equations present the equation for the mediation analysis.

$$M_i = \emptyset_0 + \emptyset_1 prepaid_{meters_i} + \sum_i \psi_i X_i + \varepsilon_i \dots\dots\dots\dots (9)$$

$$FH_i = \pi_0 + \pi_1 prepaid_{meters_i} + \pi_2 M_i + \sum_i \psi_i X_i + e_i \dots\dots\dots\dots (10)$$

Equations 9 and 10 are essentially a simultaneous equation system, a recursive one where you first determine M in 9 and then plug it into 10. This captures the fact that prepaid affects FH directly and indirectly through M. Through the utilisation of this testing methodology, if B_i (as delineated in equation 5) and $\emptyset_1$ are significant, it would suggest a direct impact of prepaid metres on hunger and an indirect impact on the mediation variable. We then observe the coefficient of π_1 and π_2. Should we observe π_1 to be insignificant while π_2 being significant, it will imply a complete mediation relationship. But, if π_1 and π_2 are significant and $\pi_1 < B_i$, then M_1 partially mediates the relationship. Furthermore, we use the Sobel, Monte Carlo, and Delta tests to validate mediators.

Baron and Kenny (1986) distinguish between the mediator and moderator variables as the latter focuses more on direct effect. Unlike a mediator, a moderator variable affects the strength or direction of the relationship between two other variables. It does not explain the relationship between the two variables but modifies it. Since our study intends to test the role of subsidies in the prepaid meter-food insecurity nexus, we employ the moderation analysis. We identified three (3) different subsidies out of the many and interacted with prepaid metering consumers to examine their effects on hunger. The subsidies used are government housing subsidies, state-subsidized dwelling (RDP), and Free Basic Electricity (FBE). We interact with prepaid metering systems and these subsidies to conduct a moderation analysis. The moderation equation is presented as follows.

$FH_i = \alpha_o + B_1 Subsidy + \sum_i \psi_i X_i + \varepsilon_i$ .... (11a)

$FH_i = \alpha_o + b_1 Subsidy * Prepaid\_meter_i + \sum_i \psi_i X_i + \varepsilon_i$ .... (11b)

This equation extends from equation (5), employing Propensity Score Matching (PSM) techniques to match the covariates X_i and estimate the effect of the corresponding subsidy on the outcome variable in equation 11a. The resulting impact coefficient is denoted as β_1. Consequently, we estimate the interaction term on hunger to obtain the moderation effect on hunger, denoted as b_1.

3.4 RESULTS AND DISCUSSION

3.4.1 Baseline regression

Table 9[1] reports the Probit regression estimates showing the probability outcome for the baseline regression.

[1] The observations for the complete sample represent cases where data was available for all variables included in the analysis, whereas the subsamples represent cases where data was available for specific subsets of variables. Therefore, the number of observations varies across the different columns of the table.

Table 9: Prepaid Metering and Hunger

Dependent VARIABLES	(1) HUNGER	(2) Adult_hunger	(3) Child_hunger
1.prepaid	0.163***	0.185***	0.170***
	(0.059)	(0.052)	(0.065)
1.No Education			
2.Primary	-0.198***	-0.277***	-0.267***
	(0.052)	(0.046)	(0.055)
3.Seconadry	-0.486***	-0.548***	-0.525***
	(0.059)	(0.052)	(0.063)
4. post-secondary	-0.828***	-0.889***	-0.837***
	(0.095)	(0.081)	(0.100)
5. Tertiary	-1.068***	-1.042***	0.940***
	(0.168)	(0.123)	(0.145)
head_age	-0.008***	-0.007***	-0.006***
	(0.001)	(0.001)	(0.001)
ln_salary	-0.306***	-0.280***	-0.236***
	(0.016)	(0.014)	(0.017)
1.Married			
2.Cohabiting	0.369***	0.355***	0.327***
	(0.055)	(0.049)	(0.057)
3.Divorced	0.219**	0.134*	0.026
	(0.086)	(0.078)	(0.104)
4.Separated	0.347***	0.283***	0.269**
	(0.110)	(0.103)	(0.123)
5.Widowed	0.131***	0.112***	0.105**
	(0.048)	(0.042)	(0.049)
6.Single	0.340***	0.263***	0.273***
	(0.042)	(0.037)	(0.044)
Household size	0.082***	0.071***	0.064***
	(0.006)	(0.005)	(0.007)
2.Metropolitan	-0.057	-0.048	-0.062
	(0.043)	(0.038)	(0.047)
1.Western			
2.Eastern Cape	-0.343***	-0.420***	-0.433***
	(0.070)	(0.059)	(0.073)
3.Northern Cape	0.332***	0.023	0.036
	(0.080)	(0.072)	(0.087)
4.Free State	0.141*	-0.103	-0.152*
	(0.075)	(0.065)	(0.080)
5.Kwazulu-Natal	-0.186***	-0.256***	-0.193***
	(0.067)	(0.0559)	(0.068)
6.Northwest	0.107	-0.240***	-0.308***
	(0.078)	(0.070)	(0.089)
7.Guateng	-0.136**	-0.428***	-0.347***
	(0.067)	(0.057)	(0.070)
8.Mpumalenga	-0.009	-0.300***	-0.344***
	(0.075)	(0.065)	(0.081)
9.Limpopo	-0.841***	-0.924***	-0.867***
	(0.084)	(0.069)	(0.083)

Constant	1.471***	1.802***	1.328***
	(0.180)	(0.162)	(0.195)
Observations	15,386	15,278	10,261

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Author's estimate

Column 1 is for the complete sample, and Columns 2 and 3 are for the sub-sample for sensitivity analysis. The study performed the sub-sample estimation to check for the robustness of the baseline results reported for adult and child hunger in Columns 2 and 3, respectively. The signs and the significance level among the variables in the Full and sub-samples appear consistent. In Column 1, the coefficient of the prepaid metering household was significant and positive at the 1% significant level. The likelihood of prepaid meter users suffering from hunger was about 0.164. Consumers having to pay for an essential need such as electricity before use experience higher episodes of hunger. Other control variables such as salary and age of household head showed a less likely outcome toward hunger. Higher forms of education likely experience less hunger compared to people with no education, while other forms of marital status increase once chance of suffering from hunger compared to married couples. The estimated relationships are consistence with economic theory and literature.

As reported in the baseline estimate, prepaid metering households increase the likelihood of hungry adults and children. At a 1% significant level, adult and child hunger is more likely to increase for prepaid metering users than for postpaid metering households. Adults' likelihood of suffering from hunger was about 0.185, whiles children's likelihood was about 0.170 for children. This estimate suggests that prepaid meters cause more hunger among adults than children.

3.4.2 Data Balancing Results

The utilisation of probit estimates in the baseline merely establishes an association. However, the Propensity Score Matching (PSM) estimation technique is employed to derive estimates for causal inference. Before using PSM to address endogeneity, it is important to provide a balancing test between the treatment and control groups. The standardised difference (B) between the treatment and control groups is tested on a particular covariate or observed characteristic. The balancing test results of the standardised difference are shown in Table 10.

Table 10: Data Balancing test

PS R2	LR Chi2	P>chi2	Mean Bias	B
0.005	194.17	0.000	4.9	16.9

*If B>25%, R outside [0.5; 2]

Source: Author's estimate

The presented findings demonstrate a balance matching test performed on a comprehensive set of covariates: education, salary, household size, age, marital status, location, and provinces. To ascertain a balance PSM, a standardised difference (B) of less than 10% or 20% between the groups on all covariates is typically recommended (Austin, 2011). The observed results indicate a B value of 16.9, which falls below the threshold of 25%. A B value below 25% in PSM indicates a substantial balance between treatment and control groups, as the groups do not differ significantly on the specified covariate (Austin, 2011).

3.4.3 Average Treatment Effects

This section presents the findings of a study on the endogeneity of prepaid meters and their effects on food insecurity, as indicated by household hunger, utilising a Propensity Score Matching (PSM) approach. Table 11 provides an overview of the average treatment effects on the treated (ATT), reported in columns 1, 2, and 3 using robust standard errors with nearest-neighbour (nnmatch), regression adjustment (ra), and inverse probability of treatment weighting (IPRW) techniques, respectively. The ATT estimates are presented for the full sample and adult and child hunger in Panels A, B, and C, respectively. The results from Panel A, column 1, reveal that prepaid metering has a positive and statistically significant impact on hunger, increasing it by approximately 3.9%. However, the robustness checks from the regression adjustment and IPRW matching techniques indicate a lower impact of 1.6% chance of experiencing hunger due to prepaid metering. The adult and child hunger estimates show a much higher impact for households utilising prepaid electricity meters. Specifically, the nearest-neighbour matching in Panel B reports an increase of 4.9% in adult hunger at a significance level of 1%. The ATT estimates for adult hunger in the RA and IPRW matching techniques, respectively, are 3.4%, significant at 1%. The estimates presented in Panel C, which assesses the ATT for child hunger resulting from prepaid metering, show a 4.4% impact in the nearest-neighbour matching technique and an average impact of 2.9% in the other robustness matching techniques. The results suggest that adults are more susceptible to hunger from prepaid metering than children. Overall, the findings from the PSM analysis validate the likelihood probability obtained from the baseline probit model and provide consistent and unbiased estimates of the impact of prepaid meters on food insecurity.

Table 11: Propensity Score Matching for Prepaid Meters and Hunger.

VARIABLES	**(1)** **ATT for nearest-neighbour matching**	**(2)** **ATT for the regression adjustment**	**(3)** **ATT for augmented inverse-probability weighting**
Panel A (Hunger)			
Prepaid	0.0390***	0.0164*	0.0164*
	(0.00957)	(0.00957)	(0.00957)
Covariates	YES	YES	YES
Observations	15,386	15,386	15,386
Panel B(Adult_hunger)			
Prepaid	0.0468***	0.0341***	0.0341***
	(0.01577)	(0.01135)	(0.01135)
Covariates	YES	YES	YES
Observations	15,278	15,278	15,278
Panel C(Child_hunger)			
Prepaid	0.0435**	0.0294**	0.0294**
	(0.02010)	(0.01487)	(0.01487)
Covariates	YES	YES	YES
Observations	10,261	10,261	10,261

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Author's estimate

3.4.4 Heterogeneity Analysis

Table 11 presents the average treatment effect on the treated (ATT) estimates, which assume that the impact of prepaid meters is homogeneous across all subgroups. However, it is plausible that the impact of prepaid meters may vary across subgroups. Therefore, Tables 12 and 13 present the differential impact results of prepaid meters based on gender, location, wealth, and racial dimensions.

Table 12 focuses on the gender and location dimensions of the impact of prepaid meters. Specifically, Panel A reports the results for males and Panel B for females, while Panel C and Panel D report the rural and urban location dimensions, respectively. The findings indicate that males are more likely to suffer from hunger when using prepaid meters, with a coefficient estimate of 4.6% reported in Panel A, column 1. The robustness checks using other matching techniques support this result, with lower coefficients reported but still exhibiting weak significance. Furthermore, Panel C, column 1, suggests that households using prepaid meters in rural communities experience a significant impact of 4.8% on hunger, with other matching techniques also indicating significant coefficients of approximately 3.1% at the 5% level. Similarly, in Panel D, column 1, households in urban communities experience a 2.5% impact on hunger at a 5% significance level, while the other matching techniques in Columns 2 and 3 are insignificant.

Table 12: Prepaid Meters and Hunger: Gender and Location Dimensions

VARIABLES	(1) ATT for nearest-neighbour matching	(2) ATT for the regression adjustment	(3) ATT for augmented inverse-probability weighting
HUNGER			
Panel A-(Male)			
Prepaid	0.0427***	0.0209*	0.0209*
	(0.0103)	(0.0111)	(0.0111)
Covariates	YES	YES	YES
Observations	8,318	8,318	8,318
Panel B-(Female)			
Prepaid	0.0175	0.0153	0.0153
	(0.0240)	(0.0171)	(0.0171)
Covariates	YES	YES	YES
Observations	7,068	7,068	7,068
Panel C (Rural)			
Prepaid	0.0483***	0.031**	0.031**
	(0.0130)	(0.0143)	(0.0143)
Covariates	YES	YES	YES
Observations	10,043	10,043	10,043
Panel D (Urban)			
Prepaid	0.0246**	0.0035	0.0035
	(0.0101)	(0.0112)	(0.0112)
Covariates	YES	YES	YES
Observations	5,343	5,343	5,343

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Author's estimate

In Table 13, we present the propensity score matching (PSM) estimates for the impact of prepaid meters on households' race and wealth status. Panel A and B provide heterogeneous results across races, nonwhite and white, respectively. For instance, nonwhite South Africans (blacks, Mixed, Indians /Asian, and coloured) have a 3.6% chance of experiencing food insecurity or hunger when using prepaid meters, as shown in column 1, at a 1% significance level. Furthermore, Panel C, column 1, indicates that rural households have a 4.8% likelihood of experiencing hunger when using prepaid meters at a 1% significance level. The alternative matching methodologies presented in Columns 2 and 3 yield reduced coefficients for both Panel A and C, exhibiting weak levels of statistical significance. Panel

B and C, which report the impact of prepaid meters on white and wealthy South African households, respectively, are insignificant. Poor and non-white South Africans primarily experience the incidence of hunger.

Table 13: A propensity score matching; race and wealth dimensions.

VARIABLES	(1) ATT for nearest-neighbour matching	(2) ATT for the regression adjustment	(3) ATT for augmented inverse-probability weighting
HUNGER			
Panel A-(NonWhites)			
Prepaid	0.0368***	0.020*	0.020*
	(0.0116)	(0.0108)	(0.0108)
Covariates	YES	YES	YES
Observations	14,319	14,319	14,319
Panel B-(Whites)			
Prepaid	-0.0009	-0.0025	-0.0025
	(0.0072)	(0.0087)	(0.0087)
Covariates	YES	YES	YES
Observations	1,067	1,067	1,067
Panel C (Poor)			
Prepaid	0.0478***	0.0234*	0.0234*
	(0.0140)	(0.0123)	(0.0123)
Covariates	YES	YES	YES
Observations	11,989	11,989	11,989
Panel D (Rich)			
Prepaid	-0.0044	0.0023	0.0023
	(0.0077)	(0.0065)	(0.0065)
Covariates	YES	YES	YES
Observations	3,397	3,397	3,397

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Author's estimate

In summary, the findings demonstrate that males are more likely to suffer from hunger when using prepaid meters because of their social responsibility as breadwinners and other competing obligations. Furthermore, individuals residing in rural areas are more likely to experience hunger when using prepaid meters compared to their point estimates for urban residents. Finally, the white population, like the wealthy South Africans, does not suffer a decrease in food income or experience hunger when using prepaid electricity meters. These findings emphasise the importance of considering differential impacts when assessing the effects of prepaid meters on various subgroups.

3.4.5 Mediation analysis

As discussed in section 3.4, the study identified chronicity as a potential channel through which prepaid metering technology influences food hunger. Therefore, we employed Baron and Kenny's approach to testing these mediations' validity, and the results are presented in Table 14. Table 14 shows the mediation results for the chronicity channel explaining hunger. As a potential channel, chronicity health issues report its association with prepaid in Column 1 and as an additional covariate in Column 2 influencing food hunger. In addition, there is a strong association between chronicity and prepaid metering, as reported in Column 1.

Table 14: Mediation Analysis

Variable	(1) Chronicity	(2) Hunger
Prepaid	0.00339*** (0.00121)	0.0631*** (0.00699)
Chronicity		0.203*** (0.0441)
Covariates	Yes	Yes
Delta test		0.001***
Sobel test		0.001***
Monte Carlo test		0.001***
RIT		0.011

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Author's estimate

Chronicity, a control variable that increases food hunger, is consistent with many reported findings. Compared to the baseline results, the coefficient of prepaid metered households on food hunger decreased in Column 2. The Delta, Sobel, and Monte Carlo tests validate chronicity as a mediator and account for about 1% of the total effects of prepaid metering on food hunger. This result provides an answer to the third research question.

3.4.6 Moderation Analysis

The previous result employs a mediation analysis to elucidate the indirect effects of prepaid meters on hunger. Subsequently, we investigate the direct impact of prepaid meters on hunger by examining their interaction with key subsidies, namely housing subsidies, the Reconstruction and Development Programme (RDP), and Free Basic Electricity (FBE) available to South African households. The outcomes of the abovementioned interaction between prepaid meters and subsidies are presented in Table 15, divided into three panels. Panel A displays the moderation results for housing subsidy, while Panel B and C present the results for RDP and FBE, respectively. In each section, the upper panel reports the results obtained from propensity score matching (PSM) analysis for the subsidy alone. In contrast, the lower panel reports the impacts of the interaction between prepaid meters and the subsidy on hunger.

Table 15: A propensity score matching for moderation effects.

VARIABLES	(1) ATT for nearest-neighbour matching	(2) ATT for the regression adjustment	(3) ATT for augmented inverse-probability weighting
HUNGER			
Panel A			
Housing_Sub	0.0287***	0.0231***	0.0231***
	(0.0077)	(0.0066)	(0.0066)
Covariates	YES	YES	YES
Observations	14,007	14,007	14,007
Housing_Sub*prepaid	0.0256***	0.0209***	0.0209***
	(0.0079)	(0.0069)	(0.0069)
Covariates	YES	YES	YES
Observations	13,291	13,291	13,291
Panel B			
RDP	0.0203***	0.0132**	0.0132**
	(0.0073)	(0.0058)	(0.0058)
Covariates	YES	YES	YES
Observations	17,411	17,411	17,411
RDP*prepaid	0.0197***	0.0137**	0.0137**
	(0.0074)	(0.0060)	(0.0060)
Covariates	YES	YES	YES
Observations	15,289	15,289	15,289
Panel C			
FBE	0.0224***	0.0175***	0.0175***
	(0.0074)	(0.0062)	(0.0062)
Covariates	YES	YES	YES
Observations	15,075	15,075	15,075
FBE*prepaid	0.0220***	0.0145**	0.0145**
	(0.0076)	(0.0064)	(0.0064)
Covariates	YES	YES	YES
Observations	15,075	15,075	15,075

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Author’s estimate

The present analysis reveals that the subsidies intended to improve household welfare may have the opposite effect by increasing the likelihood of hunger. Specifically, in Panel A, Column 1 of the upper section, receiving a housing subsidy is associated with a 2.9% increase in hunger. Similarly, in Column 1 of the lower section of Panel A, the likelihood of experiencing hunger is 2.6% for households that receive both a housing subsidy and use prepaid meters. Both sections of Panel A were statistically significant at the 1% level, as were the other matching techniques employed, albeit with lower impacts on hunger. In the case of the RDP subsidy, the likelihood of food insecurity increases by approximately 2%, as shown in Column 1 of the upper section of Panel B.

Moreover, the likelihood of hunger decreases marginally to 1.9% when the household receives both the RDP subsidy and uses prepaid meters, as shown in Column 1 of the lower section of Panel B. In the case of Free Basic Electricity (FBE), Column 1 of the upper section of Panel C reveals that providing this subsidy increases the likelihood of hunger by 2.24%. However, the likelihood of hunger decreases slightly to 2.20% when a household receives both FBE and uses prepaid meters, as shown in Column 1 of the lower section of Panel C.

Notably, subsidies aim to improve household welfare by supplementing their income streams. Still, the results of this study suggest that subsidies alone exacerbate the plight of households and increase the likelihood of hunger. However, when subsidies are combined with prepaid meters, the impact on hunger is marginally reduced. This finding is supported by the other matching techniques in Columns 2 and 3. Nonetheless, these subsidies remain relevant for addressing specific household problems, such as housing and energy, rather than food. The results of this study underscore the need for the government to re-evaluate the various subsidies to determine whether they are achieving their intended impact and how they can be restructured to improve the lives of South Africans. Additionally, the government could consider introducing a subsidy aimed explicitly at reducing hunger.

3.4.7 Discussion

Using the General Household Survey (GHS) 2020 in South Africa, this paper examined how prepayment systems affect food insecurity or hunger. The study found that prepaid electricity meters increase the likelihood of suffering from hunger or food insecurity. Given a fixed income, paying for electricity before use reduces the household expenditure on food. On the other hand, households using postpaid meters could purchase food and pay for electricity later. The findings of Nababan (2018) resonate with our study's observations regarding the influence of postpaid mechanisms on household income and food security. Nabanan's work highlights how postpaid fertilizers contribute to increased income by boosting rice production. Similarly, in our context, postpaid mechanisms can provide poorer households with access to essential resources such as electricity, thereby stimulating economic activity and enhancing income levels. Conversely, the requirement of prepayment for electricity, as observed in our study, imposes income constraints on poorer households, limiting their access to electricity for productive activities. This income constraint not only affects household income directly but also forces households to make trade-offs between competing essentials, ultimately impacting the quantity and quality of income available for food expenditure. Also, according to the behavioural theory of impulsiveness, consumers cannot control their consumption if they are impulsive. This narrative implies that consumers without self-control using prepaid meters will not check their energy consumption and that such uncontrolled expenditure will have negative consequences. Just as the works of Pirog and Roberts (2007), Hofmann et al. (2009), and Runnemark et al. (2015) predicted, the negative consequence of lack of self-control, in this research, was hunger. Since energy consumption is not checked by impulsive consumers using prepaid meters, hunger is experienced by both adults and children. The hunger caused by prepayment systems affects the adult population more than the children population. Every responsible family seeks to ensure children's food is provided before food for an adult (Schmeer & Piperata, 2017). With a limited income after paying for electricity, the household spends the remaining income in the order of priority, with children's needs being satisfied before adults. Here again, prepaid meters have constrained food consumption for children and adults. This finding is in line with the works of Jack and Smith (2015) on prepayment constraints on basic needs.

This paper further explored the possibility of suffering from hunger using prepaid meters across wealth status, race, location, and gender subgroups. There are several economic reasons why individuals across different wealth statuses, races, locations, and genders may be more vulnerable to hunger when using prepaid meters. Firstly, prepaid meters can potentially distort the income stream of households, particularly those with limited financial resources. Prepaid meters require consumers to pay for their energy usage in advance, which may require households to reduce their spending on other essential items, such as food, to afford their energy bills. This could be particularly challenging for lower-income households struggling to make ends meet (Burlinson et al., 2022). Burlinson et al. (2022) found that using prepaid meters for electricity can increase households' financial strain, affecting their food consumption. Another study by Koltai et al. (2021) suggests households cut back on food at the expense of energy. This results in a higher risk of food insecurity among low-income households in South Africa. Secondly, there are significant differences in income levels and poverty rates across different demographic groups. For instance, people of colour and in rural households typically have lower average incomes than their counterparts—the many social responsibilities of a man impede their income stream. According to the World Bank (2020), poverty rates in rural areas are often higher than in urban areas, and poverty rates among people of colour (non-whites) are higher than among whites. This suggests that individuals from these demographic groups may be more vulnerable to the negative effects of prepaid meters on their income streams and, subsequently, on their ability to access food. Secondly, there is evidence to suggest that gender can also play a role in determining vulnerability to hunger (Botreau & Cohen, 2020). While women are generally more likely to experience poverty and food insecurity (Broussard, 2019) due to various social, cultural, and economic factors, there are cases where men may also be vulnerable. For instance, in households where men are the primary income earners and experience a sudden loss of income or a reduction in income due to the use of prepaid meters, men may become more vulnerable to hunger. Women and children may also be affected in such situations due to their dependence on the male breadwinner. A study by Gladwin et al. (2001) found that men are less likely to receive food assistance compared to women despite facing similar levels of food insecurity. This suggests that men may be at risk of hunger even in situations where they are not the primary caregivers or recipients of food assistance. These economic factors suggest that individuals from different demographic groups may be disproportionately affected by the use of prepaid meters and more vulnerable to experiencing hunger as a result.

The study further explores the indirect effects of prepayment systems on hunger through the chronicity channel. The impacts of prepayment systems on food insecurity were explained by chronic health issues affecting households. Prepayment systems are associated with stress, anxiety, depression, and other chronic diseases common among households, and such chronic conditions increase the likelihood of hunger. Individuals living with Chronic health issues often experience lower income from the spending on medicine, routine checks, and other related health expenditures, reducing their income for food. Hajat and Stein (2018) and Wells et al. (1990) observed similar results. This research finding reporting chronicity increases hunger or food insecurity affirms the findings of (Gyasi et al., 2020).

The study answers whether subsidies given prepayment meters could reduce hunger. Three subsidies examined with the prepayment system suggest increasing food insecurity. In addition to the potential for food insecurity, it is noteworthy that these subsidies do not necessarily promote consistent food consumption but instead may exacerbate food insecurity (hunger). The provision of subsidies has been found to exacerbate food insecurity, although the magnitude of this effect is mitigated to some extent when prepayment mechanisms are in place. When considering the joint interactions between the subsidy and prepayment systems, the findings support a prior expectation established by the works of Hidrobo et al. (2018) and Devereux (2016a). The finding presented in this passage suggests that subsidies intended to improve household welfare may increase the likelihood of hunger. The study found that households receiving subsidies such as housing subsidies and Free Basic Electricity (FBE) are more likely to experience hunger, with this effect marginally decreasing when combined with prepaid meters. The study suggests that subsidies alone may exacerbate the plight of households and increase the likelihood of hunger. Still, when combined with prepaid meters, they increase hunger, but the impact on hunger is marginally reduced. Several academic references support this finding. A study by Hidrobo et al. (2018) emphasises the effects of subsidies on food security may depend on the specific type of subsidy and the context in which it is implemented. A study by Devereux (2016b) also established that social protection subsidies could be helpful when combined and designed to allow households access to essential goods and services. However, they may only sometimes translate to improved food security. Overall, the findings presented in this passage underscore the need for careful evaluation of subsidies and their impact on household welfare and food security. While subsidies may have benefits, they may also have unintended consequences, and policymakers must carefully consider the potential impact of subsidies on households, particularly those at risk of hunger.

3.5 CONCLUSION

Service providers increasingly adopt prepaid systems as their benefits override costs. Its impact on the consumer's well-being though gained some attention in research, yet little has been done to link it to household hunger or food insecurity. South Africa has advanced its program of switching households from postpaid to prepaid electricity meters, and it is now a standard for other developing countries. Since adopting prepaid electricity metering in South Africa, no rigorous work has been provided to determine its impact on hunger. This study fills this gap using the General Household Data (GHS) (2020) in South Africa to examine this relationship. In addition, the study explores sensitivity analysis with prepaid effects on adult and child hunger. Furthermore, mediation and moderation analyses provided evidence of direct and indirect effects. The mediating variable (chronicity) and moderating variables (housing grants, RDP houses, and Free Basic Electricity) explain hunger. Finally, the study examined the impact of pay-as-you-go systems on hunger using fractional Probit and PSM estimation.

We found strong evidence that prepaid metering households are likely to go hungry compared to postpaid metering households. The findings reported 3.9% in PSM, which addresses endogeneity estimates on food hunger. This was supported by the standardisation test, which supports balance covariates between the treatment and untreated groups. The study found similar evidence by conducting sensitivity analysis in a sub-sample, reporting 4.7% for adult hunger and 4.4% for child hunger in the PSM regression. Addressing endogeneity and ensuring robustness in the full and sub-sample, we support the PSM results by undertaking other matching techniques which support the nearest-neighbour matching techniques. Furthermore, the research conducted heterogeneity analysis for wealth status, race, location, and gender differential groups, showing poorer, Non-whites (Blacks, Indian/Asian, Mixed and Coloured), and rural dwellers suffering more from hunger using prepaid meters. Male-headed households were more vulnerable to hunger. The mediation analysis explained the effects of prepaid meters on hunger through chronicity. Chronicity accounted for only 1% of the impact of prepaid electricity metering on hunger. While subsidies may be an important tool for improving household welfare, their impact on food security may be more nuanced than previously thought.

From the findings, we can infer that prepayment systems, where payment is required before access to essential needs, can adversely affect certain important household necessities such as food. This sheds light on other prepayment systems and supports studies suggesting that households must prioritize satisfying competing needs before accessing essential services. However, this may not hold for all populations, particularly the affluent class, who have substantial savings and can plan their consumption effectively. Therefore, targeting such classes and considering the cost of raising children in a household can help ensure that income constraints do not exacerbate child hunger. The findings also demonstrate that such prepayment constraints are associated with multiple burdens of disease, necessitating further health expenses on the limited income of households. Although certain subsidies were expected to cushion household income, the findings suggested otherwise, prompting the need for food-related subsidies and food stamps for poorer households.

The discussion on the implications of prepaid metering's effects on food insecurity reveals several significant findings. Firstly, the study underscores the adverse impact of prepaid electricity meters on household food consumption, particularly among low-income and marginalized demographic groups. The constraints imposed by prepaid meters on household finances contribute to increased vulnerability to hunger, with households forced to prioritize energy expenditure over food. Additionally, the study highlights the indirect effects of chronic health issues exacerbated by prepaid systems, further exacerbating food insecurity. Moreover, the examination of subsidies reveals that while intended to alleviate household welfare, they may inadvertently worsen hunger, particularly when combined with prepaid meters. The findings suggest that policymakers should carefully evaluate the impact of subsidies on food security and consider implementing targeted interventions to address the root causes of hunger.

CHAPTER FOUR

4. Energy Poverty and Fuel Stacking: The Role of Policy Instruments in South Africa

Abstract

Energy poverty is a major global issue and has implications for the welfare of individuals and society. The main drivers and barometer in measuring this phenomenon have varied across specific indicators and country-specific case studies. An often underexplained cause is the payment systems constraining electricity consumption in multiple fuel uses, resulting in fuel switching. We use the General Household Survey data of South Africa to explain the impact of prepaid payment systems on energy poverty. Applying fractional probit regression and other robustness methods, the results show that using prepaid meters potentially increases the probability of being energy-poor between 0.03 and 0.06 percentage points. Using Propensity Score Matching (PSM) to address endogeneity and enable impact analysis through quasi-experimental methods, the study found that households using prepaid meters had a 3.35% higher likelihood of being energy-poor than those using postpaid meters. The study further revealed that households become energy-deprived by switching to unclean energy sources for cooking and heating when given prepaid meters. Specifically, the implementation of prepaid metres resulted in a statistically significant increase of 5.7% in biomass utilisation for cooking purposes, a 10.9% increase in space heating, and a 4.3% increase in room heating. The results also showed that vulnerable groups or poor South Africans suffer most from energy poverty using prepaid meters. Joint use of prepaid meters and Free Basic Electricity (FBE) could reduce energy poverty. Additionally, the study highlights the combination of the Reconstruction and Development Programme (RDP) housing scheme with prepaid meters is an effective pro-poor policy in reducing energy poverty. The study's policy implications suggest increased energy subsidies and targeted policy interventions to mitigate energy poverty.

4.1 INTRODUCTION

Clean energy is an indispensable input in a country's sustainable development and an essential requirement for human development. Understanding and addressing the deprivation of energy issues of people with low incomes is crucial. Sustainable Development Goal (SDG) 7 exhorts that energy must be accessible, affordable, reliable, and sustainable for all (Mustafa et al., 2022). The goal underscores the significance of fostering and employing cleaner and modern energy sources, given that the use of unclean energy sources results in unfavourable outcomes such as jeopardising public health (SDG 3), exacerbating climate change (SDG 13), and polluting the environment/land (SDG 15). As per the World Health Statistics report of 2021, the utilisation of unclean energy sources for cooking activities, including firewood, charcoal, coal, and dung, has been identified as a leading cause of over 3.5 million untimely deaths linked to indoor air pollution (Adane et al., 2021). Despite concerted efforts to promote clean cooking practises, approximately 50% of the global populace still depends on polluting fuels for cooking, resulting in persistent environmental degradation and deforestation challenges on a global scale (Elasu et al., 2023; Stoner et al., 2021). By 2030, approximately 31% of households will still rely on unclean energy for cooking (Stoner et al., 2021). Therefore, policies promoting the adoption of modern and cleaner energy sources must consider the potential household-level barriers that may hinder the transition from unclean to cleaner energy alternatives.

The amount of modern energy available for household consumption at any given time depends not only on the underlying supply mechanisms but also on policies that can introduce potentially significant alteration into households' payment, acquisition and consumption capacities. Most developing economies often do not have the financial resources to undertake such investment sufficient to address crucial challenges associated with the supply mechanisms of modern energy such as electricity and liquified petroleum gas (LPG) (Elasu et al., 2023; Isara & Aigbokhaode, 2014). Policy instruments that can introduce such significant alteration into households' payment, acquisition and consumption capacities are thus imperative alternatives to achieving SDG 7. It is for this and other related reasons policy instruments constitute an overarching concern of the study. Prominent among policies are the metering and payment systems associated with the use of electricity. This is because electricity is, undoubtedly, a core component of modern energy. Thus, the ability of households to use electricity and make payment later –a function of the underlying metering system – has important implications for the amount of electricity accessible to and consumed by households. For instance, prepayment electricity meters could restrict access and usage as they require payments for electricity prior to consumption. The restriction posed by payment technologies could result in self-deprivation if one cannot afford electricity or switches to cheaper and unclean energy sources (Petrova, 2018). A post-payment option allows consumers to pay after using the energy, while a prepayment option only allows payment before access to energy. The prepayment metering policy has gained wider acceptance by utility companies because it can ensure efficient use of electricity given that the post-payment option has issues of non-repayment, debt accumulation, high cost of billing, and others. Even though the policy of using prepayment metering technology could resolve the challenges associated with post-payment, it could deprive poor households of energy consumption at specific times due to cash flow constraints (Corfe & Keohane, 2018).

The mechanism through which prepaid meters induce energy poverty, a situation where households are constrained with accessibility, affordability and utilization of modern and clean energy sources, such as electricity, leads households to resort to biomass fuels like firewood or charcoal for domestic household activities. The present study identifies energy poverty at the household level as a circumstance that restricts the utilisation of electricity and promotes dependence on biomass. This concept is explained from several different approaches. First, according to the fuel stacking theory, households rely on multiple energy sources (Martínez et al. 2020) and, thus, when constrained by prepaid electricity meters, resort to other fuel consumption. Households having to cut their electricity consumption resort to other unclean energy sources for cooking and heating. Second, households with lower incomes are compelled to forgo electricity due to their financial constraints, resulting in self-imposed deprivation (Petrova, 2018). Poorer households often do not have a regular income stream and mostly supplement their income with credit to meet equally essential needs such as food and water. A payment ahead takes away a certain form of credit. It creates a choice of either foregoing electricity consumption (O'Sullivan et al., 2014c) vis-a-vis other energy fuels. In addition, any household spending more than 10% of its income on electricity is deemed energy-poor (Boardman, 1991; Legendre & Ricci, 2015), which suggests impulsive consumers who cannot control their expenditures using prepaid meters will be worse off.

South Africa has over 85% electricity access, so most of its population has access to electricity. The affordability measure considers the share of income spent on electricity, which should be less than 10% (Boardman, 1991; Legendre & Ricci, 2015). These dimensions primarily focus on a single measure of energy poverty, but a household combines or uses multiple forms of energy, both modern and traditional. Modern energy comprises electricity and biogas, and household uses different energy for different activities such as lighting, cooking, heating, Wi-Fi, watching television, etc. Traditional energy sources such as biomass are cheap but unclean and are mostly used to supplement modern energy forms to meet the energy needs of the household (Nasir et al., 2015; Ali et al., 2019; Gill-Wiehl et al., 2021). Depending on households' energy composition, given its energy mix (clean versus unclean) will suggest different levels of energy poverty. Another important gap often overlooked in the research is how prepaid meters explain the fuel stacking concept. Articles on energy poverty have suggested different impacts concerning the heterogeneous group. It has been established that urban dwellers suffer more energy poverty due to the vast use of electricity compared to the rural poor population (Sustainable Energy Africa, 2017). The gender dynamics of energy poverty seem to be an interest given the many reports on females being the most affected since they mostly use more energy given their social roles (Ngarava et al., 2022; Longe, 2021; Longe, 2020; Sustainable Energy Africa, 2017). There is also a growing interest in racial energy poverty, with the poor black and coloured race being worse off than the white group (Lin & Okyere, 2022;

Ngarava et al., 2022; Wang et al., 2021). The heterogeneous groups need more clarity using a more nationalistic dataset.

The government has introduced pro-poor policies to supplement household income and welfare to address energy poverty. Some of these pro-poor policies are directly related to energy, such as Free Basic Electricity (FBE), and others may be indirect. But whether these direct and indirect pro-poor policies tend to reduce energy poverty is still in question. The provision of Free Basic Electricity (FBE) offers lower-income households a predetermined quantity of electricity at no cost. Still, any additional electricity usage must be purchased and added to their consumption (Makonese et al., 2012b). Consequently, if a household does not purchase any electricity, they will not be able to benefit from the free basic electricity allocation. Other indirect pro-poor policies identified in South Africa include the housing subsidy and the Reconstruction and Development Programme (RDP) housing initiative. While the housing subsidy aims to assist households in renting or acquiring housing, the RDP entails the government constructing houses and providing them to eligible South Africans for habitation (Kang'ethe & Manomano, 2014). These houses are typically constructed with improved walling structures that surpass the quality affordable or achievable by many impoverished South Africans (Křičková, 2015). Additionally, RDP houses are equipped with facilities for water heating and cooking (Greyling, 2010). As a result, these initiatives can also influence the type of energy utilised and ultimately contribute to the mitigation of energy poverty among South African households. The absence of evidence in the literature regarding the potential effectiveness of energy subsidies and comprehensive housing policies in mitigating energy poverty underscores the need for further investigation. This study makes the following contribution to the literature on energy poverty. First, the paper undertakes an intensive multidimensional energy poverty measure in South Africa. A multidimensional energy poverty index highlights the different dimensions and understanding of energy poverty (Lin & Okyere, 2023). Such broad understanding will inform academics and policymakers in looking into the energy mix and end usage component and how to tackle energy poverty among the different households. Secondly, the fuel stacking patterns of households are considered, given the substitution effects and fuel switching from electricity to alternative energy sources. Thirdly, examining heterogeneous impacts such as location, wealth status, race, and gender in a nationalistic frame will give a definitive guide to tackling poverty to the most affected and vulnerable groups. Fourthly, this paper assessed whether pro-poor energy policies, notably Free Basic Electricity and other government subsidies such as housing grants and the Reconstruction for Development Project (RDP), could mitigate the problem of energy poverty. Lastly, the study is a noteworthy addition to the existing literature as it evaluates the impact of prepayment metering policy on energy poverty while taking into account supplementary welfare policy interventions, an aspect that has not been extensively explored.

Why South Africa?

Poverty dynamics and its challenges continue to grapple the South African economy. A poverty and equity policy brief released by the World Bank in 2020 revealed that more than half (55.5 percent) of 60.3 million South Africans live in poverty using the upper national poverty line (R1335) (World Bank, 2020a). The consequence associated with poverty is the deprivation of basic needs such as water, food, sanitation, and energy (Lister, 2021; Klasen, 2000). Several attempts have been made to reduce poverty through national programmes. Notably, a Housing Subsidy valued at R42.7 billion was made available to South Africans in the 2017/2018 fiscal year; the Reconstruction and Development Programme (RDP) has built about 3 million houses (Sustainable Energy Africa, 2017) and Free Basic Electricity (FBE) has about 10.1 million qualifying South Africans receiving about R11.4 billion in the 2019/2020 financial year among other programs have made significant inroads to poverty alleviation. However, poverty persists in South Africa despite these measures, and close to half of the population needs help to afford modern forms of energy such as electricity, LPG and biogas. The topic of energy poverty is currently receiving increased attention in South Africa due to recent power outages experienced in the electricity industry. About 47% of South Africans are reported to suffer from energy poverty on average, as they spend more than 10% of their income on energy poverty (Sustainable Energy Africa, 2017).

The rest of the paper is organised as follows: the next section presents a literature review and presents a conceptual framework linking policy instruments to energy poverty. Section 3 outlines the methodological procedure used in this research. Section 4 presents the results of the estimations, and the last section concludes.

4.2 LITERATURE REVIEW

4.2.1 Theoretical Model: Fuel Stacking Theory and the Impact of Prepaid Meters

Several researchers, including Baldwin (1987), Hosier and Dowd (1987), SMITH (1987) and Leach (1992), have employed the energy ladder model to examine households' energy consumption dynamics indirectly. They analysed fuel switching patterns, particularly the transition from traditional biofuels to modern fuels. However, the limitations of the linear energy ladder led Masera et al. (2000) to introduce a "multiple fuel" model. Masera's model offers insights into "fuel stacking," a concept that has garnered significant attention in recent literature. The Fuel Stacking Theory posits that households employ a combination of clean and unclean energy sources based on availability, affordability, and convenience (Muller & Yan, 2018). Prepaid meters, by requiring upfront payment for electricity, significantly influence this dynamic. Scholarly research supports this notion, indicating that the cost and accessibility of prepaid electricity often drive households to opt for cheaper but less environmentally friendly alternatives like biomass, kerosene, or coal (Dumga & Goswami, 2023). Behavioural economics studies further reveal that perceived electricity costs under prepaid schemes shape household energy consumption behaviours (Muazu & Ogujiuba, 2020). Socioeconomic factors, particularly income levels, exacerbate this trend, as low-income households, constrained by prepaid meter expenses, are more likely to resort to unclean energy sources. This understanding underscores the importance of targeted interventions to promote cleaner energy alternatives and mitigate energy poverty among vulnerable populations.

4.2.2 Conceptual Framework: energy poverty, energy subsidies, and prepaid meters

The present study introduces a conceptual framework depicted in Figure 4, which illustrates the pathways through which prepaid meters and subsidies impact energy poverty. Drawing inspiration from the measurement indicators proposed by Nussbaumer et al. (2012) for the Multidimensional Energy Poverty Index (MEPI), this research hypothesises the effects of policy instruments such as prepaid meters and competing subsidies in elucidating this phenomenon. Among the five distinct dimensions used to assess the Multidimensional Energy Poverty Index (MEPI), namely access, end-use, affordability, reliability, and efficiency, it is observed that policy initiatives focusing on transmission significantly constrain access to and end-use of electricity. The flow diagram in Figure 4 depicts how prepaid electricity meters influence electricity access and end use, ultimately leading to potential trade-offs between electricity and biomass usage for household activities. Prepaid electricity meters create a situation where households may choose to either disconnect from the electricity supply or rely on biomass such as wood, charcoal or kerosene for cooking and heating purposes. Given the multiple energy sources (fuel stacking) utilised by households, Prepaid meters result in trade-offs among different energy options to meet household needs. Households with limited access to electricity due to prepaid systems resort to using biomass for cooking and heating, which is considered energy-poor due to its unclean nature and associated health consequences.

Consequently, households tend to consume less electricity, primarily for lighting, and rely more on biomass, which is cheaper for cooking and heating. Figure 4's top panel demonstrates the trade-off between clean and unclean energy sources, which contributes to energy poverty. Although prepaid meters may restrict access to and usage of electricity and lead to trade-offs with unclean energy sources, other competing policy initiatives play a significant moderating role. Notably, policy interventions such as Free Basic Electricity, Reconstruction for Development Programme (RDP) schemes, and housing subsidies are identified as key moderators that significantly influence these transmission effects. The introduction of prepaid meters in South Africa allows poorer households to receive a minimum of 50kWh of free electricity anytime they purchase electricity to consume. This initiative enables energy-poor households to access some clean energy, which is crucial for addressing energy poverty.

Furthermore, RDP housing units are equipped with energy-efficient appliances, making electricity consumption relatively more affordable than relying on unclean biomass, thereby significantly addressing energy poverty. Housing subsidies support households in acquiring more energy-efficient homes, which is also instrumental in tackling energy poverty. The lower panel of Figure 4 illustrates the potential moderating effects of these competing policy initiatives, alongside prepaid meters, on the causal pathway leading to energy poverty.

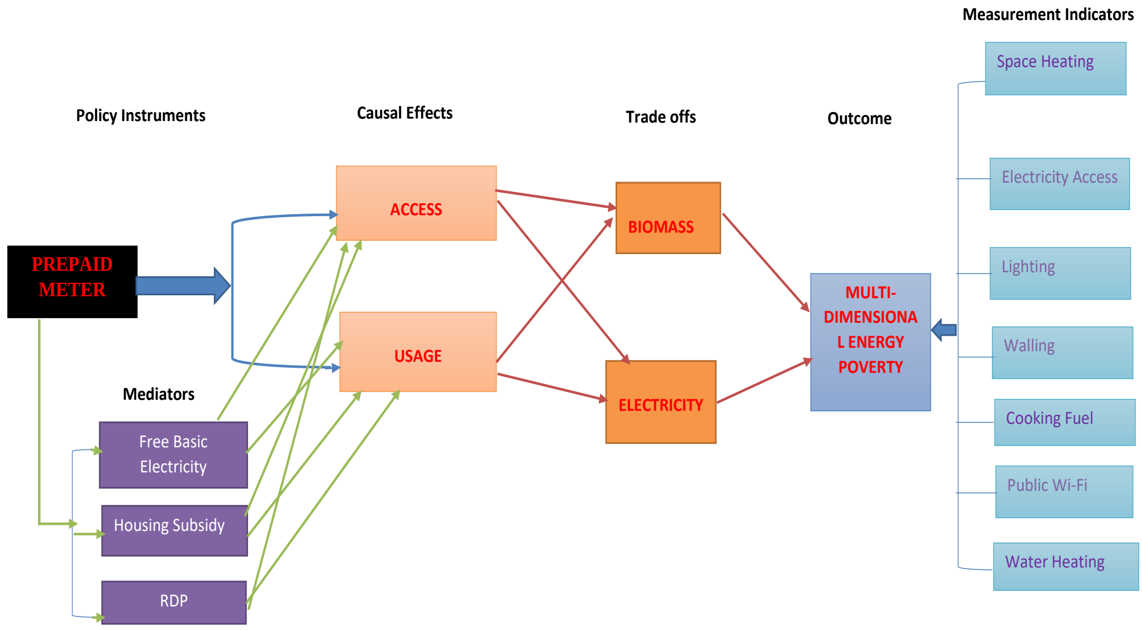

Figure 4: Transmission Mechanism of Policy Instruments on Energy Poverty

4.2.3 Energy Poverty Index: Multidimensional Measurement

Previous studies have identified factors explaining energy poverty, including low income, high energy cost, and living in a home with low efficient energy (Soko\lowski et al., 2023; Yadav et al., 2021; Soko\lowski et al., 2020a). Thus, energy poverty has had different measurements using several deprivation indicators. While some researchers employ qualitative measures such as assessing housing situation (Yadav et al., 2021; Soko\lowski et al., 2020a), ability to pay utility bills or achieve thermal comfort (Healy & Clinch, 2002; Köse, 2019; Thomson et al., 2017), others use quantitative techniques based on the incomes and expenditure. Energy poverty measurement using low income and high energy cost are found in the works of Heindl & Schüssler (2015), Hills (2012, Imbert et al. (2016) and Soko\lowski et al. (2023) and using a 10% energy expenditure threshold relative to income (Boardman, 1991; Legendre & Ricci, 2015) and metrics based on median expenditures (Herrero & Ürge-Vorsatz, 2012). In recent studies, multidimensional energy poverty measurement seems to have gained much attention. Nussbaumer et al. (2012) propose the Multidimensional Energy Poverty Index (MEPI) using poverty deprivation indicators.

Sadath and Acharya (2017) and Lin and Okyere (2020), among others, adopted it to measure energy poverty in developing countries. In South Africa, Tait (2017) employed a multidimensional energy poverty index using electricity access and fuel usage, affordability, safety and reliability from a survey in Cape Town. Israel-Akinbo et al. (2018) use the National Income Data Survey (NIDS) dataset to construct a MEPI using modern energy lighting, modern cooking fuel, appliance ownership, entertainment/education appliance ownership, and modern heating fuel. For any measurement index and variables used should strike a balance between accuracy and complexity, and efficiency in informing policymakers (Pelz et al., 2018). A research gap exists in the literature regarding a comprehensive assessment of MEPI that incorporates additional indicators, including housing conditions such as walling structure and assigns varying weights to these indicators.

4.2.4 Energy Poverty and Socio-economic Outcomes

The impact of prepaid meters on energy poverty could have elicited different effects on several socio-economic variables (Kambule et al., 2018b). According to Barnes et al. (2011), energy poverty is mainly suffered by women and children. This is because women tend to do more domestic chores such as cooking, cleaning, and childcare and spend less time in income-generating activities (Clancy et al., 2003). Therefore, energy poverty in female-headed households is more likely than in male-headed households (Ngarava et al., 2022a).

Just like poverty has a racial dimension in South Africa, energy poverty is also racially determined. The wider racial and income inequality gap in South Africa suggests poor racial groups are more likely to be energy deprived. It also established black race suffers more from energy poverty because of the high racial inequality and income gap in South Africa (Ngarava et al., 2022; Lin & Okyere, 2022).

Regarding the location effect, urban energy poverty is believed to be more likely compared to rural residents (Sustainable Energy Africa, 2017). Poor prepaid metered households must spend more to avoid disconnection or will have to self-disconnect since they cannot afford electricity. With most of these households located in urban locations, needing help to meet energy needs suggests likely energy poverty. So, prepaid electricity meters do not only reduce electricity consumption but have a strong likelihood of further entrapping households into energy poverty.

In all these socio-economic studies, the impact of prepayment systems on energy poverty considering the dimensions of gender, people experiencing poverty, location, and race need more clarity. Therefore, we again hypothesised prepaid meters to have a varying impact on energy poverty across various distinctive groups.

4.2.5 Energy Poverty and Energy Mix

Energy poverty is the absence of access to contemporary energy sources, including clean cooking fuels and electricity, and can result in significant social, economic, and environmental consequences. A proposed solution to mitigate energy poverty involves the advocacy for a diversified energy mix, which entails an increased utilisation of contemporary energy sources. Rubinstein et al. (2022) investigated the utilisation of electricity as a sustainable energy option for cooking in mitigating energy poverty in Cameroon. According to the study, electricity was primarily utilised as a secondary or tertiary source for cooking. Additionally, it was observed that smart metres, commonly associated with electricity usage, tended to indicate higher electricity consumption levels. Despite the increasing availability of electricity in Sub-Saharan Africa, there has been a sluggish shift towards its utilisation for cooking and heating purposes. This is primarily due to the comparatively higher electricity cost than the more affordable fossil fuel, as Grimm et al. (2013b) and Price et al. (2022) reported.

Furthermore, power outages and unsteady electricity provision enhance the dependability of alternative fuels (Meles et al., 2021). Rubinstein et al. (2021) identified a noteworthy discovery in the literature, which pertains to certain populations exhibiting hesitancy towards embracing electricity as a substitute for conventional fuels. This reluctance is attributed to safety apprehensions, cultural inclinations, and perceived preferences. Few similar findings have been reported in South Africa. Koomson et al. (2022) and Ye and Koch (2021) have researched energy poverty, recognising that households utilise a mix of energy sources due to varying cost differentials and may resort to alternative forms of energy for their daily activities. Based on the aforementioned context, it is suggested that households opt for alternative energy sources and switch to them in light of limitations in other forms of energy.

4.2.6 Energy Poverty and The Role of prepayment meters

This paper primarily aims to evaluate how pro-poor welfare policies influence energy poverty outcomes. However, since modern energy, such as electricity, features prominently in a household's energy mix, the study extends the analysis to discuss the effects of prepaid meters on energy poverty within the framework of pro-poor welfare policies. Much literature has enumerated the impact of prepaid metering on household electricity consumption. Accordingly, researchers have reported that introducing prepaid metering technology reduces household electricity consumption (Fischer, 2008; Faruqui & Sergici, 2010; Gans et al., 2013; Kambule et al., 2018; Jack & Smith, 2020). For example, Faruqui et al. (2010) showed prepaid meter systems reduce electricity consumption by 7%, Gans et al. (2013) reported a reduction between 11 and 17%, and Martin (2014) reported an 11% reduction. In South Africa, similar findings were found by Jack and Smith (2016), Kambule et al. (2018), and Jack and Smith (2020). A recent study by Jack and Smith (2020), who employed a Randomized Control Trial (RCT) methodology to examine the impact of a prepaid meter on consumption and utility revenue in Cape Town, concluded increased revenue and reduction in electricity consumption. Kambule et al. (2018) found a reduction in electricity consumption when household uses prepaid meters by 48% in Soweto. Some academics view the decrease in electricity when using prepaid meters as being energy efficient than deprived. The reduction in electricity could result in the household having to forgo electricity which is self-deprivation. Given this narrative, we hypothesise that the use of prepaid meters will experience energy poverty.

The primary mechanism in this study relating prepaid meters to energy poverty is the switching to other unclean forms of energy to meet household energy needs. Hence, we further interrogated the fuel stacking patterns to see how prepayment systems result in energy poverty through fuel switching. As a result, we can hypothesise that using prepaid meters increases fuel switching.

Contrary to the argument that prepayment systems benefit the service provider (Jack & Smith, 2016) and the households given efficient use of electricity and control over energy expenditure (McRae, 2015), it can result in energy poverty. For example, Kambule and Nwulu (2021) proved that poor prepaid metered households spend 60% of their income on electricity, which makes them energy impoverished. Other studies have also argued that prepayment technology, rather than causing energy poverty, reduces it through electricity and monetary savings and is a better tool to aid budgeting (Esteves et al., 2016; Malama et al., 2014).

4.2.7 Energy Poverty and Subsidies

Many studies have examined FBE policy as fundamentally linked with energy poverty. However, these studies failed to acknowledge that household prepaid electricity meters may elicit different outcomes given other potential government subsidies. Even with the

FBE policy, its impact on energy poverty has a conflicting report. Researchers notably (Gaunt, 2005; Wentzel, 2005; Prasad & Visagie, 2006) talk about the benefits of FBE in the form of monetary savings, improved health, and quality of life. Others, such as Bekker et al. (2008) and Kambule and Nwulu (2021), belittle FBE impact as irrelevant. Kambule and Nwulu (2021) believe FBE policy has failed or become obsolete as there is an increasing electricity cost ambit low-income households rely on, mostly on inefficient appliances, which leaves them trapped in a cycle of energy poverty. With all these questions surrounding FBE policy, it is important to compare other socio-economic policies to ascertain their impact on energy poverty and the role played by prepayment technology. We hypothesised that government subsidies could help mitigate energy poverty regardless of the electricity payment system.

4.3 METHODOLOGY

4.3.1 Econometric Model

The pathway explaining how energy policy instruments affect energy poverty is discussed in the background. A model that links energy deprivation to the payment structure of electricity is discussed through the replenishment of clean energy. Thus, we estimate the following equations;

$$EP_i = a_0 + B_1 PPREPAIDMETERS_i + \sum_K \psi_k X_i + \varepsilon_i \dots\dots\dots\dots\dots\dots\dots\dots\dots. (12)$$

Where EP_i represent multidimensional energy poverty index for household i ; $PPREPAIDMETERS$ denotes prepaid electricity meter used by household i. X captures the other controls used in this research; a_0 and ε represent the constant and error terms, respectively; B_1 and ψ_k represent the coefficient of the explanatory variables.

The measure of the dependent variable MEPI is continuous, bounded, and lies between [0,1]. We, therefore, use a fractional probit regression technique to estimate the effects of electricity prepayment systems on energy poverty. A fractional regression model is more suitable with continuous zero-to-one data than probit, logit, or heteroscedastic logit (Gallani, Krishnan, & Wooldridge, 2015). The least square regression likely results in biased estimates, as Gallani et al. (2015) assert that linear regression estimation goes beyond the outcome variable's natural values, making estimates unreliable. A fractional probit regression, therefore, generates estimates that are asymptotically normal and consistent (Gallani et al. 2015).

4.3.2 Impact Evaluation and Endogeneity Issues

The baseline regression's utilisation of the fractional probit model is subject to limitations and potential endogeneity concerns. In order to mitigate the issue of endogeneity, we utilise a more rigorous methodology that effectively accounts for endogeneity and enhances the dependability and coherence of our estimations. The study employed the propensity score matching technique to mitigate the potential endogeneity bias and, more significantly, to establish causal inference and impact analysis. The research acknowledged a small number of participants in the control group within the sample despite the fact that it included substantial variables as controls. In evaluating impact analysis using PSM, it is important to consider the limitations of a small control group carefully. A small control group may result in imprecise estimates of the intervention's impact, limiting the conclusions that can be drawn from the study (Dehejia & Wahba, 1999). However, it is highlighted that household datasets with a low control group can still be used for academic investigations provided they are correctly justified and suitable techniques are implemented to address issues such as selection bias, endogeneity, and measurement error (Caliendo & Kopeinig, 2008). This is because it is possible for a household dataset to have a low control group and still have a high number matching of individuals in the sample (Deaton, 1997; Wooldridge, 2002; Cameron & Trivedi, 2010).

Achieving well-balanced treatment and control groups on observable covariates is necessary to ensure the effectiveness of Propensity Score Matching (PSM) (Guo & Fraser, 2014). One suitable indicator to assess the covariates' matching quality is the standardised bias (B), suggested by Rosenbaum and Rubin (1985a). In this regard, "B" is typically used to refer to the standardised difference between the treatment and control groups on a specific covariate or observed characteristic (Austin, 2011). The standardised difference quantifies the level of imbalance between the two groups concerning that covariate, expressed as a percentage. When B exceeds 25%, the treatment and control groups differ by more than 25% of a standard deviation on that covariate (Austin, 2011), which is generally considered substantial and may suggest the groups are different. Therefore, a desirable practice is to aim for a standardised difference of less than 10% or 20% across all covariates (Austin, 2011). If B exceeds 25% for any covariate, it may be necessary to adjust for that covariate in the outcome analysis or exclude it from the matching process (Guo & Fraser, 2014). This is a common approach used in many evaluation studies and found in the works of Caliendo et al. (2008) and Sianesi (2004). The PSMATCH2 and PSTEST functions, available within the Stata software package, were utilised to achieve covariate balance and evaluate the credibility of PSM estimates (Leuven & Sianesi, 2018). After satisfying this condition, we estimated the average treatment effect of a prepaid payments system on multidimensional energy poverty.

Hence, the difference in the mean estimator is given as,

$$\tau = E(Y|t=1) - E(Y|t=0) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

$$\tau = ATT = E[Y(1) - Y(0)|W=1] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

$$\tau = ATT = E[Y(1), p(\varpi) - Y(0), p(\varpi)|W=1] \ldots\ldots\ldots\ldots\ldots\ldots (15)$$

The average treatment effect (ATE) shown in equation 9 includes the impact of individuals in the population who may not have received treatment (Heckman, 1997). We, therefore, focus on the average treatment effects for the treated (ATT) in equation 14. In addition, we use propensity score matching (PSM) techniques to ensure the robustness of our estimates. The study employed the Augmented Inverse Probability Weighting (AIPW) technique, which estimates the average treatment effects by accounting for both observed and unobserved confounding factors (Imbens & Rubin, 2015). AIPW involves using a doubly robust estimator to combine two models that can correct for potential bias from the misspecification of either model (Kurz, 2022). In addition, alternative matching methods like regression adjustment (RA) and nearest neighbour matching (NN) were also considered the robustness of estimated treatment effects. By using the AIPW and other matching techniques, the study enhances the validity and robustness of estimated treatment effects (Rosenbaum & Rubin, 1985b).

4.3.3 Data Sources

We used data from the South Africa General Household Survey (GHS) 2020. The GHS is a nationwide survey that, among other information, provides national figures on prepaid and post-paid metered households and energy deprivation indicators. The dataset is the outcome of a nationally representative survey comprising 19,649 resident South Africans across its nine (9) provinces. The questionnaire was directed to the heads of households, and information on their demographics and energy deprivation indicators was gathered. After data generation and cleaning, we used balanced observations of 15,415 households. The analysis is restricted to the household head since our measure of energy poverty is at the household level.

4.3.4 Measurement of Key Variables

Multidimensional Energy Poverty Index (MEPI)

The measure of household energy poverty forms a major contribution to this paper. We adopt the Nussbaumer et al. (2012) framework of the Multidimensional Energy Poverty

Index (MEPI) measure, which considers energy accessibility and end usage. This measure of energy poverty reflects the use of modern and clean energy services, making it imperative to reflect energy poverty in a developing nation. Additionally, the alternative sources and unclean energy forms on which households are energy-poor as considered. MEPI is derived from five dimensions of energy deprivation proposed by Nussbaumer et al. (2012). These dimensions include physical access to electricity, capacity to use energy for basic needs, energy affordability, reliability, quality of energy services, and energy efficiency.

The first dimension, physical access to electricity, examines the availability and accessibility of modern energy sources such as electricity, natural gas, or LPG. The second dimension, capacity to use energy for basic needs, examines the ability of households to use energy services to meet their basic needs, such as lighting, cooking, and heating. The third dimension, affordability of energy, measures the ability of households to pay for energy services without compromising their basic needs. The fourth dimension, reliability and quality of energy consider the reliability and quality of energy services, such as the frequency and duration of power outages. The final dimension, energy efficiency, assesses the efficiency of energy services, including the efficiency levels of appliances and the building structures that capture the affordability dimensions of energy poverty.

In developing the Multidimensional Energy Poverty Index (MEPI), Nussbaumer et al. (2012) identified specific indicators under each of the five dimensions of energy poverty. The indicators include electricity access, cooking, lighting, space and water heating, household entertainment appliances (TV), walling structures, and telecommunication. These indicators provide a comprehensive and multidimensional approach to measuring and monitoring energy poverty. For example, the access to electricity indicator captures the access dimension of energy deprivation, while the lighting, cooking, heating space and water, and telecommunication, such as TV and public wifi indicators, relate to end-use dimensions. These end-use dimensions focus on the ability of households to use energy services to meet their basic needs and the extent to which households can afford to use such services. Furthermore, the calculation of the energy index encompassed the aspects of affordability and efficiency pertaining to energy poverty, which was integrated with walling structures. This is because households tend to allocate a higher proportion of their budget towards energy services to maintain a comfortable indoor temperature when residing in inadequately insulated or structurally compromised dwellings. However, certain crucial aspects of efficiency, such as the energy efficiency rating of appliances and the standard of energy services, such as power outages (Lin & Okyere, 2022; Yadav et al., 2021), could serve as a measure of the dependability and quality of energy consumption, were predominantly disregarded owing to a lack of accessible data. We briefly describe the individuals' indicators used in the computation of MEPI below.

The index defines a household as energy deprived if; 1) the household mostly relies on and uses charcoal, firewood, and other unclean fuels for cooking and heating; 2) the household has no access to electricity (connected to the grid) or uses other renewable energy for lighting; 3) the household do not have TV sets; 4) have no access to Wi-Fi; 5) the household leave in a less insulated walling. These indicators were assigned a weighting in measuring the energy deprivation score. We set higher weights to the cooking and heating dimensions, given their relative importance and significant composition in the energy mix of households in a developing country like South Africa (Lin & Okyere, 2022; Crentsil et al., 2019). Thus, the cooking and heating dimensions were assigned a weighted score of 0.17, while the other dimensions had equal weights of 0.11. Cooking fuel is an essential energy need, and South Africans relying on biomass have health concerns and may be unsafe. Energy is used for heating water or room space, especially in a relatively cold country like South Africa. The

MEPI is computed by the sum of all these weighted indicators, resulting in a deprivation score between [0,1]. Thus, a higher deprivation score suggests a higher prevalence of energy poverty (EP). Hence, the dependent variable energy poverty is denoted by EP. Furthermore, the study performs a sensitivity analysis on how prepaid meters impact energy poverty by using predefined energy deprivation cutoffs (0.20, 0.33 and 0.50) commonly used in the literature (Lin & Okyere, 2022; Lin & Okyere, 2021; Adusah-Poku & Takeuchi, 2019). With these predefined cutoffs, the MEPI measured were categorised into a dummy. For example, using 0.20 cutoffs, MEPI scores greater or equal to 0.20 will take a value of 1 for energy poverty (EP) and 0 if otherwise. We also estimate the multidimensional energy poverty index using equal weights on all indicators to see if the findings will differ compared to the unequal weight used in the baseline MEPI measure. A more detailed and comprehensive description of this index can be traced to the works of Nussbaumer et al. (2012). Furthermore, we employed Principal Component Analysis (PCA) to generate an Energy Poverty Index as a robustness check.

Prepaid meters

The GHS survey reported on various sources of electricity available for a household. We focus on those with access to electricity only as the survey data provided information on whether the respondent is connected to the grid by the conventional or prepaid meter. The data were restricted to households using only these two types of access to electricity. The prepaid metered households took a value of 1, while the conventional metered households were 0. We discussed the prepaid meter type in reference to post-payment electricity meters to see the varying impact on energy poverty.

Other Control Variables

Previous studies have discussed the causes of energy poverty (Lin & Okyere, 2022; Ngarava et al., 2022b) and the role of prepaid meters (Kambule & Nwulu, 2021; Mbohwa et al., 2019). This study has drawn lessons from these studies on the drivers of energy poverty and has consequently controlled for other household attributes that could explain the problem under consideration. These included the household socioeconomic characteristics such as the head's level of education, age, marital status, household size, income, place of residence, and the region within which the household finds itself. A complete set of variables employed in the study can be seen in Table 16.

Table 16: Summary Variable Description/Measurement

Variable	Measurement/Description	Mean	Standard Deviation
EP	Multidimensional Energy Poverty Index (MEPI)/ Energy Deprivation Score (unequal weight)	0.241	0.193
EP1	0.20 cutoff for Energy deprivation	0.538	0.499
EP2	0.33 cutoff for Energy deprivation	0.164	0.371
EP2	0.50 cutoff for Energy deprivation	0.102	0.118
EP_u	Multidimensional Energy Poverty Index (MEPI)/ Energy Deprivation Score (equal weight)	0.107	0.115
Prepaid	Equals 1 if the household uses a prepaid electricity meter and 0 if postpaid	0.873	0.333
Education (No education)			
1.Primary education	Equals 1 if the household head completed primary education and 0 if otherwise	0.342	0.474
2.Secondary	Equals 1 if the household head completed secondary education and 0 if otherwise	0.429	0.495
3.post-secondary	Equals 1 if the household head completed post-secondary education and 0 if otherwise	0.090	0.286
4.Tertiary	Equals 1 if the household head completed Tertiary education and 0 if otherwise	0.058	0.234
Head age	Age of household head	49.34	15.66
Marital status (Married)			
1.Co-habitation	Equals 1 co-habitation and 0 if otherwise	0.108	0.311
2.Divorced	Equals 1 divorced and 0 if otherwise	0.037	0.190
3.Separated	Equals 1 separated and 0 if otherwise	0.014	0.119
4.Widowed	Equals 1 widowed and 0 if otherwise	0.169	0.375
5.Single	Equals 1 single and 0 if otherwise	0.333	0.471
Hhsize	Household size	3.511	2.355
Ln (Salary)	Log of household salary	8.382	1.176
Metropolitan areas	Equals 1 if the household is in a metropolitan area and 0 if otherwise	1.612	0.687
Provinces (Western)			

Eastern	Equals 1 if the household lives in the eastern cape and 0 if otherwise	0.130	0.337
Northern	Equals 1 if the household lives in the Northern Cape and 0 if otherwise	0.044	0.205
Free state	Equals 1 if the household lives in the Free State and 0 if otherwise	0.064	0.245
KwaZulu-Natal	Equals 1 if the household lives in KwaZulu-Natal and 0 if otherwise	0.162	0.369
Northwest	Equals 1 if the household lives in the Northwest and 0 if otherwise	0.068	0.252
Gauteng	Equals 1 if the household lives in Gauteng and 0 if otherwise	0.249	0.432
Mpumalanga	Equals 1 if the household lives in Mpumalanga and 0 if otherwise	0.080	0.273
Limpopo	Equals 1 if the household lives in Limpopo and 0 if otherwise	0.112	0.315
Housing subsidy	Equals 1 if a Housing subsidy was received and 0 if otherwise	0.223	0.46
State dwelling houses (RDP)	Equals 1 if State dwelling houses (RDP) were received and 0 if otherwise	0.204	0.403
Free Basic Electricity (FBE)	Equals 1 if Free Basic Electricity (FBE) was received and 0 if otherwise	0.232	0.422

4.4 RESULTS AND DISCUSSION

The fundamental result of this research is a more advanced computation for quantifying energy poverty. We employ MEPI as a proxy of energy poverty given different energy compositions, household characteristics, and experiences of socioeconomic outcomes such as income differences. The MEPI measures the incidence and intensity of poverty across several levels of energy deprivation, notably cooking, lighting, household and entertainment/ education appliances, walling structures, and telecommunication. First, we present the effects of electricity prepayment systems on energy deprivation score (MEPI) in a stepwise regression. This is followed by the robustness checks using different estimation simulations and sensitivity results using different cutoffs of MEPI. In addition to the robustness and sensitivity checks, we report an average propensity score estimate addressing endogeneity and causal inferences. Further, we report the heterogeneity results to see who suffers most and moderation analysis to see how government subsidies can resolve the irony that an efficient technology could also be a welfare loss. We conclude by discussing the results and policy implications obtained in this research.

4.4.1 Baseline regression

The baseline results for this study are presented in Table 17, with energy poverty as the outcome variable. Table 17 Column 1 reports a model with prepayment electricity systems as the only explanatory variable. Column 2 of Table 17 includes some explanatory variables, while Column 3 in the same table reports the full set of explanatory variables.

Table 17: Fractional probit regression of energy poverty

VARIABLES	(1) Energy Poverty	(2) Energy Poverty	(3) Energy Poverty
1.prepaid	0.293***	0.141***	0.047***
	(0.010)	(0.011)	(0.011)
1.Primary		-0.246***	-0.202***
		(0.017)	(0.016)
2.Secondary		-0.453***	-0.373***
		(0.018)	(0.017)
3.Post-Secondary		-0.506***	-0.450***
		(0.021)	(0.020)
4.Tertiary		-0.531***	-0.450***
		(0.022)	(0.022)
head_age		-0.002***	-0.002***
		(0.000)	(0.000)
ln_salary		-0.089***	-0.074***
		(0.004)	(0.004)
2.cohabitation		0.051***	0.084***
		(0.015)	(0.014)
3.Divorced		-0.032	-0.008
		(0.019)	(0.018)
4.Separated		0.105***	0.105***
		(0.029)	(0.027)
5.Widowed		0.041***	0.031***
		(0.013)	(0.012)
6.Single		0.027**	0.044***
		(0.011)	(0.010)
Hholdsz		0.014***	0.013***
		(0.002)	(0.002)

2.Rural			0.097***
			(0.009)
2.Eastern Cape			0.247***
			(0.014)
3.Northern Cape			0.016
			(0.019)
4.Free state			0.106***
			(0.016)
5.KwaZulu-Natal			0.095***
			(0.014)
6.Northwest			-0.043**
			(0.018)
7.Guateng			-0.055***
			(0.013)
8.Mpumalunga			0.140***
			(0.018)
9.Limpopo			0.316***
			(0.017)
Constant	-1.093***	0.174***	-0.116***
	(0.009)	(0.044)	(0.044)
Observations	17,192	15,415	15,415

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Author's estimate

The coefficient of using prepayment systems is consistently significant and positive across all the columns. Column 1 is a simple fractional probit regression that shows that a prepaid metered household is more likely to be energy-poor by about 0.293 at a 1% significant level. The multiple regression estimates in Columns 2 and 3 showed that using prepaid meters results in 0.141 and 0.047 chances of being energy-poor, both significant at 1%. All estimates mean a positive likelihood of energy poverty using prepaid meters compared to post-paid meters. Therefore, there is consistency in the directional and significant relationship between prepaid meters and energy poor. However, making inferences with the baseline estimates may be erroneous, given the likely endogeneity concerns. This study, therefore, applies more advanced and robust techniques to validate our findings and address endogeneity.

In the complete sample estimates, the effects of other controls explaining energy poverty must be considered. We observe important variables such as education, marital status, age of household head, household size, income, place of residence, and provinces. The results showed that having primary, secondary, post-secondary, or tertiary education reduces the likelihood of being energy-poor compared to having no education. Highly educated households have a more stable income stream and knowledge of the consequences of unclean energy, which makes them less likely to suffer from the burden of energy poverty. The results also show that energy poverty is reduced with ageing and income**.** Ageing comes with experience, knowledge, and wealth, making individuals much more comfortable enjoying clean energy. Just as ageing, higher-income earners suffer less from energy poverty since they can afford clean fuels**.** Larger household sizes and dwellings in a rural area than in an urban one likely result in energy poor. Larger household size uses more energy compared to smaller households. Compared to smaller family sizes, more energy is used for cooking and heating, explaining why energy poverty continues to be an issue among larger household sizes**.** The categorical marital status reported that co-habitation, separated, widowed, and single individuals are more likely to be energy-poor than married households. These findings could advance the discourse surrounding the allocation of responsibilities within marital partnerships. As opposed to fostering burden sharing, cohabitation may convey a sense of inadequate support, resulting in a higher probability of experiencing energy poverty when compared to those in committed marriages. Lastly, provinces such as the Eastern Cape, Free State, KwaZulu Natal, Mpumalanga, and Limpopo were more energy-poor compared to the Western Cape. At the same time, Northwest and Gauteng were less likely to be energy deficient than Western

Cape. The Western Cape province of South Africa is considered comparatively affluent in relation to other provinces and is, therefore, often utilised as a reference category. As a state with higher income levels, energy poverty appears less prevalent. However, when compared to some other states, this particular state exhibits a higher degree of energy poverty, which may be attributed to its elevated energy demands.

4.4.2 Validity and Robustness Checks

Robustness and Sensitivity analysis

The results in Table 17 employed the fractional probit model, suggesting households using prepayment electricity meters are likely to be energy-poor. We perform robustness of this baseline estimates using Beta, Poisson, and ordered logit regression shown in Table 18. Column 1 of Table 18 employs a beta regression, while Columns 2 and 3 use Poisson and Ordered logit, respectively, to check the robustness of our estimates. All three (Beta, Poisson, and Ologit) regression outputs support the fractional regression estimates that households suffer energy poverty using prepaid technologies.

Table 18: Robustness checks (Beta, Poisson and Ologit)

	(1)	(3)	(4)
VARIABLES	EP	EP	EP
	Beta	Poisson	Ordered Logit
1.prepaid	0.062***	0.084***	0.238***
	(0.019)	(0.017)	(0.053)
Covariates	Yes	Yes	Yes
Constant	-0.237***	-0.709***	
	(0.063)	(0.059)	
Observations	14,661	15,415	15,415

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Author's estimate

We further test the sensitivity of these findings by employing different cutoffs of our MEPI commonly used in most literature (Lin & Okyere, 2022). The level of cutoffs shows the severity or extent of energy poverty reported in Table 15. The measure of MEPI lies between 0 and 1, and following Nussbaumer et al. (2012), 0.33 cutoffs are preferable, especially in developing countries. This cutoff suggests MEPI score greater or equal to 0.33 implies the household is energy deprived or energy poor. We include other alternative cutoffs (0.20 and 0.50) that are also used in some works of literature. Columns 1, 2, and 3 report the sensitivity estimates for the 0.20, 0.33, and 0.50 MEPI cutoffs, respectively.

Consistent with the baseline estimates, prepayment electricity compared to postpaid meters likely increases the probability of being energy-poor across all three cutoffs. The likelihood of being energy-poor using prepaid meters lies between 0.203 and 0.334 across all alternative cut-offs of energy poverty. Specifically, the coefficient for 0.20 MEPI cut-offs was 0.203, and were 0.307 and 0.334 for 0.33 and 0.50 MEPI cutoffs, respectively, all significant at 1%. It must be noted that the conventional binary probit model was used, given the dummy outcome of our dependent variable. The study extended the sensitivity analysis by using equal weight on all indicators in deriving the energy deprivation index. The equal-weighted MEPI results were captured in Table 19 Column 4 and show prepaid meters increase a household's chance of being energy poor. The results, as presented in Table 19, are consistent with the findings from the baseline estimates that using prepaid meters, unlike postpaid ones, makes household energy poor. In addition, the results of the PCA index conducted as a robustness check for the MEPI are reported in Appendix II. These findings suggest similar outcomes, confirming the reliability of our estimates and the validity of our inferences. Consequently, the evidence indicates that prepaid metering systems could hinder the transition to clean energy and exacerbate energy poverty.

Table 19: Sensitivity Analysis: Multi dimension cut offs (0.20, 0.33 and 0.5) and an equal weight of MEPI

VARIABLES	(1) **EP1**	(2) **EP2**	(3) **EP3**	(4) **EP_u**
	0.20	0.33	0.50	Equal weight
1.prepaid	0.203***	0.307***	0.334***	0.069***
	(0.039)	(0.091)	(0.125)	(0.012)
Covariates	Yes	Yes	Yes	Yes
Constant	1.874***	-0.476**	-1.380***	-0.830***
	(0.134)	(0.227)	(0.334)	(0.046)
Observations	15,415	15,415	15,415	15,415

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Author's estimate

4.4.3 Impact and Endogeneity results

4.4.3.1 Data Balancing Results

Before using PSM to address endogeneity and suggest causal inferences, it is important to provide a balancing test between the treatment and control groups. The standardised difference (B) between the treatment and control groups on a particular covariate or observed characteristic is tested (Austin, 2011). The balancing test results of the standardised difference are shown in Table 20.

Table 20: Data Balancing test

PS R2	LR Chi2	P>chi2	Mean Bias	B
0.003	116.59	0.000	4.2	13.1
*If B>25%, R outside [0.5; 2]				

Source: Author's estimate

The presented findings demonstrate a balance matching test performed on a comprehensive set of covariates: education, salary, household size, age, marital status, location, and provinces. For a balance between treatment and control covariates, a standardised difference (B) of less than 10% or 20% between the groups on all covariates is typically recommended (Austin, 2011). The observed results indicate a B value of 13.1, which falls below the threshold of 25%. A B value below 25% in PSM indicates a substantial balance between treatment and control groups, as the groups do not differ significantly on the specified covariate (Austin, 2011).

Table 21: The Average Treatment Effects on Energy Poverty

	(1)	(2)	(3)
VARIABLES	AIPW	RA	NN
Prepaid	0.0335***	0.0335***	0.0314***
	(0.0044)	(0.0044)	(0.0074)
Covariates	Yes	Yes	Yes
Observations	15,415	15,415	15,415

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Author's estimate

Table 21 presents the average treatment effects estimates using variant matching methods of the PSM. Column 1 of Table 21 uses the Augmented Inverse Probability Weighting (AIPW) matching techniques, while Columns 2 and 3 use regression adjustment (RA) and nearest neighbour (NN) matching methods, respectively. The point estimates from the fractional regression are upward biased compared to the PSM estimates. Consistent with the fractional probit regression, using prepaid meters shows that households are likely to become energy-poor. The PSM results reported close estimates from all their matching techniques, averaging around 0.03, and all were significant at 1%. Specifically, the augmented IPW and regression adjustment estimates reported a similar coefficient of 0.0335, while the Nearest Neighbour matching was 0.0314. These PSM estimates address the problem of endogeneity, and in line, the fractional regression makes our estimates reliable and consistent. From these estimates, we have established a causal inference and can adduce that paying before the use electricity system makes the household energy poor.

Results of Prepaid Meters on Key Individual Energy Indicators

After establishing a causal inference based on our previous estimates, it is imperative to comprehend the transmission mechanism underlying how the utilisation of prepaid metres leads to energy poverty. Most households in South Africa use some degree of biomass like firewood and charcoal while having electricity access. Therefore, the fuel stacking pattern is tested to see how the use of prepaid meters affects energy for cooking and heating. The results for this energy substitution or fuel stacking pattern are shown in Table 22. Columns 1 and 2 estimate prepaid meters on energy for heating space and water, respectively, and column 3 focuses on the cooking fuel of a household.

Our study reports that using prepaid meters will continue undermining the shift to clean fuel choices (Yadav et al., 2021). A notable finding was that prepaid meters result in households switching to biomass for heating water or space and cooking at a 1% significant level: prepayment meters result in about 0.38 and 0.32 chances of households using biomass for heating room space and water, respectively, instead of electricity. This same prepayment system results in about 0.36 likelihood of using biomass for cooking. Prepaid meters led to a greater substitution and may compromise the clean energy for cooking and heating national policy reforms and campaigns (Olang et al., 2018).

Table 22[2]: Estimates for Key Indicators for Energy Poverty (Fuel Stacking)

VARIABLES	(1) Space_Heating (Biomass)	(2) Water_ Heating (Biomass)	(3) Cooking_fuel (Biomass)
prepaid (Yes)	0.380***	0.319***	0.363***
	(0.061)	(0.102)	(0.107)
Covariates	Yes	Yes	Yes
Constant	0.650***	-1.343***	-1.212***
	(0.175)	(0.281)	(0.319)
Observations	11,511	15,318	15,402

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Author's estimate

[2] Table 22 presents a probit model, given that the individual outcome variable is binary. This estimation aims to derive baseline results before employing the Propensity Score Matching (PSM) technique to analyse the individual impact on key indicators, particularly in areas such as space heating, water, and cooking.

The study's objective was to examine the effects of prepaid metres on energy poverty indicators at its individual level, with a specific focus on the utilisation of biomass for heating and cooking activities. The study found a causal relationship between prepaid meters and the indicators mentioned earlier, establishing the concept of fuel stacking as one of its primary objectives. In addition, the research employed the Propensity Score Matching (PSM) technique to establish impact analysis further to obtain endogenous results (Austin & Stuart, 2017). The augmented inverse-probability method was used in column 1 of Table 23, while columns 2 and 3 utilised other matching techniques, such as regression adjustment and nearest matching, respectively, for robustness checks.

Table 23: A propensity score matching for key individual indicators.

VARIABLES	**(1) Energy Poverty ATT for augmented inverse-probability weighting**	**(2) Energy Poverty ATT for the regression adjustment**	**(3) Energy Poverty ATT for nearest-neighbour matching**
Panel A-(Space heating)			
Prepaid	0.109***	0.109***	0.054**
	(0.0154)	(0.0154)	(0.0214)
Covariates	YES	YES	YES
Observations	11,511	11,511	11,511
Panel B-(Water Heating)			
Prepaid	0.043***	0.043***	0.027*
	(0.0089)	(0.0089)	(0.0148)
Covariates	YES	YES	YES
Observations	15,318	15,318	15,318
Panel C (Cooking Fuel)			
Prepaid	0.057***	0.057***	0.033**
	(0.0083)	(0.0083)	(0.0147)
Covariates	YES	YES	YES
Observations	15,402	15,402	15,402

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1
Source: Author's estimate

Panel A reported the Average Treatment Effect (ATE) of using prepaid meters on biomass for space heating. In contrast, Panels B and C reported the same for water heating and cooking, respectively. The results showed that prepaid meters significantly impacted households using biomass for space and water heating and cooking purposes, with an ATE of 10.9%, 4.3%, and 5.7%, respectively. The impact evaluation results in column 1 were consistent with the robustness checks in column 2 for all three panels. The column 3 results reported a lower but still significant coefficient, affirming the results in column 1.

The findings of the study support the hypothesis that prepayment of electricity meters results in households relying on unclean and cheap energy sources, leading to a state of energy poverty. The substitution effects of increasing reliance on biomass, which is cheap but potentially unclean, support the fuel-stacking hypothesis that households use multiple energy sources. A prepayment system affects income and results in switching to other energy forms to meet energy demands. Overall, the results highlight the importance of considering energy poverty in the context of prepaid meters and its potential impact on household energy use.

4.4.4 Heterogeneity Results: Gender, Race, Location, and Wealth Status

In order to provide a more comprehensive basis for policy formulation, it is essential to analyse heterogeneity. In contrast to the previous homogeneous estimates, the heterogeneity analysis considers the groups most affected by energy poverty: vulnerable populations. The results of the heterogeneity analysis, which considers gender, race, location, and wealth status, are presented in Table 24. Columns 1 and 2 of Table 24 report gender and race differences, while columns 3 and 4 report location and wealth differences.

Table 24: Heterogeneity (Gender, Race, Location and Wealth Status) effects on energy poverty

VARIABLES	(1) Energy Poverty ATT for augmented inverse-probability weighting	(2) Energy Poverty ATT for augmented inverse-probability weighting	(3) Energy Poverty ATT for augmented inverse-probability weighting	4 Energy Poverty ATT for augmented inverse-probability weighting
X	**Gender (female)**	**Race (Non-white)**	**Location (Rural)**	**Wealth (Poor)**
Prepaid*(X)	0.008***	0.051***	0.065***	0.060***
	(0.0026)	(0.0035)	(0.0020)	(0.0036)
Covariates	YES	YES	YES	YES
Observations	15,415	15,415	15,415	15,415

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Author's estimate

The results indicate that, with a significance level of 1%, female individuals exhibit a 0.8% higher likelihood of encountering energy poverty when utilising prepaid metres than their male counterparts. This phenomenon can be attributed to women being paid less than men, and their energy needs are frequently overlooked due to their socially assigned roles. Moreover, non-white South Africans, including Blacks, Coloureds, and Indians, are about 5.1% more likely to experience energy poverty when using prepaid meters than their white counterparts. Similarly, households in rural areas are 6.5% more likely to experience energy poverty than urban dwellers when using prepaid meters. Additionally, poor households are about 6% more likely to experience energy poverty than wealthy households when using prepaid meters. These results support the argument that vulnerable or marginalised groups are at a higher risk of experiencing poverty and, in this study, energy poverty compared to their more privileged counterparts (Lin & Okyere, 2022).

4.4.5 Moderation results

The present findings report the moderation effects of government subsidies on energy poverty, particularly in the context of prepaid meters in South Africa. The research investigates whether pro-poor government subsidies can mitigate the issue of energy poverty, which is a significant problem in the country. The subsidies considered in this study include the housing grant, RDP housing, and Free Basic Electricity (FBE). We commence by examining the individual subsidies' impact on energy poverty and subsequently report their interaction term. A detailed examination reveals that the identified subsidies independently reduce energy poverty. The research evaluates the interaction between these subsidies and prepayment technology to determine if they can reduce the incidence of energy poverty.

Table 25 presents the moderation results of these subsidies on energy poverty. Specifically, Column 1 reports the moderation effects of Free Basic Electricity on energy poverty, while Columns 2 and 3 report the impacts of RDP housing and housing grants, respectively. The research finds that the FBE subsidy, when interacted with prepaid meters, reduces energy poverty by 0.4% at a 1% significance level. Similarly, RDP schemes with prepaid meters reduced energy poverty by 1.9% at a 1% significance level. However, the evaluation results of housing grants and prepaid meters appeared insignificant. The findings of this study challenge the expectation that energy subsidies, such as free basic electricity, are more effective than other competing subsidies, such as the RDP housing scheme, in reducing energy poverty in South Africa. The results indicate that the effectiveness of energy subsidies can depend on various factors, such as the subsidy's design, infrastructure availability, and consumer behaviour.

Moreover, in the context of South Africa, the RDP housing scheme, a major government program aimed at providing affordable housing for low-income households, has proven to be an effective policy instrument in reducing energy poverty. The results of this research have important implications for policymakers and stakeholders. The study provides evidence that government subsidies can effectively mitigate energy poverty when targeted and designed appropriately. Therefore, policymakers should consider the interaction between subsidies and prepayment technology in designing effective policies to address energy poverty. Additionally, the findings suggest that the RDP housing scheme, which provides access to essential services such as electricity and water, can effectively reduce energy poverty in South Africa. Overall, the study underscores the importance of evidence-based policy design to address energy poverty in the country.

Table 25: Moderation estimates (FBE, RDP and Housing subsidies)

VARIABLES	**(1) Energy Poverty ATT for augmented inverse-probability weighting**	**(2) Energy Poverty ATT for augmented inverse-probability weighting**	**(3) Energy Poverty ATT for augmented inverse-probability weighting**
X	**FBE**	**RDP**	**Housing_ Sub**
FBE	**-0.011*** (0.0031)**		
RDP		**-0.056*** (0.0029)**	
Housing_Sub			**-0.007*** (0.0027)**
Prepaid*(X)	-0.004*** (0.0029)	-0.019*** (0.0026)	-0.004 (0.0029)
Covariates	YES	YES	YES
Observation	14,033	17,445	15,104
Observations*X	13,314	15,318	13,314

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Author's estimate

In order to expand on the existing findings and make a significant contribution to the literature, this study extends the analysis of moderation effects by examining the impact of prepaid meters and free basic electricity on specific dimensions of energy poverty. Given that the previous estimates established the relevance of energy subsidies, notably FBE used in conjunction with prepaid meters, in reducing energy poverty, it is essential to understand how this scenario applies to space and water heating and cooking fuel. Therefore, the joint impact of FBE and prepaid meters on biomass for space and water heating and cooking fuel is reported in Table 26. Specifically, Columns 1 and 2 report the moderation effects on space and water heating, respectively, while Column 3 reports on cooking fuel.

Table 26: Propensity score matching for Key individual Indicators

VARIABLES	**(1) ATT for augmented inverse-probability weighting**	**(2) ATT for augmented inverse-probability weighting**	**(3) ATT for augmented inverse-probability weighting**
	Space_heating	**Water_heating**	**Cooking_fuel**
FBE	-0.013	-0.005***	-0.015**
	(0.011)	(0.001)	(0.006)
Prepaid*FBE	-0.004	-0.004***	-0.011*
	(0.011)	(0.0009)	(0.0062)
Covariates	YES	YES	YES
Observation (FBE only)	10,489	13,915	13,992
Observations	9,949	13,233	13,305

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Author's estimate

According to the findings above, the utilisation of FBE and prepaid metres has resulted in a decrease of 0.4% in the dependence on biomass for water heating. This outcome has been established with a significance level of 1%, as demonstrated in Column 2. In Column 3 of Table 26, it is observed that FBE and prepaid meters used together result in a reduction of approximately 1.1% in the use of biomass for cooking. These findings underscore the role of energy subsidies in fuel stacking. FBE enables households to access clean energy while reducing their reliance on biomass for water heating and cooking. The reduction in biomass use leads to a switch to cleaner energy, such as electricity, for cooking and heating purposes.

In conclusion, the results of this study provide crucial insights into the impact of prepaid meters and energy subsidies on different dimensions of energy poverty. The findings demonstrate that using FBE and prepaid meters can significantly reduce the reliance on biomass for space and water heating and cooking fuel. The study highlights the critical role of energy subsidies in promoting access to clean energy and reducing energy poverty. Finally, the findings have important implications for policymakers, indicating that targeted energy subsidies and prepaid metering can effectively reduce unclean and cheaper energy that has health consequences for individuals.

4.4.6 Discussion

The findings from this study show households using prepayment electricity systems translate into energy deprivation. This finding is consistent with our first hypotheses and the results (Kambule & Nwulu, 2021; Kambule et al., 2018). Although the coefficient's direction is consistent with other research, the magnitude of severity differs. Another important observation using the different MEPI cutoffs suggests that higher cutoffs give more levels of energy poverty than lower cutoffs (Lin & Okyere, 2022). The importance of these cutoffs implies a country-specific understanding of its energy mix and energy switch to unclean sources. The role of prepayment electricity systems on energy poverty can be explained from several perspectives. First, pay before use affects the amount of electricity consumption (Jack & Smith, 2020; Kambule & Nwulu, 2021). With reduced electricity consumption, households resort to other cheaper and unclean energy sources to meet their daily energy consumption, the fuel stacking concept. Introducing prepaid meters is supposed to be an efficient tool to control household electricity consumption. An efficient use implies households cutting down on electricity use for unproductive activities and using electricity when needed. A situation arises when a household decides not to use electricity due to the constraint posed by prepaid meters in paying ahead, resulting in a self-deprivation of electricity consumption (Kambule et al., 2019; O’Sullivan et al., 2013). In addition, an impulsive household may be unable to control its expenditure (Pirog &

Roberts, 2007; Runnemark et al., 2015), including electricity consumption, even with prepaid meters. Impulsive consumers spend much of their income beyond the 10% threshold on energy, making them energy-poor. Following our first hypothesis on the impact of prepaid metering on energy poverty, it is evident that it exacerbates the financial burden on low-income households. While prepaid metering does not inherently increase the per-unit cost of energy consumption compared to postpaid systems, it poses significant challenges for the economically disadvantaged. Unlike postpaid systems, prepaid metering requires individuals to accumulate savings over time to purchase energy units in advance, thereby depriving them of immediate access to essential services. Additionally, the necessity of traveling to the nearest purchase depot to load units incurs additional transportation costs, further straining limited budgets. Moreover, in situations where online purchases are unavailable or during odd hours, households relying on prepaid metering may be forced to endure periods without access to electricity, particularly if nearby purchasing centers are closed or internet connectivity is weak, which is often the case in rural areas. Taken together, these factors underscore how prepaid metering systems contribute to energy poverty among households, aligning with the first objective of our study. The possible causal effects discussed were further interrogated by the fuel stacking patterns in using prepaid meters on key individual energy deprivation indicators. The fuel stacking theory explains the energy switching or substitution effects considering household energy mix patterns (Yadav et al., 2021). Prepaid meters result in households switching from electricity to biomass for heating water, room space, and cooking. Several studies have reported similar findings. For example, a study by Malama et al. (2014) found that the use of prepaid meters in Zambia was associated with high disconnection among low-income households. Similar findings were reported by Mbohwa et al. (2019a) in South Africa. According to Mbohwa et al. (2019a), households, in response, switch from electricity to wood, coal, kerosene, and fuel paraffin, a cheaper and unclean form of energy since they pollute the environment and have health consequences. The study noted that this switch was particularly common among low-income households, who were more likely to experience disconnections and rationing of electricity. The works of Beyene et al. (2022) and Barnes et al. (2016) reported the same for their studies on Ethiopia. Biomass, such as firewood for space and water heating and cooking purposes, has health concerns and thereof considered unclean or unsafe energy source patterns (Yadav et al., 2021; Ali et al., 2019). It must be noted that cooking, spacing, and water heating activities form the greatest share of household energy expenditure (Lin & Okyere, 2022; Crentsil et al., 2019). Poorer households utilizing electricity prepayment systems face heightened costs associated with electricity usage, particularly for essential activities like cooking and heating. These increased costs often compel them to switch to cheaper but unclean forms of energy to meet their basic household needs. In periods of income constraints, which are common among households using prepaid payment methods, limited access to electricity further exacerbates the situation. Consequently, households are compelled to rely predominantly on alternative, more affordable energy sources to carry out basic household activities. This observation provides support for our second hypothesis, highlighting the link between electricity prepayment systems, increased costs, and the subsequent reliance on cheaper but less environmentally friendly energy sources.

The study observed the heterogeneity effects of energy poverty by vulnerable groups using prepaid meters. Mbohwa et al. (2019a) reported that prepaid meters in South Africa reduced electricity consumption among low-income households. Similarly, this study observed that vulnerable groups such as women, the poor, non-white race, and rural areas tend to suffer most from energy poverty (Ngarava et al., 2022c; Longe, 2021b). Women, non-white, rural, and poor South Africans are mostly income disadvantaged or constrained compared to their counterparts (Mbohwa et al., 2019a). Post-paid payment structure directly or indirectly cushions the income stream of poorer households. Paying after use gives individual consumers time to work and save income to pay electricity expenses later. Vulnerable groups do not have a reliable or paid fixed income like wealthy populations who could plan their expenditure, and energy expenditures form an insignificant portion of their income streams. The gender effects of energy poverty are very important, given the social roles assigned to men and women (Sustainable Energy Africa, 2017). The social responsibilities of cooking and taking care of the household given to women mean they often choose energy use (Oparaocha & Dutta, 2011). Paying ahead system forces women to use unsafe and cheaper energy sources.

Furthermore, non-white South Africans are poorer than the wealthy white population (Lin & Okyere, 2022). The poorer race may have to switch to unclean energy or reduce energy consumption since they must consider other household expenditures, given their limited income. Using unclean energy or, having to forgo electricity use sometimes, or spending a high percentage of the income on electricity, infers energy poverty among the poorer races (Gill-Wiehl et al., 2021). The same argument is made for rural dwellers who rely on unclean alternative energy sources due to a constraint on income from the prepayment of electricity systems (Lin & Okyere, 2021b). The resulting high energy poverty in rural communities contradicts a report from Sustainable Energy Africa (2017), assessing a high urban energy poverty due to increased energy demand.

This study's central and paramount objective was to examine the efficacy of policies in alleviating energy poverty and promoting the adoption of cleaner energy sources, mainly electricity. Additionally, we investigated the impact of different government subsidies in mitigating the negative consequences associated with the use of prepaid meters. Government subsidies such as free basic electricity (FBE) and RDP schemes interacted with prepaid meters to reduce energy poverty. But, the housing grant interaction with prepaid meters could have been more significant. These subsidies supplement households' income, enabling them to afford clean energy. The International Institute for Sustainable Development published a policy brief in 2019 wherein the authors contend that government subsidies, such as FBE and RDP schemes, have the potential to alleviate energy poverty significantly. When these subsidies are combined with other policy interventions, such as implementing energy efficiency measures (prepaid systems), they promote clean and modern energy. The authors note that subsidies alone are not enough to address energy poverty, but when combined with energy efficiency technologies and measures, the benefit becomes evident. As suggested in the policy brief, this research used an energy efficiency tool, notably prepaid meters, and established a possible reduction of energy poverty. Free Basic Electricity (FBE), which gives about 50kWh for lifeline consumers, was vital in reducing energy poverty when interacting with prepaid meters. The significance of this finding is that more energy-related subsidy help is important. Free basic electricity offers some support to poorer households, so they are not worse off using prepaid meters and the minimum amount of electricity given they can enjoy clean energy. The availability of a minimum amount of free electricity with every purchase encourages poorer households to invest in purchasing electricity. Similar findings were evident in Mbohwa et al. (2019a) and Lin and Okyere (2023) work.

The RDP housing initiative, a government-targeted housing program, has provided compelling evidence for addressing energy poverty. Government-built structures boast quality walling structures, installed appliances, improved wiring, and standardized homes, features that were previously unattainable for many low-income households. This state assisted building provides targeted support to vulnerable households, such as energy-efficient appliances or the installation of renewable energy systems, which can help to reduce energy costs and improve energy access (Lin & Okyere, 2023). The better walling structure under RDP homes suggests reduced electricity consumption for space heating. The installation of energy-efficient appliances further contributes to lower electricity usage. Consequently, prepaid metering systems may not necessarily burden poorer consumers excessively. This noteworthy evidence highlights the potential of housing infrastructure with appropriate structures and installed appliances to effectively address energy poverty. These results imply that prepaid meters become a catalyst for a household to consume more proportion of clean energy (electricity).

Finally, our study found that the combination of free basic electricity (FBE) and prepaid meters led to reduced use of biomass for water heating and cooking, indicating a shift towards cleaner energy sources. This finding is consistent with previous research on the benefits of FBE and prepaid metering in reducing energy poverty and improving energy access. Hence, policies promoting cleaner energy sources to reduce the negative health impacts of household energy use should be encouraged. Unclean energy sources, such as kerosene, charcoal, and firewood, are often used by households in developing countries, leading to adverse health and environmental impacts. A study by Davis et al. (2008) reported the relevance of free basic electricity subsidies to the household. Consequently, there is a growing trend towards diminishing reliance on conventional energy sources, such as kerosene and firewood, while simultaneously enhancing the availability and utilisation of electricity.

In summary, prepaid meters have been found to contribute to energy poverty, primarily through a switch from cleaner electricity to unclean energy sources. This impact is felt most acutely by vulnerable groups. Nevertheless, energy subsidies such as Free Basic Electricity (FBE) and other government subsidies such as Reconstruction and Development

Programme (RDP) schemes have demonstrated the potential to reduce energy poverty and promote the adoption of cleaner energy sources.

4.5 CONCLUSION

The study employs the South Africa General Household Survey 2020 to examine the impacts of using prepaid electricity meters on multidimensional energy poverty. Applying fractional probit estimation techniques for the baseline regression, Beta, Poisson, and Ologit regression for robust checks, and Propensity Score Matching (PSM) techniques for endogeneity issues, we found that using prepaid electricity systems results in energy poverty. The effects of prepayment electricity technology on energy poverty ranged between 0.03 to 0.06 depending on regression or robustness estimation. Considering the notion of fuel stacking, the study found that prepaid electricity systems resulted in households relying on unclean energy for cooking and heating. We observed that prepaid meters and Free Basic Electricity subsidies jointly reduce energy poverty and that subsidies directly linked to energy are important. Furthermore, the RDP scheme significantly impacts energy poverty compared to other housing subsidies. The effects were also found to be heterogeneous across different subgroups. Thus, the impacts of prepayment electricity meters on energy poverty were adverse for women, the poor, non-white race, and rural communities in South Africa.

The findings of this study underscore the detrimental impact of prepaid electricity meters on energy poverty, particularly through the transition from cleaner electricity to unclean energy sources, disproportionately affecting vulnerable groups. However, government subsidies like Free Basic Electricity (FBE) and initiatives such as the Reconstruction and Development Programme (RDP) have shown promise in mitigating energy poverty and fostering the adoption of cleaner energy sources. These results highlight the importance of effective targeted policy interventions to address energy poverty. By emphasizing standard building structures with inbuilt energy-efficient appliances, governments can alleviate the burden of energy costs on low-income households and improve overall energy access. Moreover, the observed shift from unclean energy sources towards electricity usage underscores the potential health and environmental benefits of cleaner energy options. This study emphasizes the need for comprehensive policy strategies to promote clean energy usage, reduce energy poverty, and advance sustainable energy practices.

CHAPTER FIVE

5. Conclusions and Policy Recommendations

5.1 Concluding the Thesis

The thesis presents the impact of electricity metering and usage on household welfare in South Africa and Ghana. To this end, we researched three separate but related questions on the relationship between productive electricity use and prepayment electricity systems on household welfare, notably enterprise income, hunger, and energy poverty.

Chapter Two reported the first paper and centred on the Impact of Energy Type on Household Non-farm Enterprise Income in Ghana. The research employs the Ghana Living Standard Survey (GLSS7) data to examine the importance of electricity usage on household enterprise income. This study further shows the relevance of fuel expenditure and other firm characteristics in the enterprise production process. The study employed the Instrumental Variable (IV) method as a foundational estimation technique, complemented by the Lewbel estimation for its enhanced estimates. The results demonstrated a positive influence of electricity and fuel expenditures on enterprise performance. Nevertheless, the test for a linear difference between the coefficients of electricity and fuel did not yield statistically significant evidence to support the claim that one input has a more substantial impact on enterprise income than the other. This conclusion is consistent with findings from sub-sample analyses and heterogeneity estimates. In light of the statistically insignificant impact of electricity and fuel, the broader external implications of these varied energy inputs are considered. Electricity, as a modern and cleaner energy source, emerges as a more environmentally friendly option for government investment relative to fuel. Our results have significant policy implications and advance the need for government electricity for all programs. Also, the government electricity expansion program should be target-specific if the goal is to facilitate household welfare through the productive use of electricity and, again, promote modern fuel supply to improve household enterprise income in Ghana.

Chapter three examined how payment mechanism results in household income redistribution, which intends to affect food consumption. Food insecurity in South Africa can be attributed to multiple factors, including income, employment, and access to food. However, prepayment systems could also explain food insecurity in the country as it requires households to pay in advance, potentially leading to a reduction in saving money. This research investigates the differential impact of electricity prepayment systems and competing policy instruments on food insecurity. Applying robust techniques such as the propensity score matching to the General Household Survey 2020 from South Africa, the findings show that households that use prepaid electricity meters have a higher probability of experiencing hunger. Specifically, we find that using prepaid meters increases hunger in families and among adults and children by 3.9%, 4.7%, and 4.4%, respectively. However, hunger marginally decreases when households receive social interventions with prepaid meters. The study further observed multiple burdens of chronic diseases to mediate the relationship between using prepaid electricity meters and hunger. Therefore, the policy implications of the results suggest reviewing prepaid metering and subsidy schemes for poor-income households. Also, the study suggests that providing food assistance programs or subsidies may prove vital in directly addressing hunger in these vulnerable households.

Chapter four expounded on the correlation between policy instruments and energy poverty. Additionally, it delved into the concept of fuel-stacking behaviour among households. We use the General Household Survey data of South Africa to explain the impact of prepaid payment systems on energy poverty. Applying fractional probit regression and other robustness methods, the results show that using prepaid meters potentially increases the probability of being energy-poor between 0.03 and 0.06 percentage points. Using

Propensity Score Matching (PSM) to address endogeneity and enable impact analysis through quasi-experimental methods, the study found that households using prepaid meters had a 3.35% higher likelihood of being energy-poor than those using postpaid meters. The study further revealed that households become energy-deprived by switching to unclean energy sources for cooking and heating when given prepaid meters. Specifically, the implementation of prepaid metres resulted in a statistically significant increase of 5.7% in biomass utilisation for cooking purposes, a 10.9% increase in space heating, and a 4.3% increase in room heating. The results also showed that vulnerable groups or poor South Africans suffer most from energy poverty using prepaid meters. Joint use of prepaid meters and Free Basic Electricity (FBE) could reduce energy poverty. Additionally, the study highlights the combination of the Reconstruction and Development Programme (RDP) housing scheme with prepaid meters is an effective pro-poor policy in reducing energy poverty. The study's policy implications suggest increased energy subsidies and targeted policy interventions to mitigate energy poverty.

We conclude this thesis by consolidating the essential findings from the three substantive papers and their relevance to policy and literature.

5.2 Policy Implications

Based on the findings of this thesis, there exist a number of essential elements within an energy policy framework that governments ought to evaluate in order to improve the well-being of households. The present research investigates how energy policies are often formulated without due consideration of their implications for household welfare. Consequently, it is imperative that policy initiatives factor in both productive fuel and electricity usage. Moreover, policies concerning payment mechanisms must be meticulously developed to address the increasing resistance to such critical and efficient energy policies.

The research findings in chapter two present several practical and specific policy recommendations, including enhancing access to reliable and affordable electricity for Ghanaian businesses. The relevance of electricity to enterprise development, which generates significant revenue or becomes the primary source of income for many households, suggests that Ghana's government electricity for all programs is relevant. One of the key objectives of the electricity expansion program is to allow households to use electricity for productive activities such as enterprise development other than consumption. The government should encourage electricity expansion favouring manufacturing and female-owned and urban enterprises, as electricity is a key driver of income for these businesses. Government policy should also ensure that electricity supply is a reliable and cheaper source to drive enterprise profit. The negligible disparity between electricity and fuel energy usage underscores the imperative for government investment in the electricity sector. Electricity represents a modern and cleaner energy alternative, which facilitates productive activities, safeguards human health and mitigates environmental degradation often associated with traditional fuel energy sources. This finding underscores the importance of prioritizing investments in electricity infrastructure to foster sustainable development and address pressing energy and environmental challenges. The results suggest such an expansion drive is relevant, the same as fuel energy, and should not be overlooked.

Rather than focusing on one type of energy source, policymakers could promote the diversification of energy sources available to enterprises. This would allow firms to choose the energy input that is most cost-effective for their specific production requirements and market conditions. Modern fuel usage is profitable for growth, especially for micro and rural enterprises. Supporting micro or small-scale enterprises with zero to one employee accessing reliable and affordable modern fuel energy sources is also recommended. The cost of diverse energy sources may still be significant for small enterprises. Policies aimed at improving access to cheap energy, such as subsidies or tax incentives, could help reduce expenditure costs and enhance these enterprises' profitability. Policies aimed at expanding infrastructure for energy distribution, such as building new power lines or fuel pipelines, could help improve access to energy sources and support the growth of a rural enterprise. The study's recommendation advocates for a balanced approach to government investment in energy infrastructure, emphasizing both electricity and modern fuel sources. While acknowledging the vital role of electricity, particularly in urban areas, the study highlights the continued relevance of fuel energy, especially in rural and small-scale sectors. However, it underscores the negative environmental and health impacts associated with traditional fuel energy, making electricity investment justifiable. The absence of substantial disparities in the influence of electricity and fuel energy on enterprise income underscores the importance of diversifying energy sources to stimulate economic productivity effectively. This recommendation emphasizes the need for comprehensive energy policies that consider both electricity and modern fuel alternatives to achieve sustainable economic development.

Given the Chapter Three (3) findings, the scaling up of prepaid metering for the household must be targeted toward household income levels and health considerations. Develop targeted interventions to address the food security needs of households using prepaid meters. These could include initiatives such as food assistance programs or subsidies for low-income households that use prepaid meters. In addition, lower-income and chronic health households should be allowed to use post-paid metering, given the income constraint of prepaid metering on hunger. The study establishes a strong correlation between chronic health conditions and food insecurity. Therefore, policymakers should prioritise programs aimed at providing affordable healthcare options to low-income households. Such programs could include subsidies for healthcare expenses, free medical check-ups, and preventive health education. Chronic health conditions may result in higher medical expenses, reducing households' available food income. As such, governments should establish financial support programs, such as cash transfers, food stamps, and tax breaks, to alleviate the financial burden of medical expenses on low-income households. Alternatively, promoting healthy food environments is necessary to combat food insecurity. Governments and organisations can support initiatives that increase access to healthy food options in low-income areas, such as farmers' markets, community gardens, and nutritious food subsidies. The correlation between prepayment systems and food security underscores the importance of examining payment mechanisms comprehensively and understanding their impact on household welfare. Beyond simply addressing energy access, policymakers must recognize the broader socio-economic implications, particularly the potential trade-offs between essential needs like food security and electricity when faced with limited income. Therefore, there is an urgent need to explore alternative payment mechanisms that alleviate these trade-offs for poorer households while ensuring equitable access to both energy and food resources. Such an approach would foster inclusive development and enhance overall societal well-being by prioritising household welfare and reducing trade-offs.

Moreover, the government should review the current subsidies aimed at improving household welfare to determine their effectiveness in achieving their intended impact, particularly in light of the study's findings that these subsidies may exacerbate the plight of households and increase the likelihood of hunger. The government may consider revising the subsidies or introducing new ones that are better targeted to address the specific needs of households, such as those focused on reducing hunger. More importantly, to better address the issue of hunger, a food-related subsidy will be more directed toward reducing food insecurity among households. Such a subsidy could be targeted at low-income households or those with a high risk of food insecurity. The present study posits that impulsive behaviour, as evidenced in the context of prepayment systems, may reflect an inability among consumers to exercise control over their purchases, thereby leading to harmful outcomes. Specifically, hunger is the negative consequence of such impulsive behaviour in this study. In order to address the adverse outcomes, it is advisable to establish and execute policies that foster financial literacy and education among households utilising prepaid metres. Such measures may involve providing financial planning and management resources and support and leveraging diverse channels, such as schools and community centres, to promote financial literacy.

Chapter Four (4) findings present some useful policy considerations. First, it reinforces the need for further investment in social interventions, especially for vulnerable groups. The 50kwh free basic electricity initiative was beneficial, helped reduce EP, and should be increased or maintained. This subsidy in the form of electricity consumed is more important as it allows households to consume cleaner energy than biomass for cooking and heating. The household will have no choice but to consume the energy amount compared with other subsidies, which could be diverted into other household expenses. From a practical perspective, it is difficult to ascertain if the 50kwh FBE is enough and whether it can be adjusted to improve the quality of life. Second, the direct link between prepaid electricity meters and FBE-reducing EP makes advocating for more energy-related subsidies necessary.

We, therefore, propose other energy subsidies, which are commonly used by households and should be in the form of clean energy rather than cash. First, governments should provide subsidies for households to adopt cleaner energy sources, such as electricity, through programs like Free Basic Electricity (FBE) and Reconstruction and Development

Programme (RDP) schemes. This would enable households to afford alternative energy sources and reduce their dependence on unclean sources like kerosene, charcoal, and firewood. One of the RDP's main components is providing households with basic services, including electricity. This provision can help reduce energy poverty by enabling households to access a reliable and affordable energy source. By promoting electricity access and usage of energy-efficient appliances, the RDP can reduce reliance on traditional energy sources that are often unclean and harmful to human health. The RDP aims to address poverty and inequality, and as such, it targets vulnerable groups such as low-income households, rural communities, and informal settlements. By prioritising these groups in its energy policies, the RDP can help ensure they have access to affordable and reliable energy sources. Therefore, policymakers must prioritize the implementation of standardized building codes and guidelines under initiatives like the RDP. Such initiatives can ensure the construction of energy-efficient buildings equipped with modern appliances, further enhancing energy access and reducing energy poverty among vulnerable populations. This holistic approach to policy-making is essential for advancing sustainable energy practices and promoting inclusive development.

Third, given its contribution to energy poverty, should the implementation of prepaid meters be abandoned? No. Aside from using this metering technology helps the service provider enormously, we have seen the importance of using prepaid meters and government subsidies. The implementation of prepaid meters should be targeted, given the heterogeneous effects. The rollout of the prepaid meters' deployment initiative could be targeted at male-headed households and urban, white, and wealthy South Africans. Also, the government should develop targeted energy efficiency programs to help households reduce their overall energy consumption. Finally, it is imperative to enhance regulatory and oversight measures within the energy sector to facilitate universal access to cleaner yet affordable and reliable energy services for all households, regardless of socioeconomic status. Accomplishing this objective may necessitate partnering with energy providers to devise equitable pricing policies and enhance the availability of energy-efficient technologies. Additionally, promoting awareness campaigns that explain the adverse health and environmental ramifications of using unclean energy sources is critical to mitigating energy poverty and protecting household well-being.

Our proposition entails advancing government initiatives about universal electricity access and fuel energy accessibility to improve enterprise income. Furthermore, amalgamating government subsidies and prepaid metering mechanisms is imperative in addressing hunger and energy poverty issues. Furthermore, implementing targeted policies towards vulnerable demographic groups and awareness campaigns to elucidate the health and environmental implications of utilising unclean energy sources represents a vital step in safeguarding household welfare.

5.3 Implications on Literature

The literature on sustainable energy policies and household welfare can benefit from the implications of this research. The study highlights the importance of investing in modern and diverse energy sources to improve businesses' access to reliable and affordable energy. These policy recommendations align with the literature that emphasises the significance of productive energy use in promoting entrepreneurial growth and reducing poverty rates. Additionally, the study suggests investing and providing modern fuel energy to firms can be a valuable tool for policymakers to increase enterprise income to households and reduce poverty rates. The recommendation to encourage electricity expansion favouring manufacturing enterprises also aligns with the literature that underscores the importance of promoting industrialisation to enhance economic growth and reduce poverty. Overall, the research's call for further investigation into the factors that influence energy input choices can contribute to the literature by identifying the key drivers of energy use and informing the development of more targeted policies and recommendations.

This research adds to the growing body of literature on factors explaining hunger or household food insecurity. Chapter three identifies an important transition mechanism that explains the effects of prepayment meters on food insecurity or hunger. This proposes other potential transmission mechanisms the literature is yet to consider. The study suggests that addressing issues of poverty and hunger, particularly among low-income households, requires targeted interventions that consider household income levels and health considerations. The study recommends policies such as affordable healthcare options, subsidies for low-income households, and promoting healthy food environments to combat food insecurity.

Furthermore, the study highlights the need for financial literacy and education among households using prepaid meters to mitigate the negative consequences of impulsive behaviour. Finally, the study suggests that policymakers should review the current subsidies to improve household welfare to determine their effectiveness in achieving their intended impact. Particularly in light of the study's findings that these subsidies may exacerbate the plight of households and increase the likelihood of hunger. This study also underscores the need for interventions such as food assistance programs and food-related subsidies for low-income households.

The findings presented in Chapter Four of this study have implications for the literature on addressing energy poverty issues, particularly for low-income households. This study contributed significantly to the literature by including the concept of fuel stacking. The link between prepayment systems and the tendency to switch from electricity to biomass to meet energy needs was a significant finding in the existing literature. The prevailing literature on energy poverty primarily concentrates on various pathways, such as minimising electricity consumption, addressing power outages, and affordability challenges. However, a crucial aspect, namely, the use of unclean energy sources, which has received substantial recognition in contemporary energy campaigns, programs, and policies that promote clean energy for cooking and heating, has not been adequately addressed concerning the role of prepayment meters. This study further implies that investment in social interventions, particularly for vulnerable groups, is necessary to reduce energy poverty and improve household well-being. The study highlights the importance of energy-related subsidies, such as the Free Basic Electricity (FBE) and Reconstruction and Development Programme (RDP) schemes, to enable households to access clean energy sources and reduce their dependence on unclean sources. The RDP initiative can be crucial in promoting the adoption of energy-efficient appliances and reducing energy poverty. The findings suggest governments should prioritise vulnerable groups in their energy policies and develop targeted energy efficiency programs to help households reduce their energy consumption. Additionally, the study emphasises the need for enhanced regulatory and oversight measures within the energy sector to facilitate universal access to cleaner yet affordable and reliable energy services for all households, regardless of their socioeconomic status. The study provides policy recommendations for governments to address energy poverty, reduce energy consumption, and protect household well-being, which can be useful for future research and policy development in this field.

5.4 Limitations of the Thesis and Future Research

Research as a tool to solve social problems faces some difficulties stemming from issues of survey data, measurements of a variable, or the extent to which data can be applied. This study was no exception; it relied on survey data with some limitations. Future research, particularly at a more categorised enterprise level, would help validate the findings. Limitations in the data affected the coefficients of the result, and the influence of unobserved factors changes the direction of a relationship. The study restricted its findings, not considering the productivity and other infrastructure needed for the growth of the enterprise due to insufficient data. Further research should explore additional surveys with varying information and specific industry types. Better electricity usage and expenditure instruments would significantly enhance the robustness of causal effects on household enterprise income.

Further research is required to show the right amount of free basic electricity subsidy needed or other subsidies that directly discourage hunger. Establishing other prepayment systems, such as water and mobile data services usage, affect hunger is also important. Additional investigation is warranted to explore the intersection of prepaid metering electricity with other prepayment systems to examine their effects on hunger.

Furthermore, the cross-sectional survey could not provide the before and after information of the respondents to thoroughly track the impact of the transition from post-paid to prepaid meters. Similarly, the various prepaid meter types could impact energy poverty differently but were not identified in the survey data. Although our measure of energy poverty identified important indicators consistent in the literature, other relevant factors, reliability and power outages, and other energy-efficient appliances were not accounted for due to data limitations. We propose future studies to adopt a survey or panel data with baseline information on consumers and how they transition from post-paid to prepaid meters and have information on the different types of prepaid meters. Also, other relevant indicators should be considered for measuring energy poverty in developing country datasets.

In conclusion, it is crucial to acknowledge the presence of a small control group in the survey data, which must be taken into account in future research. The use of a small control group in quasi-experimental research must be approached with caution, as it may introduce bias into the estimates. In order to enhance the precision of the comparison between the treated and control groups, forthcoming studies should endeavour to employ a more equitable dataset.

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APPENDIX

APPENDIX I- FIRST STAGE FOR STANDARD IV REGRESSION

VARIABLES	(1) Electricity
Past Electricity Consumption	1.477***
	(0.021)
Percentage share of income	-0.210
	(0.170)
Fuel Energy	0.006
	(0.014)
Years of operation	0.001
	(0.002)
2. Bank/micro/loan	0.006
	(0.052)
3. External Support	0.084
	(0.124)
1. Training	0.590***
	(0.116)
1. incomebelong	0.366
	(0.372)
1. Registered	1.594***
	(0.299)
2. Capital/credit	0.142***
	(0.044)
3. Technical	0.245
	(0.184)
4.Governmnet_Regulation	0.130
	(0.355)
5. Others	0.808***
	(0.241)
Number of employed	0.020
	(0.015)
2. Weekly	0.167***
	(0.062)
3. Fortnightly	0.141*
	(0.085)
4. Monthly	0.126*
	(0.072)
5. Quarterly	-0.158
	(0.136)
6. Yearly	-0.437***
	(0.096)
Workhours	0.072***
	(0.013)
2. Rural	-0.341***
	(0.046)

2. Central	0.130
	(0.103)
3.GreaterAccra	-0.084
	(0.102)
4. Volta	-0.228**
	(0.089)
5. Eastern	0.054
	(0.104)
6. Ashanti	0.118
	(0.109)
7. Brong Ahafo	0.118
	(0.116)
8. Northern	-0.266***
	(0.094)
9. Upper East	-0.204**
	(0.097)
10. Upper West	-0.042
	(0.115)
Constant	0.425
	(0.385)
Observations	6,957
R-squared	0.351

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

APPENDIX II: The Average Treatment Effects on Energy Poverty (PCA)

	(1)	(2)	(3)
VARIABLES	AIPW	RA	NN
Prepaid	0.3722***	0.3722***	0.2502***
	(0.0474)	(0.0474)	(0.0849)
Covariates	Yes	Yes	Yes
Observations	11485	11,485	11,485

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1