The impacts of energy systems and services on sustainable development in developing countries.

PhD Thesis

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This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

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Abstract

Enabling access to energy has been recognised as vital in addressing many of the present global development issues which affect people's economic, health and social well-being as well as the ability to meet the goal of reducing carbon emissions through clean energy use. Lack of access to energy, termed energy poverty, in the developing world has several key aspects – lack of access on demand to electricity is one aspect, but lack of access to clean cooking fuels is also a critical factor that leads to continued use of solid fuels. Yet, in spite of increased attention from multiple agencies and governments on the energy poverty issue, the strong praise for action, and the deployment of large-scale energy programs and interventions, lack of access to clean cooking fuels continues to be an overlooked aspect of the energy poverty. Currently, over 2.8 billion people lack access to clean energy for cooking. However, despite this, few studies have shed light on the barriers to, the enablers of, and the impacts of inaccessibility to clean cooking alternatives on development outcomes, using rigorous methodologies. This thesis addresses this recent strand of research. The contributions of this thesis are multi-fold. Firstly, it performs and presents the results of the first quantitative analyses which examine the impacts of household use of solid fuels on the economic and social pillars of sustainable developments: in the most impoverished countries. Secondly, it provides evidences of the effects of current non-energy policies and interventions on addressing the issue. Lastly, it reviews the trends of and barriers to household accessibility to clean cooking fuels. The results obtained from the analyses vary across the countries investigated but generally speaking, it is observed that the household use of solid fuels significantly affects aspects of sustainable development such as education and life expectancy.

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List of Abbreviations

CO2 Carbon Dioxide

CVs Control Villages

DD Difference-in-Difference

EA East Asia

EI Earth Institute

ESMAP Energy Sector Management Assistance Program

ICS Improved Cook Stoves

IEA International Energy Agency

MDG Millennium Development Goals

MVP Millennium Village Project

MVs Millennium Villages

SA South Asia

SDG Sustainable Development Goals

SSA Sub-Saharan Africa

UN United Nation

UNICEF United Nations International Children's Emergency Fund

WB World Bank

WHO World Health Organisation

This thesis is dedicated to my beloved late Grandmother, Mrs. Oluwafunsho Ayoade-Ogodo, who started this doctoral studies with me, but passed away before i finished the journey.
My grandmother throughout her life, loved me unconditionally, always believed in me, and instilled in me the confidence that i am capable of achieving anything i put my mind to do.
I had promised to make my grandmother proud by the achievement of this monumental academic goal and i hope that i have fulfilled that promise.

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I am very grateful to the persons and organisations for their help and support to complete my research. Foremost, I will like to express my heartfelt gratitude to my first supervisor, Mr. Richard Bellingham for his unflinching support and inspiration throughout my doctoral programme. I am also very grateful to my second supervisor, Dr. Stuart McIntyre, for always providing guidance and advise throughout the doctoral programme. The professionalism, brilliance and exceptional supervisory roles of my supervisors have gone a long way in shaping the content of this thesis.

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Finally, I am thankful to everyone who helped me directly or indirectly in my research.

Thank you all from the bottom of my heart.
Ifeoluwa Garba, 2020.

Chapter 1

Introduction

> *"Energy is essential to improving the quality of life and opportunities in developed and developing nations. Therefore, ensuring sufficient, reliable and environmentally responsible supplies of energy at prices reflecting market fundamentals is a challenge for our countries and for mankind as a whole."*

The role of energy as a key factor in tackling many of the current global development challenges has become widely recognized by the global community. This is evidenced by the fact that the Sustainable Development Goals (SDGs) now include access to affordable, reliable, sustainable, and modern energy for all by 2030, as an explicit target [1]. In recent years, it has become widely acknowledged that although access to affordable modern energy by itself is not an elixir for all development problems in developing countries, it is fundamental to social, economic and human development [2]–[5].

Across the world, more than 1.2 billion people still lack access to electricity whilst over 2.8 billion people still lack access to modern cooking fuels and/or technology [1]. This absence, often labelled as energy poverty, has been suggested to impact on people's health, productivity, and income [6]. More generally, energy poverty is suggested to act as a dominant obstacle in attaining development goals including the Sustainable Development Goals (SDGs). In fact, studies such as the work by Kanagawa and Nakata [7] have suggested that countries with limited energy accessibility and/or affordability, experience serious social, as well as economic development impairments.

In response to this issue, national and international governments, agencies and academics, have focussed on issues of access, equity and investment in socio-technical systems linked to modern energy supply [8], [9]. The prevailing underlying theory of change from these expositions has viewed the provision of electricity as a stimulus for wider socio-economic development [10]. However, whilst the absence of access to electricity is clearly important, one could argue that the notion that only through access to electricity can sustainable developments be achieved, is ungrounded. The reality in most developing countries remains that even where access to electricity exists, people are often faced with issues of unaffordability, inefficiency and unreliability [11]. Therefore, for these populations as well as those without any access, the continued use of solid fuels to meet the basic needs of cooking and/or heating is a necessity: a cause and effect of nearly a third of the world's population relying on polluting solid fuels for their daily needs.

Recently, studies such as the work by Rehfuess [12], Karekezi et al., [3], the International Energy Agency (IEA) [13], [14], amongst others, have been contextualising these populations to better understand the factors that inhibit change - as part of the drive for sustainable development. Across all of these studies, there is an assumption that the continued use of non-modern energy sources is detrimental to sustainable development. Yet, despite these assumptions and the proportion of the global population affected, the aspect of energy poverty involving the lack of clean cooking fuels remains unexplored. Empirical studies investigating the link between the household use of solid fuels and sustainable development are few and far between.

Therefore, this dissertation takes a step forward and provides the first empirical evidences of the explicit link between the household use of solid fuels and two key pillars of sustainable development. It examines the relationship between the phenomenon and economic development, as well as the impacts on aspects of social development: education, life expectancy, employment and labour force participation. For the purpose of these analyses, the dissertation considers the three most energy deprived regions: South Asia (SA), East Asia (EA) and Sub-Saharan Africa (SSA). In addition, it reviews the barriers to accessibility to clean cooking alternatives within these regions.

Finally, this dissertation evaluates the impact of current interventions on the issue of household use of solid fuels. For the purpose of this analysis, the case of the Millennium Village Project (MVP) in northern Ghana is evaluated.

1.1 Research question and objectives

Following the recognition of the severe lack of attention and policies addressing the issues surrounding household energy for cooking and heating in the developing world, the analyses performed in this thesis are driven by the motivation to quantify and present the impacts of household utilization of solid fuels on the economic and social aspects of sustainable development. The works reported in this thesis explore and establish the impacts of continued household use of solid fuels such as coal, firewood, animal dung, etc., on the social and economic pillars of sustainable development: in the most deprived regions across the globe. With recent advancements and international emphases in the areas of energy accessibility as well as sustainable development within these regions, the cognisance of the significance of this overlooked aspect of energy services (cooking and heating) is important. Through the observation of these impacts, governments and stakeholders can become aware of the significance of a reality faced by approximately one-third of the global population. Consequently, future policies can be designed to effectively incorporate solutions which can address the issue and thus, support the goal of sustainable development in these regions. It is for this reason that this thesis explores the significance of the household use of solid fuels in these regions and seeks to answer the following research question:

> ***"To what degree does the household use of solid fuels in developing countries impact on sustainable development?"***

To answer this main question, the objectives of this thesis are to provide answers to the following sub-questions:

Q1. What is the proportion and distribution of the global population relying on solid fuels for cooking and heating due to lack of access to modern, cleaner alternatives;

Q2. What are the most impoverished regions in the context of household reliance on solid fuels for cooking and heating;

Q3. What is the impact of the phenomenon on aspects of the social pillar of sustainable development;

Q4. What is the impact of the phenomenon on the economic aspect of sustainable development;

Q5. What are the obstacles to accessibility of cleaner cooking fuel alternatives for households in these impoverished regions;

Q6. How effective have current interventions and/or policies been in addressing the issue.

It is important to recognise that it is widely acknowledged that energy services are vital for the attainment of sustainable development objectives. However, although there are various aspects of energy services, current literature focus mainly on impacts of accessibility to electricity. However, studies have observed that for varying reasons, electricity services are rarely utilised in fulfilling cooking and/or heating needs. Therefore, most households in developing parts of the world continue to utilise solid fuels to meet cooking and/heating demands. Therefore, understanding and quantifying the impacts of the situation will be key in the design of future policies which would support the attainment of sustainable development objectives. It is believed that the results obtained in this work will lead to enhanced exploration as well as enhanced knowledge of the subject topic.

1.2 Thesis statement

The issue of lack of access to modern cooking fuel alternatives affects approximately 2.8 billion people worldwide - accounting for nearly a third of the population. It is important to recognise that only a handful of literature exist on the subject. In addition, of the limited literature, existing studies have focused on either the health or environmental impacts of the phenomenon only. Very few studies exist which consider the economic and/or social aspects of the issue. To the best of our knowledge and echoing the comments in the studies by Makonese et al., [15] and Mclean et al., [16] which emphasise the complete lack of studies in the area, the analyses in this thesis would be the first which extensively examine the causal relationship between household use of solid fuels for cooking and the different aspects of sustainable development investigated.

1.3 Main contributions of thesis

The work presented in this thesis resulted in several contributions that complement the current existing literature in the field of energy-development nexus. Specifically, this research:

- Established an empirical evidence of the relationship between household use of solid fuels and education (primary and secondary) for three regions across the globe: East Asia, South Asia and sub-Saharan Africa - using the fixed effects methodology.
- Established the first empirical evidence of the relationship between household use of solid fuels and economic development for the three regions: East Asia, South Asia and sub-Saharan Africa - applying the panel Granger methodology.
- Produced empirical results on the links between household use of solid fuels and life expectancy, employment, as well as labour force participation for the three regions: East Asia, South Asia and sub-Saharan Africa - through the application of fixed effects methodology,.
- Produced empirical evidences of the relationships between household use of solid fuels and life expectancy, employment as well as labour force participation for the female population within the regions. Comparing the obtained results to the results obtained for the general populations within the regions.

- Provided country-level empirical evidences of the links between household use of solid fuels and education (primary and secondary), life expectancy, employment as well as labour force participation for all countries within the regions. The country-level results are presented based on the effects on the general population as well as the effects on the female population.
- Lastly, it established the first evidence on the impact of current government interventions on household use of solid fuels experiences - using the case of the MVP in Northern Ghana and the difference-in-difference methodology.

1.4 Thesis Outline

This thesis consists of seven Chapters.

Chapter two provides a comprehensive overview of the current state of the energy poverty phenomenon across the globe. Using the current internationally acknowledged definition of energy poverty, the Chapter examines the level of accessibility to the different energy services - across the various regions of the world. In so doing, the most energy impoverished regions are determined. This chapter also gives an overview of sustainable development - discussing the pillars and factors. Furthermore, a review of relevant previous research work on the subject of the relationship between energy and sustainable development is presented in this chapter.

In Chapter three, the relationships between the household use of solid fuels and various constituents of the first examined pillar of sustainable development (social development) are examined. The Chapter investigates and establishes the relationship between the household use of solid fuels and Education (Primary and Secondary), Employment, Labour force participation and life expectancy across the three regions. The investigations consider the relationships using both region-level and country-level data. Furthermore, these relationships are also investigated from a gender standpoint: the linkages are examined with respect to the female populations.

Chapter four analyses and determines the causal relationship between the household use of solid fuels and economic development. Using a five step panel cointegration approach, it establishes the nature and direction of the causality between the variables in both the long-run and the short-run - for all three regions. Thus, this chapter establishes the first solidfuel-growth nexus hypothesis for the considered regions.

Having established the significance and impacts of the issue of continued household use of solid fuels, in Chapter five, the barriers to accessibility to modern cooking fuels are reviewed and considered from both the supply and demand perspective. In so doing, the Chapter determines the contributing factors to the continued use of household solid fuels - with the aim of understanding and highlighting if current government policies and interventions effectively address the issue.

In Chapter six, using data from the recent MVP in Northern Ghana, the effectiveness of current international sustainable development policies and interventions are examined. The MVP are projects designed by the United Nation (UN) across the world in an attempt to accomplish the Sustainable Development Goals (SDG). As such, by utilising data from one of the project sites, it is possible to test how current international policies and interventions impact the issue. The Chapter examines how household cooking fuel patterns and/or experiences are influenced as a result of the implementation of the SDG interventions.

Finally, Chapter seven is a summary of the findings of all the research proposed in this thesis. It provides a conclusion as well as direction and recommendations for future work.

1.5 Research publications

The works within this thesis have produced the following published outputs.

Peer Reviewed Journals

- I. Garba and R. Bellingham, ”Energy poverty: Estimating the impact of solid cooking fuels on GDP per Capita in developing countries - case of sub-sahara Africa”, Energy, 2020. - accepted
- I. Garba and R. Bellingham, ”Energy for Cooking and social development: the case of East Asia and Pacific”, World Development, 2020. - under review

Peer Reviewed Conferences

- I. Garba, ”Cooking fuels and sustainable social development: the case of Africa,” 2019 IEEE PES/IAS PowerAfrica, Abuja, Nigeria, 2019, pp. 622-626. doi: 10.1109 /PowerAfrica.2019.8928736, URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8928736&isnumber=8928628
- I. Garba, and R. Bellingham, ”Clean Cooking Fuel And Sustainable Development In Developing Countries.” Local Energy, Global Markets, 42nd IAEE International Conference, May 29-June 1, 2019. International Association for Energy Economics, 2019.
- I. Garba, and R. Bellingham, ”The Impact of Lack of Clean Cooking Fuels on Sustainable Development in Developing Countries.” Proceedings of the ASME 2018 12th International Conference on Energy Sustainability collocated with the ASME 2018 Power Conference and the ASME 2018, 12th International Conference on Energy Sustainability. Lake Buena Vista, Florida, USA. June 24–28, 2018. V001T01A001. ASME. https://doi.org/10.1115/ES2018-7112
- I. Garba, and R. Bellingham, ”Impacts Of Inaccessibility To Clean Cooking Fuels: Global Vs Regional Perspective.” Energy Resources of the Caspian and Central Asia: Regional and Global Outlook, 4th IAEE Eurasian Conference, October 17-19, 2019. International Association for Energy Economics, 2019.

Peer Reviewed Book chapters

- I. Garba, K. Nieradzinska, and R. Bellingham. ”The Energy Poverty Situation: A Review of Developing Countries.” Advanced Studies in Energy Efficiency and Built Environment for Developing Countries. Springer, Cham, 2019. 41-49.

- I. Garba, and R. Bellingham. ”Impacts of inaccessibility to clean cooking fuels: global vs regional perspective.” Advances in Science, Technology and Innovation. Springer, 2020. - Accepted and in print.

Posters

- I. Garba, ”The investigation of the impacts of optimized energy policy and energy business models on large-scale urban programs in developing countries.”, 20th Annual All-energy conference, May 13-14, Glasgow, 2017.

- I. Garba, ”Energy business models and sustainable development in developing countries.”, 3rd Annual Future wind and Marine conference, 11 Jan, Glasgow, 2017.

Chapter 2

Energy and Sustainable development

This chapter provides an overview of the current state of the energy poverty phenomenon across the globe. It discusses the current definitions of energy poverty in literature; highlights the definition adapted in this thesis; and specifies the definitions of the other important terms used within this thesis. In addition, it answers questions 'Q1' and 'Q2' of the research sub-questions outlined in section 1.1: "What is the proportion and distribution of the global population relying on solid fuels for cooking and heating due to lack of access to modern, cleaner alternatives" and "What are the most impoverished regions in the context of household reliance on solid fuels for cooking and heating". Finally, it provides an insight into the concept of sustainable development - discussing the pillars and factors.

2.1 Introduction

As evidenced in the several development reports from international organisations such as the World Bank (WB) and International Energy Agency (IEA), it has become a common notion that generally speaking, energy is crucial for development [1], [17], [18]. In recent years, the global energy sector has been undergoing three major transformations which encompass focus on climate change, security of supply and energy poverty [19], [20]. The first two areas have been extensively researched in literature but only in recent years has the third aspect started to gain attention - even though it has a great influence on the lives of billions of people. The existing literature on energy poverty holds many views on the definition, composition of and ways of quantifying the issue. One of the most commonly cited definitions in literature is based on the study by Reddy and defines energy poverty as [21]:

> *"the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe and environmentally benign energy services to support economic and human development."*

This definition is adopted here as it incorporates numerous components and nuances [22]. Firstly, it highlights the absence of choice - a key aspect of development. The significance of the absence of choice for development is best demonstrated in the study by Sen. The pioneering work by Sen [23] indicates that in the concept of poverty and development, the incapability or lack of choice may or can be viewed to affect elements that are essential for development and/or alleviation of poverty. Secondly, the adapted definition emphasises the notion of satisfying demand for energy service. This is important because as people, the consumption of energy sources is ultimately to satisfy demands such as cooking and heating.
With the definition established, the ways in which the phenomenon can be measured are considered.

Based on this definition, the conclusions from the literature review show that energy poverty can be measured using three different but complementary approaches based on technological, physical or economic thresholds [24]:

- Physical threshold: Similar to the World Bank (WB) absolute poverty estimation approach, this approach is based on estimating the minimum energy consumption necessary for basic needs. Households below the estimated threshold are considered as energy poverty households. The drawback of this approach lies in the difficulty in defining what constitutes basic needs.
- Economic threshold: Similar to the approach used by developing countries to estimate relative poverty, this approach attempts to indicate the maximum per-

centage of household income that should be spent on energy. The drawback of this approach is that it is relative in nature and as such, can not be utilised for comparison between countries (especially countries with varying economic status).

- Technological threshold: This approach incorporates the aforementioned notion of poverty by Sen. Therefore, it is based on the notion that energy poverty is primarily a problem of accessibility to modern energy services.

The third approach is selected in this thesis because it incorporates the concept of poverty and development based on the pioneering work of Sen.

2.1.1 Defining energy access, electricity access and modern cooking energy

Energy access

There is no widely accepted definition for the term "energy access" [25]. For example, the study by Hammond argues that the definition of energy access should be simple and thus consider only accessibility [24] whilst on the other hand, the International Energy Agency (IEA) defines energy access as:
"a reliable and affordable access to clean cooking services, a first connection to electricity and then an increasing level of electricity consumption over the time to the regional average".
In this study, following on from the quantification approach selected above, the term energy access is used to refer to the availability of modern energy carriers such as electricity, natural gas or liquefied petroleum gas (LPG) to households.

Electrification

Similar to the case of energy access, various definitions exist in literature for the term "electrification" or "electricity access". Studies such as Zomer consider only the basic connection to a national grid as electrification [26] while some studies considered electrification at community levels. For example, the study by Barnes considers a community electrified only if transmission and distribution infrastructures exist within the community and at least 10% of the households and public institutions such as schools, hospitals, and community centres, are electrified [24]. For the purpose of this thesis, electrification or electricity access refers to the basic connection of households to grids.

Modern and traditional cooking energy

Due to factors such as availability of resources, income of households, reliability of supply, etc., different types of fuels are utilised for cooking and heating within households [25]. Based on the level of cleanliness and efficiency of the combustion of the fuels, cooking fuels can be broadly categorised into two groups: (a) solid fuels (also referred to as traditional fuels) such as coal, wood, straw and dung, and (b) modern (also referred to as clean) cooking fuels such as biogas, liquefied petroleum gas, natural gas and electricity [14]. Generally speaking, solid fuels are mostly used in traditional stoves with low conversion efficiencies such as, mud stoves or just three stone open stoves [27]. Solid fuels are also sometimes used in improved stoves which in recent years, have been promoted in developing countries [18] but have been reported to have only between 10% and 15% more efficiencies than traditional stoves [18].
Regardless, in this thesis, the World Health Organisation (WHO) definition of clean fuels has been adopted and as such, cleanliness is defined in terms of emitted household pollutants while using the fuels for cooking. Therefore, for the purpose of this study, currently available fuel options considered as clean at point-of-use include electricity, liquefied petroleum gas, alcohol fuels, biogas, solar and compressed biomass pellets burned in high performing gasifier stoves. Accordingly, only the households with access to these aforementioned fuels are considered as having access to clean fuels. On this account, in this thesis, the households that are considered as using solid fuels include households with no access to these clean fuel options, thus relying on kerosene and other traditional fuels - regardless of what cooking stoves are being utilised.

2.1.2 Note on the literature review

The literature review process conducted in this thesis involved the iterative collection, review, and coding of literature. The keywords used to code literature were based on the areas of focus and the lists of these are presented in Appendix A[1]. The journal articles included in the literature, as well as a brief introduction to the representation of the common coding terms in energy focused journals are presented in Appendix A.

2.2 Energy access: an overview

Access to modern energy services has become requisite for the enhanced development of any society with a developed economy, as well as a representation of civilisation [24], [28]. It is a vital factor for the overall health and well-being of communities, as well as most production and consumption activities which lead to the increased productivity observed in economic factors such as, capital and labour. Hence, modern energy accessibility has been termed a principal driver of economic growth, industrialisation and urbanisation [29], [30]. However, despite its importance, a large portion of the global population have no access to basic modern energy services. In recent years, governments and agencies across the world have understood the significance of the energy access issues and significant efforts have been made to address these issues at global, regional and national levels. Therefore, the provision of reliable, affordable and clean energy has become a part of, and is now viewed as a must, in attaining the Sustainable Development Goals (SDG). What's more, international agreements have been made in the direction of reducing the issue of energy inaccessibility.

In 2000, the dedication of the UN General Assembly to a international collaboration to attain the Millennium Development Goals (MDG) by the end of 2015, was a milepost to reducing poverty and although the MDG did not explicitly include energy amongst its eight goals, the access to modern energy services was deemed a crucial necessity in attaining some of these goals. However, following this, the international focus on the issue of energy inaccessibility (termed energy poverty), expanded [31]–[33]. In 2012, the UN commissioned the year as the "International Year of Sustainable Energy for All" and following this, launched the global initiative "Sustainable Energy for All",

[1] It is worth noting that the literature review within this thesis suffers from similar problems observed by Sovacool [10]. Sovacool defines this issue to be caused by "the somewhat subjective nature of synthesizing and coding qualitative data as well as the limited sample size of articles in the area"

with the principal objective of facilitating universal access to modern energy services, advancing energy efficiency as well as expanding the exploitation and utilisation of renewable energy forms [34].

However, despite these strong praises for action and the deployment of large-scale energy programs, universal access to sustainable energy is still not yet a reality for many across the world: billions of people across the world still continue to live without access [35].

2.3 Current energy access situation

2.3.1 The global picture

Across the world, currently approximately 1.4 billion people lack access to electricity while approximately 2.7 billion people lack access to modern cooking energy [17], [36]. This means that around one in seven people and one in three people are still faced with the challenge of inaccessibility to electricity and clean cooking fuels, respectively.

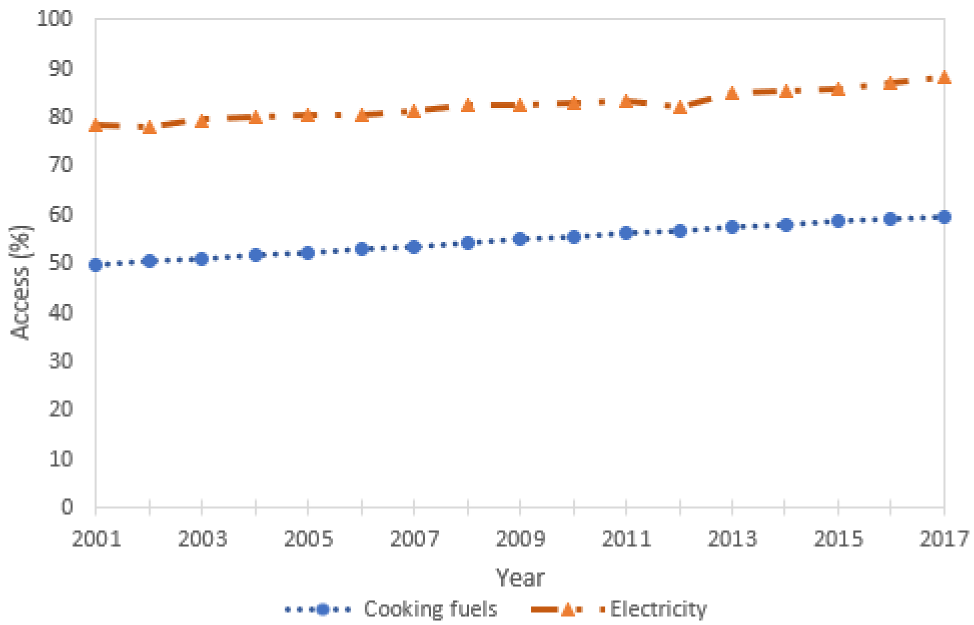

Figure 2.1: Global trend of access to electricity and clean cooking fuels: 2000 - 2017

Figure 2.1 illustrates the trend of access to electricity and modern cooking fuels across the world, for the past decades. It shows the percentage of households across the world that have access to modern energy services. Based on the figures in Figure 2.1, in 2017, just a little over 50% of the world population had access to modern cooking fuels, while approximately 80% had access to electricity. In addition, the global trends obtained shows that the general progress towards the attainment of universal energy access has been slow.

What's more, despite the currently observed progress, the IEA predicts that a business-as-usual scenario, which sees no additional, dedicated polices implemented, will result in impeded progress. According to the report, current policies and strategies will see the population with inaccessibility to electricity reduce by only 0.2 billion by 2030 while the population relying on traditional biomass will increase from 2.7 billion to 2.8 billion, by 2030 [37]. This implies that the current goal of universal energy by 2030 would remain unfulfilled.

The geographical distribution of the population affected by this phenomena is uneven across the world. It is estimated that approximately 80% of the population lacking access to modern energy services live in rural areas, and are concentrated mostly in the developing Asian, sub-Saharan African and western Pacific regions.

Figures 2.2 and 2.3 present the trends of access to electricity and cooking fuels, respectively, for the different geographical regions of the world.

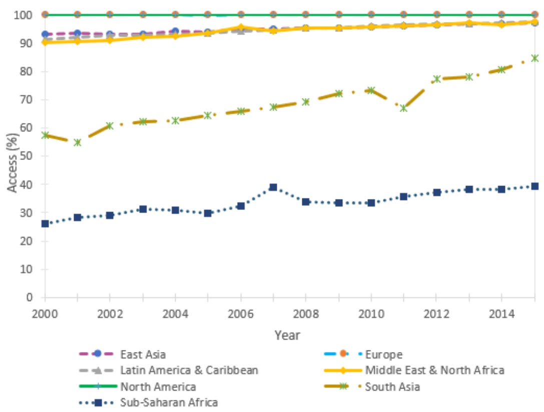

Figure 2.2: Trend of access to electricity across global regions: 2000 - 2017.

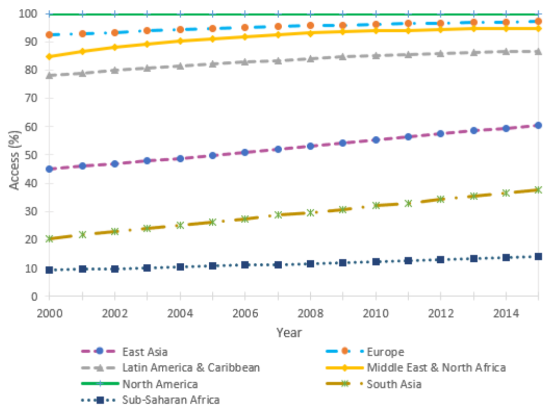

Figure 2.3: Trend of access to cooking fuels across global regions: 2000 - 2017.

Starting with access to electricity. Figure 2.2, shows that in the case of the European and North American regions, universal access to electricity has been achieved while over the past decades, the Middle East & North African, Latin America & Caribbean, and east Asian regions have progressed towards approaching universal access. However, the most remarkable progress is observed in South Asia, where a very high growth of 46.40% was achieved over the last two decades. The region grew from 42.91% electrification rate in 1990 to 80.05% by 2014. Across all regions, the sub-Saharan region has experienced the slowest progress (approximately 8%) and continues to have the lowest access rates in the world. In fact, from Figure 2.2, it can be seen that the electrification level reported for sub-Saharan Africa in 2014 is still significantly lower than the electrification levels reported for any other developing regions in 2000.

With regard to clean cooking fuels, Figure 2.3, universal access has been achieved in the North American region whilst in the past twenty years, the European, Middle-East & North African and Latin America & Caribbean regions continuously made progress towards universal access. In east and south Asia, although progress has been made over the decades, a significant amount (approximately 48% and 70%, respectively) of the population within the regions still lack access to modern cooking fuels. However, the worst case of the phenomenon is seen in the sub-Saharan African region, where over 85% of the population still continue to live without access to clean cooking fuels. In growth trend terms, over a period of 15 years, the East Asian region experienced the highest growth, with a growth rate of 14.4%. In South Asia, access to clean cooking fuels increased by 9.8% whilst the worst growth rate is obtained in sub-Saharan Africa, with a growth rate of 1.62% .

The illustrations from Figures 2.2 and 2.3, can be summarised into three key synopsis: (a) across the world, the inaccessibility situation is more severe in the context of access to clean cooking fuels; (b) the progress towards universal access is much slower in the case of access to clean cooking fuels than in the case of electricity; (c) as previously mentioned, the most affected regions are sub-Saharan Africa, south Asia and east Asia.

2.3.2 The African situation

Due to the under-developed nature of the system, the African energy system is termed the most impoverished part of the global energy system [11]. According to the IEA, it is estimated that about 60% of the population in Africa, lack access to any form of modern energy services [32]. What's more, the severity of this phenomenon is reported to be more acute in the Sub-Saharan parts of the region, where an estimated 65% of the population lack access to any form of modern energy services [1], [5], [36]. Although the continent as a whole, crucially needs energy system and socio-economic development, the severity of the energy situation is observed to vary drastically across the region.

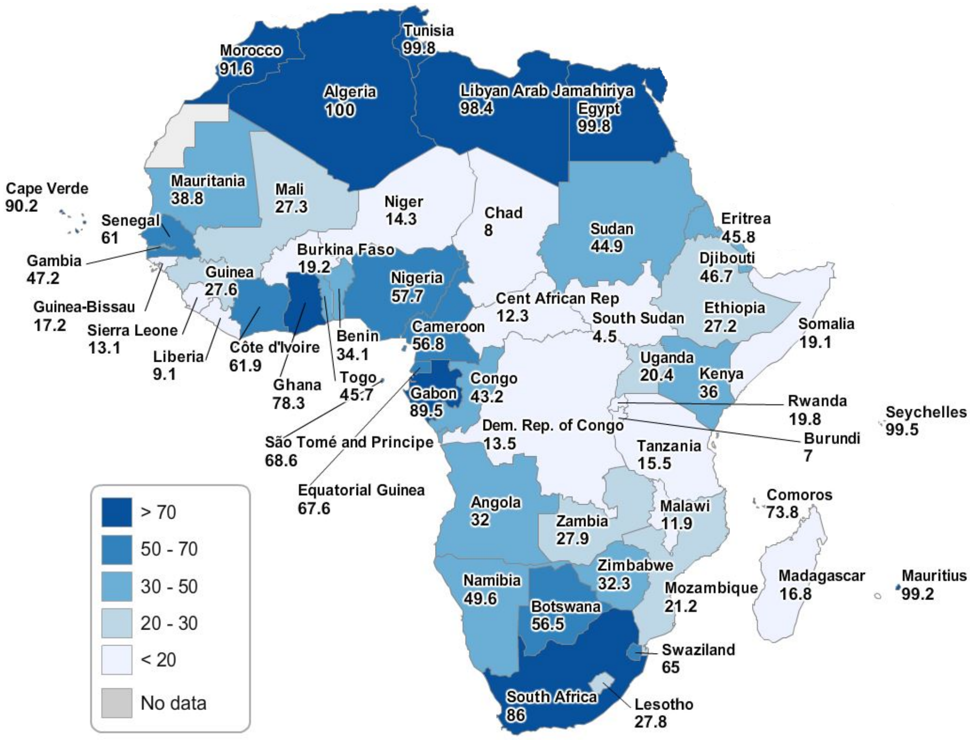

Figure 2.4: Access (%) to electricity across Africa. (Source: the author)

Based on the data from the World Bank (WB), Figure 2.4 illustrates the current situation of access to electricity across the African region. From Figure 2.4, with the exception of Algeria and Egypt, which have both already achieved universal electricity access, it can be seen that most countries in the northern African region are close to achieving universal access. However, besides these northern African countries, only three other countries: Mauritius (with 99.2% access); Seychelles (with 99.5%) access and Cape Verde (with 90.2%) are close to achieving universal access to electricity. For other countries in the region, especially the sub-Sahara Africa sub-region, access levels remain very poor, with countries such as Burundi, South Sudan, Chad and Liberia, having lower than 10% electricity access levels.

Yet, despite this poor state of energy accessibility, lack of accessibility is not the only issue in the energy situation in Africa. Even in countries with improved access such as South Africa, there have been reports warning against deterioration in supply reliability and price increase [11]. Therefore, in addition to inaccessibility at household levels, unreliability and low incomes, coupled with inefficient and costly forms of energy supply, make the energy situation across the countries in the African region more severe.

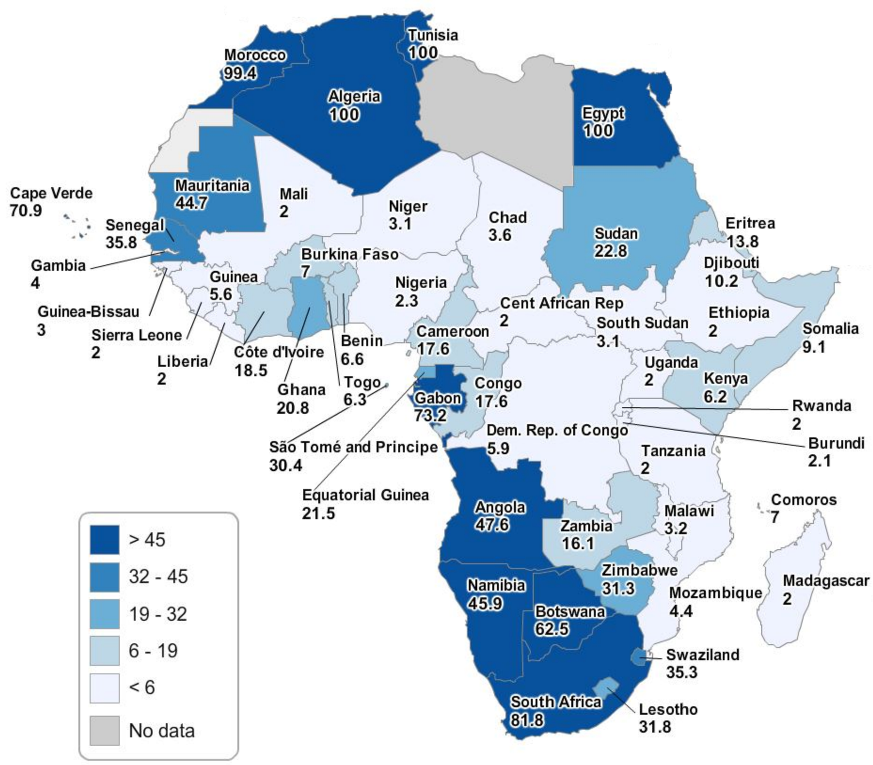

Figure 2.5: Access (%) to clean cooking fuels across Africa. (Source: the author)

In the case of access to clean fuels for cooking, as illustrated in Figure 2.3, the progress across the African region has been much slower. Over the examined period of 15 years, a growth rate of less than 2% was observed for the region. Taken together, in 2015, almost 90% of the sub-Saharan African population still lacked access to clean energy for cooking.
Figure 2.5 shows the current situation across the different countries in the region. Similar to the case of access to electricity, only three countries (Algeria, Egypt, Tunisia) which are located in the northern part of the region have achieved universal access. In addition to these countries, all countries but South Africa, Gabon, Botwana and Cape Verde in the African region have less than 50% access levels. In the case of the countries within the sub-Saharan region, less than 10% of the population within the countries are seen to have access to clean cooking fuels. Many countries such as Liberia, Mali and Uganda, are reported to have less than 2% access levels. Generally speaking, every four in five households within the sub-Saharan Africa region rely on forms of solid fuels for cooking.

2.3.3 The South Asian situation

In South Asia, due to population growth, industrialization and increased economic activities, the energy demand within the region has expanded two-and-a-half times in the past two decades [38]. The energy access levels within the region have significantly improved (although at a slower pace) to meet this increase in demand [38]. Over the past decades, access to electricity has significantly increased with about 62% of the overall population within the region now having access to electricity.

However, although the region has a higher electrification rate than Sub-Sahara Africa, due to its high population, more people in south Asia live without electricity than anywhere else in the world. In fact, the population without access in south Asia account for approxmiately 42% of the overall global population without access [25].

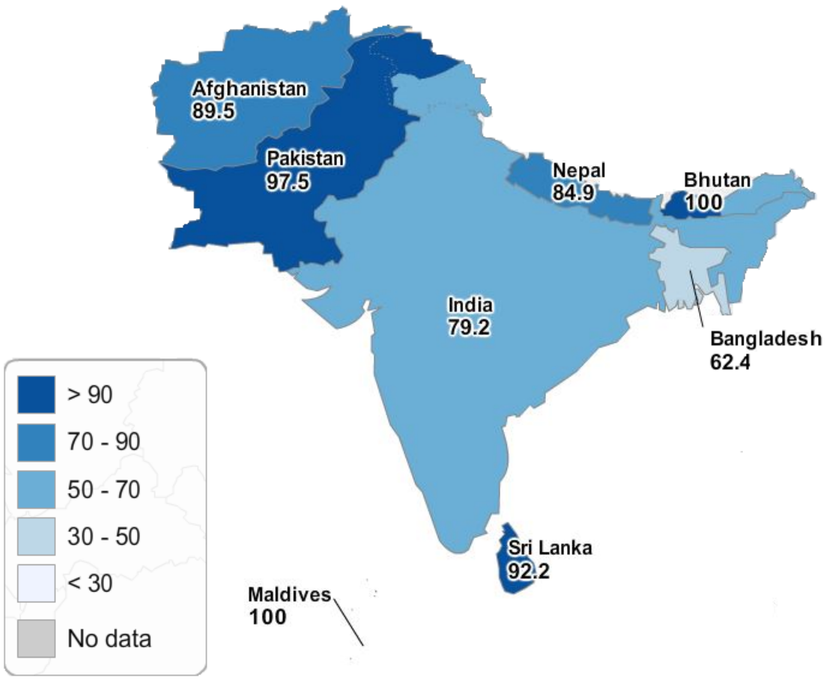

Figure 2.6: Access (%) to electricity across South Asia. (Source: the author)

Figure 2.6 presents the current situation of access levels to electricity within the region. Across the region, only Bhutan has achieved universal access while Sri Lanka and Pakistan both have more than 90% accessibility levels. Although the lowest access rate is observed in Bangladesh, in absolute number, India has the highest number of people without access to electricity within the region. What's more, literature suggest that due to the uneven distribution of the phenomenon within the countries, access to electricity is mostly confined to only the urban areas of these countries [39], [40]. A large proportion of the population within these countries: 67% and 66% in India and Bangladesh respectively, live in rural areas [1]. Therefore, although access to electricity levels within the region might appear relatively high (compared to Africa), in reality, more than one in four people in India and Nepal live without electricity access while more than one in three people in Pakistan and Bangladesh live without electricity access [41].

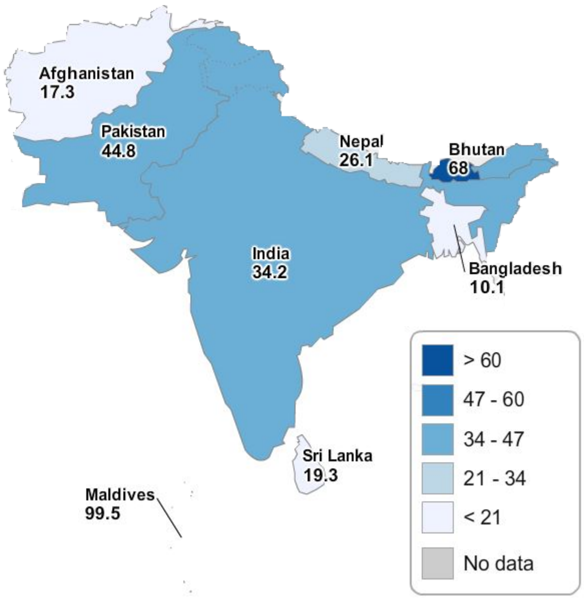

Figure 2.7: Access (%) to clean cooking fuels across South Asia. (Source: the author)

The current levels of access to clean cooking fuels across the south Asian region are presented in Figure 2.7. The highest level of access to clean cooking fuels across the south Asian region is found in Bhutan (68%). Across the region, even countries such as Sri Lanka which have relatively high electrification rates, have significantly low portion of their population with access to clean cooking fuels. Generally speaking, access to clean cooking fuels is low across the region, approximately every two in three households within the region lack access to clean cooking fuels and thus rely on solid fuels for cooking.

2.3.4 The East Asian & Pacific situation

East Asia

Across East Asia, tremendous progress has been made towards the goal of universal access to electricity. In comparison to the sub-Saharan and south Asian regions, electricity levels across the east Asian region are relatively high.

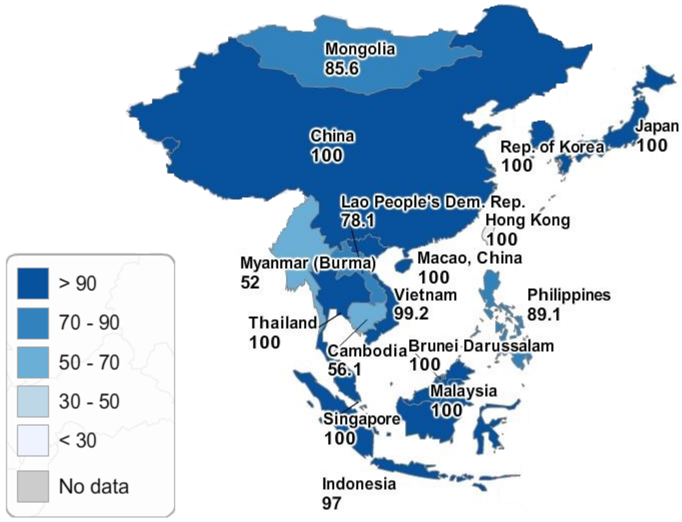

Figure 2.8: Access (%) to electricity across East Asia. (Source: the author)

As illustrated in Figure 2.8, most countries across the region have attained levels of universal access. Across the region, only four countries: Myanmar, Cambodia, Lao People Democratic Republic and Mongolia which have electricity access levels of 52%, 56.1%, 78.1% and 85.6%, respectively; have less than 95% electrification levels.

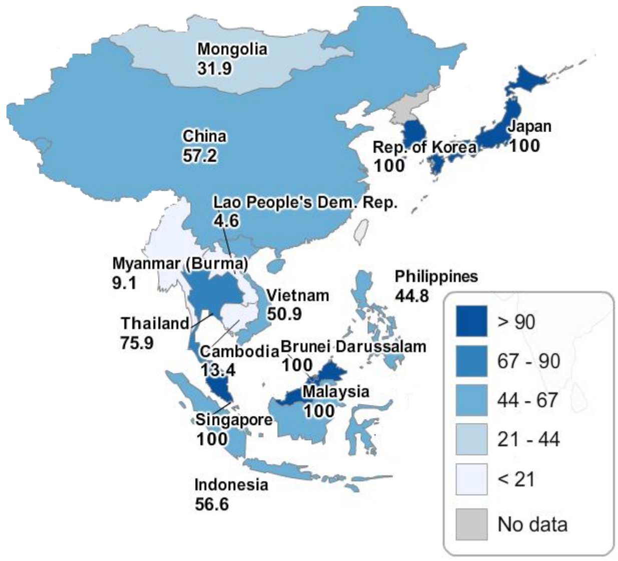

Figure 2.9: Access (%) to clean cooking fuels across East Asia. (Source: the author)

Current access levels in the context of clean cooking fuels are presented in Figure 2.9. In the case of access to clean cooking fuels, some countries in the east Asian region such as Brunei Darussalam and Singapore, have attained universal access. What's more, unlike the previously discussed regions where most of the countries have less than 50% access levels, only four countries in the east Asian region have below 50% access levels. The countries in the east Asian region which have the lowest population with access to clean cooking fuels are Lao People Democratic Republic (4.6%), Myanmar (9.1%) and Cambodia (13.4%).

Pacific

In the case of countries in the pacific region, only Australia, New Zealand and Fiji have attained universal access to electricity (see Figure 2.10). The lowest access to electricity within the region is observed in Papua New Guinea where only 20.3% of the population have access to electricity.

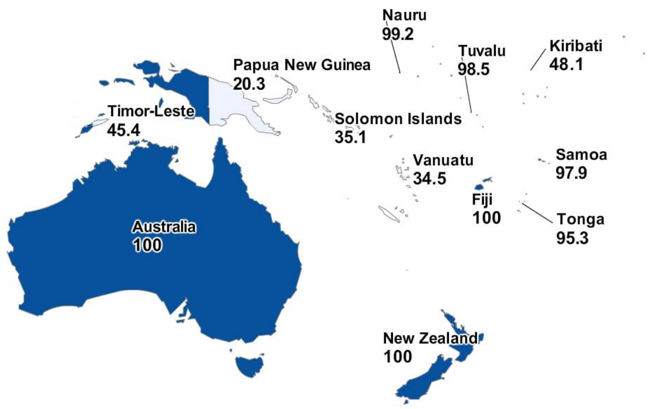

Figure 2.10: Access (%) to electricity across the Pacific. (Source: the author)

With regard to access to clean cooking fuels, as illustrated in Figure 2.11, only Australia and New Zealand have achieved universal access levels. In addition to these countries, only Tonga and Fiji with 64% and 37% access levels respectively, have over 20% of population with access to clean cooking fuels. Other countries within the region are observed to have less than 20% access levels to clean cooking fuels.

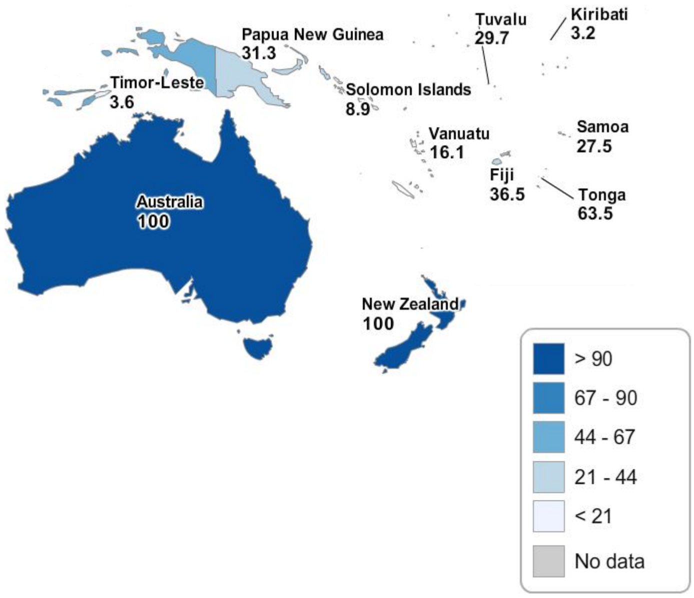

Figure 2.11: Access (%) to clean cooking fuels across across Pacific. (Source: the author)

2.4 Sustainable development: an overview

The concept of development has been discussed from several viewpoints. Nevertheless, the core of the concept, it appears, lies in the positive advancement of individual lives and the society as a whole. Leaders around the globe have articulated the fundamental focus of development in terms of expansion and improvement of the range of choices accessible to people. Starting in December 1986, when the UN general assembly passed a declaration on development as an inherent right of individuals and the society at large, the preamble of development as since then been declared as:

> *"a comprehensive economic, social, cultural and political process, which aims at the constant improvement of the well being of the entire population and of all the individuals on the basis for their active, free and meaningful participation in development and in the fair distribution of benefits resulting there from."*

However, in the recent decades, sustainability has become the key word centred on development. The concept of sustainable development evolved in the 1980s, due to worries about a sustainable society and the management of resources (human and natural) [42]. Prior to the conceptualisation of sustainable development, debates surrounding development focused on two primary areas: 'brown' issues and 'green' issues. The debates on 'brown' issues focused on the areas of pollution, population growth, poverty, etc., whilst the debates on 'green' issues focused on preservation or conservation of natural resources, limits of resources, maximum sustained yield, etc [43]. It is in attempts to connect these areas of concerns that the notion of sustainable development originated. Later in the 1980s, the concept became popularised by the Brundtland commission which then defined sustainable development as:

> *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*

Since then, sustainable development has been widely used in many different areas with multiple differing definitions. For example, Pachs defined sustainable development as *"any growth path characterised by non-decreasing stocks of assets (or capital: natural or human)"* [42] whilst Daly and Cobb refined the definition to include levels of sustainability: 'weak' and 'strong' sustainability [42]. The definition by Daly and Cobb suggested that weak sustainability assumes that the distinctive types of capital .i.e. human or natural assets, can be substituted for one another to attain development whilst strong sustainability assumes that the capital types are complements [42]. In recent years, building on the definition by the Brundtland commission, as well as the definition by Daly and Cobb, Munasinghe defined sustainable development as [44]:

> *"[A]n approach that will (inter alia) permit continuing improvements in the present quality of life at a lower intensity of resource use, while leaving behind for future generations enhanced stocks of assets (i.e. manufactured, natural and social capital) that will provide undiminished opportunities for improving their quality of life"*

This definition by Munasinghe, as well as the definition by the Brundtland commission have since become the most commonly cited definitions. Although it is worth noting that till date, there exists no consensus in academic or policy circles on the concept or its application in practice. Nonetheless, despite the absence of a single universally acknowledged definition, there does appear to be a consensus that sustainable development encompasses three broad dimensions - also referred to as pillars.

Figure 2.12: Dimensions of sustainable development.

Figure 2.12 illustrates the three dimensions of sustainable development: economic, social and environmental dimensions.

The economic dimension of sustainable development focuses on welfare in respect to monetary income and material consumption. It emphasises the ability to enhance employment, as well as income, while inducing more efficient production and consumption of goods and services and stabilising their prices [44].

The environment dimension of sustainable development focuses on the overall viability and health of ecological systems. It emphasises the management of scarce natural resources in a prudent manner, the reduction of pollution and the protection of biodiversity, amongst others [44].

Lastly, the social dimension of sustainable development focuses on development which seeks to improve both individual well-being and the overall welfare of society (broadly speaking). It emphasises the importance to reduce vulnerability and maintain the health in terms of resilience, vigour and organization of social and cultural systems as well as the ability of these systems to withstand shocks: economic and physical [44].

This conception is used as the working definition of sustainable development in this thesis.

To measure sustainable development, complex multi-indicator indices exist in literature. Indices such as the Multi-Tier Framework (MTF), the Sustainable Development Index (SDI), and the Human Development Index (HDI) have been employed within the development literature to quantify sustainable development of countries [45]. Amongst other studies in development literature, the works by Wilson et al. [45] and Mori et al. [46], both extensively reviewed the different indices - highlighting and emphasising the strengths and shortcomings of the different sustainable development quantification metrics (see Chapter 3). The outcomes of the reviews suggest that regardless of the quantification index used, the most impoverished regions in the context of sustainable development are sub-Saharan Africa, east Asia and south Asia.

2.5 Sustainable development and energy access

The dynamics between energy access and sustainable development has become an area of increasing attention in the past decades [36]. Studies such as the work by Bhattacharyya [47] which reviewed the impacts of energy access on sustainable development; the work by Oyedepo [48] which reviewed the role of energy on sustainable development in the case of Nigeria; as well as the study by Akinlo [49] which looked into the relationship between energy consumption and economic growth for eleven countries in sub-Saharan Africa; amongst several others have echoed the significance of energy access on sustainable development. Across these studies, the role of the end use of energy (.i.e. energy services) in promoting sustainable development through the key sectors: residential, commercial, transportation and industrial; is repeatedly emphasised. Amongst others, the provision of lighting, cooling, food storage, road and/or air transportation, communication, etc., have been observed as factors in aiding sustainable development. A detailed review of studies on the dynamics between energy and sustainable development is presented in Chapters 3 and 4.

2.6 Conclusions and research objective selection

Based on the findings within this chapter, it is recognised that the global phenomenon of household lack of access to clean fuels for cooking is severe across parts of the world, and its effects on the social and economic aspects of sustainable development remain undiscovered. The effects of this gap in literature can be anticipated to be multi-fold: (a) it hinders the understanding of the holistic impacts of energy access, and (b) it impedes efforts of attaining the goals of sustainable development. Therefore, it is important for this area of literature to be addressed. This thesis aims to fill this gap in literature by providing empirical evidences on the effects of lack of access to clean cooking fuels on the social and economic dimensions of sustainable development. The effects on the environmental dimension of sustainable development are not covered in this thesis because it is a well researched area in literature.

Summary of key findings

In general, the outcomes of this review can be summarised as follows:

(a) It is a widely accepted concept that energy is vital for sustainable development.

(b) The absence of energy, termed energy poverty, has several dimensions and aspects.

(c) In the context of energy access, billions of people still continue to lack access to basic clean energy services .i.e. electricity and cooking fuels.

(d) More people across the world lack access to clean cooking fuels than lack access to electricity.

(e) The most energy impoverished regions are east Asia, south Asia and sub-Saharan Africa.

(f) These are also the most impoverished regions in terms of sustainable development.

(g) The concept of sustainable development encompasses three principal dimensions: social, environmental and economical.
(h) Reviewed literature heavily focuses on two key areas: (i) general energy consumption and its effects on sustainable development; (ii) accessibility (or inaccessibility)) to electricity and its effects on the dimensions of sustainable development.
(i) In the context of cooking fuels, the limited literature available on the impacts of access to (or lack of) clean cooking fuels on sustainable development, focus principally on the environmental dimension of sustainable development.
(j) There are currently no studies capturing the effects of lack of access to modern cooking fuels on the economic dimension of sustainable development and the few studies examining the effects on the social dimension have examined the impacts from only the health perspective.

Chapter 3

Impacts on social development

This chapter answers question 'Q3' of the research sub-questions outlined in section 1.1: "what is the impact of the phenomenon on aspects of the social pillar of sustainable development". This chapter investigates and establishes the relationship between the household use of solid fuels and some indicators of social development: education (primary and secondary), employment, labour force participation and life expectancy, across the three regions. The investigations consider the relationships using both region-level and country-level data. Furthermore, these relationships are also investigated with respect to the female populations within the regions.

3.1 Introduction

In Chapter 2, an overview of an aspect of energy poverty and its aspects was presented, as well as an analysis of the regions most affected by energy poverty across the globe. In addition, a background on the concept and dimensions of sustainable development was presented.

The review of literature has shown that energy is widely acknowledged as a crucial contribution to sustainable development due to the wide array of services it delivers in the form of light, space heating, cooking energy, etc., [50]–[53]. In addition, the analysis of available data has shown in Figures 2.2 to 2.3 that the issue of lack of access to energy, is most prominent in the sub-Saharan African, South Asian and East Asian regions. These regions have also been shown to be the most impoverished regions in the context of sustainable development [17]. Motivated by the recognition of the importance of energy on sustainable development, this Chapter investigates the effects of the energy poverty aspect of lack of clean cooking fuels on one of the dimensions of sustainable development: social development. The analyses in this chapter address research gap identified in the literature review and contribute to the existing literature by exploring the relationship between social development and the household use of solid fuels for cooking: in the context of sub-Saharan Africa, east Asia and south Asia. Using data from these regions for the period of almost two decades and applying fixed and random effects models, this relationship is explored - asking one main research question:

How does the household use of solid fuels for cooking influence different measures of social development within the most impoverished regions?

Upon the review of literature, a further sub-question emerged. I also ask:

"are the observed impacts on social development different when considering only the female population?"

The measures of social development that are addressed within this Chapter have been chosen based off of indicators in literature surrounding social development, as well as, the current focus areas of social development within the United Nation's SDG framework [1]. The measures adapted in this chapter are: education (primary and secondary); employment; labour force participation and life expectancy. Therefore, the impacts of household use of solid fuels for cooking on these measures are investigated for sub-Saharan Africa, east Asia and south Asia.

The conclusions derived from the results varied across the regions and variables of interest. However, on the whole, it was established that there is a statistically significant relationship between household use of solid fuels and education (both primary and secondary enrolment rates); and life expectancy. When considering only the female population, the most significant impacts are observed also in education(both primary and secondary) and life expectancy. In addition, these impacts are observed to be greater in the female population - across some countries.

These obtained results provide important insights into the significance of this overlooked aspect of energy poverty and these new insights underline the importance to addressing this issue in order to tackle energy poverty, as well as, have important implications for the design of development policy for these parts of the world.

The outline of this chapter is as follows: in Section 3.2, the background and existing empirical literature on the subject of social development and energy are presented. The data and methodologies used for the analyses in this Chapter are discussed in Section 3.4. Section 3.5 presents the results of these analyses for each variable across each region, whilst in Section 3.6, the wider significance, implications and conclusions are discussed. Finally, Section 3.7 provides a summary of the chapter: emphasising the significant findings.

3.2 Background

In this section, the evolution of social development as well as relevant studies on the subject are examined in Section 3.2.1. The indicators constituting to social development are examined in Section 3.2.2 whilst studies which have examined the link between energy and these factors of social development are investigated and presented in Section 3.2.3. The aim being to observe the important constituents of social development as well as investigate the currently applied approaches and findings from studies examining the relationship between energy and these components. Finally, findings from the review of available studies examining the explicit link between household use of solid fuels and social development are presented.

3.2.1 An overview of social development

In the most basic terms, development is a process that has gone on throughout human history; with studies on the concept of general development and evidences of concerted efforts dating back to the 19th century [54]. However, until the 1950s, when the concept of social development became internationally recognised as a result of its popularisation by the UN [55], the general idea of development revolved solely around economic development.

Prior to this, there had been activities surrounding social development practices through the distorted development concept created by colonial welfare officials in West Africa. However, these concepts focused on the inequalities in income and wealth primarily for economic gains. In fact, initially, all development planning focused narrowly on economic activities such as investments in industry, agricultural production and trade, with little if any attention, given to planning the social sectors of education, health care, housing, community development and family welfare services. Therefore, although the merit for formulating the first social development programmes is usually conferred to these colonial welfare administrators in West Africa; it was not until the release of Article 55 of the UN Charter in 1945 which promoted higher standards of living and employment conditions as well as economic and social advancement and development [56], that the focus on social development evolved. Following the Charter in 1945, amongst other occasions, two significant occasions further altered the concept of development and the perception of the constituents of sustainable development: the declaration on development passed by the General Assembly of the UN in December 1986, and the Social Development Summit in Copenhagen in 1995.

In the wake of these events, over the last two decades, there have been significant changes which have taken place in the discussion and direction of development: including social development. One of these established discussions in literature is the notion that economic growth cannot be achieved in isolation and without reference to social values and goals. Furthermore, in recent literature, the concept of Social Development is considered to be inclusive of economic development. Although, it is perceived to differ from economic development in its emphasis on the development of the totality of society in its economic, political, social and cultural aspects. Indeed, there are many areas, apart from social or welfare services, wherein the significance of social perspective has been recognised [55].

Owing to these realisations, social conditions across the world have improved significantly. Although poverty and deprivation have not been eradicated, incomes have increased, and the basic needs of a large population of the world have been met.

To exemplify, more people than ever before attend school - a situation which has led to an increase in literacy rates: a large population of the world now have access to modern medical services - causing the life expectancy to increase, amongst other advancements. All these advancements have occurred due to the establishment of the significance of social development which in turn, paved the way for the implementation of a great range of projects, programmes and interventions such as the expansion of community-based projects; construction of safe water supplies schools and clinics; the adoption of gender-equality policies, amongst others interventions. Consisting of comprehensive programs and projects, social development interventions have been effected around the world and have contributed positively to the global welfare [57].

However, despite these advancements, it cannot be affirmed that social development has sufficiently tackled the social issues challenging most developing countries. Many studies correctly maintain that social development has been unequal and that welfare progressions have been unequally apportioned. To exemplify, although there has been significant reduction in the prevalence of global poverty, these have primarily occurred in the global west, with only smaller reductions observed in Sub-Saharan Africa, South Asia, and Central America. Contemporaneously, substantial international differences exist in the evolution of infrastructure and services such as housing, education, health, amongst others. Broadly speaking, access to quality education or schooling, health care, modern energy services, amongst others have been poor in these regions. Whilst there could be a close relationship between the state of economic development within these regions and the populations' social wellbeing, the absence of governmental projects, programmes and interventions supporting social development, have been deemed attributable to the distorted development within these regions [57]. On a whole, countries that have strived to resolve this issues have done so through the combination of economic and social development policies whereas, governmental negligence, corruption and lack of adequate policies has resulted in economic stagnation and widespread poverty within the Sub-Saharan Africa, South Asia, and Central America regions.

It is in this context that this Chapter seeks to investigate an overlooked aspect in governmental policies - energy policies addressing cooking and/or heating needs. It explores what role the lack of access to modern energy (specifically for cooking and heating) plays in the social development in the Sub-Saharan Africa, South Asia and East Asian regions. To attain this objective, the definitions and thus, factors constituting social development are examined to aid in the establishment of relevant social development variables to be considered.

3.2.2 Indicators of social development

The concept of social development comprises of three principal connotations established in literature. One approach encompasses definitions which recognise that economic development constitutes a powerful component of social development and thus focus on the planning and connecting of social and economic developments. Examples of this approach include the studies by Gore which discuss the concept, aspects and models of development [58], as well as the work by Barker [59]. A second approach taken by scholars such as Pathak [60] and Mohan [61], encompasses definitions which focus on transforming societies and ensuing structural changes. Lastly, a final group of definitions focus principally on actualizing human potential, meeting needs and improving quality of life (see [62]–[64]). All these approaches are with merits and drawbacks. However, the decades of developmental experiences and the emerging perception demonstrate that although economic development is crucial, it remains only an integral aspect of social development [57]; as opposed to the previous misperception of social versus economic development. This Chapter acknowledges this standpoint and therefore, adapts the definition by Midgley [65] which states that:

"social development is a process of planned social change designed to promote the well-being of the population as a whole and in conjunction with economic development".

In the context of the indicators of social development, one of the earliest studies on the development of a coherent conceptual framework for emerging social indicator was the work by Bauer [66]. Following his study which offered a comprehensive review of potential social indicators, many more studies such as the noteworthy works from

David Morris [67]; Drenowski and Scott [68], as well as the work from Anand and Sen [69] have all proposed several indicators as reflections of social development. However, the varying definitions in literature has resulted in studies considering different factors as determinants of social development - a cause and effect of ideological, theoretical, and practical challenges in the subject area.
However, despite these challenges, there have been a unified consensus on two key aspects of social indicators: the nature and basic categories of the indicators. When considering the nature of indicators, studies suggest that social indicators can fall into one of two groups: direct or indirect indicators. Social indicators such as divorce rates, number of deaths due to an incident, etc., which tend to be a direct representation of the phenomena intended to be measured are classed as direct indicators while for more complex phenomena which cannot be easily measured, they tend to act as proxies and are termed indirect indicators [57]. Each of the groups have their advantages and drawbacks. To exemplify, direct indicators have the ease of interpretation and representation while having the drawback of being unable to represent more complex phenomena. Yet, on the other hand, whilst indirect indicators (namely proxies) can represent complex phenomena (which is the nature of human conditions and experiences), there are possibilities of having wrong representation due to selection error and/or interpretation of indicators.
Social indicators are further categorised into three basic categories: leading, coincident and lagging indicators. Leading indicators tend to show the direction of future economic or social activity; Coincident indicators tend to comparatively track social and economic activities while lagging indicators show the past economy or social activities [67]. For the purpose intended in this Chapter, the coincident indicators are applied in these analyses.

Considering coincident indicators, the most relevant literature center around the considerable studies done in advancing indicators which measure social development at national, regional and international levels. The sources of much of these works stem from major agencies such as the UN and other international organisations which focus heavily on development in developing countries. Many scholars have also taken up the challenge of developing relevant measures of changes in national and international social development. The most widely acknowledged measures in literature are: the Physical Quality of Life Index (PQLI); the Index of Social Progress (ISP; WISP), and the United Nations Development Program's Human Development Index (HDI)[1].

Developed in the mid-1960s by Morris David and his colleagues to refocus international attention on the primacy of social development as well as measure the changes over time, the PQLI consisted of three indicators: infant mortality, life expectation at the age of one and basic literacy [70]. Although advantageous due to its ease of use, despite its initial influence in the development field, the PQLI is rarely used in recent studies. Due to the lack of variation in the indicators, studies consider the PQLI as too narrow. Building on the PQLI, the ISP in its present form consists of forty-five social indicators divided among 10 sectors of development: Education, Health, Women, Defence Effort, Economic, Demographic, Geographic, Political Chaos, Cultural Diversity, and Welfare Effort [71]–[73]. Introduced by the UN in 1990, the HDI builds upon the conceptual legacy of both the PQLI and the ISP. It utilises three main indicators to assess national and international advancement in human and social development: longevity which is measured by life expectation at birth; educational attainment which is measured by adult literacy rates in combination with primary, secondary, and tertiary school enrolment levels; and standard of living which is measured by real Gross Domestic Product or Purchasing Power Parity. Due to its transparency, simplicity and popular resonance around the world, the HDI is acknowledged in literature as one of the most globally, significantly successful indices and the indicators are deemed widely accepted across literature [57], [74], [75].

As a final point, it is observed that across all indices, three main themes remain consistent: life expectancy, basic literacy, and standard of living. Therefore, these themes are considered for analyses in this chapter. Based off of these findings in literature, two of the three main indicators of the HDI: longevity and literacy rates, are adapted in the analyses performed in this Chapter.

[1] IHDI is a newer version of HDI which adjusts for the cost of inequality. However, the indicators within the two indices are the same.

3.2.3 Energy and social development

As mentioned in Chapter 1, the role of energy as a principal factor to sustainable development is now widely acknowledged by the global community, as evidenced by the fact that the Sustainable Development Goals (SDG) now include access to affordable, sustainable, and modern energy for all by 2030 as an explicit target. Studies on the impacts of energy on general development started emerging in the 1970s following the work by Kraft and Kraft [76] while studies focusing on these impacts in developing economies (the focus of this research), started emerging in the 1980s - following the work by Fluitman in 1983 [77]. In more recent years, generally speaking, studies in the area of energy and development are observed to fall under three main groups:

1. The first group of studies focus on the link between energy and development. This is the area commonly referred to as the energy-growth nexus and these studies tend to focus on solely the economic impacts of energy consumption.
2. Another strand of literature focus on the explicit link between electricity and economic growth
3. The third and smallest group focus on the relationship between electricity and socio-economic or human development.

Despite extensive discussion in the literature about the socio-economic impacts of energy and/or electricity consumption, there is a lack of quantitative studies that investigate the explicit link between cooking fuels and social development. From the limited literature, most analyses done have been in the context of health impacts [78]–[81]. Regardless, the extant literature is drawn upon from the aforementioned third group of studies, for an insight into potential impacts, relevant variables and methodologies.

Table 3.1: Summary of relevant literature

Authors	Countries	Variables	Methods	Conclusions
Akarca and Long (1979)	United States	Final energy consumption; rate of employment (%)	Regression; Granger	Unidirectional causality running from energy to employment [82]
Murry and Nan (1990)	United States	Total employment (%); Final energy consumption	Granger causality test; Sim's test	Unidirectional causality running from employment to energy
Burney (1995)	93 countries	Per Capita GNP; Years of schooling; etc.	OLS and random effects regression	Electricity consumption increases literacy, share of industry and urbanization, etc. [83]
Johan Martins (2005)	South Africa	Access to electricity (%); level of education (%); source of energy (%); Household expenditure	Pre-structured questionaires	Comparison of quality of life of people with and without electricity shows improvement due to electrification [84]
Kanagawa and Nakata (2008)	India	Electrification rate (%), literary rate (%)	Multiple regression analysis	Energy access improvement influences significantly socio-economic factors such as health and education [7]
Mulder and Tembe (2008)	Mozambique	Access to electricity (%); level of education (%); source of energy (%); Household expenditure	Cost-benefit analysis	The direct benefits like increased productivity; indirect benefits include improved educational and health services [85]
Zahnd (2009)	Nepal	Health; education; social life and income generation	Surveys	Significant positive benefits on health, education, social and economic [86]
Mazur (2011)	21 industralised countries	Final energy consumption; infant mortality rate; life expectancy;secondary and tertiary enrollment rates (%), etc.	Regression	Energy use is strongly correlated with diverse indicators of quality of life among the world's nations [87]
Bergasse (2013)	11 Southern and eastern Mediterranean countries	Final energy consumption; rate of employment (%); GDP per Capita	Policy assessment	Energy plays a great role in improving household welfare [88]
Niu et al (2013)	50 countries	Access to electricity (%); life expectancy; adult literacy rate (%); GDP per Capita, etc	Fixed effects regression; Panel granger causality test	Granger causality tests prove that a long-run bidirectional causal linkage exists between electricity consumption and the variable [89]
Ouedraogo (2013)	15 countries	Access to electricity (%); life expectancy; adult literacy rate (%); GDP per Capita, etc	Regression; Granger; Error correction model	Long-term negative cointegration between energy and variables; a positive cointegration between electricity consumption and variables. Neutral relationship in short-term [90]
Sovacool (2013)	Mali	Net enrollment in primary school (%); Average life expectancy; Literacy rate of 15 - 24years old (%), etc.	Questionaires and survey	Energy empowered women, improved educational opportunities, and enhanced food security [91]
Alaali et al. (2015)	130 countries	GDP per Capita; Primary enrollment (%); Secondary enrollment (%); Life expectancy at birth; Primary Energy consumption per capita (quadrillion Btu)	Generalised method of moments (GMM)	Education capital affects developed countries positively; health capital affects oil exporting countries and economic growth negatively [92]
Magnani and Vaona (2016)	31 countries	Access to electricity (%); enrolment in secondary education (%); lower secondary completion rate (%); GDP per Capita, etc.	Fixed effects regression; Random effects regression	Positive link between education; GDP per Capita
De Faria et al. (2017)	Brazil	Access to electricity (%); life expectancy; average income; primary enrollment (%); secondary enrollment (%); etc.	Difference-in-difference	Short-term boom; long-term trickle of economic activity; little to no socio-economic development [93]
Dos Santos et al (2018)	Brazil	Access to electricity (%); enrollment in education - primary, secondary (%); source of energy (%); Household income; Life expectancy; GDP per Capia; etc.	Spatial econometric modeling	Electricity consumption allows provision of other services such as education, health, drinking water and sanitation [50]

Table 3.1 presents a summary of studies found on the subject. The conclusions from these studies highlight a unified recognition that energy is necessary, although not sufficient for social and economic development. Furthermore, the findings from these reviewed studies suggest that energy access significantly influences socio-economic factors such as health, education and employment. In addition, these studies suggest that energy has substantial ripple effects on other factors, such as gender equality and the environment. Figure 3.1 presents a summary of some of the links observed (from

these studies) between energy and aspects of social development.

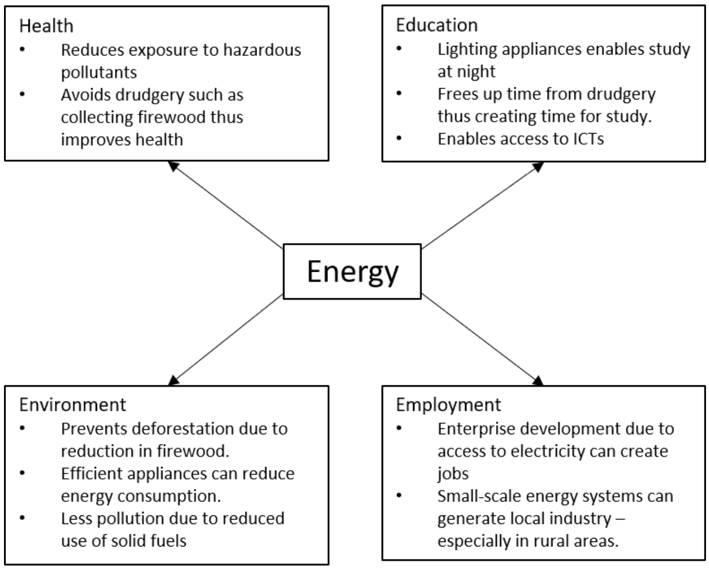

Figure 3.1: Links between energy and components of social development

Given the premises in Section 3.2.2, in particular, emphasis placed on three key aspects of these reviews: the dynamics of energy and (i) health, (ii) education, and (iii) employment. These dynamics are discussed in the following sub-sections.

3.2.3.1 Energy and Education

Most extant literature on the subject of the link between energy and education have mostly focused on the impact of electrification on education. As such, the significant impact of access to electricity on education is a widely discussed topic in this area of literature. Generally speaking, the findings from most studies on the topic suggest that electricity consumption is associated with improved educational standards - especially in developing countries. For example, the study by Aglina et al., conducted in 2016 across the Economic Community of West African States (ECOWAS), found that an increase in electricity access was correlated with improved literacy rates and that countries with low electrification rates suffer from lower literacy rates [94]. The study by Sovacool et al., also observed that communities with higher electrification rates in Mali, experienced lower drop-out rates; higher enrolment rates and higher test scores -

in comparison to communities with little or no electrification [91]. The study by Grogan and Sadanand in rural Nicaragua also found that people were more than twice likely to have enrolled in and/or completed primary education if they lived in a household with access to electricity [95]. These amongst several other studies such as those by Khandker [96], Gurung et al., [97], have all mentioned positive impacts of electrification on education. Across these studies, there appears to be a shared reasoning that the use of electric light is beneficial for extended study hours: allowing for early morning or evening study hours - both at home and in school. In addition, it is deduced from these studies that electrification reduces drudgery and allows children to expand their opportunities for school attendance, as well as other educational activities.

When considering studies on the link between cooking fuels and education, no literature on the topic was found. As previously mentioned, despite the potential relevance of the impact on education, no empirical analyses of this relationship exist.

3.2.3.2 Energy and Health

The literature on energy and health suggests that increased accessibility to modern energy is beneficial to the health of the population. Unlike Section 3.2.3.1, a review of literature reveals studies examining the relationship from both electricity consumption and cooking services standpoints.

From an electricity standpoint, studies such as Wolde-Rufael which investigated the relationship between energy use per capita and development in nineteen african countries [98]; the work by Sovacool et al., which examined the impact of electricity in Mali [91] and the work by Grimm et al., which examined the impacts of the deployment of Pico-Photovoltaic kit in Rural Rwanda [99]; have all suggested energy (mostly electricity) as an important driver for improved health within households. Their observations suggested that the use of electric lighting appliances resulted in reduced household air pollutions and lung diseases caused by the use of kerosene. Other impacts observed include the use of electric fans resulting in increased comfort in households which in turn increased the perceived comfort inside bed nets, thus aiding the use of these nets and consequently, reducing the risks of Malaria. The authors also suggested the likelihood of further ripple effects. For example, due to the reduced illnesses and diseases, households reported having more disposable income and as a consequence of more income and free time following electricity use, people were reported to care more for their health. This thus created a feedback loop where an improved health status reduced the need to frequently spend time being sick and money for health service(s), preserving households' finances and allowing for free-time for other activities.

When considering the literature on cooking services, literature suggests that accessibility to modern cooking fuels and/or cookstoves would be beneficial to the health status within households. To clarify, studies such as that of Clark et al. which examined the relationship between household air pollution and solid fuel use [78]; the work by Balmes which analysed the impact of solid cooking fuels on health due to indoor pollution [81] as well as the work by Arlington et al., which investigated the association of solid cooking fuels with acute lower respiratory infection [80]; amongst several others, have all established that the use of solid cooking fuels has a detrimental impact on the health of household members. Some of the impacts being respiratory illness and/or diseases and in some cases, premature death. According to the WHO, approximately 4 million deaths attributable to indoor pollution, are recorded annually. What's more, these impacts were observed to be more severe in women and children.
All-in-all, from these literature, there is reason to believe that the household use of solid fuels for cooking could contribute to reduced life expectancy.

3.2.4 Solid fuels and social development

As mentioned in sections 3.2.3.1 and 3.2.3.2, current studies which examine the impacts of household use of solid fuels on social development have done so explicitly from the context of impacts on health. Impacts on other measures of social development have been left unexplored. However, given the positive impacts unearthed by the aforementioned studies in sections 3.2.3.1 and 3.2.3.2, although most of the reviewed studies were conducted in the context of general energy and/or electricity access, the use of modern energy sources for cooking would appear to have the potential to offer positive impacts on the areas discussed above. Whilst the absence of modern cooking energy sources (and thus, the continued use of solid fuels) can be speculated to have negative impacts. For example, considering that the tasks of gathering solid fuels and cooking tend to fall on women and children [91], through the adoption of modern cooking energy sources, one could anticipate that the women and children will have more free time to pursue other (perhaps more productive) activities. In addition, considering the health impacts associated with the use of solid fuels, the use of modern alternatives should result in less health issues which could have ripple effects such as perhaps improved educational attainment, amongst other ripple impacts. It is in this context that potential causal mechanisms between adoption of modern cooking alternatives and these variables are explored, conceptualised and presented in Figures 3.2 and 3.3.

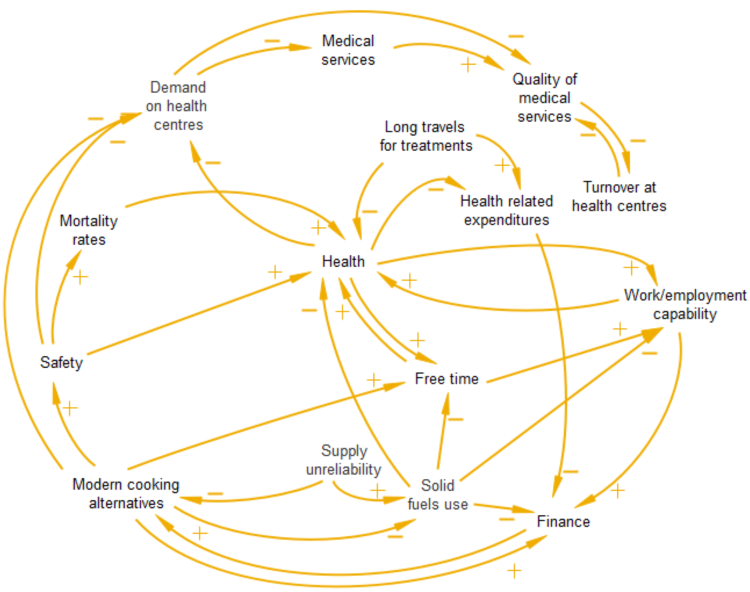

Figure 3.2: Causal-loop diagram illustrating potential dynamics between modern cooking adaption and health

Figure 3.2 illustrates a summary of potential causal mechanisms between cooking alternatives, health-related factors and associated impacts; whilst Figure 3.3 illustrates a summary of potential paths between cooking alternatives, education-related factors and associated impacts.

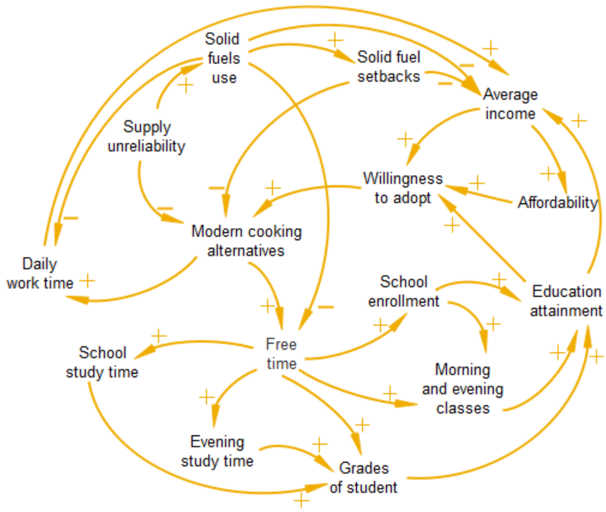

Figure 3.3: Causal-loop diagram illustrating potential dynamics between modern cooking adaption and education

From Figures 3.2 and 3.3, a few possible mechanisms can be explored for links between solid fuel use, employment, education and health.
Firstly, for employment, the household use of solid fuels can impact on people's employment through the following:

- due to diseases and illnesses caused by household use of solid fuels, ill-health of the individual and/or family member can result in reduced work/employment capability (*solid fuels use* → *health* → *Work/employment capability*). Although the impacts of cooking-related activities on employment have not been analysed in literature, the impacts of ill-health and care-giving on employment is established in literature. For example, the studies by Schuring et al., [100] and Burdorf et al., [101], amongst others, found that ill health significantly increased displacement from the labour market;

- as a result of the time-consuming task of collecting and managing solid fuels, free-time which could otherwise be used for productive purposes such as employment, etc., is reduced [14], [102], [103]. Therefore, household use of solid fuels could result in reduced work/employment capability (*solid fuels use* → *free time* → *Work/employment capability*);

- due to demand of solid fuels, production and preparation of solid fuels could generate income and/or unskilled employment for population (especially in rural areas) [104]–[106] (*solid fuels use → Work/employment capability*)

1. in addition, family members could suffer from reduced work capability due to the task of caring from ill family members (immediate or extended).

In the case of education, the household use of solid fuels could impact on education through the following paths:

- although the impact of cooking-related activities on education is absent in literature, the impact of ill health on school absenteeism has been established in literature. For example, the study by Mustapha et al., reported that in southern Nigeria, up to 2.5% (5.7% in rural areas), reported not attending school due to respiratory illnesses [107] (*solid fuels → health → school study time*).
- In addition to poor health of school children resulting in absenteeism, the ill health of family members could also contribute to lack of enrolment in school and/or absenteeism. The study by Orkin which investigated the impact of parental illness on school enrolment and attendance in Ethopia [108]; the work by Ainsworth which investigated this subject in Tanzania [109]; and the study by Culver which investigated the subject in South Africa [110], are amongst studies which have reported that ill health of parents and/or family members affect school enrolment and/or attendance rates (*solid fuels → health → school enrolment*); (*solid fuels → health → study time → grades → education attainment*).
- Other mechanism pathways focus on time and resource factors. To illustrate, the data from a survey performed in Malawi by United Nations International Children's Emergency Fund (UNICEF) shows that boys and girls spend on average nine and twelve hours per week, respectively, on fuel-wood collection [111]. Although the effect of this task on education was not investigated, previous studies such as the work by Porter et al., have reported child porterage has negative effects on education [112]. As such, it can be anticipated that the task of fuel

collection could impact negatively on education (*solid fuels* → *free time* → *school enrolment*); (*solid fuels* → *free time* → *study time* → *grades of student* → *education attainment*); (*solid fuels* → *free time* → *morning and evening classes* → education attainment);

- a reduction in household finance(s) due to lack of/reduced income caused by unemployment as a result of ill health could lead to inability to enrol children in education (*solid fuels use* → *health* → *work/employment capability* → *finance* → *school enrolment*);

- high health-related expenditure could also lead to unaffordability of education and thus, school unenrollment (*solid fuels use* → *health* → *health-related expenditure* → *finance* → *school enrolment*);

- Lastly, the impact of income poverty on education is well established in literaure. It can be anticipated that the high costs associated with use of solid fuels could hinder households from meeting schooling costs such as costs of exercise books, pens and clothes, which in the case of Malawi, have been shown to amount to approximately 6% (per child) of the total financial resources of the poorest Malawian households [113] (*solid fuels use* → *average income* → affordability → school enrolment)

Finally, as mentioned in section 3.2.3.2, it has been established in literature that the use of solid fuels negatively impact on health.

3.3 Review of methodology

Taking into account the absence of studies on the subject, to investigate the impacts of household use of solid fuels on social development, methodologies applied in general development studies are considered. A range of analytical techniques are observed to be applicable in analysing the degree of association between household use of solid fuels and social development outcomes - life expectancy, education, and employment. Based on the reviewed studies in sections 3.2.2 and 3.2.3, the relevant, prominent methodologies which are utilised in current literature are identified and the suitability of these methods for the analyses within this chapter are examined. A breakdown of the strengths and weaknesses of the most dominant methods are then summarised and are presented in Table 3.2. The applied methods in existing literature can be broadly categorised into two groups: time-series and panel-data methods. The time-series methods investigate impacts either over a period of time or across a group of entities but are unable to investigate both. On the other hand, the panel data methods investigate impacts over time and across multiple entities. Therefore, considering that the research question investigates the impacts of household use of solid fuels on multiple measures, across a period of 15 years, for multiple regions and countries, the panel data method is adapted in this chapter.

Table 3.2: Summary of relevant methods

Methods	Strengths	Weakness
Instrumental Variables	Widely known for its ability to address endogeneity problems	Only identifies causal effects based on only the group whose behaviour is influenced by the instrument.
		Use of variables which are weakly correlated with treatment and/or with residuals in the outcome equation could lead to larger bias problems
Ordinary Least Squares (OLS)	Simplicity and ease of implementation and interpretation	Test statistics might be unreliable when the data is not normally distributed (but with many data points that problem gets mitigated)
	It is the maximum-likelihood solution and, if the Gauss-Markov conditions apply, the best linear unbiased estimator	Tendency to over-fit data
		Sensitive to Outliers
Traditional granger test	Can be used for smaller sample sizes	Conditional on the assumption that the underlying variables are stationary, or integrated of order zero.
	Ease of application	Can suffer from specification bias and spurious regression
	Does not require additional tests to determine direction of causality	Requires pre-testing
Fixed effects	Controls for all time-invariant differences between entities	Cannot be used to investigate time-invariant causes of the dependent variables
	Coefficients of the fixed-effects models cannot be biased because of omitted time-invariant characteristics	Cannot identify the effects of any variables that vary only across units
	Fixed-effects models are fully efficient as N gets large even if the true model is random effects	
Random effects	Time invariant variables such as gender can be included in model	The individual characteristics that may or may not influence the predictor variables must be specified
	Allows to generalize the inferences beyond the sample used in the model	Possibility of omitted variable bias in the model
		Assumes that the unit-specific error term are independent of the included regressors. This is often not sensible.

The panel data structure allows for the examination of correlation and causal links using several methods that differ in how cross-country and temporal heterogeneity is imposed. In most cases, data structures tend to fall under two categories: cross-country homogeneity with temporal heterogeneity and cross-country heterogeneity with temporal homogeneity. To clarify: the former refers to data consisting of cross countries (N) where period, T is allowed to change faster than N, whilst the latter refers to data consisting of cross countries with diversified characteristics across slower changing period, T [114], [115]. As such, the analysis of panel data can be categorised into non-stationary panel data analysis and traditional panel data analysis.

In the case of cross-country homogeneity with temporal heterogeneity such that T>N, where T is the Period and N is cross-countries, literature suggests the use of non-stationary panel data analysis such as Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), Pooled Mean Group (PMG), amongst others [114], [116], [117]. Conversely, in the case of cross-country heterogeneity with temporal homogeneity such that N>T, literature suggests the use of traditional panel data analysis such as fixed effects regressions, random effects regressions, pooled Ordinary Least Squares (OLS), amongst others [118], [119]. To further determine the most efficient tests type, literature suggests the use of the Hausman and Breusch Pagan LM tests. If the results obtained from the Hausman test are found significant, it is suggested to utilise the Fixed effects regression method whilst if the obtained results are insignificant, the Random effects regression method is to be used [119]. Lastly, for cases where insignificant Hausman test results are obtained, the Breusch Pagan LM is to be implemented to decide the most effective method between the random effects regression and pooled OLS methods. For a significant Breusch Pagam LM result, the Random effects regression method is suggested while for an insignificant result, the pooled OLS is suggested [119].

Overall, considering the nature of data to be utilised in this Chapter .i.e. (N>T), the latter approach comprising of traditional panel data analyses is utilised for the analyses.

3.4 Data and Methodology

For the analyses in this Chapter, recent data from various international organisations are drawn upon to examine the relationships between the use of solid fuels and the measures of social development of interest: education, employment, labour force participation and life expectancy. The panel Fixed Effects (FE) and Random Effects (RE) regressions are then applied to the obtained data to investigate these relationships.

3.4.1 Methodology

Due to the model assumptions, the fixed effects model is applied to investigate the relationship between the household use of solid fuels and the variables of interest, for the entire population within the regions and countries. On the other hand, both the fixed effects and random effects models are applied to estimate the effects on only the female population within the region and countries.

3.4.1.1 Fixed Effects (FE) model

The Fixed Effect (FE) model explores the relationship between the independent and dependent variables within the examined entities (countries) through using a transformation to eliminate the unobserved effects within the entities (countries), before estimating of the relationship between the variables [120].
The most common types of unobserved variables are fixed effect and as such, tend to be time invariant characteristic of the entities (countries). For example, race, culture, gender, etc. Therefore, due to the model controlling for these time-invariant differences between the countries, the obtained estimated coefficients of the models are unbiased by omitted time-invariant characteristics.

To illustrate: for the balanced panel data, let Y and $X \equiv (X_1, X_2, \ldots, X_N)$ represent the observable variables and u represent the unobservable variable. The observation of interest is the effect(s) of variable X_j in the population regression function which can be written as:

$$E\left[Y|X_1, X_2 \cdots X_N, u\right] \tag{3.1}$$

Since the observations will be based on the sample of $c = 1, 2, \ldots, N$ cross sectional countries for $t = 1, 2, \ldots, T$ time periods, for each country c, the observable variables for all time periods can be defined as: $Y_{ct}, X_{ct} : t = 1, 2, \ldots, T$ where, $X_{ct} \equiv$

$(X_{ct1}, X_{ct2}, \ldots, X_{ctk})$ and is a $1 \times K$ vector. So, for a single country, c, across all the time periods, t, the observable variables can be expressed as;

$$Y_c = \begin{pmatrix} Y_{c1} \\ \vdots \\ Y_{ct} \\ \vdots \\ Y_{cT} \end{pmatrix}_{T\times 1} \qquad X_c = \begin{pmatrix} X_{c,1,1} & X_{c,1,2} & \ldots & X_{c,1,K} \\ \vdots & \vdots & & \vdots \\ X_{c,t,1} & X_{c,t,2} & \ldots & X_{c,t,K} \\ \vdots & \vdots & & \vdots \\ X_{c,T,1} & X_{c,T,2} & \ldots & X_{c,T,K} \end{pmatrix}_{T\times K} \tag{3.2}$$

Following equation 3.2, the entire panel with all countries can therefore be written as:

$$Y = \begin{pmatrix} Y_1 \\ \vdots \\ Y_c \\ \vdots \\ Y_N \end{pmatrix}_{NT\times 1} \qquad X = \begin{pmatrix} X_1 \\ \vdots \\ X_c \\ \vdots \\ X_N \end{pmatrix}_{NT\times K} \tag{3.3}$$

Considering the unobservable variable in equation 3.1, for a single cross-sectional country, c, randomly drawn from equation 3.3, the unobserved effects model for time periods, T can then be expressed as:

$$Y_{ct} = \beta X_{ct} + u_c + \varepsilon_{ct} \qquad\qquad t = 1, 2, \ldots, T \tag{3.4}$$

where, Y is the observable dependent variable such as education. X is the observable independent variable (household use of solid fuels) while β is the returns to X. u_c is the unobservable heterogeneity and represents the sum of all time-invariant characteristics of the country. ε represents the idiosyncratic error term while c and t represent country and period, respectively.

Applying OLS estimation, with N individual dummies in regression of Y_{ct} on X_{ct}:

$$\left(\hat{\beta}, \hat{u}_1, \ldots, \hat{u}_N\right) = \underset{b, m_1, \ldots, m_N}{\operatorname{argmin}} \sum_{c=1}^{N} \sum_{t=1}^{T} \left(Y_{ct} - X_{ct} b - m_c\right)^2$$

The first order conditions (FOC) for this minimisation can be written as:

$$\sum_{c=1}^{N} \sum_{t=1}^{T} X'_{ct} \left(Y_{ct} - \hat{\beta} X_{ct} - \hat{u}_c\right) = 0 \tag{3.5}$$

and

$$\sum_{t=1}^{T} \left(Y_{ct} - \hat{\beta} X_{ct} - \hat{u}_c\right) = 0 \tag{3.6}$$

Therefore, for $c = 1, \ldots, N$,

$$\hat{u}_c = \frac{1}{T} \sum_{t=1}^{T} \left(Y_{ct} - \hat{\beta} X_{ct}\right) = \bar{Y}_c - \hat{\beta} \bar{X}_c \tag{3.7}$$

where

$$\bar{X}_c \equiv \frac{1}{T} \sum_{t=1}^{T} X_{ct}; \qquad \hat{Y}_c \equiv \frac{1}{T} \sum_{t=1}^{T} Y_{ct}$$

Inputting equation 3.7 into equation 3.5,

$$\hat{\beta} = \left(\sum_{c=1}^{N} \sum_{t=1}^{T} \left(X_{ct} - \bar{X}_c\right)' \left(X_{ct} - \bar{X}_c\right)\right)^{-1} \left(\sum_{c=1}^{N} \sum_{t=1}^{T} \left(X_{ct} - \bar{X}_c\right)' \left(Y_{ct} - \bar{Y}_c\right)\right) \tag{3.8}$$

Therefore,

$$\hat{\beta} = \left(\sum_{c=1}^{N} \sum_{t=1}^{T} \ddot{X}'_{ct} \ddot{X}_{ct}\right)^{-1} \left(\sum_{c=1}^{N} \sum_{t=1}^{T} \ddot{X}'_{ct} \ddot{Y}_{ct}\right) \tag{3.9}$$

As shown in equation 3.9, the unobserved effect becomes eliminated.

A simplified explanation clarifying the FE transformation and estimation processes shown from equations 3.1 to 3.9 can be found in Appendix B.1.

There are two primary assumptions necessary in order to identify β using the fixed effects model [121]:

- The strict exogeneity assumption (FE1): $E\left[\varepsilon_{ct}|X_{1t}, X_{2t} \cdots X_{cT}, u_c\right] = 0; t = 1, 2, \ldots, T$. This assumes a strict exogeneity of the independent/explanatory variable(s) conditional on the unobserved effect. It implies that although X_{ct} is allowed to be arbitrarily related to u_c in any time period, the idiosyncratic error ε_{ct} should be uncorrelated with any of the independent/explanatory variables across all time periods. This assumption mainly concerns the relationship between X_{ct} and ε_{ct}, not the link between X_{ct} and u_c.

- The rank condition assumption (FE2): rank$\left(\sum_{t=1}^{T} \ddot{X}'_{ct}\ddot{X}_{ct}\right) = K$, in plain terms, explains the exclusion of time invariant variables in FE models. It demonstrates that the regressor must vary over the time period, t, for at least some entities, c, but not be collinear such that $\hat{\beta} \approx \beta$. For example, if X_{ct} consists of an element which remains constant over time, $\ddot{X}_{ct} = 0$ for all c and t. Since $\ddot{X}_{ct}$ would contain a column of zero for all entities, c, the estimated coefficient becomes problematic.

Although the FE model is argued to be one of the best econometric methods in addressing omitted variable bias and/or biased coefficient problems [121], [122] when dealing with panel data, the models have a few drawbacks. To ensure the validity of the methodology, these drawbacks are reviewed and considered. One of the principal disadvantages of FE models is that they cannot be utilised in analysing time-invariant elements of the dependent variable(s). Secondly, due to the FE transformation and estimation processes, FE models are inefficient when analysing data in which the variations within entities are minimal or possess slow changing variables over time. For example, if the rate of change within a country is slow, an FE model might produce inefficient results. Lastly, FE models cannot be used to investigate and/or address reverse causality or simultaneity bias in observational data. However, due to the nature of the data used in this Chapter which does not consist of time-invariant or slow changing variables, these shortcomings are deemed to not apply in the analyses performed in this Chapter.

3.4.1.2 Random Effect (RE) model

On the other hand, the Random Effect (RE) model explores the relationship between the independent and dependent variables within the examined entities by assuming that the unobserved effect is random and uncorrelated with each independent variable. The model assumes the two key assumptions of the FE model plus the aforementioned assumption that the unobserved effect is uncorrelated with each independent variable. Therefore, the unobserved effects model represented in equation 3.4 becomes a RE model when it is assumed the unobservable heterogeneity u_c is uncorrelated with each independent variables:

$$Cov\left(X_{ct}, u_c\right) = 0, \qquad t = 1, 2, \ldots, T$$

To clarify: following the strict exogeneity assumption in section 3.4.1.1: $E\left[\varepsilon_{ct} | X_{1t}, X_{2t} \cdots X_{cT}, u_c\right] = 0; t = 1, 2, \ldots, T$, the strict exogeneity assumption for the RE, can be expressed as:

$$E\left(\varepsilon_{ct} \mid X_c, u_c\right) = 0; t = 1, \ldots, T \tag{3.10a}$$

$$E\left(u_c \mid X_c\right) = E\left(u_c\right) \tag{3.10b}$$

Defining a composite error term $\psi_{ct} = u_c + \varepsilon_{ct}$, equation 3.4 can be rewritten as:

$$Y_{ct} = \beta X_{ct} + \boldsymbol{\psi}_{ct} \qquad t = 1, 2, \ldots, T \tag{3.11}$$

where, u_c is the composite error in each time period thus, ψ_{ct} is serially correlated across time.

Equation 3.10b above can then be rewritten as:

$$E\left(\psi_{ct} \mid X_c\right) = 0, \qquad\qquad t = 1, 2, \ldots, T \tag{3.12}$$

Since equation 3.12 continues to satisfy strict exogeneity asumption in model equation 3.11, for ease of representation, equation 3.11 can be rewritten for all time periods, T, as:

$$\mathbf{Y_c} = \boldsymbol{\beta}\mathbf{X_c} + \boldsymbol{\psi_c} \tag{3.13}$$

where, $\boldsymbol{\psi_c}$ is expressed as $\boldsymbol{\psi_c}$ = $u_c\,\boldsymbol{j_T} + \boldsymbol{\varepsilon_c}$, with $\boldsymbol{j_T}$ being the $T \times 1$ vectors of ones. Defining the variance matrix of ψ as:

$$\boldsymbol{\varrho} = E\left(\boldsymbol{\psi}_c\boldsymbol{\psi}_c'\right) \tag{3.14}$$

where $\boldsymbol{\varrho}$ is a $T \times T$ matrix assumed to be positive definite, the RE estimator can be expressed as:

$$\hat{\boldsymbol{\beta}}_{RE} = \left(\sum_{c=1}^{N} \mathbf{X}_c'\hat{\boldsymbol{\varrho}}^{-1}\mathbf{X}_c\right)^{-1} \left(\sum_{c=1}^{N} \mathbf{X}_c'\hat{\boldsymbol{\varrho}}^{-1}\mathbf{Y}_c\right) \tag{3.15}$$

Similar to the section3.4.1.1, a simplified explanation clarifying the process of obtaining the RE estimator can be found in Appendix B.1.

Regarding primary assumptions necessary in obtaining β using the RE model, there are three key assumptions:

- Strict exogeneity assumption (RE1): Represented in equations 3.10a and 3.10b, this assumption is similar to the assumption, FE1 of the FE model
- Rank condition assumption (RE2): This assumption aids in the derivation of the variance matrix defined in equation 3.14: rank $E(X_c'\varrho^{-1}X_c) = K$.

  In the case of the RE, two further sub-assumptions are included on the idiosyncratic errors ε.

  - The idiosyncratic errors ε_{ct} have a constant unconditional variance across period T (RE2a):

$$E\left(\varepsilon_{ct}^{2}\right)=\sigma_{\varepsilon}^{2}, \qquad t=1,2,\ldots,T \tag{3.16}$$

– The idiosyncratic errors are serially uncorrelated (RE2b):

$$E\left(\varepsilon_{ct}\varepsilon_{cs}\right)=0, \qquad t\neq s \tag{3.17}$$

These sub-assumptions aid in the derivation of the variance and covariance of the composite error elements of ψ which then result in the derivation of the variance matrix ϱ above. A breakdown of these derivations have been included in AppendixB.1.

- This third assumption comprises of two sub-assumptions (RE3):
  - Building on the first assumption and assumption equations 3.16 and 3.17, this assumption implies that the conditional variances are constant and the conditional covariances are zero: $E(\varepsilon_{ct}^{2} \mid X_c, u_c) = \sigma_{\varepsilon}^{2}$ for $t = 1, \ldots, T$
  - The homoskedasticity assumption on the unobserved effect, u_c: $E(u_c^2 \mid X_c = \sigma_u^2$

Due to the nature of the RE estimator, a major advantage of this model over the FE and most existing models would in this case be the ability to include time invariant variables such as gender, in the models. Unlike in the FE model where these variables are absorbed, as shown in equation 3.11, these variables are considered uncorrelated with the independent variables and as such, are treated as explanatory variables in the model.

However, although advantageous to this effect, the RE model has a disadvantage of potential omitted bias. Thus, most entity (country) characteristics which may or may not influence the dependent variable should/must be included in the model.

3.4.1.3 Fixed Effects or Random Effects

To answer the main research question in this chapter, due to its strengths, the main model and as such, primary focus lies on the results from the FE model. The RE models have been included to examine the link between the variables from the perspective of the female population and thus, answer the posed research sub-question. The motivation for using both models is based on the differences in the ways in which the models treat unobserved variables.

To clarify, as mentioned in section 3.4.1.1, the FE models control for unobserved variables .i.e. variables which have not or cannot be measured such as time invariant characteristics like culture, etc., by treating each entity as its own control. Thus, essentially excluding such time invariant characteristics and considering only the effects within the entities. This is particularly optimal for our analyses as the results obtained would represent solely the relationship between the household use of solid fuels and the dependent variables of interest.

On the other hand, as shown in section 3.4.1.2, RE models include and treat these unobserved variables as random variables with specified probability distributions. Therefore, RE models generalise the effects beyond the variables utilised in the models and as such, allow for the effects both within and between the entities to be considered. In addition, RE models allow for the estimation of time invariant characteristics like gender. Therefore, it is optimal for investigating the relationship between the variables from the female only population perspective.

Thus, by using both models, it is possible to examine the unbiased links between the independent and dependent variables in the FE models whilst observing these links when influenced by other unobserved variables such as culture, gender, etc., in the RE models. Using these models, the relationship between the household use of solid fuels and the aforementioned selected aspects of social development are explored at the global, regional and country levels (using the FE models for the entire country population and the RE models for the female only population). Figure 3.4 below illustrates the analyses process undertaken in this chapter.

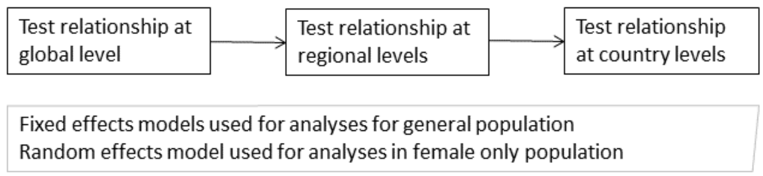

Figure 3.4: Illustration of the analysis process

Firstly, these relationships are tested using global aggregate data. Following this, for each region, the relationships are tested firstly using aggregate regional level data for each region, then followed by analyses using country level data. Lastly, these steps are repeated using the female only population data.

3.4.2 Data

The analyses performed in this Chapter are based on data collated for *forty-six* sub-Saharan Africa; *seven* South Asian as well as *twenty-four* East Asian and Pacific countries. The variables used in this study were developed based on the combination of the current focus of the UN SDG, as well as, from studies in the literature on energy and social development (section 3.2.3). As such, these selected variables are based on the annual time series on solid fuels use; primary education enrolment rate; secondary education enrolment rate; life expectancy and employment rate. The panel data used is for the period of 15 years, spanning across 2000 to 2015. In terms of classification of countries for regional aggregates, the World Bank's regional categorisation approach has been used. For all variables, excluding life expectancy, the variables used in the analyses are deprived from the 100 percent census, kept in their natural log forms to reduce heteroscedasticity and as such, are unweighted.

The data measuring households utilizing solid fuels as the primary energy sources have been collected from the regional World Health Organisation (WHO) Global Household Energy database [123]. It measures the percentage of households using solid fuels in each country. These data have been collected primarily through household surveys but have been augmented by estimates for the purposes of the observation of trends and the provision of point estimates for countries and regions in explicit years [123]. Although, previously there were few national representative surveys making trend analysis problematic, in recent years increased numbers of national surveys and additional surveys by the WHO have expanded available data points. In addition, the recent data draw together information gathered in most countries at national and sub-national censuses and survey. For this variable, the variance of 'access to clean cooking fuels and technology' data is used as a proxy. However, it is worth noting that even with access to clean cooking fuel, some households might still rely on solid fuels for cooking. As such, there exists a possibility of negligible imperfection in the variable.

The data measuring education: primary and secondary education enrolment rates have been collected from the United Nations Educational, Scientific and Cultural Organization (UNESCO) database [124]. The data measures the percentage of enrolment at each education level. Although UNESCO gather data annually through three primary surveys, the data used here have been gathered through two main surveys - the UIS Survey of Formal Education and the UIS Survey on Literacy and Educational Attainment. These data cover formal education in public (or state); private and special needs education (both in regular and special schools), for the primary and secondary education levels. The variables chosen represent the ratio of children of official school age who are enrolled in school to the population of the corresponding respective official school ages.

For the data on employment rate and labour force participation, the data have been collected from the International Labour Organization (ILO) database [125]. The labour force participation rate measures the proportion of the working-age population that engage actively in the labour market, either by working or looking for work while the employment rate measures the proportion of working-age population that are employed. Both variables are utilised to ensure the inclusion of population in less obvious forms of work, such as unpaid family work, apprenticeship or non-market production, which would not be captured in the labour force participation data. The working-age is considered to be ages 15 and older.

Finally, the data on life expectancy is regional World Health Organisation (WHO) Global Household Energy database [123]. Similar to the solid fuels data, the life expectancy data is collected through national and sub-national surveys and consensus.

Table 3.3: Descriptive summary of variables - Global aggregate

Variables	Min	Max	Mean	Std. Dev
Solid	0.00	88.79	33.82	33.30
Primary	60.23	97.97	90.93	9.04
Secondary	20.70	90.85	65.50	20.34
Employment	40.87	70.48	57.47	7.80
Life	50.51	79.06	70.29	7.47
Force	47.02	73.89	61.97	7.48
F - primary	56.57	98.18	89.93	10.29
F - secondary	18.87	92.06	64.96	21.69
F - employment	14.90	62.69	44.22	14.56
F - life	52.04	81.48	72.61	8.08
F - force	19.07	65.40	48.13	14.86

$Primary$ = Enrolment in primary education; $Secondary$ = Enrolment in Secondary education; $Employment$ = Proportion of population employed (aged 15+) (%); $Force$ = Proportion of population in labour force (%); $Life$ = Life expectancy at birth; F = % of female population for each variable

Table 3.3 shows the descriptive statistics of the key variables at the global level - using the global aggregate data. As shown in Table 3.3, a substantial (a little over a third) amount of households across the world utilise solid fuels. A global average of 33.82% households use solid fuels for cooking. Approximately 90.93% of primary school age children are enrolled in primary school across the globe while approximately 65.50% of secondary school age children are enrolled in secondary education. In terms of employment and labour force participation, approximately 57.47% and 61.97%, respectively, of the global working-age population (17 - 65 years of age) are active. And lastly, the average global, life expectancy at birth is approximately 70 years. Focusing on the female only population, across the world, it is observed that on average, less female children are enrolled in primary (89.93%) and secondary (64.965%) education. Also in the area of labour force and employment, the data shows less females are active. And finally, when considering life expectancy, it is seen that on average, the female population have a higher life expectancy at birth.

Table 3.4: Descriptive summary of variables - region level

	Min	Max	Mean	Std.Dev
EA	75.38	99.89	93.71	4.803
SA	50.22	99.92	80.6	15.07
SSA	26.83	99.05	73.77	16.17

(a) Enrolment in primary education (%)

	Min	Max	Mean	Std.Dev
EA	15.62	98.17	62.28	21.42
SA	22.07	85.3	40.36	15.86
SSA	3.28	90.54	31.9	18.77

(b) Enrolment in Secondary education (%)

	Min	Max	Mean	Std.Dev
EA	54.71	84.21	65.19	8.691
SA	50.34	68.95	55.88	6.483
SSA	36.75	85.59	63.16	12.47

(c) Population in employment (%)

	Min	Max	Mean	Std.Dev
EA	58.43	82.4	69.91	6.341
SA	60.88	76.32	67.85	4.503
SSA	42.6	74.35	57.2	6.75

(d) Life expectancy at birth

	Min	Max	Mean	Std.Dev
EA	56.96	85.39	67.38	7.978
SA	50.72	71.7	57.74	6.684
SSA	45.79	88.41	68.99	10.45

(e) Labour force participation (%)

EA = East Asia & Pacific; SA = South Asia; SSA = sub-Saharan Africa

Moving onto the country level data and focusing on each regions of interest, Table 3.4 showcases the differences across the key variables, between the three regions of interest. A breakdown for each region can be found in Appendix B.2. The average rate of enrolment in primary education across the sub-Saharan, east and south Asian regions are 73.77%, 93.71% and 80.60% respectively, in comparison to a global average of 90.93%. However, in the secondary enrolment, the average difference becomes more pronounced. In the sub-Saharan, East and South Asian regions, the average secondary enrolment rates are observed to be approximately 31.9%, 62.28% and 40.36% respectively. For life expectancy, there is an average difference of approximately 13 years, 2.5 years and less than a year, between the global average and the sub-Saharan, East and South Asian respective averages. Implying that on average, people in sub-Saharan, East and South Asian are expected to live 13, 2.5 and 0.5 years less than the global average of approximately 70 years. Finally, considering the literature surrounding employment levels in developing regions, it is striking to see that compared against the global average, there are approximately 5.69% and 7.72% more people employed in the sub-Saharan African and East Asian regions, respectively while there are 1.59% less people formally employed in the South Asian region.

Table 3.5: Descriptive summary of variables - Country level - female population

	Min	Max	Mean	Std.Dev
EA	60.62	85.2	72.73	6.617
SA	61.12	79.69	69.28	5.623
SSA	45.1	77.79	58.98	7.081

(a) Life expectancy - female

	Min	Max	Mean	Std.Dev
EA	33.12	80.84	55.07	13.28
SA	15.9	63.51	34.71	15.58
SSA	24.45	85.97	55.58	16.41

(b) Female population in Employment (%)

	Min	Max	Mean	Std.Dev
EA	36.26	84.81	60.84	13.85
SA	16.35	69.33	38.3	16.68
SSA	29.02	88.51	63.21	14.49

(c) Female labour force participation(%)

EA = East Asia & Pacific; SA = South Asia; SSA = sub-Saharan Africa

As previously mentioned, in view of literature ([80], [81]) which has suggested that the impacts of lack of access to energy might be greater on the female gender, the impacts of lack of solid fuels on these indicators are also examined from the context of the female population within these regions. However, due to the lack of data on the education indicators for the female population at country-level, the education variables are not considered at country-level. Nonetheless, the other three indicators are included in the country-level gender-based analyses.

With regard to female life expectancy, the sub-Saharan African region has the lowest average life expectancy at approximately 59 years whilst the east Asian region has the highest female life expectancy at approximately 73 years. Noticeably, when considering female employment and labour force participation, the sub-Saharan African region has the highest percentage of females in employment and labour force while the south Asian region has the lowest percentages of females in employment and labour force participation. For the east Asian region, across all variables, the obtained averages are higher than the obtained global averages.

A final note on the data: following the technical note from UNESCO on the education data for Singapore and the technical note from ILO for Australia and New Zealand, these countries have been removed from the analyses performed in this Chapter. The specific notes have been included in Appendix B.2

3.5 Results

The results from the analyses suggest that in most countries, household use of solid fuels is significantly associated with the reduced probability of children being enrolled in primary and secondary education. In addition, the findings suggest that across all countries, the household use of solid fuels is also significantly associated with reduced life expectancy. In terms of impacts on employment and labour force participation, the results show no significant association in most countries. With regard to the female population, the results obtained suggest that the impacts of household use of solid fuels might be slightly higher on females.

The impact of the household use of solid fuels for cooking on the education enrolment rates (primary and secondary), employment rate, labour force participation and life expectancy, has been observed from the global, regional and country-level perspectives, for both the general (entire) populations, as well as for the female populations.

For all the results presented, the coefficients show the expected marginal change(s) in the dependent variables (employment, etc.,) due to a unit change in the independent variable (household use of solid fuels) while the null hypothesis (H_0) of the utilised models indicate no correlation between the variables. Therefore, to reject the null hypothesis of no correlation between the variables, the probability value (*p-value*) of the models must be less than 0.05.

3.5.1 Global level

As illustrated in figure 3.4, the impacts on the various variables are firstly observed from a global perspective, using the global aggregate data. The results obtained are presented in Table 3.6. In Table 3.6, the estimates obtained from the fixed effects and random effects models are presented.

As mentioned in section 3.4.1, for the general population, the fixed effects model is considered while when considering the impacts on the female population only, both fixed and random effects models are utilised to account for the gender factor. However, although the results from both models are presented for the female population, considering that the differences between the coefficients obtained across both models are minimal, for consistency in interpretation, only the results from the fixed models is interpreted for both the general and female populations.

Table 3.6: Impacts of household use of solid fuel across the globe

	Models	
Variables	Fixed effects	Random effects
Primary education	-0.053*	–
	(0.021)	–
Secondary education	-0.142**	–
	(0.039)	–
Employment	-0.034**	–
	(0.012)	–
Life expectancy	-0.052**	–
	(0.017)	–
Labour force	-0.014	–
	-0.011	–
F - Primary education	-0.072**	-0.068***
	(0.026)	(0.019)
F - Secondary education	-0.162**	-0.175***
	(0.049)	(0.049)
F - Employment	-0.079**	-0.075***
	(0.025)	(0.024)
F - life expectancy	-0.049**	-0.051***
	(0.015)	(0.015)
F - Labour force	-0.056**	-0.053***
	(0.021)	(0.020)

Standard Errors are clustered at the region Level; Robust standard errors in parentheses, ();
'F' denotes impacts for female population; *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Starting with the general population models. For all variables, with the exception of labour force participation where the obtained result is not statistically significant, as well as, primary school enrolment rate which is significant at only 10% significance level; negative, statistically significant coefficients are observed for all variables at 5% significance levels. *This implies that from a global perspective, the household use of solid fuels is negatively associated with these variables. Meaning that the household use of solid fuels could reduce children's enrolment to primary and secondary education; reduce life expectancy and reduce employment participation.* Amongst the results, the most significant impact is seen in the secondary education enrolment rate, where the obtained result suggests that a 1% increase in household use of solid fuels could result in a 14% decrease in secondary school enrolment rates, while the lowest impact is observed in employment rates, where the impact elasticity is approximately 3.4%.

When considering these impacts on the female population; with the exception of life expectancy which has a lower coefficient in comparison to the general population, across all variables, the coefficients are observed to be larger when considering only the female population. These imply that the effects of household use of solid fuels are higher in females. As such, these findings are in agreement with studies such as the study by Sovacool [91] which have suggested that the impacts associated with household energy use might be larger in females. The most notable differences are seen in the employment and labour force participation variables. For the employment variable, an effect of 7.9% is observed for the female population - in comparison to the effect of 3.4% observed for the general population while for the labour force participation variable, an effect of 5.6% is observed for the female population - in comparison to the impact of 1.4% for the general population. *All-in-all, these obtained results can therefore be interpreted as such: when considering education and employment, the impacts of the household use of solid fuels are greater in females than males.*

Regional and country-level

With regard to the specific regions, the results of the impact of the household use of solid fuels on the variables of interest, for sub-Saharan Africa, east Asia and South Asia are presented in Sections 3.5.1.1, 3.5.1.2 and 3.5.1.3, respectively.

At the regional level, for the entire population, two empirical models are estimated: these are panel fixed effects and panel fixed effects model with country-level covariates, models. The purpose of the second model is twofold: a) the impacts across each country is observable. Therefore, these results point to the relationship between country-level characteristics and household use of solid fuels within countries, while controlling for time-invariant country effects. b) by controlling for each country, potential bias and error are reduced and thus, the accuracy of the results increased. Therefore, although the coefficient estimates obtained from both models are the same, the standard errors from the second models are lower. For the female only population, three models are presented: the fixed effects, fixed effects with covariates, and random effects models.

At country-level, only the results of the fixed effects with covariate models are presented.

A final note on the results: due to lack of data for some countries, not all countries have been included in the country-level panel analyses examining impacts on primary and secondary education. Therefore, for these variables, the reported results are for only a part of these regions.

3.5.1.1 Sub-Saharan Africa

Table 3.7 presents the results of the impacts of the household use of solid fuels on the entire population across the sub-Saharan African region, while Table 3.8 presents the country-level breakdown of the impacts in respect to each country within the region.

The results obtained in Table 3.7 demonstrate a negative link between the household use of solid fuels and all variables implying that in the case of sub-Saharan Africa, the household use of solid fuels reduces primary and seconday school enrolment; life expectancy and employment, across the region.

Starting with primary education; the results obtained suggest that households which rely on solid fuel use are less likely to enrol their children for primary education. From the analyses, a negative, statistically significant, link is observed between the household use of solid fuels and the rate of enrolment to primary education (for children within the appropriate school age).

Table 3.7: Impacts of household use of solid fuel in sub-Saharan Africa - general population

Variables	Models	
	Fixed effects	Fixed effects$^+$
Primary education	-0.0888	-0.0888**
[432]	(0.103)	(0.0402)
Secondary education	-0.7370**	-0.7370***
[224]	(0.556)	(0.200)
Life expectancy	-0.237***	-0.237***
[768]	(0.0693)	(0.0280)
Labour force	-0.0164	-0.0164
[752]	(0.0519)	(0.0122)
Employment	-0.119***	-0.119***
[752]	(0.0431)	(0.0148)

Robust standard errors in parentheses, (); Observations in square brackets, [];
$^+$ is Fixed effects with covariates; *** $p<0.01$, ** $p<0.05$, * $p<0.1$

The obtained result suggests that a unit increase in the household use of solid fuels by 1% could result in a decrease in the rate of enrolment in primary school by approximately 8.9%.

When considering enrolment to secondary education, similar to the results obtained in the global aggregate models, the impact is observed to be larger in comparison to the impact on primary education enrolment. At a 1% statistical significance level, the obtained coefficient implies that a 1% increase in the household use of solid fuels could result in a decrease in secondary school enrolment by about 7.3%.

For employment, results show that higher household use of solid fuels result in lower employment rates, as shown by the negative and statistically significant impact of 11.9% observed in the model. While for labour force participation, although a negative coefficient is observed, the coefficient is not statistically significant and thus, interpreted as insignificant.

The largest impact is observed in life expectancy, which has a statistically significant coefficient of -0.237. Thus implying that the household use of solid fuel is negatively and statistically linked to life expectancy.

Table 3.8: Impacts of household use of solid fuel in sub-Saharan Africa - general population, country-level.

	Variables				
	Primary	Secondary	Life	Force	Employment
fe	-0.0888**	-0.737***	-0.237***	-0.0164	-0.119***
	(0.0402)	(0.200)	(0.0262)	(0.0122)	(0.0148)
Benin	0.213***	-0.857***	-0.221***	-0.0765***	0.127***
	(0.0666)	(0.103)	(0.0250)	(0.0107)	(0.0129)
Botswana	0.126**	-0.0661	-0.0167	-0.199***	-0.264***
	(0.0548)	(0.237)	(0.0221)	(0.00916)	(0.0111)
Burkina Faso	-0.325***	0.0867	-0.163***	-0.0682***	0.104***
	(0.0659)	(0.104)	(0.0248)	(0.0106)	(0.0128)
Burundi	0.0173	-0.219	-0.172***	0.0419***	0.244***
	(0.0684)	(0.140)	(0.0255)	(0.0109)	(0.0132)
Cabo Verde	0.191***	0.178*	-0.178***	-0.179***	-0.184***
	(0.0655)	(0.105)	(0.0247)	(0.0105)	(0.0127)
Cameroon	-0.268***	0.267**	-0.115***	0.0252**	0.182***
	(0.0684)	(0.103)	(0.0234)	(0.00983)	(0.0119)
Central African Republic	-0.206***	-0.307**	-0.00288	-0.0608***	0.0862***
	(0.0586)	(0.119)	(0.0255)	(0.0109)	(0.0132)
Chad	-0.326***	-0.343***	-0.0695***	-0.0730***	0.130***
	(0.0539)	(0.103)	(0.0251)	(0.0107)	(0.0130)
Comoros	-0.0678	-0.120	-0.272***	-0.599***	-0.425***
	(0.0629)	(0.103)	(0.0251)	(0.0107)	(0.0130)
Congo, Dem. Rep.	-0.118*	-0.977***	-0.165***	-0.122***	0.0594***
	(0.0676)	(0.138)	(0.0250)	(0.0107)	(0.0129)
Congo, Rep.	-0.0969	-1.223***	-0.180***	-0.114***	-0.0840***
	(0.0670)	(0.103)	(0.0233)	(0.00983)	(0.0119)
Cote d'Ivoire	-0.0273	-0.0484	-0.0675***	-0.224***	-0.0802***
	(0.0619)	(0.111)	(0.0230)	(0.00964)	(0.0117)
Equatorial Guinea	-0.110	-0.599	-0.0970***	-0.245***	-0.144***
	(0.0681)	(0.419)	(0.0219)	(0.00905)	(0.0109)
Eritrea	0.0101	–	-0.238***	0.0311***	0.171***
	(0.0651)	–	(0.0241)	(0.0102)	(0.0123)
Eswatini	0.134**	–	-0.107***	-0.444***	-0.581***
	(0.0546)	–	(0.0212)	(0.00870)	(0.0105)
Ethiopia	-0.225***	–	-0.233***	0.0517***	0.246***
	(0.0682)	–	(0.0253)	(0.0108)	(0.0131)
Gabon	-0.0495	–	-0.0214	-0.491***	-0.599***
	(0.0512)	–	(0.0274)	(0.0119)	(0.0144)
Gambia	0.0698	–	-0.231***	-0.272***	-0.156***
	(0.166)	–	(0.0251)	(0.0107)	(0.0130)
Ghana	0.0763	–	-0.227***	-0.0891***	0.0519***
	(0.0670)	–	(0.0238)	(0.0101)	(0.0122)
Guinea	-0.456***	–	-0.172***	-0.170***	0.00733
	(0.0680)	–	(0.0254)	(0.0109)	(0.0132)
Guinea-Bissau	0.225***	–	-0.143***	-0.0653***	0.110***
	(0.0577)	–	(0.0254)	(0.0109)	(0.0131)
Kenya	-0.0860	–	-0.204***	-0.146***	-0.0337***
	(0.0527)	–	(0.0246)	(0.0105)	(0.0127)
Lesotho	0.0735	–	-0.0892***	-0.113***	-0.274***
	(0.0809)	–	(0.0220)	(0.00913)	(0.0110)
Liberia	0.154**	–	-0.212***	-0.319***	-0.122***

Continued on next page

	Primary	Secondary	Life	Force	Employment
	(0.0680)	–	(0.0255)	(0.0109)	(0.0132)
Madagascar	0.218***	–	-0.295***	0.126***	0.316***
	(0.0672)	–	(0.0254)	(0.0109)	(0.0132)
Malawi	0.125**	–	-0.112***	0.00223	0.149***
	(0.0604)	–	(0.0253)	(0.0108)	(0.0131)
Mali	–	–	-0.139***	-0.0855***	0.0490***
	–	–	(0.0254)	(0.0109)	(0.0132)
Mauritania	–	–	-0.184***	-0.487***	-0.427***
	–	–	(0.0212)	(0.00871)	(0.0105)
Mauritius	–	–	-0.120**	-0.317***	-0.429***
	–	–	(0.0535)	(0.0246)	(0.0297)
Mozambique	–	–	-0.107***	0.0761***	0.261***
	–	–	(0.0251)	(0.0107)	(0.0130)
Namibia	–	–	-0.0586***	-0.293***	-0.349***
	–	–	(0.0212)	(0.00872)	(0.0105)
Niger	–	–	-0.175***	0.0269**	0.234***
	–	–	(0.0254)	(0.0109)	(0.0131)
Nigeria	–	–	-0.0644**	-0.339***	-0.159***
	–	–	(0.0253)	(0.0108)	(0.0131)
Rwanda	–	–	-0.237***	0.0950***	0.306***
	–	–	(0.0255)	(0.0110)	(0.0132)
Sao Tome and Principe	–	–	-0.300***	-0.289***	-0.253***
	–	–	(0.0228)	(0.00953)	(0.0115)
Senegal	–	–	-0.208***	-0.450***	-0.354***
	–	–	(0.0216)	(0.00890)	(0.0108)
Seychelles	–	–	-0.00590	–	–
	–	–	(0.0423)	–	–
Sierra Leone	–	–	-0.00530	-0.214***	-0.0316**
	–	–	(0.0255)	(0.0109)	(0.0132)
Somalia	–	–	-0.138***	-0.507***	-0.445***
	–	–	(0.0254)	(0.0109)	(0.0132)
South Africa	–	–	-0.103***	-0.372***	-0.602***
	–	–	(0.0288)	(0.0126)	(0.0152)
South Sudan	–	–	-0.138***	-0.0465***	0.0350***
	–	–	(0.0255)	(0.0109)	(0.0132)
Sudan	–	–	-0.217***	-0.469***	-0.438***
	–	–	(0.0221)	(0.00920)	(0.0111)
Tanzania	–	–	-0.197***	0.115***	0.304***
	–	–	(0.0254)	(0.0109)	(0.0131)
Togo	–	–	-0.189***	0.0298***	0.229***
	–	–	(0.0252)	(0.0108)	(0.0130)
Uganda	–	–	-0.153***	-0.0880***	0.104***
	–	–	(0.0255)	(0.0109)	(0.0132)
Zambia	–	–	-0.0794***	0.00455	0.0876***
	–	–	(0.0234)	(0.00987)	(0.0119)
Zimbabwe	–	–	-0.0426**	0.0574***	0.189***
	–	–	(0.0216)	(0.00893)	(0.0108)

Robust standard errors in parentheses, ()

*** p<0.01, ** p<0.05, * p<0.1

Moving onto country-level results, Table 3.8 illustrates the effects of household use of solid fuels on the variables at country-level, using the fixed effects with covariates model.

For the education indicators; when considering primary education enrolment, the results obtained for the countries demonstrate that countries with high levels of household use of solid fuels would have low levels of primary school enrolment. In statistical terms, for such countries, statistically significant negative links are observed, while for the remaining countries, most demonstrate either statistically significant positive, or no correlation to household use of solid fuels. With coefficients of -0.456, -0.326 and -0.325, the largest impacts are observed to occur in Guinea, Chad and Burkina Faso, respectively, whilst the lowest impact is seen in Democratic Republic of Congo. For secondary education enrolment, across most countries, the impacts are observed to be greater, although only eight countries across sub-Saharan Africa, demonstrate statistically significant results.

With respect to life expectancy, the results across all countries except Central Africa Republic, Gabon, Botswana, Sierra Leone and Seychelles, suggest that the household use of solid fuels could be linked to reduced life expectancy. The obtained coefficients demonstrate negative, statistically significant correlation between the household use of solid fuels and life expectancy. The largest effects are observed in Comoros and Sao Tome and Principe, which had coefficients of -0.272 and -0.300, respectively whilst the lowest impact of household use of solid fuels on life expectancy is observed in Namibia.

For labour force participation, although the group fixed effects obtained is not statistically significant, the results obtained for most countries show statistically significant effects of solid fuel use on labour force participation. With the exception of Burundi; Cameroon; Eritea; Ethiopia; Madagascar; Mozambique; Niger; Rwanda; Tanzania and Togo which show positive correlation results, the results obtained across other countries indicate a negative correlation between the household solid fuel use and labour force participation.

Lastly, looking at employment rate, the obtained results are similar to labour force participation. All but one country demonstrate statistically significant correlations between household solid fuels use and employment. Although the obtained relationships vary between positive and negative associations.

In the context of the effects on the female population, at the regional level, Table 3.9 shows the results obtained from the three models.

Table 3.9: Impacts of household use of solid fuel in sub-Saharan Africa - female population

	Models		
Variables	Fixed effects	Fixed effects^{+}	Random effects
Life expectancy	-0.234***	-0.234***	-0.178***
[768]	(0.0696)	(0.0260)	(0.0315)
Labour force	-0.137**	-0.137***	-0.129
[752]	(0.0404)	(0.0168)	(0.0458)
Employment	-0.236***	-0.236***	-0.222***
[752]	(0.0649)	(0.0277)	(0.0626)

Robust standard errors in parentheses, (); Observations in square brackets, [];
$^{+}$ is Fixed effects with covariates; *** p<0.01, ** p<0.05, * p<0.1

The results show that in comparison to the general population, household use of solid fuels have larger effects on employment and labour force participation for the female population, but similar effects on life expectancy of the female population. To clarify, the effect of household use of solid fuels on labour force participation is seen to increase from 1.6% for the general population to 13.7% for the female population while the effect on employment is seen to increase from 11.9% for the general population to 23.6% for the female population.

Table 3.10: Impacts of household use of solid fuel in sub-Saharan Africa - female population, country-level

	Variables		
	Life	Force	Employment
fe	-0.234***	-0.137***	-0.236***
	(0.0260)	(0.0168)	(0.0277)
Benin	-0.197***	-0.0312**	0.179***
	(0.0248)	(0.0147)	(0.0168)
Botswana	-0.0121	-0.302***	-0.414***
	(0.0219)	(0.0126)	(0.0144)
Burkina Faso	-0.128***	-0.118***	0.0431***
	(0.0246)	(0.0146)	(0.0166)
Burundi	-0.153***	0.156***	0.376***

Continued on next page

	Life	Force	Employment
	(0.0253)	(0.0150)	(0.0172)
Cabo Verde	-0.178***	-0.282***	-0.343***
	(0.0245)	(0.0145)	(0.0166)
Cameroon	-0.0902***	0.0478***	0.217***
	(0.0232)	(0.0135)	(0.0154)
Central African Republic	-0.0147	-0.0534***	0.0907***
	(0.0253)	(0.0150)	(0.0172)
Chad	-0.0462*	-0.0940***	0.129***
	(0.0249)	(0.0148)	(0.0169)
Comoros	-0.251***	-0.704***	-0.532***
	(0.0249)	(0.0148)	(0.0169)
Congo, Dem. Rep.	-0.143***	-0.0540***	0.149***
	(0.0248)	(0.0147)	(0.0168)
Congo, Rep.	-0.151***	-0.0602***	-0.0353**
	(0.0231)	(0.0135)	(0.0154)
Cote d'Ivoire	-0.0494**	-0.393***	-0.239***
	(0.0228)	(0.0133)	(0.0151)
Equatorial Guinea	-0.0714***	-0.304***	-0.215***
	(0.0217)	(0.0124)	(0.0142)
Eritrea	-0.224***	0.0504***	0.182***
	(0.0239)	(0.0140)	(0.0160)
Eswatini	-0.0980***	-0.676***	-0.885***
	(0.0210)	(0.0120)	(0.0137)
Ethiopia	-0.211***	0.0678***	0.249***
	(0.0250)	(0.0149)	(0.0170)
Gabon	-0.0447*	-0.721***	-0.939***
	(0.0271)	(0.0163)	(0.0186)
Gambia	-0.204***	-0.342***	-0.259***
	(0.0249)	(0.0148)	(0.0169)
Ghana	-0.194***	-0.0341**	0.110***
	(0.0236)	(0.0139)	(0.0158)
Guinea	-0.130***	-0.0781***	0.101***
	(0.0252)	(0.0150)	(0.0171)
Guinea-Bissau	-0.137***	-0.0583***	0.124***
	(0.0252)	(0.0150)	(0.0171)
Kenya	-0.191***	-0.119***	0.00225
	(0.0244)	(0.0144)	(0.0165)
Lesotho	-0.0764***	-0.133***	-0.381***
	(0.0218)	(0.0126)	(0.0143)
Liberia	-0.188***	-0.262***	-0.0565***
	(0.0253)	(0.0150)	(0.0172)
Madagascar	-0.268***	0.206***	0.397***
	(0.0252)	(0.0150)	(0.0171)
Malawi	-0.115***	0.0500***	0.195***
	(0.0251)	(0.0149)	(0.0170)
Mali	-0.103***	-0.122***	-0.00999
	(0.0252)	(0.0150)	(0.0171)
Mauritania	-0.164***	-0.931***	-0.908***
	(0.0210)	(0.0120)	(0.0137)
Mauritius	-0.115**	-0.754***	-0.986***
	(0.0531)	(0.0338)	(0.0386)
Mozambique	-0.102***	0.177***	0.387***
	(0.0249)	(0.0148)	(0.0169)
Namibia	-0.0461**	-0.332***	-0.416***
	(0.0210)	(0.0120)	(0.0137)

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	Life	Force	Employment
Niger	-0.143***	-0.0169	0.197***
	(0.0252)	(0.0150)	(0.0171)
Nigeria	-0.0323	-0.376***	-0.167***
	(0.0251)	(0.0149)	(0.0170)
Rwanda	-0.212***	0.187***	0.415***
	(0.0253)	(0.0151)	(0.0172)
Sao Tome and Principe	-0.284***	-0.519***	-0.617***
	(0.0226)	(0.0131)	(0.0150)
Senegal	-0.186***	-0.748***	-0.691***
	(0.0214)	(0.0122)	(0.0140)
Seychelles	-0.0128	–	–
	(0.0419)	–	–
Sierra Leone	-0.0268	-0.111***	0.0825***
	(0.0253)	(0.0151)	(0.0172)
Somalia	-0.120***	-1.344***	-1.311***
	(0.0252)	(0.0150)	(0.0171)
South Africa	-0.0989***	-0.510***	-0.849***
	(0.0286)	(0.0173)	(0.0198)
South Sudan	-0.112***	0.0297**	0.0947***
	(0.0253)	(0.0150)	(0.0172)
Sudan	-0.199***	-1.082***	-1.146***
	(0.0220)	(0.0126)	(0.0144)
Tanzania	-0.180***	0.191***	0.383***
	(0.0252)	(0.0149)	(0.0171)
Togo	-0.153***	0.122***	0.331***
	(0.0249)	(0.0148)	(0.0169)
Uganda	-0.144***	-0.0571***	0.136***
	(0.0252)	(0.0150)	(0.0171)
Zambia	-0.0733***	0.00622	0.117***
	(0.0232)	(0.0136)	(0.0155)
Zimbabwe	-0.0548**	0.0396***	0.189***
	(0.0215)	(0.0123)	(0.0140)

Robust standard errors in parentheses, ()

*** p<0.01, ** p<0.05, * p<0.1

Table 3.10 shows the results of the impacts on the female population, at country-levels, using the fixed effects with covariates model. Looking at country-level effects, starting with life expectancy, similar to the results obtained for the general population, across all countries except Botswana, Central Africa Republic, Gabon, Nigeria Sierra Leone and Seychelles, the household use of solid fuels is observed to be linked to reduced life expectancy in the female population. This is demonstrated by the negative, statistically significant relationship between household solid fuels use and life expectancy observed in the countries.

In connection with labour force participation and employment rates, although with larger coefficients, again, results similar to those obtained for the general population are observed. Some countries such as Malawi and Zimbabwe demonstrate that the household use of solid fuels is associated with increased employment rates and labour force participation for the female population .i.e. have positive, statistically significant relationships. While on the other hand, other countries such as Cabo Verde and Namibia demonstrate that the household use of solid fuels is associated with reduced employment rates and labour force participation (negative, statistically significant effects).

3.5.1.2 East Asia and Pacific

Table 3.11 shows the impacts of household use of solid fuels on the general population in the context of east Asia - at the regional level. The first three variables are observed to have statistically significant relationships with household use of solid fuels whilst the last two variables show no statistically significant relationship to household use of solid fuels.

Table 3.11: Impacts of household use of solid fuel in east Asia - general population

	Models	
Variables	Fixed effects	Fixed effects$^+$
Primary education	-0.0590*	-0.0590***
[176]	(0.0280)	(0.0115)
Secondary education	-0.554**	-0.554***
[112]	(0.171)	(0.0824)
Life expectancy	-0.117***	-0.117***
[400]	(0.0381)	(0.0151)
Labour force	0.0230	0.0230
[368]	(0.0370)	(0.0145)
Employment	-0.00505	-0.00505
[368]	(0.0392)	(0.0136)

Robust standard errors in parentheses, (); Observations in square brackets, [];
$^+$ is Fixed effects with covariates; *** p<0.01, ** p<0.05, * p<0.1

For enrolment in primary education, the obtained results indicate that an increase of 1% in the household use of solid fuels could result in a decrease of 5.9% in primary education enrolment, while the results for secondary education suggests an associated decrease of approximately 55% in education enrolment.

With regard to life expectancy, negative statistically significant results are also obtained, indicating that if the use of solid fuels increases, life expectancy could decrease.

Lastly, the results for labour force participation and employment show no statistically significant outcomes, which means that in the context of east Asia, the household use of solid fuels does not have any statistically impact on the labour force participation and/or employment rate of the general population.

Table 3.12: Impacts of household use of solid fuel in east Asia - general population, country-level.

	Variables				
	Primary	Secondary	Life	Force	Employment
fe	-0.0590***	-0.554***	-0.117***	0.0230	-0.00505
	(0.0115)	(0.0824)	(0.0151)	(0.0145)	(0.0136)
Brunei Darussalam	-0.257**	-0.965***	-0.0883***	0.0310*	0.0229
	(0.0992)	(0.348)	(0.00746)	(0.0166)	(0.0169)
Cambodia	-0.255***	-0.744***	-0.296***	0.142	0.310**
	(0.0920)	(0.106)	(0.0547)	(0.122)	(0.124)
China	-0.0203*	-0.066**	-0.355***	0.0277	0.147
	(0.0931)	(0.375)	(0.0469)	(0.104)	(0.106)
Fiji	-0.0953***	-0.599***	-0.289***	-0.191*	-0.0597
	(0.0296)	(0.117)	(0.0507)	(0.113)	(0.115)
Indonesia	0.160	-0.746***	-0.322***	-0.0751	0.0367
	(0.100)	(0.371)	(0.0513)	(0.114)	(0.116)
Japan	-0.0962	0.0859*	-0.0162**	-0.0655***	-0.0546***
	(0.0325)	(0.337)	(0.00746)	(0.0166)	(0.0169)
Kiribati	-0.204**	–	-0.317***	–	–
	(0.0933)	–	(0.0556)	–	–
Korea, Rep.	-0.203**	–	-0.118***	-0.0779**	-0.0232
	(0.0992)	–	(0.0165)	(0.0366)	(0.0372)
Lao PDR	-0.182**	–	-0.279***	0.0911	0.264**
	(0.0903)	–	(0.0553)	(0.123)	(0.125)
Malaysia	-0.0237***	–	-0.0683***	-0.0791**	-0.0177
	(0.0902)	–	(0.0180)	(0.0401)	(0.0408)
Micronesia, Fed. Sts.	–	–	-0.319***	–	–
	–	–	(0.0545)	–	–
Mongolia	–	–	-0.292***	-0.179	-0.0647
	–	–	(0.0514)	(0.114)	(0.116)
Myanmar	–	–	-0.269***	-0.0438	0.129
	–	–	(0.0547)	(0.122)	(0.124)
New Zealand	–	–	-0.0117	0.0359**	0.0381**
	–	–	(0.00746)	(0.0166)	(0.0169)
Papua New Guinea	–	–	-0.247***	-0.248**	-0.0898
	–	–	(0.0547)	(0.122)	(0.124)
Philippines	–	–	-0.325***	-0.133	0.00155
	–	–	(0.0497)	(0.111)	(0.112)
Samoa	–	–	-0.369***	-0.778***	-0.663***
	–	–	(0.0522)	(0.116)	(0.118)
Singapore	–	–	-0.00744	0.0180	0.0286*

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	Primary	Secondary	Life	Force	Employment
	–	–	(0.00746)	(0.0166)	(0.0169)
Solomon Islands	–	–	-0.381***	0.00781	0.170
	–	–	(0.0550)	(0.122)	(0.124)
Thailand	–	–	-0.290***	0.0365	0.175*
	–	–	(0.0411)	(0.0914)	(0.0929)
Timor-Leste	–	–	-0.311***	-0.439***	-0.290**
	–	–	(0.0554)	(0.123)	(0.125)
Tonga	–	–	-0.300***	-0.166	-0.0241
	–	–	(0.0465)	(0.104)	(0.105)
Vanuatu	–	–	-0.358***	-0.0202	0.100
	–	–	(0.0543)	(0.121)	(0.123)
Vietnam	–	–	-0.392***	0.0740	0.226**
	–	–	(0.0497)	(0.111)	(0.112)

Robust standard errors in parentheses, ()

*** p<0.01, ** p<0.05, * p<0.1

Table 3.12 shows these results at the country-levels (using the fixed-effects with covariates model). For primary education, for Indonesia and Japan, the results obtained show no statistically significant effects while the result obtained for China is only significant at 10% significance level. This means that for these countries, the effects of the household use of solid fuels on primary education enrolment, are not statistically significant. Thus, implying that in the case of these countries, household use of solid fuels does not play a significant role on enrolment to primary education. However, for the other seven countries, namely Brunei Darussalam; Cambodia; Fiji; Kiribati; Korea; Lao PDR and Malaysia, the results suggest that household use of solid fuels is associated with reduced enrolment to primary education. For these countries, statistically significant, negative effects on primary education enrolment rates are observed - with the highest impact observed in Cambodia and the lowest impact seen in Malaysia. With reference to secondary education enrolment, the results from all countries except Japan, suggest that household use of solid fuels is associated with reduced enrolment to secondary education. The results show a statistically significant negative relationship with household use of solid fuels.

Looking at life expectancy, the results indicate that with the exception of New Zealand and Singapore which show no statistically significant association, across all other countries, the household use of solid fuels and life expectancy are negatively and statistically significantly related with each other. These results are similar to the case of sub-Saharan Africa and suggest that the household use of solid fuels is associated with reduced life expectancy. The largest impacts on life expectancy are observed in Vietnam, Solomon Islands and China, while the lowest effects are observed in Singapore and new Zealand.

Lastly, in the context of labour force participation and employment rates, statistically significant effects are observed in only seven countries. For labour force participation, the associated coefficients for the seven countries are observed to be negative: indicating that as the household use of solid fuels increases, the labour force participation decreases. In the case of employment rates, four of the seven statistically significant coefficients are positive implying that for those four countries, an increase in household use of solid fuels is associated with increases in employment rates, whilst the remaining three countries have negative coefficients, implying that solid fuel use is associated with decreases in employment rates.
For both variables, the largest effects are observed in Samoa, while the lowest effects are observed in Japan.

Table 3.13: Impacts of household use of solid fuel in east Asia - female population

	Models		
Variables	Fixed effects	Fixed effects^{+}	Random effects
Life expectancy	-0.119***	-0.119***	-0.0544***
[400]	(0.0390)	(0.0120)	(0.0082)
Labour force	-0.0188	-0.0188	-0.0134
[368]	(0.0456)	(0.0187)	(0.0257)
Employment	-0.0494*	-0.0494**	-0.0268*
[368]	(0.0545)	(0.0218)	(0.0333)

Robust standard errors in parentheses, (); Observations in square brackets, [];
$^{+}$ is Fixed effects with covariates; *** p<0.01, ** p<0.05, * p<0.1

Turning to the effects on the female population, Table 3.13 presents the results obtained at the regional level. From Table 3.13, it can be observed that the household use of solid fuels does not statistically, significantly, affect the participation of the female population in labour force. The result shows that the null hypothesis of no correlation can not be rejected at 10% or 5%, for the female labour force participation.

With regard to employment, the result suggests that there might be some significant correlation with household use of solid fuels. This is evidenced by the fact that the null hypothesis of no correlation can not be rejected at 5% but can be rejected at 10% for the variable. Lastly, Table 3.13 shows that there is a strong statistically significant association between household use of solid fuels and female life expectancy. The results obtained show that an increase in solid fuels use would result in a slightly higher (in comparison to the general population) decrease in female life expectancy.

Table 3.14: Impacts of household use of solid fuel in east Asia - female population, country-level

	Variables		
	Life	Force	Employment
fe	-0.119***	-0.0188	-0.0494**
	(0.0120)	(0.0187)	(0.0218)
Brunei Darussalam	-0.102***	-0.149***	-0.0366*
	(0.00743)	(0.0200)	(0.0202)
Cambodia	-0.309***	0.250*	0.579***
	(0.0544)	(0.147)	(0.148)
China	-0.362***	0.114	0.343***
	(0.0467)	(0.126)	(0.127)
Fiji	-0.294***	-0.451***	-0.178
	(0.0505)	(0.136)	(0.137)
Indonesia	-0.329***	-0.218	0.0372
	(0.0511)	(0.138)	(0.139)
Japan	-0.0279***	-0.101***	-0.150***
	(0.00743)	(0.0200)	(0.0202)
Kiribati	-0.350***	–	–
	(0.0553)	–	–
Korea, Rep.	-0.134***	-0.209***	-0.0530
	(0.0164)	(0.0442)	(0.0445)
Lao PDR	-0.288***	0.256*	0.571***
	(0.0551)	(0.149)	(0.150)
Malaysia	-0.0719***	-0.337***	-0.151***
	(0.0180)	(0.0485)	(0.0488)
Micronesia, Fed. Sts.	-0.324***	–	–
	(0.0542)	–	–
Mongolia	-0.330***	-0.115	0.141
	(0.0512)	(0.138)	(0.139)
Myanmar	-0.300***	-0.0685	0.226
	(0.0544)	(0.147)	(0.148)
New Zealand	-0.0153**	0.0283	0.0484**
	(0.00743)	(0.0200)	(0.0202)
Papua New Guinea	-0.251***	-0.112	0.216
	(0.0544)	(0.147)	(0.148)
Philippines	-0.360***	-0.251*	0.0416
	(0.0495)	(0.134)	(0.134)
Samoa	-0.384***	-0.890***	-0.660***
	(0.0520)	(0.140)	(0.141)
Singapore	-0.00788	-0.119***	-0.0371*
	(0.00743)	(0.0200)	(0.0202)
Solomon Islands	-0.386***	0.0191	0.359**
	(0.0547)	(0.148)	(0.149)
Thailand	-0.317***	0.0863	0.328***
	(0.0409)	(0.110)	(0.111)
Timor-Leste	-0.318***	-0.721***	-0.416***
	(0.0552)	(0.149)	(0.150)
Tonga	-0.302***	-0.299**	-0.0292
	(0.0463)	(0.125)	(0.126)
Vanuatu	-0.361***	-0.0200	0.273*
	(0.0541)	(0.146)	(0.147)
Vietnam	-0.427***	0.201	0.464***
	(0.0495)	(0.134)	(0.134)

Robust standard errors in parentheses, ();
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

The effects on the female populations at country-levels are analysed using the fixed effects with covariates model, and presented in Table 3.14. Similar to the results obtained for the general population, with the exception of Singapore, the household use of solid fuels is seen to be associated with reduced life expectancy for the female population. With the exception of Singapore, the effects of household use of solid fuels on female life expectancy is observed to be negative and statistically significant across all countries: with the largest effects observed in Vietnam, Solomon Islands and Samoa, and the lowest effect observed in New Zealand.

With regard to labour force participation, the obtained results show statistically significant relationship with household solid fuels use for only nine of the countries, while for employment rates, statistically significant effects are observed in only eleven countries. For both variables, similar to the results obtained for the general population, the largest effects are observed in Samoa, while the lowest effects are observed in Japan.

On a whole, for both variables, the results show that countries with high levels of household use of solid fuels experience lower levels of employment and labour force participation, lower life expectancy and lower education enrolment.

3.5.1.3 South Asia

The results of the impacts of household use of solid fuels, in the case of the south Asian region are presented in Table 3.15 - for the regional level.

Before proceeding to examine the results, it is important to highlight that although the results obtained show statistically significant effects of household solid fuel use, due to the limited data used for these analyses, the following results must be interpreted with caution.

From Table 3.15, it can be observed that in the case of south Asia, the household use of solid fuels is strongly negatively correlated with all the indicators. This implies that an increase in household solid fuels use could result in a decrease in primary education enrolment rates (by 9%); secondary education enrolment rates (by 23.8%); life expectancy (by 6.6%); labour force participation (by 8.3%) and employment rates by (6.9%).

Table 3.15: Impacts of household use of solid fuel in south Asia - general population

	Models	
Variables	Fixed effects	Fixed effects^{+}
Primary education	-0.0905**	-0.0905***
[64]	(0.278)	(0.0842)
Secondary education	-0.238**	-0.238***
[48]	(0.084)	(0.027)
Life expectancy	-0.0661**	-0.0661***
[128]	(0.0265)	(0.0111)
Labour force	-0.0833***	-0.0833***
[128]	(0.0160)	(0.00687)
Employment	-0.0690***	-0.0690***
[128]	(0.0144)	(0.00581)

Robust standard errors in parentheses, (); Observations in square brackets, [];
$^{+}$ is Fixed effects with covariates; *** p<0.01, ** p<0.05, * p<0.1

The effects at the country-levels are presented in Table 3.16. However, due to lack of data, only three of south Asia countries have been included in the analyses for primary education enrolment, while only two have been included when considering the secondary school enrolment.

Table 3.16: Impacts of household use of solid fuel in south Asia - general population, country breakdown

	Variables				
	Primary	Secondary	Life	Force	Employment
fe	-0.0905***	-0.238***	-0.0661***	-0.0833***	-0.0690***
	(0.0842)	(0.027)	(0.0111)	(0.00687)	(0.00581)
Bangladesh	-0.313***	-0.169***	-0.147***	-0.110***	-0.126***
	(0.0246)	(0.0808)	(0.00970)	(0.00907)	(0.00812)
Bhutan	-0.0682***	-0.032***	-0.0842***	0.0380***	0.0414***
	(0.0238)	(0.0571)	(0.0102)	(0.00956)	(0.00856)
India	-0.547***	–	-0.0835***	-0.156***	-0.155***
	(0.0339)	–	(0.00981)	(0.00918)	(0.00822)
Maldives	–	–	-0.139***	-0.162***	-0.154***
	–	–	(0.0151)	(0.0142)	(0.0127)
Nepal	–	–	-0.104***	0.269***	0.280***
	–	–	(0.00968)	(0.00905)	(0.00810)
Pakistan	–	–	-0.0681***	-0.233***	-0.216***
	–	–	(0.00984)	(0.00920)	(0.00824)
Sri Lanka	–	–	-0.224***	-0.142***	-0.180***
	–	–	(0.00968)	(0.00905)	(0.00810)

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

Starting with the primary education enrolment rate: across all three countries, it is

observed that the household use of solid fuels is associated with reduced enrolment rates of children - since negative and statistically significant relationships are observed for the countries. The largest effect is observed in India while the lowest is observed in Bhutan.
Looking at the secondary education enrolment rate, for both Bangladesh and Bhutan, a strong link between household use of solid fuels and secondary enrolment rate is observed since the hypothesis of no correlation can be strongly rejected at 1%. Considering the negative coefficients, this means that as household use of solid fuels increases, secondary education enrolment in these countries would decrease.

With regard to life expectancy, similar to sub-Saharan Africa and east Asia, the results suggest that household use of solid fuels is associated with reduced life expectancy across all countries. This is evidenced by the coefficients which are observed to be negative and statistically significant across all countries. The largest effects are observed in Sri-Lanka and Bangladesh, while the lowest effect is observed in Pakistan.

For labour force participation and employment, all coefficients are observed to be statistically significant. In Nepal and Bhutan, the results suggest that increase in household use of solid fuels in these countries could result in an increase in labour force participation, and employment rates in these countries. This is evidenced by the obtained coefficients for these countries, which are observed to be positively correlated with household use of solid fuels. On the other hand, for the other five countries, the obtained results show that an increase in household use of solid fuels could result in a decrease in labour force participation and employment rates, in these countries.

Moving on now to consider the effects in the context of the female population, Table 3.17 presents the effects observed across the female population at the regional level.

Table 3.17: Impacts of household use of solid fuel in south Asia - female population

	Models		
Variables	Fixed effects	Fixed effects^{+}	Random effects
Life expectancy	-0.0689**	-0.0689***	-0.0691***
[128]	(0.0268)	(0.00849)	(0.0261)
Labour force	-0.114***	-0.114***	-0.114***
[128]	(0.0302)	(0.0148)	(0.0302)
Employment	-0.0842**	-0.0842***	-0.0842***
[128]	(0.0277)	(0.0122)	(0.0144)

Robust standard errors in parentheses, (); Observations in square brackets, [];
$^{+}$ is Fixed effects with covariates; *** p<0.01, ** p<0.05, * p<0.1

Table 3.17 shows that for all three variables, there exists negative, statistically significant relationships between the household use of solid fuels and the variables. A 1% increase of household use of solid fuels is observed to have a 6.9% reduction in female life expectancy; 11.4% reduction in female labour force participation, and 8.4% reduction in female employment rate. In addition, when compared to the results from the general population, these results indicate that in the case of south Asia, the household use of solid fuels has a greater effect on the females population.

Table 3.18: Impacts of household use of solid fuel in south Asia - female population, country breakdown

	Variables		
	Life	Force	Employment
fe	-0.0689***	-0.114***	-0.0842***
	(0.00849)	(0.0148)	(0.0122)
Bangladesh	-0.141***	-0.394***	-0.438***
	(0.00995)	(0.0278)	(0.0255)
Bhutan	-0.0638***	0.310***	0.310***
	(0.0105)	(0.0293)	(0.0269)
India	-0.0748***	-0.455***	-0.479***
	(0.0101)	(0.0281)	(0.0258)
Maldives	-0.131***	-0.179***	-0.161***
	(0.0155)	(0.0434)	(0.0399)
Nepal	-0.100***	0.610***	0.618***
	(0.00992)	(0.0277)	(0.0255)
Pakistan	-0.0590***	-0.816***	-0.805***
	(0.0101)	(0.0282)	(0.0259)
Sri Lanka	-0.247***	-0.140***	-0.268***
	(0.00992)	(0.0277)	(0.0255)

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

Lastly, the effects on the female population at the country-levels are presented in

Table 3.18. For all three variables and across all the countries, statistically significant links are observed. In the case of life expectancy, across all countries, the obtained coefficients demonstrate a negative correlation between household use of solid fuels and life expectancy: meaning that as household use of solid fuel grows, life expectancy of the households could reduce.
With respect to labour force participation and employment rate, similar results to those obtained for the general population are observed. In Nepal and Bhutan, positive relationships are observed, while for the other countries, negative relationships are observed.

3.6 Discussion

Many countries in the developing world are in need of sustainable development. In literature, energy poverty has been suggested as an obstacle to the needed development in the developing world. An aspect of the energy poverty phenomenon is the lack of access to clean cooking fuels. The issue of lack of access to clean cooking fuel and thus, reliance on solid fuels for cooking remains a reality for billions of households across many developing countries. As such, in this Chapter, I set out seeking to fill a significant gap in literature, by exploring one key research question:

> how does this issue impact on the social dimension of sustainable development?

The statistical analyses in this chapter are the first quantitative analyses which focus on understanding the dynamics between this aspect of energy poverty and elements of social development. To this effect, the empirical evidences of the relationships between the household use of solid fuels and aspects of social development have been examined in this Chapter: using panel data for the period of 2000 to 2015, for *forty-six* sub-Saharan Africa; *seven* South Asian as well as *twenty-four* East Asian and Pacific countries.
For this purpose, primary and secondary school enrolment rates; life expectancy; labour force participation rates and employment rates were used as variables for the analyses while the fixed and random effects models were applied. The analyses were performed at a global level using global aggregate data, as well as, at regional and country levels,

using regional and country-level data. In addition, owing to studies which suggest that impacts of energy accessibility might be more prominent in female populations, the effects of household use of solid fuels on these variables have also been examined for the female only population.

The results obtained from the global analyses have shown that the household use of solid fuels is strongly, negatively correlated with the investigated variables while the results obtained from the different regional investigations have been varied. Generally speaking, although statistically significant relationships were observed in most countries investigated, the degree and nature of the correlation have been heterogeneous and in some cases, contradictory.

Moving on to panel and country-level analyses, starting with the primary education enrolment: across all regions, the obtained panel results show statistically significant negative association with household use of solid fuels while at country-level, some countries showed no association between the two variables. In substantive terms, the results from the panel analyses and the significantly influenced countries indicate that if household use of solid fuels grow, the primary education enrolment rate for children within the school-age group decreases. These results do not only confirm the speculations in previous reports such as those from the World Bank and IEA, but also provide quantitative evidence to these qualitative studies. These reports have claimed that the tasks of solid-fuels gathering and processing which often fall on children cause less free-time which can otherwise be used for pursuing productive alternatives [14], [27]. When the impacts on secondary education are considered, the results show the effects to be more severe. One could anticipate that this might be the case due to the fact that in most cases, older children would be assigned the task of travelling to gather fuels, as well as, helping with meal preparations.
The significance of these obtained results are consequential. One can argue that the considerable decline in the likelihood of the enrolment of children in schools can be anticipated to bring about factors such as prominent illiteracy, deficit of educated professionals in the labour force, to name a few, which all act as determinants to lack of socio-economic development.

For labour force participation, in terms of the regional analyses, only the south Asian region showed significant association to household use of solid fuels while for employment rates, only the east Asian region showed no significant association between the variables. For both variables, the results obtained from the country-level analyses varied, with some countries showing no statistically significant association, some countries showing positive association while some countries showed negative association between the variables. This findings suggest that in some countries, the household use of solid fuels plays no significant roles on both variables, while in some countries, the household use of solid fuels causes a decline in employment rates and labour force participation. Lastly, for countries with positive association, the results suggest that an increase in household solid fuels use could increase employment rates and labour force participation. This positive association can be explained in the case of countries such as Zimbabwe and Nepal, where obtainment and preparation of solid fuels such as coal and fuel-wood, creates unskilled jobs for the local population (especially in rural areas).

Life expectancy had the strongest link with household use of solid fuels both across countries and over time (within the individual countries). Unlike other variables where some countries produced statistically non-significant results, the results obtained for all the countries examined showed strong negative associations with household use of solid fuels. These results confirm the various reports from the WB and the IEA which claim that indoor smoke inhalation is one of the primary causes of pneumonia and heart diseases, which are among the leading causes of the global burden of diseases and death [14]. Indeed, household air pollution is estimated to be responsible for approximately four million deaths per year: causing more deaths than malaria, HIV/AIDS and tuberculosis. Therefore the weightiness of these obtained results is quite significant.

Literature suggests that the tasks of fuel-gathering and cooking is mainly carried out by women and children and as such, the burdens of the effects of household use of solid fuels might be larger on women and children. The results that have been obtained from the female population-based analyses are in agreement. Using the results obtained from the regional analyses: for life expectancy, the results show that for east Asia and south Asia, the impacts on life expectancy are higher in females than in the general population. In terms of labour force participation, with the exception of east Asia where no statistical association was observed, stronger and larger effects were observed in the results obtained. For employment, across all regions, larger and stronger effects on female employment rates were also observed.

In sum, the results from this chapter provide a quantitative complement to the existing, mostly qualitative contributions in the literature. The results have shown that a strong interactive relationship exists between household use of solid fuels and aspects of social development, in most of the countries studied herein. These results reveal the significance of this phenomenon on a key dimension of sustainable development: social development. Therefore, from the perspective of policy-making, this study points to policy areas where governments should take actions with the goal of reducing household use of solid fuels. I consider more attention for and a better understanding of the dynamics of household use of solid fuels in developing countries are essential components of strategies to increase access to modern cooking alternatives for the impoverished. For example, a potential starting point for tackling the issue could be the establishment of adequate and comprehensive national databases. To clarify, the extensive lack of data on most indicators of sustainable development as well as household energy patterns, means that extensive analyses at country, regional, as well as local levels, are hindered. Therefore, adequate energy policies cannot be advised or designed. In fact, without these comprehensive data, crucial energy-planning inputs such as the national energy demands for these countries can not be adequately estimated. In terms of cooking energy sources specifically, without data showing the stove types used by households; fuel types utilised for cooking; cost components; to name a few, an adequate understanding of the problem would be impossible. Furthermore, such data on potential fuel sources; stove types; cost analyses; estimates of the ability and willingness to pay, as a function of income; could provide policy-makers with crucial details necessary for the development of more efficacious policies which could address the very high inaccessibility figures.

Finally, following these findings which have shown that household use of solid fuels is associated with the social dimension of sustainable development, in the next chapter, the impact of the household use of solid fuels on the economic dimension of sustainable development is investigated, for the regions that have been explored within this chapter.

3.7 Summary of key findings

The results from the panel analyses show that the relationship between household use of solid fuels and the measures of social development vary for all three regions: sub-Saharan Africa, south Asia and east Asia.

For life expectancy, the results obtained demonstrated strong association with households use of solid fuels across all three regions and show that household use of solid fuels reduces life expectancy.

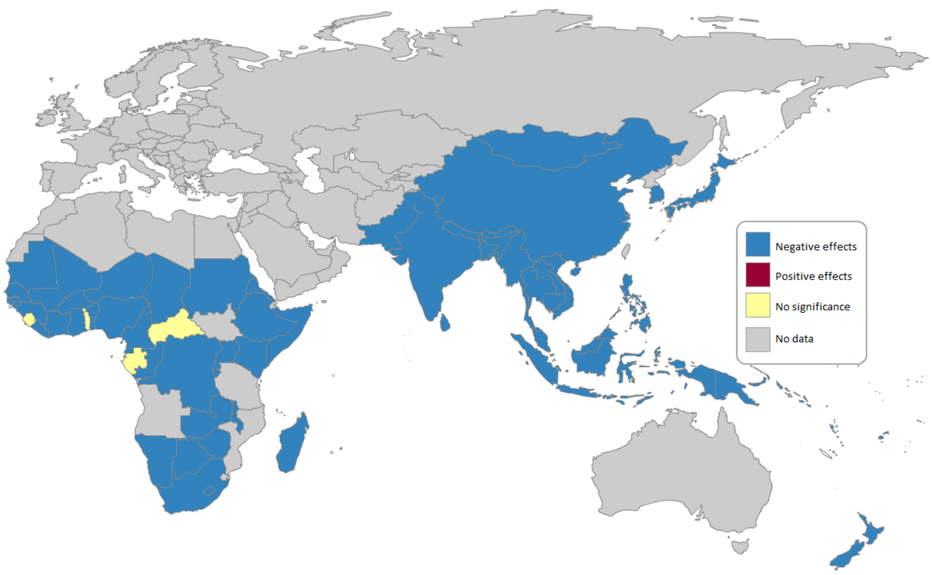


Figure 3.5: Map showing effect of household use of solid fuels on life expectancy across the regions

For education: for primary education, the results show that household use of solid fuels is strongly associated with lower proportions of children attending primary education while the result obtained for effects on secondary eduction enrolment rates shows similar (although with larger magnitude) outcomes to the results obtained for primary education enrolment rates.

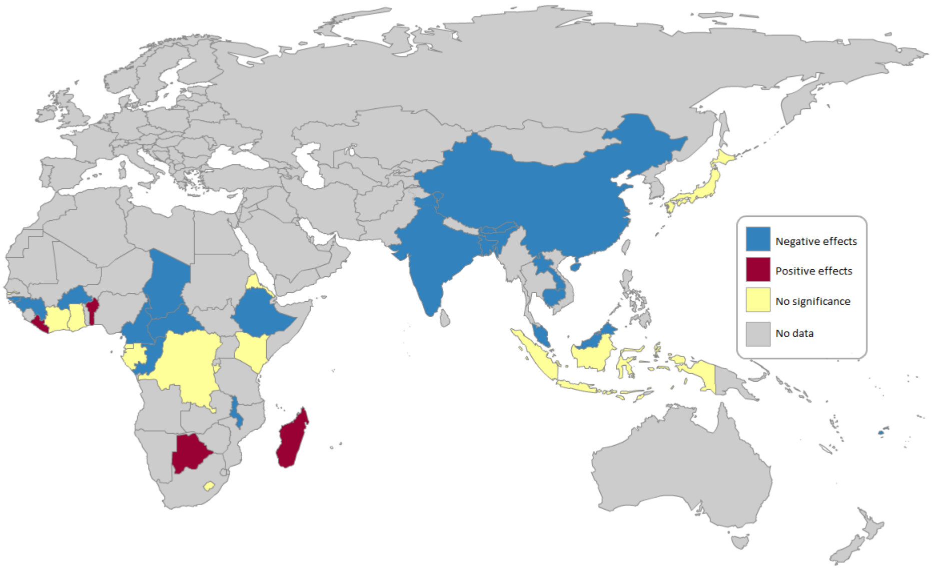


Figure 3.6: Map showing effect of household use of solid fuels on primary education across the regions

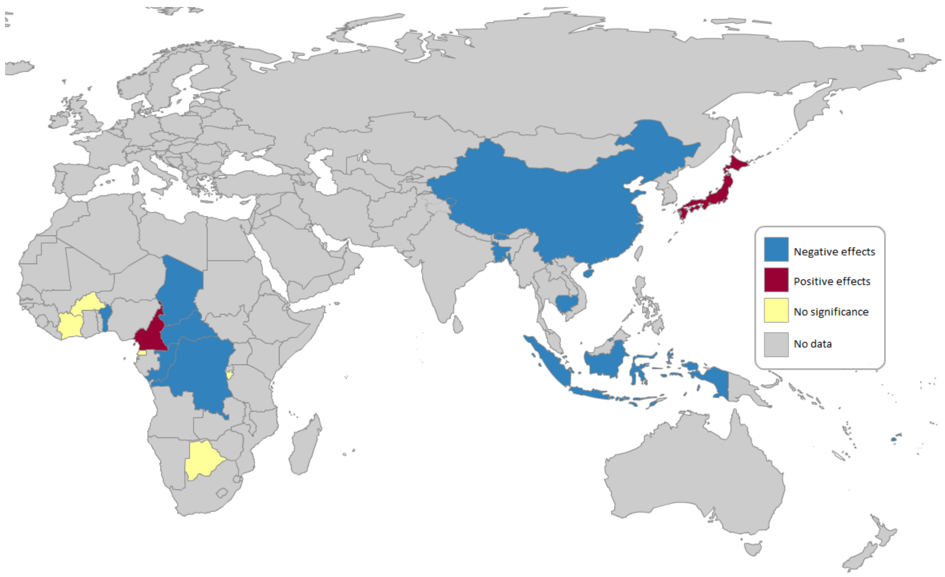


Figure 3.7: Map showing effect of household use of solid fuels on secondary education across the regions

For employment and labour force participation, for sub-Saharan Africa and south Asia, the results show that household use of solid fuels is associated to these variables, while no significant association was observed for east Asia.

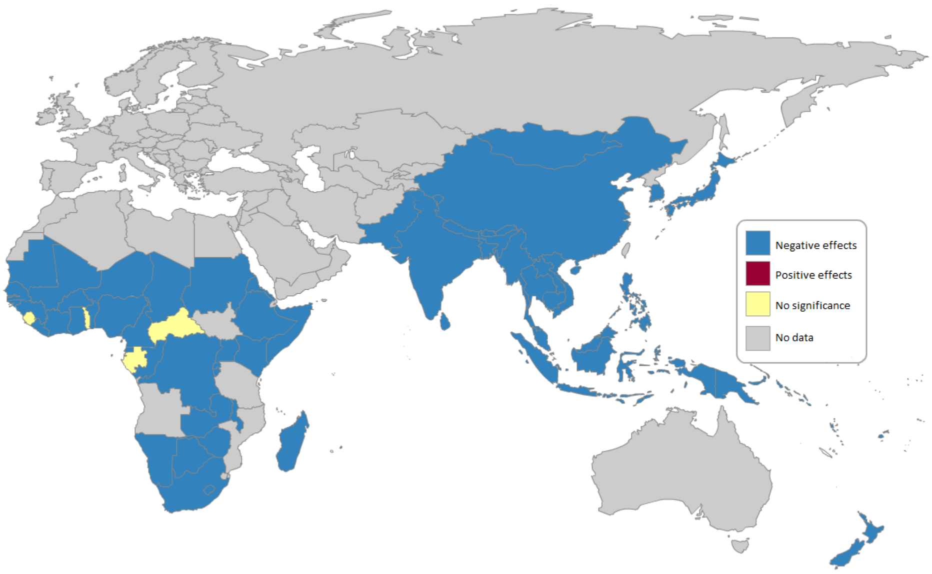


Figure 3.8: Map showing effect of household use of solid fuels on labour force participation across the regions

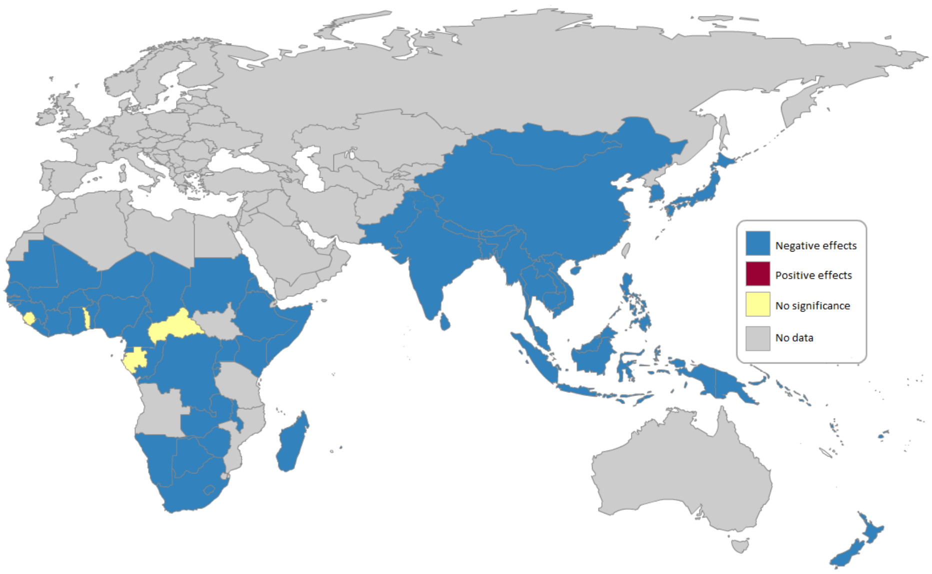


Figure 3.9: Map showing effect of household use of solid fuels on employment across the regions

These impacts were also investigated in the context of the female population. With the exception of female life expectancy in sub-Saharan Africa, which showed no significant difference to the results obtained for the general population; the results obtained for all variables across the three regions, indicated that the effects of household use of solid fuels are greater and more significant in the female population.

Lastly, at country-level, the results obtained are diversified across the countries (figures 3.5 to 3.9): some countries have exhibited strong association (positive or negative) between the examined variables whilst others have shown that no significant correlation exist between the variables.

In conclusion, the results obtained from these analyses have indicated that the household use of solid fuels is significantly associated with aspects of social development for most countries in the regions. In addition, these results confirm that these effects are more significant on children and women - the portion of the population mainly responsible for the tasks of cooking and fuel-gathering.

Chapter 4

Impacts on economic development

This chapter answers question 'Q4' of the research sub-questions outlined in section 1.1: "what is the impact of the phenomenon on the economic dimension of sustainable development". Using a five step panel cointegration approach, it analyses and establishes the nature and direction of the causal relationship between the household use of solid fuels and economic development: in both the long-run and the short-run, for all three regions. This chapter establishes the first solidfuel-growth nexus hypothesis for the investigated regions.

4.1 Introduction

In Chapter 3, the impacts of household consumption of solid fuels on measures of the social dimension of sustainable development were investigated and established. The results obtained from Chapter 3 demonstrated that household use of solid fuels for cooking had significant impacts on measures of social development in the sub-Saharan Africa, east Asia and south Asia regions.

Motivated by the discovery of the significant impacts of household use of solid fuels on social development, this Chapter seeks to examine the impacts of household use of solid fuels for cooking, with respect to the economic dimension of sustainable development, for each of the regions investigated in Chapter 3. The analyses in this chapter address a significant research gap identified in literature, and contribute to existing literature by presenting the first quantitative analyses which explore the dynamics between the household use of solid fuels and economic development. As far as is known, there are currently no studies investigating the explicit link between household use of solid fuels and economic development. Similar to Chapter 3, the analyses performed within this Chapter are in the context of sub-Saharan Africa, east Asia and south Asia. Using the data from these regions, for the period of two decades, and applying panel co-integration and causality models, we explore this relationship asking the research question:

How does household use of solid fuels influence economic development in these regions?

Following the review of literature on energy-growth nexus, we recast this research question and ask:

Based on the energy-growth hypothesis in literature, what are the potential causal hypotheses reflected in the dynamics between the household use of solid fuels and economic development?

To this effect, the GDP per Capita is used in these analyses as the explanatory variable for economic growth. The panel co-integration and causality methods used in this Chapter adapt five stages of analyses to draw conclusive evidences of the dynamic between household use of solid fuels and economic development, in both the long-run and short-run.

The conclusions derived from the results varied across the three regions investigated, as well as, varied depending on the long-run or short-run perspectives.
For sub-Saharan Africa, in both the long-run and the short-run, the results demonstrate that the dynamics between the household use of solid fuels and economic development in the region, fall under the negative-growth hypothesis. This implies that in both long-run and short-run, household use of solid fuels negatively impacts on economic development. Therefore, for policy-making purposes, household solid-fuels conservative policies would be favourable in the region.
For east Asia, the results obtained in the long-run demonstrated a feedback relationship - implying that both variables mutually influenced each other. Thus for policy-making purposes, an approach whereby household solid-fuels conservative and expansion

policies are balanced would be beneficial for the region. In the short-run, the results show that the dynamics between the variables falls under the conservation hypothesis: implying that household solid fuels conservative policies would encourage economic growth in the short-run.
Lastly, in the case of south Asia, a neutrality hypothesis is observed for the long-run - implying that household use of solid fuels and economic development do not influence each other in the long-run. In the short-run, household use of solid fuels is seen to influence economic development in the region: confirming that a conservation hypothesis exists between the two variables, in the short-run, in the region. Thus, for policy-making purposes, household solid fuels conservative policies would be advantageous for short-run economic development within the region.

The obtained results within this Chapter contribute to the body of existing literature in multiple ways. Firstly, the results establish and present the first empirical evidences on the co-integration relationship between household use of solid fuels and economic development for the world's most impoverished regions: sub-Saharan Africa, east Asia and south Asia. Secondly, the causality results presented within this Chapter provide important insights into the causal dynamics between household use of solid fuels and economic development, in both the short-run and long-run. Finally, these insights on the causal dynamics between household use of solid fuels and economic development, have important implications for the design of appropriate development policies for these parts of the world.

The outline of this Chapter is as follows: in Section 4.2, the background and existing empirical literature for each region is presented. The data and methodologies used for the analyses in this Chapter are discussed in Section 4.3. The Section outlines the four stages associated with the panel co-integration approach, and summarises the basis for the subsequent analyses. Section 4.4 presents the results of these analyses for each region. Finally, in Section 4.5, the wider significance, implications and conclusions are discussed. Section 4.6 provides a summary of the Chapter: emphasising the significant findings.

4.2 Background

In this section, an overview of the energy-growth (also referred to as energy-development) nexus is presented in Section 4.2.1. The studies surrounding the subject in the context of sub-Saharan Africa, east Asia and south Asia are presented in Sections 4.2.2, 4.2.3, and 4.2.4, respectively.

4.2.1 An overview of the energy-development nexus

The topic of the relationship between general energy consumption and economic development, in both developing and developed countries is a well established area in literature. The study by Kraft and Kraft in 1978 [76] provoked an extensive interest in the area of energy consumption-economic development nexus. Alone, the study by Ozturk [126] highlights that over the years, more than sixty studies have investigated this link, empirically. Indeed, the studies demonstrating the empirical link between energy and economic development hold important policy implications. Not only do these studies give important perceptions about the influence of energy on economic development, they also give a premise for the evaluation and design of policies relating to energy and environment. However, despite these policy implications, empirical studies on the link between energy and economic development are yet to provide an unequivocal answer. In fact, there still exists no unanimity on the nature of the link. Along with institutional, structural and policy dissimilarities, methodological differences such as definitional specifications of variables, types of tests and lag structures, are contributing factors to these variations in outcomes.

Nonetheless, over the years, literature have indicated four potential relationship hypotheses and their policy implications: neutrality, conservation, growth and feedback hypotheses [126].

- The neutrality hypothesis refers to cases where no causal link is observed between energy and economic development. Thus, implying that economic development and energy are not correlated. Consequently, for a country with such scenario, neither energy conservation nor energy expansion policies would influence the economy.

- In the conservation scenario, the causality is observed to run unidirectionally from economic development to energy. Therefore, policies which support the conservation of energy such as policies focusing on demand management, reduction of fossil fuels, amongst others, would not negatively impact on the economy of the country.
- On the other hand, the growth hypothesis denotes scenarios where the causality is observed to run from energy to economic development; meaning the economic development of the country is dependent on energy. This hypothesis implies that directly or indirectly, energy is a crucial determinant in a country's economic development.
- Finally, the feedback hypothesis refers to cases where there exists a bidirectional causal link between energy and economic development. Thus, in this scenario, energy and economic development are implied to be interconnected.

The work within this Chapter adapts these hypothesis. The analyses will seek to establish the potential hypothesis relationship between the household use of solid fuels and economic development - for sub-Saharan Africa, east Asia and south Asia.

4.2.2 Sub-Saharan Africa (SSA)

A. Energy-economic development nexus in SSA

In the context of SSA, the issues experienced in the region's energy sector are becoming well documented; with scholars increasingly investigating and documenting the significance of energy on the economic development of the region. The outcomes from the various studies across the region have all varied. Starting in 1996, using the Granger causality method, Ebohon investigated the causal relationship between energy and economic development in two SSA countries: Tanzania and Nigeria [127]. His study concluded a feedback hypothesis in the energy-growth dynamic for the investigated countries.

More recently, using the Autoregressive Distribution Lag (ARDL) bounds as well as

Table 4.1: Summary of empirical studies on energy consumption and economic development nexus for SSA.

Author(s)	**Countries**	**Variables**	**Methods**	**Conclusions**
Ebohon (1996)	Nigeria, Tanzania	Energy consumption; GDP	Engle-Granger causality	EC $\leftrightarrow$ GDP
Soytas and Sari (2003)	South-Africa	Energy consumption; GDP	Co-integration, causality	EC $\leftarrow$ GDP
Wolde-Rufael (2005)	19 African countries	Energy consumption; GDP	ARDL bounds test; Toda and Yamamoto causality	EC $\rightarrow$ GDP (Cameroon, Morroco and Nigeria) EC $\leftarrow$ GDP (Algeria, Congo DR, Egypt, Ghana and Ivory Coast) EC $\leftrightarrow$ GDP (Gabon and Zambia) EC $\nLeftrightarrow$ GDP (Benin, Congo RP, Kenya, Senegal, South Africa, Sudan, Togo, Tunisia and Zimbabwe)
Akinlo (2008)	11 sub-Saharan countries	Energy consumption; GDP	ARDL bounds test	EC $\nLeftrightarrow$ GDP (Gambia, Ghana, Senegal) EC $\leftarrow$ GDP (Zimbabwe)
Wolde-Rufael (2009)	Algeria, Benin and South Africa	Energy consumption; GDP	Toda and Yamamoto causality	EC $\leftrightarrow$ GDP
Odhiambo (2009a)	Tanzania	Energy consumption; GDP	ARDL bounds test	EC $\rightarrow$ GDP
Odhiambo (2010)	Congo RD, Kenya and South Africa	Energy consumption; GDP	ARDL bounds test	EC $\rightarrow$ GDP (Kenya, South Africa) EC $\leftarrow$ GDP (Congo RD)
Esso (2010)	7 African countries	Energy consumption; GDP	Threshold cointegration	EC $\leftarrow$ GDP (Congo and Ghana) EC $\leftrightarrow$ GDP (Ivory Coast) EC $\nLeftrightarrow$ GDP (Cameroon, Kenya, Nigeria and South Africa)

the Granger causality method based on vector error correction model (VECM), Akinlo examined the causative link between energy and economic development across eleven sub-Saharan Africa countries - concluding the feedback hypothesis for Gambia, Ghana and Senegal; the growth hypothesis for Zimbabwe, and the neutrality hypothesis for the other countries [49]. Similar to the paper by Akinlo, the paper by Esso et al., that investigates the causal link between energy and economic development in five African nations, found varying hypothesis conclusions for the countries [128]. Menegaki's study which looks into the energy-growth nexus for sub-Saharan Africa [129], amongst other recent works, are all attempting to understand this relationship. In addition to these aforementioned studies, several other studies have investigated this causal link with varying and sometimes conflicting conclusions. Table 4.1 above presents a summary of some studies on the subject. It highlights the utilised variables, applied methods and diversified outcomes observed in the literature. The outcome from Table 4.1 further supports the previously stated stance that non-conclusive, varying, and in some cases, contradictory results have been observed in previous studies.

With regard to specific energy services, thus far, many studies have primarily focused on either the general energy-economic development link, or on the explicit link between electricity and economic development [130]. Recently, the relationship between access to and/or increased electricity consumption and economic development, across the region, has received significant academic and policy attention [131], [132]. For example, in 2017, using panel data across 174 countries (including African countries), Atems and Hotaling [133], investigated the effects of renewable and non-renewable electricity generation on economic development. The result from their study produced contradicting outcomes on the hypotheses observed.

Table 4.2: Summary of empirical studies on electricity consumption and economic development for SSA

Author(s)	Countries	Variables	Methods	Conclusions
Abosedra	Lebanon	Electricity consumption; GDP	Granger causality	ELC $\rightarrow$ GDP
Akinlo (2007)	Nigeria	Electricity consumption; GDP	Johansen-Julius; Cointegration; VECM; co-feature analysis	ELC $\rightarrow$ GDP
Jumbe (2004)	Malawi	Electricity consumption; GDP	Granger causality; ECM	EC $\leftarrow$ GDP (Granger); ELC $\leftrightarrow$ GDP (ECM)
Ouedrago (2010)	Burkina Faso	Electricity consumption; GDP	ARDL bounds test	ELC $\rightarrow$ GDP
Odhiambo (2009)	Tanzania	Electricity consumption; GDP	ARDL bounds test; cointegration; VECM	ELC $\rightarrow$ GDP
Odhiambo (2009)	South Africa	Electricity consumption; GDP	Johansen-Julius; cointegration; VECM	ELC $\leftrightarrow$ GDP
Wolde-Rufael (2006)	18 African countries	Electricity consumption; GDP	Todo-Yamamoto causality	ELC $\rightarrow$ GDP (Benin, Congo DR, Tunisia) ELC $\leftarrow$ GDP (Cameroon, Gabon, Ghana, Nigeria, Senegal, Zambia and Zimbabwe) ELC $\leftrightarrow$ GDP (Egypt, Morocco) ELC $\nLeftrightarrow$ GDP (Algeria, Congo RP, Kenya, South Africa and Sudan)

In their study, Boukhelkhal and Bengana, using the ARDL approach, investigated the impact of electricity consumption on economic development, amongst other indicators, for four African countries [134]. Their results observed a feedback hypothesis between the examined variables. Also using ARDL, as well as the Toda and Yamamoto causality test, Bah and Azam examined the link between electricity consumption and economic development in South Africa [135] with similar results. These studies, in addition to other studies, some of which are presented in Table 4.2, have examined the causal link between electricity and economic development across the region. Similar to studies on the general energy-growth nexus, varying and in some cases, contradictory outcomes have also been reported.

B. Solid fuels and economic development in SSA

As mentioned in Chapter 2, approximately 80% of the sub-Saharan African population still lack access to clean cooking fuels. What's more, over the past two decades, the aggregate annual access rate grew by less than 1% on average.

Yet, although literature acknowledges the severity of the situation, much less attention has been given to the resolution of the issue.

Table 4.3: Summary of empirical studies on biomass consumption and economic development for SSA

Author(s)	Countries	Variables	Methods	Conclusions
Bildirici (2016)	8 African countries	Wood consumption; GDP	ARDL bounds test; Granger causality	W $\leftrightarrow$ GDP (Benin, Mauritania, Nigeria and South Africa) W $\rightarrow$ GDP (Angola, Guinea-Bissau and Niger) W $\leftarrow$ GDP (Seycelles)
Adewuyi (2017)	Some west African countries	Biomass; CO2 emission; GDP	Granger causality	B $\rightarrow$ GDP (Benin, Burkina-Faso, Gambia, Ghana, Mali, Nigeria and Senegal) B $\rightarrow$ GDP $\rightarrow$ CO2 (Burkina-Faso, Gambia, Mali, Nigeria and Togo)
Ozturk (2015)	Some sub-Saharan countries	Biomass (B); Openness (O); Population (P); GDP	OLS and DOLS; cointegration	B + O + P $\rightarrow$ GDP

In fact, as mentioned in Chapter 3, studies investigating the link between household use of solid fuels and development are limited and far fewer studies have analysed the impact on economic development. Indeed, in the recent study by Adewuyi and Awodumi [136], the authors stress that only the study by Ozturk and Bilgili [137] has considered this relationship in the context of sub-Saharan Africa. However, this study by Ozturk and Bilgili was based off of time-series data of individual countries [137].

Thusly, as far as is known, there exists no studies which utilise panel unit root and co-integration methods to analyse the solid fuels-economic development relationship. In addition, to the best of my knowledge, there are currently no studies investigating the link between household use of solid fuels and economic development in the context of sub-Saharan Africa.

4.2.3 East Asia (EA)

A. Energy-economic development nexus in EA

In east Asia, rapid population growth, trade expansions and technological advancements, have all contributed to the expeditious energy-demand and economic growth

experienced across the region in the past decades [138]. In response to these changes, studies have attempted to establish the energy-economy dynamics for the region, and similar to the case of SSA, there have been varying outcomes.
Starting in 1985, Yu and Choi explored the relationship between GDP and energy consumption in South Korea, for the period of 1954 to 1976, using the standard Granger test [139]. Following this study, using the same method, in 1997, Glasure and Lee also investigated the energy-economic relationship for South Korea and Singapore for the period of 1961 to 1990 [140]. Also using the standard Granger test, the study by Yang in 2000 explored this relationship for Taiwan for the period of 1954 to 1997 [141]. Across all these studies, uni-directional causalities running from energy to economic development were observed: confirming the presence of the growth hypothesis in these countries. Thus, implying that the economic development of the countries in these studies were influenced by the levels of energy consumption within the countries. These studies amongst several other exemplary analyses have attempted to establish the relationship between these variables within the east Asian region. And although the aforementioned studies had coherent outcomes, other studies have reported varying outcomes (see table 4.4).

Table 4.4: Summary of empirical studies on energy consumption and economic development for EA

Author(s)	**Countries**	**Variables**	**Methods**	**Conclusions**
Aslan and Kum (2010)	11 East Asian and Pacific region countries	Energy consumption; GDP	FMOLS and DOLS	GDP $\leftrightarrow$ EC
Soytas and Sari (2003)	South Korea, Japan	Energy consumption; GDP	Standard Granger causality test	GDP $\rightarrow$ EC (Japan) EC $\rightarrow$ GDP (South Korea)
Oh and Lee (2004)	Korea	Energy consumption; GDP	VECM	EC $\leftrightarrow$ GDP
Lee (2006)	Japan	Energy consumption; GDP	Toda-Yamamoto causality test	GDP $\rightarrow$ EC
Lee and Chang (2008)	16 Asian countries; including East Asian countries	Energy consumption; GDP	Pedroni, FMOLS cointegration	EC $\rightarrow$ GDP
Shuyun and Donghu (2011)	China province	Energy consumption; GDP	Pedroni, Panel Granger causality test	GDP $\leftrightarrow$ EC
Yu and Choi (1985)	South Korea	Energy consumption; GDP	Standard Granger causality test	EC $\rightarrow$ GDP
Hwang and Gum (1992)	Taiwan	Energy consumption; GDP	Standard Granger causality test	EC $\rightarrow$ GDP
Yang (2000)	Taiwan	Energy consumption; GDP	Standard Granger causality test	GDP $\leftrightarrow$ EC
Chang (2010)	China	Energy consumption; GDP	Granger causality test; VECM	EC $\leftrightarrow$ GDP

Similar to the sub-Saharan Africa based studies; studies have extended upon existing energy-growth nexus methodologies to investigate the specific relationship between electricity consumption and economic development within the region.

Table 4.5: Summary of empirical studies on electricity consumption and economic development for EA

Author(s)	Countries	Variables	Methods	Conclusions
Chen et al (2007)	China, Taiwan, Hong Kong, Korea	Electricity consumption; GDP	ECM; Pedroni panel cointegration; Panel causality; Johansen cointegration	GDP $\nLeftrightarrow$ ELC (Taiwan) GDP $\rightarrow$ ELC (Korea) GDP $\rightarrow$ ELC (Hong Kong)
Murray and Nan (1996)	15 Asian countries	Electricity consumption; GDP	Standard Granger causality test	ELC $\rightarrow$ GDP (Hong Kong, South Korea)
Yang (2000)	Taiwan	Electricity consumption; GDP	Standard Granger causality test; Hsiao's Granger	ELC $\leftrightarrow$ GDP
Yoo (2005)	Korea	Electricity consumption; GDP	ECM	ELC $\leftrightarrow$ GDP
Ho and Siu (2007)	Hong Kong	Electricity consumption; GDP	Co-integration; VECM	ELC $\leftrightarrow$ GDP
Yuan et al (2007)	China	Electricity consumption; GDP	Co-integration test	ELC $\leftrightarrow$ GDP
Hu and Lin (2008)	Taiwan	Electricity consumption; GDP	Hansen-Seo threshold co-integration; VECM	GDP $\rightarrow$ ELC
Yuan et al (2008)	China	Electricity consumption; GDP	Johansen cointegration; VECM	ELC $\rightarrow$ GDP
Shiu and Lam (2004)	China	Electricity consumption; GDP	Johansen-Julius cointegration; VECM	ELC $\rightarrow$ GDP

Some of these studies, the applied methodologies and variables are presented in Table 4.5. For example, using the standard Granger causality test, Murry and Nan examined the relationship between electricity consumption and GDP for some developing countries: including some east Asian countries [142]. Employing Error-correction model, Shiu and Lan investigated the relationship between electricity and GDP in China between 1971 and 2000 [143]. Both studies confirmed growth hypothesis in the electricity-GDP dynamics within the countries.

Also, Aslan and Kum [144] using FMOLS and DOLS, examined the relationship between electricity and GDP at national levels for 11 countries in the east Asian and Pacific region. The outcome hypotheses of these studies, as well as other examples of studies within the region are presented in Table 4.5.

Having said these, there appears to be a shortage of studies which have investigated the panel energy-economic growth and/or electricity-economic growth nexus in the context of east Asia. Even at country-level, most studies investigating these dynamics have done so in relation to China, with little-to-no studies considering other countries such as Korea or Mongolia.

B. Solid fuels and economic development in EA

A review of literature on solid fuels-economic development nexus revealed no current studies on the subject matter in the case of east Asia. The study by Hou et al. [145] which uses multinomial and binary logit regression models to investigate the role of poverty on cooking fuel transition in China is perhaps amongst the first existing studies within the region. In fact, in 2011, the study by Demurger and Fournier [146] which investigated the determinants of firewood consumption using data from a rural town in northern China, heavily emphasised the lack of literature in the subject matter. What's more, a broader search on household consumption of general biomass produced mostly studies investigating the environmental impacts of biomass consumption, as well as broader energy poverty related studies.

4.2.4 South Asia (SA)

A. Energy-economic development nexus in SA

Nearly a quarter of the global population who coincidentally account for almost 40% of the world's income and energy poor, reside in the south Asian region [35]. As a result, in recent years, there has been an increase in academic and policy works attempting to understand the relationship between energy consumption and economic development within the region. The work by Siddique and Majeed which applied the panel co-integration technique to examine the relationship between energy consumption, trade and financial development for five south Asian countries [147]; the study by Nasreen et al. which used FMOLS and DOLS models to investigate the energy-growth nexus in 15 Asian countries [138], are examples of studies which have attempted to understand this dynamic. The observed outcome hypotheses from these studies as well as other related studies are presented in Table 4.6. Similar to sub-Saharan Africa, varying hypothesis outcomes have been observed across the region and in some cases, differing hypotheses are observed for the same countries.

Table 4.6: Summary of empirical studies on energy consumption and economic development for SA

Author(s)	Countries	Variables	Methods	Conclusions
Asafu-Adjaye (2000)	India	Energy consumption; GDP	Cointegration; ECM	EC → GDP
Tariq et al (2018)	Pakistan, India, Bandladesh and Sri Lanka	Energy consumption; GDP	Instrumental variable regression	EC ↔ GDP
Asghar (2008)	South Asia (excluding Bhutan)	Energy consumption; GDP	Toda Yamamoto; ECM	GDP → EC (Pakistan; Sri Lanka) GDP ⇎ EC (India)
Jamil and Ahmad (2010)	Pakistan	Energy consumption; GDP	Johansen cointegration; VECM	GDP → EC
Alam et al (2012)	Bangladesh	Energy consumption; GDP	Johansen cointegration; Granger causality test	EC → GDP
Mirza and Kanwal (2017)	Pakistan	Energy consumption; GDP	Johansen-Julius cointegration; ARDL; VECM	EC ↔ GDP
Javid and Sharif (2015)	Pakistan	Energy consumption; GDP	Cointegration	GDP → EC
Nain et al (2015)	India	Energy consumption; GDP	ARDL bounds test; Toda Yamamoto	EC → GDP
Aqeel and Butt (2001)	Pakistan	Energy consumption; GDP	Hsiao's Granger causality	GDP → EC
Rezitis and Ahammad (2015)	South Asia	Energy consumption; GDP	Cointegration; VECM; IRFs	EC → GDP
Shahbaz et al (2012)	Pakistan	Energy consumption; GDP	Cobb-Douglas production function; ARDL bounds test; VECM	EC ↔ GDP
Shakeel et al (2013)	South Asia	Energy consumption; GDP	Panel cointegration	EC ↔ GDP
Cheng (1999)	India	Energy consumption; GDP	Cointegration; ECM	GDP → EC

Table 4.7 presents a summary of studies which have examined the explicit relationship between electricity consumption and economic development. Similar to other regions, varying outcomes are observed across and within countries.

Table 4.7: Summary of empirical studies on electricity consumption and economic development for SA

Author(s)	Countries	Variables	Methods	Conclusions
Ghosh (2002)	India	Electricity consumption; GDP	Standard Granger causality test	GDP → ELC
Morimoto and Hope (2004)	Sri Lanka	Electricity consumption; GDP	Standard Granger causality test	ELC → GDP
Aqeel and Butt (2001)	Pakistan	Electricity consumption; GDP	Hsiao's Granger causality test	ELC → GDP
Mozumder and Marathe (in press)	Bangladesh	Electricity consumption; GDP	Cointegration; VEC model	GDP → ELC
Murry and Nan (1996)	India, Pakistan	Electricity consumption; GDP	Standard Granger causality test	GDP ⇎ ELC (India) ELC → GDP (Pakistan)
Chen et al (2007)	India	Electricity consumption; GDP	Cointegration; ECM	GDP ⇎ ELC
Shahbaz and Feridun (2010)	Pakistan	Electricity consumption; GDP	ARDL bound test	GDP → ELC
Shahbaz and Lean (2012)	Pakistan	Electricity consumption; GDP	ARDL bound test; Granger causality test	GDP → ELC
Jamil and Ahmad (2010)	Pakistan	Electricity consumption; GDP	VECM	ELC → GDP
Ahamad and Islam (2011)	Bangladesh	Electricity consumption; GDP	VECM	GDP ↔ ELC
Shahbaz et al (2014)	Bangladesh	Electricity consumption; GDP	ARDL bound test; VECM	ELC → GDP
Ghosh (2009)	India	Electricity consumption; GDP	Cointegration; Granger causality test	GDP → ELC
Asghar (2008)	South Asia (excluding Bhutan)	Electricity consumption; GDP	Toda Yamamoto; ECM	GDP → ELC (Pakistan; Sri Lanka) GDP ⇎ ELC (India) GDP → ELC (Bangladesh)
Dhungel (2017)	South Asia	Electricity consumption; GDP	Cointegration; Standard Granger causality test	ELC → GDP

B. Solid fuels and economic development in SA

As in the case of east Asia, a review of literature shows no existing studies examining the impact of household solid fuels consumption on economic development in the south Asian region. Upon a broader search on general household biomass consumption and sustainable development, only studies relating to the environmental and health impacts of biomass consumption are unearthed.

Taken together, the findings from the review of literature show that GDP and GDP per capita are commonly used indicators in development studies. However, several studies been criticised their use as indicators of development and human well-being: due to their omission of important aspects of well-being [148] and economic factors [149]. However, since this chapter is only interested in economic development, only the economic development-related limitations are considered.

Some of the important economy-related limitations of GDP have been highlighted by studies [149], [150] to include: a) exclusion of non-market transactions; b) failure to account for or represent the degree of income inequality across countries; c) failure to indicate if rate of economic growth is sustainable; amongst others.

GDP per capita does not address all the limitations of GDP. However, it is viewed by studies [151], [152] as a more suitable indicator when considering economic development within countries: due to its ability to indicate the average income of a country's population. Thus, addressing the issue of exclusion of non-market transactions, as well as accounting for the degree of income inequality across countries.

It is worth noting that in lieu of GDP and GDP per capita, other indicators such as Gross National Income (GNI); GNI per capita; and Gross national product (GNP); have been proposed as indicators for economic development [152]. However, due to barriers which are commonly categorised into: a) indicator factors; b) user factors; and c) context factors barriers, as well as limitations in terms of data availability, these alternative indicators are rarely used in studies [149], [153].

Consequently, in this study, the GDP per capita is used as an indicator of economic development.

Finally, the findings from the review also show that the outcomes of various analyses investigating the impact of energy and/or energy services on economic development are diverse and in some cases contradictory. Lastly, it is observed that there are no studies investigating the explicit link between household use of solid fuels and economic development, in these regions.

4.2.5 Review of methodologies

Although there exists a complete absence of studies on the subject, studies on the literature of energy-growth nexus provide an insight into applicable methodologies that can be adopted in this study. Based on these studies, a range of analytical techniques are observed to be applicable to the analyses of the degree of association between household use of solid fuels and economic development. Firstly, as stated in section 3.3, for cases of cross-country homogeneity with temporal heterogeneity such that $T>N$, literature suggests the use of non-stationary panel data analysis [114]. Therefore, considering the structure of the data to be used for the analyses in this Chapter, the non-stationary panel data analysis approach is deemed fitting. Accordingly, following the review of the existing literature presented in Sections 4.2.2 to 4.2.4, the dominant non-stationary panel data methodologies utilised in the energy-growth nexus studies are summarised and presented in Table 4.8.

Table 4.8: Breakdown of the most utilised methodologies in literature

Methods	Strengths	Weakness	Note
Instrumental Variables	Widely known for its ability to address endogeneity problems	Only identifies causal effects based on only the group whose behaviour is influenced by the instrument. Use of variables which are weakly correlated with treatment and/or with residuals in the outcome equation could lead to larger bias problems	IV heavily relies on having valid instruments. However, selection of instrument is subjective.
Toda-Yamamato	Does not require pre-testing for cointegrating properties of the system	Inefficient and suffers some loss of power due to the intentional overfitted of the VAR model	The method proposes an augmented level VAR modeling
	Avoids potential bias that can be associated with unit roots and cointegration by ignoring any possible non-stationarity or co-integration between series.	For small sample sizes, the asymptotic distribution is a poor approximation to the distribution of the test statistic thus can be inaccurate	The main advantage over traditional Granger is it is easier due to the lack of pre-tests needed for model specification
	Causality testing can be performed with possibly integrated and cointegrated systems	Requires large sample sizes	
Traditional Granger test	Can be used for smaller sample sizes	Conditional on the assumption that the underlying variables are stationary, or integrated of order zero.	The method proposes an unrestricted VAR framework
	Ease of application	Can suffer from specification bias and spurious regression	
	Does not require additional tests to determine direction of causality	Requires pre-testing	
Autoregressive distributed lag (ARDL)	Does not require that all the variables in analysis must be integrated of the same order	Can suffer from inaccuracy if lag values are mis-specified	
		Requires pre-testing Test can be inconclusive if test statistics fall between bounds	

Across most of the reviewed studies, due to its higher efficiency of econometric estimates, the panel cointegration approach is utilised. That said, the ARDL, Engle and Granger, Toda-Yamamoto and Instrumental Variable approaches appear to be the most commonly used of the non-stationary panel data analysis methodologies in examining causal relationships.

The breakdown of the strengths and weaknesses of these methodologies are presented in Table 4.8 and these give an overview of the reasons for the methodological approach taken. From Table 4.8, it becomes evident that the viable methodologies to perform the analyses in this Chapter are the Toda-Yamamoto, and the Engle and Granger causality methods. However, upon the evaluation of the data and the aim of the analyses, the Engle and Granger methodology is selected as the most appropriate.

To clarify this decision: the Instrumental Variable methodology would be inappropriate in this Chapter as there are no treatment and/or control groups in the dataset. Additionally, there is no requirement for instrument variables.

With regard to the Toda-Yamamoto technique, in existing literature, the approach is considered as a more effective technique in causality testing in comparison to conventional causality tests. This is due to its lack of requirement for pre-testing and thus its ability to avoid biases associated with pre-tests [154], [155]. However, studies have also highlighted the inappropriateness of the Toda-Yamamoto methodology for small data analyses [156]. Therefore, the Toda-Yamamoto methodology is deemed inappropriate for the analyses performed in this Chapter due this principal shortcoming. In smaller data sizes such as those used in the analyses in this Chapter, due to its overfitting of the VAR model, studies have shown that redundant regressors may lead to costly losses in power and efficiency [156]. Furthermore, literature suggests that the Toda-Yamamoto methodology is unable to distinguish between short run and long run causality [136], [157] - a significant detail required in the analyses in this Chapter. Lastly, the Toda-Yamamoto methodology is insufficient in comparison to Error Correction Model (ECM), where cointegration is explicitly considered. Other methods such as the Haugh-Pierce test and Hsiao test were considered. However, there is a significant lack of literature extensively testing the accuracy and efficiency of these methods. Therefore, these methods were not adopted in the analyses within this study.

4.3 Data and methodology

For the analyses in this Chapter, we draw upon recent data from international organisations to examine the dynamics between the household use of solid fuels and economic development. The panel unit root; panel co-integration and panel causality models are applied to the obtained data to investigate the dynamics.

4.3.1 Methodology

To examine the causal relationship between economic development and household solid fuels consumption, the Granger causality approach is taken. As this approach requires pre-testing, panel unit root tests and panel co-integration tests are applied, before testing for causality between the variables. Furthermore, to ensure the robustness of the causality results, different Vector AutoRegression (hereafter VAR) specifications are implemented later in the analysis. An illustration of the analysis process is presented in Figure 4.1.

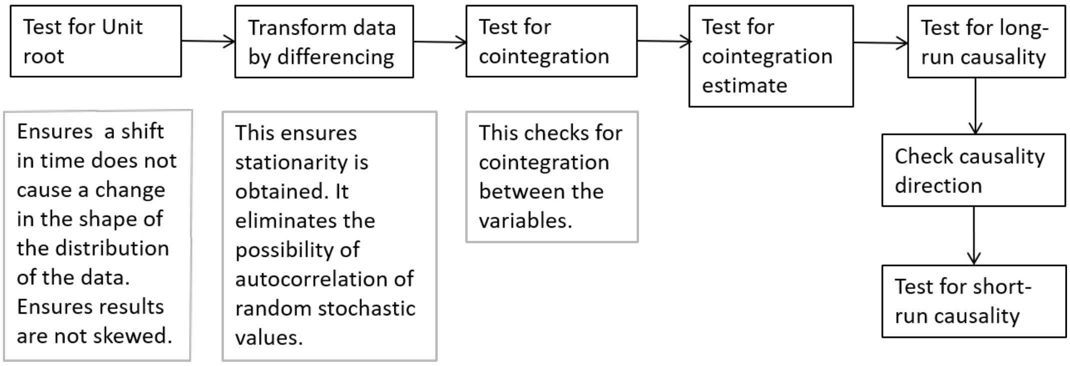


Figure 4.1: Illustration of the analysis procedure

Firstly, the panel unit root tests are performed on the series, to examine the stationarity properties of the variables – GDP and household use of solid fuels .i.e. to test if statistical properties such as mean, variance, etc., of the variables appear constant over time. Also, in so doing, the order of integration of the series is determined. This pretesting stage of the analysis is crucial as errors in the first stages of the analyses could have great impacts on the final conclusions regarding the Granger causality. As such, we ensure that potential errors are eliminated. Next, following the confirmation that the variables are integrated at order one I(1) .i.e. after first differencing, panel cointegration tests are implemented to examine the presence of a long-run relationship between the series. At this stage, to determine the test type to be used, the guidelines in literature are considered. To clarify, literature suggests that if all variables are stationary at level, the least squares estimator can be utilised. However, in the case where all variables are cointegrated at order I(1), the panel Vector Error Correction Models (hereafter VECM), Fully Modified Ordinary Least Square (hereafter FMOLS) and Dynamic Ordinary Least Square (hereafter DOLS) can be utilised. Whereas, in cases where all variables at order I(1) are without cointegration, the panel VAR should be used whilst an evidence of a mix of integration would suggest that the Pooled mean group of panel ARDL method be utilised [114], [115], [119].

Therefore, based off of the results from the cointegration analysis stage, since the variables are cointegrated at I(1), the cointegration vectors are estimated utilizing panel FMOLS and DOLS. Next, a restricted VAR: VECMs are developed to determine the long-run and short-run causal relationship between the variables. As stated above, to ensure the robustness of the causality results, different lag specification are implemented and tested. The obtaining of similar results at different lags would confirm the robustness. Finally, applying the Granger causality test, the directions of causality of the causal relationships are examined.

The details of the individual tests involved in each stage of the analyses are presented in Sections 4.3.1.1 to 4.3.1.4.

4.3.1.1 Panel unit roots tests

Econometric studies such as [158]–[160] have demonstrated that traditional unit root tests for individual series, like the Augmented Dickey Fuller (ADF) test, tend to have low test powers. As such, these studies have employed panel unit root tests to investigate the degree of integration between variables of interest. Due to their varying strengths and weaknesses, the Levin, Lin and Chu (hereafter LLC); Im, Pesaran and Shin (hereafter IPS); Breitung; ADF and PP Fisher (hereafter MW) and Hadri tests are used here. To exemplify, the LLC test assumes a homogeneous panel under null and alternative hypotheses; a drawback which is addressed by IPS. Yet, both LLC and IPS fail to account for cross-section dependence - a factor considered by Breitung, MW and Hadri. Although, Hadri argues that for stronger test power, the null hypothesis should be stationarity [161]. Accordingly, to consider these shortcomings and comprehensively examine the stationarity characteristics of the variables, the five different panel unit tests are applied.

A. LLC unit root test

Due to its ease of implementation, the most commonly used panel unit root test is the LLC test. Based on the Augmented Dickey-Fuller (hereafter ADF) technique, LLC which is considered a pooled test, follows the ADF regression process. As such, firstly, independent ADF regressions are performed for each country. For a panel data $y_{c,t}$ This process is modelled as follows:

$$\Delta y_{ct} = \alpha_c + \rho_c y_{c,t-1} + \sum_{j=1}^{l_c} \alpha_{c,j} \Delta y_{c,t-j} + \varepsilon_{ct} \tag{4.1}$$

where: c is the panel member (individual country), l_c is the lag order allowed across the countries. Upon obtaining the maximum lag order; based on the t-statistics for cj, the optimal lag order is then determined. Following this step, two auxiliary regressions defined as (4.2) and (4.3) are implemented to obtain the residuals, $\tilde{\eta}_{ct}$ and $\tilde{\eta}_{c,t-1}$ respectively:

$$\Delta y_{ct} = \alpha_c + \sum_{j=1}^{l_c} \eth_{c,t-j} \Delta y_{c,t-j} + \eta_{ct} \Rightarrow \tilde{\eta}_{ct} \tag{4.2}$$

$$y_{c,t-1} = \partial_c + \sum_{j=1}^{l_c} \ell_{c,t-j} \Delta y_{c,t-j} + \eta_{c,t-1} \Rightarrow \tilde{\eta}_{c,t-1} \tag{4.3}$$

These obtained residuals are then normalised by regressing on the standard error obtained in (4.1):

$$\tilde{\eta}_{ct} = \frac{\tilde{\eta}_{ct}}{\hat{\sigma}_{\varepsilon i}} \qquad \tilde{\eta}_{c,t-1} = \frac{\tilde{\eta}_{c,t-1}}{\hat{\sigma}_{\varepsilon i}} \tag{4.4}$$

Finally, re-applying equation (4.1), the test statistics are obtained through the implementation of the pooled OLS regression:

$$\tilde{\eta} = \rho_c \tilde{\eta}_{c,t-1} + \tilde{\varepsilon}_{ct} \tag{4.5}$$

LLC assumes that under both the null and alternative hypotheses, all groups have the same autoregressive (AR) coefficient, ρ_c. As such, it assumes a homogeneous panel [162].

B. IPS test

The IPS technique extends on LLC but allows for heterogeneity by utilising the averages of the ADF tests and likelihood ratio [163]. This is accomplished through the implementation of ADF tests on individual series, thus obtaining individual short-run dynamics. Hence, for the series (EC_{ct}, EG_{ct}), the ADF is defined as:

$$\Delta y_{ct} = al\bar{p}ha_j + r\tilde{ho}_c y_{c,t-1} + \sum_{j=1}^{l_c} \phi_{cj} \Delta y_{c,t-j} + \varepsilon_{ct} \tag{4.6}$$

Following the ADF process, different augmentation lags for the individual countries are derived. As such, the next stage substitutes the terms $E(t_T)$ and $var(t_T)$ with the coinciding group averages $E(t_T, L_c)$ and $var(t_T, L_c)$ respectively. Consequently, the IPS unit root model and test statistics can be defined as (4.7a) and (4.7b) respectively:

$$t_{NT} = \frac{1}{N} \sum_{c=1}^{N} t_{ct}(L_c) \tag{4.7a}$$

$$A_t = \frac{\sqrt{N(T)}[t_T - E(t_T)]}{\sqrt{var(t_T)}} \tag{4.7b}$$

where, N is the number of cross-sectional countries; T represents time dimension; t_{ct} is the ADF t-statistic of unit root test for each country; L_c is the lag order in the ADF tests; and c represents the countries. In comparison to LLC, fewer time observations are required for a higher test power[1] [164].

Nonetheless, both the LLC and IPS techniques have the disadvantage of assuming independence across the cross-section of the panel units [164]. Therefore, to account for the possibility of cross-sectional correlation and probable spillage across countries, we apply the Breitung, MW and Hadri techniques.

C. Breitung test

The first stage of the Breitung process is similar to the LLC process: see equation (4.1) - except here, the deterministic terms are excluded. Following regression, the

[1] Power here refers to the probability of rejecting the null when it is false.

'pre-whitening'[2] process is performed:

$$\Delta y_{ct} = \alpha_c + \sum_{j=1}^{l_c} \rho_{cj} \Delta y_{c,t-j} + \varepsilon_{ct} \tag{4.8}$$

From which the residuals $\tilde{\eta}_{ct}$ and $\tilde{f}_{c,t-1}$ are obtained and modelled as:

$$\tilde{\eta}_{ct} = \Delta y_{ct} - \sum_{j=1}^{l_c} \rho_{cj} \Delta y_{c,t-j} \tag{4.9a}$$

$$\tilde{f}_{ct-1} = y_{c,t-1} - \sum_{j=1}^{l_c} \rho_c y_{c,t-j-1} \tag{4.9b}$$

Similar to the LLC process, these residuals are normalised using the error term in (4.8) to obtain $\hat{\eta_{ct}}$ and $\hat{f}_{c,t-1}$. Following this, the residuals are orthogonalised as follows:

$$\eta^*_{ct} = \sqrt{\frac{T-t}{T-t+1}} \left(\Delta\hat{\eta}_{ct} - \frac{1}{T-t} \left(\Delta\hat{\eta}_{ct+1} + \ldots + \Delta\hat{\eta}_{cT} \right) \right) \tag{4.10a}$$

$$f^*_{ct} = \hat{f}_{c,t-1} - \hat{f}_{c1} + \frac{t-1}{T} \left(\hat{f}_{cT} - \hat{f}_{c1} \right) \tag{4.10b}$$

where, T here denotes the sample size of the data. Finally, utilising pooled regression, the unit root test is modelled as follows:

$$\eta^*_{ct} = \rho^* f_{ct} + \varepsilon^*_{ct} \tag{4.11}$$

Unlike the LLC and IPS tests which apply bias-corrected estimators, the Breitung test uses unbiased estimators. Thus, exhibits a higher test power [165], [166].

D. MW test

In contrast to the tests in sections A to C which are asymptotic, the MW test is a non-parametric analysis derived from the Fisher test [167]. It combines p-values of individual unit root tests to obtain results which are non-dependent on the lag lengths

[2]Pre-whitening is one of the two ways of removing serial-correlation. The other being resorting of the preliminary regressions

of individual ADF regressions. To clarify, for the null hypothesis, the p-values (p_c) are uniformly distributed on interval [0,1]. As such, $-2logp_c$ is distributed as $\mathcal{X}_2^2$. Therefore, the test statistics for the series can be calculated as:

$$\lambda = -2\sum_{c=1}^{N} log_e(p_c) \backsim \mathcal{X}_{2n}^2(d.f.) \tag{4.12}$$

where, p_c is the value of the probability from the ADF unit root tests for country c. Due to its lag length selection sensitivity, the MW test has a higher test power in comparison to the LLC and IPS tests [167].

E. Hadri test

Finally, the Hadri test, a residual-based Lagrange Multiplier (LM) test where OLS residuals are obtained by regressing an output on a constant [161], is considered. The Hadri test which can be considered a KPSS fluctuations test, is a panel expansion of the Kwiatkowski test [168]. The test statistic is given as:

$$H_{LM} = \frac{1}{NT^2}\sum_{c=1}^{N}\sum_{t=1}^{T}\frac{S_{ct}^2}{\tilde{\sigma}_{ec}^2} \tag{4.13}$$

where,

$$\tilde{\sigma}_{ec}^2 = \frac{1}{T}\sum_{t=1}^{T}\tilde{e}_{ct}^2 \qquad S_{ct} = \sum_{j=1}^{t}\tilde{e}_{cj} \tag{4.14}$$

Here, t represents time across period, T; N is cross-section of countries, S_{ct} is the partial sum of the obtained OLS residuals, $\tilde{e}_{cj}$.

The null hypotheses, H_0 for the various tests are as follows: both the LLC and IPS tests assume a unit root as the null hypothesis (thus non-stationarity) whilst the Breitung null hypothesis assumes that the panel series have non-stationary differences. The MW tests also assume a unit root (non-stationarity) null hypothesis while the Hadri and Heteroscedastic consistent z-stat tests assume a no unit root null hypothesis (stationarity).

4.3.1.2 Panel cointegration tests

An extension of unit root approaches to the multivariate models found in panel frameworks, the panel cointegration methods have been extensively used to examine the stable long-run relationship between variables [126]. Generally, panel cointegration tests are in two-fold: those with null hypothesis of no cointegration and those with the null hypothesis of cointegration. [169], [170] argue that in order to determine if economic series are cointegrated, it is essential to perform a test for the null hypothesis of no cointegration, as well as of cointegration. However, it is acknowledged that the no co-integration null hypothesis tests do not reject the null hypothesis unless there is strong evidence to the contrary. As such, only this group is considered. However, this group is further categorised into residual-based tests which are based on severe restrictions and likelihood-based tests which are able to relax such restrictions or alternatively, incorporate them into a maximum-likelihood framework. In addition to the varying restriction criteria, studies show that the relative sizes of T and N significantly impacts the characteristics of the tests. See [170] for a detailed review and analysis on cointegration tests. The study shows that for data of large N vs small T, the Pedroni, Kao and Johansen tests have higher test powers.
Consequently, based on their test powers for the compatible T and N dimensions; to examine the long-run relationship between household use of solid fuels and GDP, the panel cointegration tests created by Pedroni; Kao and Johansen are utilised.

A. Pedroni cointegration test

The Pedroni test consists of seven statistics which categorised into the within and between dimensions, use heterogeneous panel and group mean panel cointegration statistics respectively, to test for panel cointegration between variables [171], [172]. A generic Pedroni cointegration test is defined as follows:

$$y_{c,t} = \alpha_c + \rho_c t + \beta_{1c} x_{1c,t} + \ldots + \beta_{Rc} x_{Rc,t} + \varepsilon_{ct} \tag{4.15}$$

where, y and x are assumed cointegrated at order one $I(1)$. Here, t still represents

time across period, T; and c still represents countries across cross-section, N. α_{ct} and $\rho_c t$ represent the individual-specific intercept and deterministic time trend, respectively. β is slope coefficient of regressors, R; and ε_{ct}, the estimated residual which demonstrates the deviation from the long-run relationship [171].
Thus, the cointegration relationship between GDP per capita and household use of solid fuels is defined as follows:

$$GDP_{c,t} = a_{ct} + \rho_c t + \beta_c solid + \varepsilon_{ct} \tag{4.16}$$

where,

$$t = 1, \ldots ., T \qquad\qquad c = 1, \ldots, N$$

The within dimension statistics are defined in equations (4.17) to (4.19) whilst equations (4.21) to (4.23) represent the between dimension statistics. According to Pedroni [171], the panel *v-statistic* (4.17), is a non-parametric variance ratio statistic whilst the panel *ρ-statistic* and panel *t-statistic* represented in equations (4.18) and (4.19) respectively, are the panel variations comparable to the Phillips-Perron *ρ-statistic* and *t-statistic* respectively.

$$T^2 N^{\frac{3}{2}} R_{\hat{v}N,T} \equiv T^2 N^{\frac{3}{2}} \left(\sum_{c=1}^{N} \sum_{t=1}^{T} \hat{L}_{11c}^{-2} \hat{e}_{c,t-1}^2 \right)^{-1} \tag{4.17}$$

$$T\sqrt{N} R_{\hat{\rho}N,T-1} \equiv T\sqrt{N} \left(\sum_{c=1}^{N} \sum_{t=1}^{T} \hat{L}_{11c}^{-2} \hat{e}_{c,t-1}^2 \right)^{-1} \sum_{c=1}^{N} \sum_{t=1}^{T} \hat{L}_{11c}^{-2} (\hat{e}_{c,t-1} \Delta \hat{e}_{c,t} - \hat{\lambda}_c) \tag{4.18}$$

$$R_{tN,T} \equiv \left(\tilde{\sigma}_{N,T}^2 \sum_{c=1}^{N} \sum_{t=1}^{T} \hat{L}_{11c}^{-2} \hat{e}_{c,t-1}^2 \right)^{-\frac{1}{2}} \sum_{c=1}^{N} \sum_{t=1}^{T} \hat{L}_{11c}^{-2} (\hat{e}_{c,t-1} \Delta \hat{e}_{c,t} - \hat{\lambda}_c) \tag{4.19}$$

The second panel *t-statistic* defined in equation (4.20) is an augmented Dickey-Fuller (ADF) equivalent panel statistic.

$$R^{*}_{tN,T} \equiv \left(\tilde{s}^{*2}_{N,T} \sum_{c=1}^{N} \sum_{t=1}^{T} \hat{L}^{-2}_{11c} \hat{e}^{*2}_{c,t-1} \right)^{-\frac{1}{2}} \sum_{c=1}^{N} \sum_{t=1}^{T} \hat{L}^{-2}_{11c} \hat{e}^{*}_{c,t-1} \Delta \hat{e}^{*}_{c,t} \tag{4.20}$$

The group *ρ-statistic* defined in equation (4.21), represents a Phillips-Perron comparable *ρ-statistic*.

$$TN^{-\frac{1}{2}} \tilde{R}_{\hat{\rho}N,T-1} \equiv TN^{-\frac{1}{2}} \sum_{c=1}^{N} \left(\sum_{t=1}^{T} \hat{e}^{2}_{c,t-1} \right)^{-1} \sum_{t=1}^{T} (\hat{e}_{c,t-1} \Delta \hat{e}_{c,t} - \hat{\lambda}_c) \tag{4.21}$$

Lastly, equations (4.22) and (4.23), similar to the panel statistics, are group mean panel statistics comparable to the Phillips-Perron and ADF statistics respectively.

$$N^{-\frac{1}{2}} \tilde{R}_{tN,T} \equiv N^{-\frac{1}{2}} \sum_{c=1}^{N} \left(\hat{\sigma}^{2}_{c} \sum_{t=1}^{T} \hat{e}^{2}_{c,t-1} \right)^{-\frac{1}{2}} \sum_{t=1}^{T} (\hat{e}_{c,t-1} \Delta \hat{e}_{c,t} - \hat{\lambda}_c) \tag{4.22}$$

$$N^{-\frac{1}{2}} \tilde{R}^{*}_{tN,T} \equiv N^{-\frac{1}{2}} \sum_{c=1}^{N} \left(\sum_{t=1}^{T} \hat{s}^{*2}_{c} \hat{e}^{*2}_{c,t-1} \right)^{-\frac{1}{2}} \sum_{t=1}^{T} \hat{e}^{*}_{c,t-1} \Delta \hat{e}^{*}_{c,t} \tag{4.23}$$

Across all tests; $\hat{e}_{ct}$ is the estimated residual; $\hat{L}^{-2}_{11c}$ is the estimated long-run covariance matrix for $\Delta \hat{e}_{c,t}$ whilst $\hat{\rho}^{2}_{c}$ and $\hat{s}^{*2}_{c}$ are respectively, the long-run and contemporaneous variances for countries, c.
Lastly, it is worth noting that the Pedroni panel statistics are based on the pooling of the residuals along the within dimension of the panel [171] whilst the group mean statistics are based on the pooling of the residuals along the between dimension of the panel [171]. However, since the Pedroni tests assume cross-sectional dependence, we apply further cointegration tests. As such, the Kao and Fisher cointegration tests are used for robustness check.

B. Kao cointegration test

The Kao test is a parametric residual based test which is based on the Engle-Granger two step cointegration [173]. Kao derived two cointegration tests based on the residuals from panel Least Square Dummy Variables (LSDV) estimates. For the single regressor model presented in equation (4.24), the first test which is a DF type test is obtained as follows:

$$y_{ct} = \alpha_c + x_{ct}\beta + e_{ct} \tag{4.24}$$

Here, again, y_{ct} would represent GDP_{ct} and x_{ct} represents $solid_{ct}$. The LSDV residuals can be written as:

$$\hat{e}_{ct} = \rho\hat{e}_{ct-1} + \xi_{ct} \tag{4.25}$$

Using the residuals from equation (4.25), the OLS estimate of ρ can be expressed as:

$$\hat{\rho} = \frac{\sum_{c=1}^{N}\sum_{t=2}^{T}\hat{e}_{ct}\hat{e}_{c,t-1}}{\sum_{c=1}^{N}\sum_{t=2}^{T}\hat{e}_{c,t-1}^{2}} \tag{4.26}$$

Following this, the DF test statistic can be written as:

$$\sqrt{N}T(\hat{\rho} - 1) = \frac{\frac{1}{\sqrt{N}}\sum_{c=1}^{N}\frac{1}{T}\sum_{t=2}^{T}\hat{e}_{ct-1}\Delta\hat{e}_{ct}}{\frac{1}{N}\sum_{c=1}^{N}\frac{1}{T^2}\sum_{t=2}^{T}\hat{e}_{ct-1}^{2}} \tag{4.27}$$

The second test, an ADF type test is calculated as:

$$\hat{e}_{ct} = \rho\hat{e}_{ct-1} + \sum_{j=1}^{r}\phi_j\Delta\hat{e}_{ct-1} + e_{ctr} \tag{4.28}$$

The ADF test statistic is then derived using the usual t-statistic with $\rho = 1$ in the ADF equation. See [173] for full derivation.

C. Johansen fisher's cointegration test

The Johansen fisher cointegration test is a non-parametric test based on maximum likelihood [169]. The test is derived from aggregates of the p-values of individual Johansen maximum eigenvalues as well as trace statistics. The trace test statistics is defined as:

$$\lambda_{trace}(ce) = -T\sum_{c=ce+1}^{N}\ln(1 - \hat{\lambda}_c) \tag{4.29}$$

where, ce represents cointegrating vectors. The maximum eigenvalue test statistic is defined as:

$$\lambda_{max}(ce, ce+1) = -T \ln(1 - \hat{\lambda}_{ce+1}) \tag{4.30}$$

See [174] for a detailed derivation of the test statistics. The trace test, one sided test, tests for a null hypothesis of a maximum of ce cointegrating vectors against an alternative hypothesis of complete cross-section, N, cointegrating vectors. In the case of the maximum eigenvalue test, separate tests are done for each eigenvalue to test for a null hypothesis of ce cointegrating vectors against an alternative hypothesis of $ce + 1$ cointegrating vectors.

All three cointegration tests assume a null hypothesis, H_0 of no cointegration.

4.3.1.3 Estimation of panel cointegration regression

Following the detection of a long-run relationship from the analyses in Section 4.3.1.2, the associated long-run parameters are estimated. However, in the presence of cointegration, the conventional OLS regression is acknowledged to produce inconsistent and biased results. For this, the panel Dynamic Ordinary Least Square (hereafter DOLS) and Fully Modified Ordinary Least Square (hereafter FMOLS) tests are considered.
Note: For better readability, in following equations, $solid$ and GDP would be substituted to x and y, respectively.

A. DOLS

Proposed by Mark and Sul, the DOLS test is a parametric asymptotically normally distributed test which adjusts errors through reinforcing the static regressor with the lags, leads and values of regressors in the first differences [175], [176]. Consequently, although degrees of freedom are lowered in the process, for small sample sizes, the test is argued to be promising. Moreover, in its alternative hypothesis, cross sectional heterogeneity is restricted. The DOLS estimator is defined as:

$$\beta^*_{dols} = N^{-1} \sum_{c=1}^{N} \left(\sum_{t=1}^{T} Z_{ct} Z'_{ct} \right)^{-1} \left(\sum_{t=1}^{T} Z_{ct} y^*_{ct} \right) \tag{4.31}$$

where, $y^*_{ct} = y_{ct} - \bar{y_{ct}}$, $Z_{ct} = x_{ct} - \bar{x_{ct}}, \Delta solid_{ct-l}, \ldots, \Delta x_{ct+l}$, a $2(L+1)1$ vector. The t-statistics is therefore then calculated as:

$$t_{\hat{\beta}^*_{dols}} = N^{-0.5} \sum_{c=1}^{N} t_{\beta^*_{dols,c}} \tag{4.32}$$

where, $\beta^*_{dols,c}$ is the DOLS estimator applied to country, c. Therefore,

$$t_{\beta^*_{dols,c}} = (\beta^*_{dols,c} - \beta_0) \left[\hat{\sigma}_c^{-2} \sum_{t=1}^{T} (x_{ct} - \bar{x}_{ct})^2 \right]^{0.5} \tag{4.33}$$

where, $\sigma_c^2 = \lim_{T\to\infty} E \left[T^{-1} \left(\sum_{t=1}^{T} \mu_{ct} \right)^2 \right]$

B. FMOLS

On the other hand, the FMOLS is a non-parametric test proposed by Pedroni [172] which considers correlation between the error term and the first differences of the regressors. The FMOLS has fewer assumptions but more importantly, in the alternative hypothesis, it allows for cross-sectional heterogeneity, endogeneity and serial correlation. Thus, produces consistent and asymptotically unbiased cointegrating vectors estimates. Following from Equation (4.16),

$$y_{ct} = \alpha_c + \beta_c x_{ct} + \sum_{l=-l_c}^{l_c} \gamma_{cl} \Delta x_{ct-l} + \mu_{ct} \tag{4.34}$$

The FMOLS estimator is defined as:

$$\hat{\beta}^*_{fmols} = N^{-1} \sum_{c=1}^{N} \left[\sum_{t=1}^{T} (x_{ct} - \bar{x}_c)^2 \right]^{-1} \left[\sum_{t=1}^{T} (x_{ct} - \bar{x}_c) \, y^*_{ct} - T\hat{\gamma}_c \right] \tag{4.35}$$

Similar to the DOLS model, the FMOLS t-statistics can using Equation (4.32) by substituting $t_{\beta^*_{dols,c}}$ for $t_{\beta^*_{fmols,c}}$. Using Equation (4.33), $t_{\beta^*_{fmols,c}}$ can then be calculated by substituting $\beta^*_{dols,c}$ and $\hat{\sigma}_c^{-2}$ with $\beta^*_{fmols,c}$ and Ω_{11c}^{-1}, respectively.

4.3.1.4 Panel Granger causality tests

Following the evidence of cointegration and thus, long-run association, the direction of causality is investigated using the Granger causality test. Two stages are involved in this process. Firstly, the residuals from the DOLS and FMOLS models are evaluated. Secondly, we fit the evaluated residuals from Equation (4.34) into a Vector Error Correction Model (hereafter VECM). The VECM models are defined as:

$$\Delta GDP_{ct} = \sum_{j=1}^{L} \beta_{1j} \Delta GDP_{c,t-j} + \sum_{j=1}^{L} \gamma_{1j} \Delta solid_{c,t-j} + \lambda_1 ECT_{c,t-1} + \Delta \phi_{1ct} \tag{4.36}$$

$$\Delta solid_{ct} = \sum_{j=1}^{L} \beta_{2j} \Delta solid_{c,t-j} + \sum_{j=1}^{L} \gamma_{2j} \Delta GDP_{c,t-j} + \lambda_2 ECT_{c,t-1} + \Delta \phi_{2ct} \tag{4.37}$$

where, β and γ are adjustment coefficients, L denotes lags and ϕ denotes disturbance terms, whilst ECT is the error correction term from the residuals obtained in Equation (4.34).

At this point, we test for the source of causality using the statistical results from the coefficients of the lagged dependent variables. We consider the speed of adjustment (coefficients) and significance of the error correction terms from Equations (4.36) and (4.37), to confirm or infirm the presence (or absence) of long-run causality between the variables. The speed of adjustment demonstrates the speed at which deviations from the long-run equilibrium are corrected based on changes in the variables. The significance of λ demonstrates the long-run relationship of the cointegration process. As such, movements along this path are deemed permanent. Following the long-run causality estimation, we investigate for presence of short-run causality using the Wald tests.

4.3.2 Data

The analyses performed in this Chapter are based on data collated for forty-six sub-Saharan Africa; eight South Asian as well as twenty-seven East Asian and Pacific countries. The variable used in this study to represent economic development is the GDP per Capita. This variable has been selected based on its frequent use in considering economic growth and trends in existing energy-growth nexus literature (see studies in

Section 4.2). For household use of solid fuels, the percentage on households using solid fuels is used as variable. The selected variables in this Chapter are based on the annual time series on household use of solid fuels and GDP per Capita. The panel data used is for the period of 15 years, spanning across 2000 to 2015. In terms of classification of countries for regional aggregates, similar to Chapter 3, the World Bank's regional categorisation approach has been used. For the household use of solid fuels variable, the variable used in the analyses is derived from the 100 percent census. For the GDP per Capita variable, the data is derived from the current US dollars. Both variables have been transformed into their natural log forms to reduce heteroscedasticity, are unweighted and are denoted GDP and solid fuels.

Similar to Chapter 3, the data measuring households utilizing solid fuels as the primary energy sources have been collected from the regional World Health Organisation (WHO) Global Household Energy database [123]. It measures the percentage of households using solid fuels in the country. These data have been collected primarily through household surveys but have been augmented by estimates for the purposes of the observation of trends and the provision of point estimates for countries and regions in explicit years [123]. Although, previously there were few national representative surveys making trend analysis problematic, in recent years increased numbers of national surveys and additional surveys by the WHO have expanded available data points. In addition, the recent data draw together information gathered in most countries at national and sub-national censuses and survey. For this variable, the variance of 'access to clean cooking fuels and technology' data is used as a proxy. However, it is worth noting that even with access to clean cooking fuel, some households might still rely on solid fuels for cooking. As such, there exists a possibility of negligible imperfection in the variable

For the data measuring GDP per Capita, these have been collected from the regional WB database. GDP per Capita is measured by dividing the gross domestic product [3] by midyear population. Similar to the household use of solid fuels variable, this is obtained through censuses and surveys.

[3]This is obtained through the sum of the gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products

4.4 Results

The results from all three regions satisfy the first three stages of the analyses. The results from the final stage of the analyses suggest that in sub-Saharan Africa, in both the long-run and the short-run, household use of solid fuels negatively influences economic development. In east Asia, the results suggest that both variables mutually influenced each other, in the long-run while in the short-run, household use of solid fuels negatively influences economic development. Lastly, in the case of south Asia, the results suggest that household use of solid fuels and economic development do not influence each other in the long-run but in the short-run, household use of solid fuels influences economic development in the region.

The results from each stage of analyses detailed in Section 4.3.1 are presented in Sections 4.4.1, 4.4.2 and 4.4.3, for SSA, EA and SA respectively.

4.4.1 Sub-Saharan Africa (SSA)

A. Panel unit roots results

The results for the panel unit root tests for GDP per capita and household use of solid fuels are presented in Table 4.9. The results obtained demonstrate the stationarity (or lack of) properties of the variables, at level and at first differenced states. For both states, the variables are considered with and without time effects (trend).

Starting with the level state, for GDP per capita with no time effect, the null hypothesis of a unit root cannot be rejected at 5% significance levels across all tests; excluding the *Hadri* and *Heteroscedastic consistent z-stat* tests which have the null hypotheses of no unit root. As such, we consider that GDP per capita is non-stationary when time effects are not considered. With time effects, only two out of five tests strongly reject the null hypothesis of non-stationarity for GDP per capita whilst the *Hadri* and *z-stat* tests continue to reject the null hypothesis of stationarity. Ergo, we can also conclude non-stationarity for GDP per capita at level, when time effects are included.

For solid, results similar to the GDP per capita variable are obtained in both the constant and constant with time effects cases. Thus, both variables are first differenced to verify the fulfilment of cointegration conditions.

At the first differenced state, for both variables, the null hypothesis of unit root can be strongly rejected at both 1% and 5% significance levels, with and without time effects being included in the models.

		Null: Unit root					Null: No unit root	
	Tests / Variable	LLC	IPS	Breitung	ADF - Fisher	PP - Fisher	Hadri	z-stat
Level	GDP	-0.64	4.80	. . .	39.10	38.37	16.85	16.56
		(0.26)	(1.00)		(1.00)	(1.00)	(0.00)	(0.00)
	GDP	-3.73	-1.27	-0.65	103.73	125.06	11.91	14.05
	(trend)	(0.00)	(0.10)	(0.26)	(0.09)	(0.00)	(0.00)	(0.00)
	SOLID	3.46	1.48	. . .	154.98	220.86	19.42	20.97
		(1.00)	(0.93)		(0.00)	(0.00)	(0.00)	(0.00)
	SOLID	-22.03	-32.46	-1.26	465.68	425.70	14.40	31.85
	(trend)	(0.00)	(0.00)	(0.10)	(0.00)	(0.00)	(0.00)	(0.00)
First difference	GDP	-11.43	-9.89	. . .	257.39	381.98	5.64	5.15
		(0.00)	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)
	GDP	-12.41	-6.94	-6.25	204.71	383.81	34.36	30.10
	(trend)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	SOLID	-28.59	-31.84	. . .	462.86	498.47	11.98	11.03
		(0.00)	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)
	SOLID	-24.27	-32.07	-13.52	417.15	405.48	11.52	12.07
	(trend)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(00)

Table 4.9: Results for panel unit root tests for GDP per capita and solid fuels for SSA.
p-value in parentheses, ();

Hence, the panel unit root results can be concluded as such: the variables are deemed initially non-stationary but when integrated at order one (I(1)), become stationary. Thus, fulfil the conditions required for cointegration analyses. The significances of these results can be interpreted in twofold. Firstly, variables with unit root have properties such as mean, (co)variances[4],etc., which tend to be infinite and dependent on time. Hence, their (co)variances approach infinity as time approaches infinity and considering the properties of most econometric models, such variables are unsuitable for modelling. Secondly, due to their arbitrary paths, the observed effects in non-stationary variables could actually be due to random shocks. Consequently, the observed results in Table 4.9 which demonstrate stationarity after first differencing indicate that the variables are stable with finite properties and thus, can be used in further econometric modelling.

B. Panel cointegration results

In Table 4.10, the results obtained from the Pedroni within and between cointegrated tests are presented.

Starting with the *unweighted* cointegration tests; for the *within* panel statistics, the null hypothesis of no cointegration can be strongly rejected at 1% significance, for all but the *v-statistic* test. For the *between* panel statistics, the null hypothesis of no cointegration could be strongly rejected in the *ADF-statistic* test, can be considered marginal in the *PP-statistic* test, but can not be rejected in the *rho-statistic* test.

Considering the *weighted* cointegration tests, the panel *ADF-statistic* and *PP-statistic* tests strongly reject the null hypothesis of no cointegration whilst the *v-statistic* and *rho-statistic* tests do not reject this hypothesis.

[4]Variances for time series datasets; covariance for panel datasets

Table 4.10: Results for Pedroni residual cointegration tests for SSA.

Tests	Within panel statistics			Between panel statistics		
	Type	Statistic	p-value	Type	Statistic	p-value
GDP, SOLID	panel v-statistic	0.2938	0.3845	group rho-statistic	1.5652	0.9412
	panel rho-statistic	-2.9587	0.0015	group PP-statistic	-1.4196	0.0779
	panel PP-statistic	-2.5640	0.0052	group ADF-statistic	-4.8626	0.0000
	panel ADF-statistic	-3.8289	0.0001			
GDP, SOLID (weighted statistic)	panel v-statistic	-1.4410	0.9252			
	panel rho-statistic	-0.9927	0.1604			
	panel PP-statistic	-2.9727	0.0015			
	panel ADF-statistic	-5.3892	0.0000			

At this point, we consider Pedroni's remarks on these tests. In his work [177], Pedroni shows that in data samples with small time dimension, T, such as ours, the *ρ-statistic* test tends to reject the null hypothesis of no cointegration whilst the *ADF-statistic* and *PP-statistic* tests tend to have the best properties. Therefore, although the obtained results across all tests are valuable, the aforementioned tests can be considered more cogent. Accordingly, from the six *ADF-statistic* and *PP-statistic* related tests, we can infer cointegration between the GDP per capita and household use of solid fuels. This implies that there is potentially a long-run relationship between household use of solid fuels and GDP per capita, in the context of sub-Saharan Africa.

However, for robustness check and to account for potential cross-sectional spillovers .i.e. spillovers between countries within the region, the other tests are applied, to confirm or infirm these results.

Table 4.11: Results for Kao's residual cointegration test for SSA.

Model	ADF	p-value
GDP, SOLID	-4.2680	0.0000

Table 4.11 presents the results from the Kao's residual panel cointegration test. The obtained result strongly rejects the null hypothesis of zero cointegration at 1% significance. Therefore, affirms the results from the Pedroni panel tests: implying the presence of a long-run relationship between GDP per capita and household use of solid fuels. Nonetheless, we implement a different test type (likelihood based) test to validate these results.

Table 4.12: Results for Fisher-type cointegration tests in SSA.

Null hypothesis	Fisher stat* (trace test)	p-value	Fisher stat* (max-eigen test)	p-value
ce = 0	1255	0.0000	727.600	0.0000
ce $\leq$ 1	180.600	0.0000	180.600	0.0000

In Table 4.12, we present the results from the Fisher-type panel cointegration tests. For these tests, as shown in Section 4.3.1.2C, the cointegrating elements have been expressed as *ce*. Hence, the tests have been computed under the following null hypotheses: for the trace test, null hypothesis: H_0 : ce $\leq$ c, alternative hypothesis, H_1 : $ce_0 >$ c; whilst for the max-eigenvalue test, null hypothesis: H_0 : ce_0 = c, alternative hypothesis H_1 : $ce_0 >$ c.

Similar to the Kao's cointegration test, the results obtained from the two analyses: the trace and max-eigen tests, strongly reject the null hypotheses of no cointegration at 1% significance. Further providing evidence of cointegration between GDP per capita and household use of solid fuels.

Therefore, considering the results obtained from the four different cointegration tests, the premise of cointegration between GDP per capita and household use of solid fuels is accurate and it can be deduced that in the case of sub-Saharan Africa, long run, GDP per capita and household use of solid fuels move in unison. Put simply, these results suggest that in the case of sub-Saharan Africa, there is a steady, long-run relationship between household use of solid fuels and GDP per Capita. However, the nature and/or direction of this relationship remains undetermined. As such, the nature of the cointegration are examined in the next stage.

C. Long run cointegration results

The results obtained from the DOLS and FMOLS models which have been used to estimate the long run equilibrium are presented in Table 4.13.

Table 4.13: Results from DOLS and FMOLS tests for SSA.

	Models	
	DOLS	FMOLS
Co-efficient	-0.8467	-0.458
t-statistic	-0.0518	-0.4148
p-value	0.0000	0.0000

For both the DOLS and FMOLS models, simulations were performed declaring and testing each variable as the independent variable in the model. The results obtained from these models demonstrate the nature of the observed relationship between GDP per capita and household use of solid fuels - showing how the variables stimulate each other. However, considering the fact that the differences in results when GDP per capita is declared as the independent variable were minuscule but insignificant, only the results for the solid fuels model are presented. As such, the estimated coefficients from the models are elasticities of GDP per capita in relation to household use of solid fuels. It is also essential to emphasis that the DOLS model has the shortcoming of reducing the number of degrees of freedom. Thus, could lead to less robust estimates and considering the relatively small dimensions of time, T, and cross section, N of the dataset, the robustness of the DOLS could be affected. However, the DOLS effectively allows for the estimation of trend and direction of the relationship.

Nonetheless, for both models, the obtained results indicate a negative and significant (at 1% significance level) relationship. Implying that the observed relationship has a statistically significant and negative effect between the variables. Overall, these estimates suggest that household solid fuels use is a significant factor that impacts GDP per capita negatively.

D. Panel Granger causality results

At this stage, following establishing that GDP per capita is negatively and significantly cointegrated in the long run with household use of solid fuels, the direction of causality between the two variables is investigated. Table 4.14 presents the outcomes for the long run causality between household use of solid fuels and GDP per capita.

Table 4.14: Results for Granger causality test for SSA (L = lags).

Independent variable	f-statistic	p-value	Sense of causality
		GDP	
SOLID (L = 1)	4.8956	0.0273	SOLID → GDP
SOLID (L = 2)	3.4176	0.0135	
SOLID (L = 3)	3.1960	0.0076	
		SOLID	
GDP (L = 1)	2.6932	0.1013	GDP → SOLID
GDP (L = 2)	3.1260	0.0447	
GDP (L = 3)	6.5783	0.0070	

Firstly, the model with solid fuels declared as the independent variable indicating a causal relationship running from household use of solid fuels to GDP per capita is considered. For the first and second lags, the null hypothesis of no causality can be strongly rejected at 5% significance whilst for the third lag, the null hypothesis can be strongly rejected at 1% significance.

Turning to the model with GDP per capita declared as the independent variable, indicating a causal relationship running from GDP per capita to household use of solid fuels, although marginal at 10% significance, the null hypothesis of no causality cannot be rejected at 5% or 10% significance levels for the first lag. Whilst for the second and third lags, the null hypothesis can be rejected at 5% and 1% significance levels respectively.

However, since the optimal lag structure has been established to be one (1): based on the Akaike and Schwarz criteria, from Table 4.14, we can conclude that in the case of sub-Saharan Africa, for the long run, there is a uni-directional causality running from household use of solid fuels to GDP per capita. Accordingly, these findings can be interpreted as such: the household use of solid fuels has a negative and significant impact on economic growth within the region of sub-Saharan Africa. Thus, an increase in the household use of solid fuels would result in a decrease in economic growth in the long run. Furthermore, these results also show that based on the hypothesis set out in Section 4.2, the dynamics between household use of solid fuels and economic development, for sub-Saharan Africa as a region, can be categorised under the growth (although negative) hypothesis.

Lastly, the short run relationship between household use of solid fuels and GDP per capita is considered using the Wald test.

Table 4.15: Short run causality results for SSA.

Dependent variable	Chi-square	p-value	Sense of causality
SOLID	2.1847	0.3354	GDP $\rightarrow$ SOLID
GDP	9.7124	0.0078	SOLID $\rightarrow$ GDP

Table 4.15 presents the results for the short run causality. The results obtained are similar to those of the long run causality. For the case of causality running from GDP per capita to household use of solid fuels, the obtained probability of causality was over 33%. As such, the null hypothesis of no causality can not be rejected for this case. However, considering the causality running from household use of solid fuels to GDP per capita, the null hypothesis of no causality can be rejected at 1% significance levels. Thus, this demonstrates that there is a strong and significant short-run causal relationship running from household use of solid fuels to GDP per capita.

Overall, in the context of sub-Saharan Africa for the period 2000 to 2015, the relationship between the household use of solid fuels and economic growth can be considered as a uni-

directional relationship which satisfies the reverse-growth hypothesis: in both the long run and short run. In other words, household use of solid fuels negatively affects the economic growth of the region in both the long-run and the short-run.

4.4.2 East Asia (EA)

A. Panel unit root results

Table 4.16 presents the results obtained from the panel unit root tests for GDP per capita and household use of solid fuels, in the case of east Asia.

At level, starting with GDP per capita (with and without time effects), the null hypothesis of a unit root cannot be rejected at 5% significance across the first 5 tests. Implying for these five tests, that unit roots exist between the GDP variable. For the Hadri and z-stat tests, the null hypothesis of no unit root can be strongly rejected - implying that there is a unit root in the variable's panel data. For household use of solid fuels (with and without time effects), the hypothesis of a unit root can be accepted in four of the seven tests.

However, at first difference, for both the GDP per capita and household use of solid fuels variables, the premise of a unit root can be strongly rejected across five tests, at 1% significance levels while the Hadri and z-stat tests continue to reject the null hypothesis of no unit root.

	Tests	Null: Unit root					Null: No unit root	
	Variable	LLC	IPS	Breitung	ADF - Fisher	PP - Fisher	Hadri	z-stat
Level	GDP	2.2570	5.4712	...	19.8104	19.0957	11.9589	11.7796
		(0.9880)	(1.0000)	...	(1.0000)	(1.0000)	(0.0000)	(0.0000)
	GDP (trend)	-1.0837	0.4211	4.8843	53.5642	58.6138	5.2050	6.9176
		(0.1393)	(0.6631)	(1.0000)	(0.6408)	(0.4528)	(0.0000)	(0.0000)
	SOLID	-0.5297	2.9023	...	150.4890	161.1330	11.6556	12.9616
		(0.2982)	(0.9981)	...	(0.0000)	(0.0000)	(0.0000)	(0.0000)
	SOLID (trend)	-2.3340	1.3852	5.4586	74.0328	106.2010	10.4744	11.0813
		(0.0098)	(0.9170)	(1.0000)	(0.0930)	(0.0000)	(0.0000)	(0.0000)
First Difference	GDP	-7.5259	-5.6539	...	131.9050	132.5590	0.4797	3.2620
		(0.0000)	(0.0000)	...	(0.0000)	(0.0000)	(0.0000)	(0.0000)
	GDP (trend)	-8.8694	-2.1424	-0.4979	83.1103	103.5840	9.1256	15.9319
		(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
	SOLID	-9.0361	-7.9864	...	179.8340	203.8050	7.7853	9.2472
		(0.0000)	(0.0000)	...	(0.0000)	(0.0000)	(0.0000)	(0.0000)
	SOLID (trend)	-7.0102	-9.3970	-5.0472	190.1240	279.0670	11.5218	14.5157
		(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)

Table 4.16: Results of panel unit root tests for GDP per capita and solid fuels for EA.
p-value in parentheses, ();

Hence, since the variables become stationary upon being integrated at first order, the conditions needed for cointegration are deemed fulfilled.

B. Panel cointegration results

The results for the Pedroni cointegration tests are presented in Table 4.17.

Table 4.17: Results for Pedroni residual cointegration tests for EA.

Tests	Within panel statistics			Between panel statistics		
	Type	Statistic	p-value	Type	Statistic	p-value
GDP, SOLID	panel v-statistic	1.9027	0.0285	group rho-statistic	1.0666	0.8569
	panel rho-statistic	-2.2574	0.0120	group PP-statistic	-0.7578	0.2243
	panel PP-statistic	-1.7550	0.0396	group ADF-statistic	-2.5732	0.0050
	panel ADF-statistic	-2.2893	0.0110			
GDP, SOLID (weighted statistic)	panel v-statistic	1.5486	0.0607			
	panel rho-statistic	-1.3164	0.0940			
	panel PP-statistic	-1.9603	0.0250			
	panel ADF-statistic	-3.1052	0.0010			

Firstly, we consider the *unweighted* tests. For the *within* statistics, all four tests strongly reject the null hypothesis of no cointegration at 5% significance whilst for the *between* statistics, only the *group ADF-statistics* indicates cointegration.

Turning to the *weighted* tests; similar to the case of sub-Saharan Africa, at 5% significance, the null hypothesis of no cointegration can be rejected for only the *ADF-statistic* and *PP-statistic* tests whilst at 10% significance, the further two tests can be regarded. Nonetheless, to validate (or refute) these results, we consider the other cointegration tests.

Table 4.18: Results for Kao's residual cointegration test for EA.

Model	ADF	p-value
GDP, SOLID	-2.8403	0.0023
SOLID, GDP	-1.9280	0.0269

The results obtained from Kao's residual panel cointegration are presented in Table 4.18. These also strongly reject the null hypothesis of no cointegration at 5% significance, further confirming the premise of a presence of a long-run relationship between GDP per capita and household use of solid fuels.

Finally, the results from the Fisher-type panel cointegration tests are presented in Table 4.19.

Table 4.19: Results for Fisher-type cointegration tests for EA.

Null hypothesis	Fisher stat* (trace test)	p-value	Fisher stat* (max-eigen test)	p-value
ce = 0	285.5	0.0000	241.1	0.0000
ce $\leq$ 1	114.0	0.0000	114.0	0.0000

The results obtained from the trace and max-eigen tests are in agreement with those obtained from the Kao's tests - with both results strongly rejecting the null hypotheses of no cointegration at 1% significance levels.

Therefore, considering the results from all four tests confirm cointegration, we can strongly conclude that a long run relationship exists between GDP per capita and household use of solid fuels.

C. Estimating the long-run cointegration relationship

Table 4.20 presents the results obtained from the FMOLS and DOLS models. To evaluate the nature of the observed cointegration, solid fuels and GDP have been used as dependent variables. The results obtained from both models appear significant and consistent, with only little differences shown in the coefficients.

Table 4.20: Results from DOLS and FMOLS tests for EA.

	Models	
	DOLS	FMOLS
	GDP as dependent	
Co-efficient	0.5743	0.4333
t-statistic	18.7754	15.0601
p-value	0.0000	0.0000
	Solid as dependent	
Co-efficient	0.0252	0.0301
t-statistic	4.5079	16.1465
p-value	0.0000	0.0000

Starting with the DOLS models, for both GDP per capita and solid fuels as dependent variables, positive and significant relationships are observed between household use of solid fuels and GDP per capita. Similar to the DOLS models, the results obtained from the FMOLS models also demonstrate positive and significant relationships for both the GDP and solid fuels dependent models. Thus, it can be deduced that in the context of east Asia, the relationship between the household use of solid fuels and GDP per capita is positive and significant.

D. Panel Granger causality tests

In terms of the nature and direction of causality between the variables, Table 4.21 presents the results obtained from the granger long run causality models.

Starting with GDP as the dependent variable, it is observed that across lags 1 to 3, the null hypothesis of no causality can be strongly rejected at 1% significance. These imply that there is a strong and statistically significant long run causality running from household use of solid fuels to GDP per capita.

Table 4.21: Results for Granger causality test for EA (L = lags).

Independent variable	f-statistic	p-value	Sense of causality
	GDP		
SOLID (L = 1)	11.6652	0.0007	SOLID → GDP
SOLID (L = 2)	8.3574	0.0003	
SOLID (L = 3)	4.8451	0.0026	
	SOLID		
GDP (L = 1)	34.9692	7E-09	GDP → SOLID
GDP (L = 2)	2.0059	0.1359	
GDP (L = 3)	1.5674	0.1969	

When considering solid fuels as the dependent variable, for the first lag, the null hypothesis of no causality can be strongly rejected at 1% significance. However, for lags 2 and 3, the results obtained are not statistically significant. The probability values associated to the null hypothesis are both over 5% and as such, the null hypothesis of no causality is accepted for these lags. However, considering that the optimal lag structure was established to be lag 1 (again using the AIC Schwarz criteria), the premise of causality running from GDP per capita to household use of solid fuels, can be confirmed.

Taken together, it can be concluded that for east Asia, in the long run, a bi-directional causal relationship exists between household use of solid fuels and GDP per capita. *Accordingly, these findings can be interpreted as such: GDP per capita and household use of solid fuels mutually influence each other in the long-run. That is, a feedback hypothesis exists between the variables. This further implies that in the long-run, the household use of solid fuels has a significant impact on economic growth and vice versa, within the region of east Asia.* Finally, the results of the short-run causality are presented in Table 4.22.

Table 4.22: Short-run causality results for EA.

Dependent variable	Chi-square	p-value	Sense of causality
GDP	1.5559	0.1620	SOLID → GDP
SOLID	10.1843	0.0000	GDP → SOLID

For model with the solid fuels as the dependent variable, the null hypothesis of no causality can be strongly rejected at 1% significance whilst for the model with GDP as dependent variable, the null hypothesis of no causality can not be rejected and thus, must be accepted. This result implies that in the short run, in the case of east Asia, the causal relationship is observed to run from GDP per capita to household use of solid fuels.

Essentially, in the short run, economic growth influences the household use of solid fuels but the household use of solid fuels does not cause a short run shock or effect to the economic growth of the region.

4.4.3 South Asia (SA)

A. Panel unit roots results

The results of the panel unit root tests performed for GDP per capita and household use of solid fuels, in the case of south Asia are presented in Table 4.23.

At level, for GDP per capita (with and without time effects), across all tests, the hypothesis of stationarity cannot be accepted at 5% significance. With regard to household use of solid fuels (with and without time effects), a unit root is observed in four of the seven tests. This means that at level, for both variables, there is the presence of a unit root and as such, it can be suspected that the parameters of these variables probably suffer from 'random walk'. However, after first difference, for both GDP per capita and household use of solid fuels (with and without time effects), at least five of the seven tests confirm the absence of a unit root. These suggest that both variables can be considered stationary - after first difference.

Thus, since the variables are considered stationary after integration at first order, the conditions needed for cointegration are deemed fulfilled.

	Tests	Null: Unit root					Null: No unit root	
	Variable	LLC	IPS	Breitung	ADF - Fisher	PP - Fisher	Hadri	z-stat
Level	GDP	4.4449	6.5186	...	0.9117	0.7388	6.6142	6.5729
		(1.0000)	(1.0000)	...	(1.0000)	(1.0000)	(0.0000)	(0.0000)
	GDP (trend)	-0.7677	0.0328	3.3635	15.9027	14.2413	3.6289	3.3049
		(0.2213)	(0.5131)	(0.9996)	(0.4598)	(0.5807)	(0.0001)	(0.0005)
	SOLID	1.6421	5.9875	...	15.8829	58.9590	7.8669	6.9637
		(0.9497)	(1.0000)	...	(0.4612)	(0.0000)	(0.0000)	(0.0000)
	SOLID (trend)	0.2832	1.6759	6.2539	20.0980	20.6510	7.4363	6.44997
		(0.6115)	(0.9531)	(1.0000)	(0.2158)	(0.1923)	(0.0000)	(0.0000)
First Difference	GDP	-6.0827	-4.6874	...	51.2181	67.9043	-0.0454	2.6063
		(0.0000)	(0.0000)	...	(0.0000)	(0.0000)	(0.5181)	(0.0046)
	GDP (trend)	-6.8321	-3.3074	-3.1091	37.9812	49.8624	2.4110	10.3620
		(0.0000)	(0.0005)	(0.0009)	(0.0015)	(0.0000)	(0.0080)	(0.0000)
	SOLID	-2.3204	-3.9854	...	59.2256	71.0456	7.8236	6.0660
		(0.0102)	(0.0000)	...	(0.0000)	(0.0000)	(0.0000)	(0.0000)
	SOLID (trend)	-5.2146	-5.2929	-0.4061	56.8392	132.197	3.8261	25.4241
		(0.0000)	(0.0000)	(0.0019)	(0.0000)	(0.0000)	(0.0001)	(0.0000)

Table 4.23: Results for panel unit root tests for GDP per capita and solid Fuel for SA.
p-value in parentheses, ();

B. Panel cointegration results

Table 4.24 shows the results of the Pedroni cointegration tests for south Asia.

Table 4.24: Results for Pedroni residual cointegration tests for SA.

Tests	Within panel statistics			Between panel statistics		
	Type	Statistic	p-value	Type	Statistic	p-value
GDP, SOLID	panel v-statistic	2.2624	0.0118	group rho-statistic	0.4057	0.6575
	panel rho-statistic	-0.0802	0.4680	group PP-statistic	-1.8043	0.0356
	panel PP-statistic	-0.2506	0.4011	group ADF-statistic	-1.7773	0.0378
	panel ADF-statistic	-1.2328	0.1088			
GDP, SOLID (weighted statistic)	panel v-statistic	2.9086	0.0018			
	panel rho-statistic	-0.8635	0.1939			
	panel PP-statistic	-1.7868	0.0370			
	panel ADF-statistic	-1.9102	0.0281			

For the *unweighted* tests, with regard to the *within* statistics, the null hypothesis of no cointegration can be strongly rejected in only the *v-statistic* test whilst the other three tests accept the no cointegration hypothesis. Looking at the *between* statistics, the null hypothesis of no cointegration is strongly rejected by the *group PP-statistics* and *group ADF-statistics* tests but accepted by the *rho-statistic* test.
As for the *weighted* tests, the null hypothesis of no cointegration is strongly rejected by all but the *rho-statistic* test. It is worth noting that the co-efficient of the tests are negative. These indicate that perhaps low data point is resulting in inefficient and low test powers. As such, further testing is crucial and thus, applied.

For additional analysis, the Kao's residual cointegration test is implemented.

Table 4.25: Results for Kao's residual cointegration test for SA.

Model	ADF	p-value
GDP, SOLID	0.1402	0.4442
SOLID, GDP	0.5789	0.2813

As shown in Table 4.25, the null hypothesis of no cointegration can not be rejected for both models. Implying that between GDP per capita and household use of solid fuels, no long run relationship is detected by the Kao tests.

Due to the inconclusive results from the Pedroni and Kao test, the Fisher-type tests are implemented to further investigate the cointegration between GDP per capita and household use of solid fuels.

Table 4.26: Results for Fisher-type cointegration tests for SA.

Null hypothesis	Fisher stat* (trace test)	p-value	Fisher stat* (max-eigen test)	p-value
ce = 0	97.31	0.0000	89.44	0.0000
ce = 1	30.23	0.0168	30.23	0.0168

Table 4.26 shows the results from the Fisher-type panel cointegration tests. Unlike the results obtained in the Kao's test, the results from the trace and max-eigen tests strongly reject the null hypotheses of no cointegration at 5% significance. Thus, indicating a strong long run relationship between household use of solid fuels and GDP per capita.

Taken together, two of the four tests strongly indicate a long run relationship between household use of solid fuels and GDP per capita whilst a third test can be considered marginal. These results suggest that there are probable causes of cointegration between the variables. However, due to these results, the cointegrating relationship is suggested to be weak. Similar results were obtained in the study by Akinlo [49]. In their study, the authors also derived similar interpretations from their results.

A further note on the conflicting results: it is worth highlighting a probable reason for the obtained results. The results could be suggesting that for the south Asian region as a whole, there *may be a long run relationship between GDP per capita and household use of solid fuels across the regions. However, there is a possibility that some countries have extreme non-cointegration properties or vice versa.*

C. Estimating the long-run cointegration relationship

The results from the DOLS and FMOLS models are presented in Table 4.27.

Table 4.27: Results from dols and fmols tests for SA.

	Models	
	DOLS	FMOLS
	GDP as dependent	
Co-efficient	-0.1080	-0.1135
t-statistic	-10.1876	-27.944
p-value	0.0000	0.0000
	Solid as dependent	
Co-efficient	-0.0137	-0.0142
t-statistic	-30.8693	-30.4088
p-value	0.0000	0.0000

Similar to the results for east Asia, the results from both models appear significant and considerably consistent, with slight differences shown in the coefficients. For both the DOLS and FMOLS models, regardless of which variable is declared as the dependent variable, the results obtained demonstrate negative and statistically significant relationships.

As such, it can be inferred that for south Asia, the relationship between the household use of solid fuels and GDP per capita is negative and significant.

D. Panel Granger causality tests

Finally, similar to other regions, the nature and direction of causality between household use of solid fuels and GDP per capita in south Asia are examined. Table 4.28 shows the results obtained from the tests examining the long run causality between the variables.

For the GDP dependent model, the result obtained for the first lag shows an approximate 60% probability value of no causality and whilst this value reduces in the second and third lags, the null hypothesis of no causality still can not be rejected for any of the applied lags. As such, in the instance of south Asia, in the long run, household use of solid fuels does not influence economic growth.

Table 4.28: Results for Granger causality test for SA (L = lags).

Independent variable	f-statistic	p-value	Sense of causality
	GDP		
SOLID (L = 1)	0.2798	0.5978	SOLID → GDP
SOLID (L = 2)	1.5044	0.2268	
SOLID (L = 3)	1.7205	0.1678	
	SOLID		
GDP (L = 1)	0.3688	0.5449	GDP → SOLID
GDP (L = 2)	0.4255	0.6546	
GDP (L = 3)	1.0483	0.3748	

Similar to the GDP dependent model, the results obtained for all lags across the solid fuels dependent model show that the null hypothesis of no causality can not be rejected at any of the significance levels. This result implies that for south Asia, in the long run, there is no causal relation running from GDP per capita to household use of solid fuels. These results confirm the initial suspicions in section B. In the case of south Asia, although the household use of solid fuels and GDP per capita might be moving in a somewhat unison direction, there are no causal relationship between the variables. Although, this relationship might exist in some countries, for the region as a whole, in the long-run, the household use of solid fuels and GDP per capita do not influence one another.

Therefore, these results can be interpreted to suggest that for south Asia, in the long run, the household use of solid fuels does not have a significant impact on the economic growth of the region and coincidently, the economic growth within the region does not in the long run, impact on the household use of solid fuels. Therefore, these results suggest that in the long-run, a neutrality hypothesis exists between the two variables, in the case of south Asia.

Lastly, the short run causality for the region is investigated and the results presented in Table 4.29.

Table 4.29: Short-run causality results for SA.

Dependent variable	Chi-square	p-value	Sense of causality
GDP	9.1759	0.0270	SOLID $\rightarrow$ GDP
SOLID	0.1252	0.9887	GDP $\rightarrow$ SOLID

For the solid fuels dependent model, the probability of no causality running from GDP per capita to household use of solid fuels is observed to be over 98%. As such, the null hypothesis of no causality is strongly accepted for this model. However, for the GDP dependent model, the null hypothesis of no causality can be strongly rejected at 5% significance. This implies that in south Asia, in the short run, the causal relation runs from household use of solid fuels to GDP per capita. Therefore, for the region, a growth hypothesis exists in the short-run between the variables.
Essentially, in the short-run, the household use of solid fuels impacts on the economic growth within the region but economic growth within the region does not in the short run, influence the trend of household use of solid fuels.

4.5 Discussion

Motivated by the recognition that energy poverty is considered an obstacle to the needed development in the developing world, the impacts of household use of solid fuels (a result of the lack of clean cooking fuels which is an aspect of energy poverty) on social development, was investigated in Chapter 3. Following the discovery that the household use of solid fuels significantly impacts on measures of social development, this Chapter set-out to fill further gaps in literature by seeking to answer the research question:

how does household use of solid fuels influence the economic dimension of sustainable development?.

The statistical analyses in this Chapter are the first quantitative analyses which focus on understanding the dynamics between the household use of solid fuels and economic development. To this effect, the empirical evidence of the relationship between

household use of solid fuels and economic growth has been examined in this Chapter: using panel data for the period of 2000 to 2015 from twenty-five Pacific and East Asian countries; forty-seven sub-Saharan countries; and eight south Asian countries.
For the purpose of the analyses, GDP per capita and percentage of population depending on traditional (solid) fuels were used as variables whilst the panel unit roots, panel cointegration, and panel causality methods have been applied. For robustness, the outcomes at each stage of the analyses have been tested by utilising multiple methods per stage.
The results obtained from the regions have been interesting. Across all regions except the south Asian region, strong co-integration results: suggesting a strong relationship between household use of solid fuels and economic growth were observed. However, similar to the results from studies presented in Section 4.2, the observed results on the causal nature of these relationship have been diverse and in the case of south Asia, contradictory.

The causal relationship between general energy consumption and economic development has been described to generally speaking, fall within one of four hypotheses - as discussed in Section 4.2 [126]. The neutrality hypothesis, where there exists no causal link; the growth hypothesis, where causality runs from energy to economic development; the conservation hypothesis where causality is observed to run from economic development to energy; and finally, the feedback hypothesis where causality is bi-directional. Accordingly, the relationship between household use of solid fuels and economic development can be intuited and has been hypothesised in this chapter to fall into one of these hypotheses.
These hypotheses do not only provide important insights into the impacts of household use of solid fuels on economic development, but can also provide a premise for the assessment and formulation of policies relating to this aspect of energy poverty.

Starting with the first region analysed: sub-Saharan Africa. With statistically significant error correction terms, the estimations show a negative relationship between solid fuels use and GDP per capita. The direction of this observed relationship is observed to flow from the household use of solid fuels to GDP per Capita: in both the short and long run. This signifies that in both cases, an inverse-growth hypothesis is observed in the solid fuel-economic development scenario for sub-Sahara Africa. The implications of these results can thus be translated as follows: in the context of sub-Saharan Africa, in the short term, an increase in the household use of solid fuels such as coal, animal dung, dried crops, etc., for cooking and/or heating, negatively impacts on the GDP per capita of the region. Also, in the long term, the household use of solid fuels for cooking and/or heating acts as an inhibitor to economic development within the region. These further indicate that the economic performance within the region is partly influenced by the proportion of the population having to rely on solid fuels for day-to-day activities. A cause for this obtained result can be reasoned thusly: although it is a known notion that the economic development of a country is a complex dynamic influenced by several factors, the level of productivity within the country still remains a large influence on the economic performance of the country. As such, at the most simplistic level, although arguably that household use of solid fuels could contribute to economic inputs (for example, serve as a form of revenue or employment for the unskilled), one could still associate the reduced productivity caused by household use of solid fuels to reduced economical productivity. To exemplify, several studies (as mentioned in Chapter 3) have emphasised that women and children in developing countries spend several hours daily on the tasks of collecting and preparing of solid fuels. All of which result in reduced time for economically productive activities for the affected population. In addition, as established in Chapter 3, several studies (see [178]–[181]) have associated the household use of solid fuels with several severe health problems including respiratory diseases, physical impairment and in some cases, higher mortality rates (see [182], [183]). Therefore, it can be anticipated that the reduction in productivity resulting from these health problems/debility attributable to household use of solid fuels, could indeed generate a shock effect on the economic state of countries.

From a policy perspective, the implication of these findings is that changes in the household energy profile would have a significant effect on changes in the economic development of sub-Saharan Africa. Although in growth hypothesis scenarios, energy conservative policies: temporal or permanent, are seen to hinder economic development, the reverse-growth relationship obtained in the case of sub-Saharan Africa, would indicate that this would be different for the region. Due to the negative relationship, solid fuels conserving measures might be not only beneficial in preventing harmful impacts, but also beneficial for the socio-economic development of the region. However, implementing solid-fuels reducing policies within a region where most of the population have little-to-no access to modern alternatives, might not be an ideal policy strategy. Therefore, policies which support alleviation of income poverty, as well as policies which aid provision of modern energy alternatives, in addition to these solid fuels conservative policies are necessary for effective forward movement within the region.

From these results, it is evident that sub-Saharan African countries need to increase access to modern fuels for cooking and/or heating, to facilitate economic development. So, although the requirement of a hefty capital investment can be anticipated: due to declining and/or lacking infrastructures, the substantial impact of the current situation on socio-economic development, as well as environmental sustainability, make the argument that these investments are necessary and inevitable.

All in all, it can be inferred that it is beneficial for sub-Sahara African countries to continue to strive to move from household use of solid-fuels to cleaner forms energy - as this is likely to reinforce the much needed economic development. To aid this progress towards clean cooking fuels, there is also a need for the incorporation of policies aimed at addressing barriers.

Lastly, the relationship between the household use of solid fuels for cooking and economic development needs to be further investigated. To clarify, for a region where most countries are considered economically low-income, the hypothesis that through rising economy or better still, improved economic conditions (for example, in the way of increased household incomes), the household use of solid fuels can be addressed, was rejected by the causality estimations in this chapter. However, this hypothesis might be true for some countries within the region. Sub-Saharan Africa is known to have a complex dynamics: there are vast differences across and within the countries. Therefore. to further explore this issue and better understand these dynamics, as a starting point, more attention needs to be placed on effective data collection at national levels. By using sub-national data, it might be possible to uncover some of these complex relationships within the countries. A current drawback of country level studies is the lack of data, resulting in small time series sample sizes which might cause unreliable econometric tests. As such, the collection of quality data is essential. Although it would require a long duration before analyses can provide reliable results, the implementation of good data collection practices could contribute to the success of future investigations.

In the case of east Asia, the results obtained not only show that there is a strong correlation between household use of solid fuels and economic development across the region, but also reflect a strong and significant causal relationship between these variables. For the east Asian region, in the short-run, a statistically significant causal relationship which can be categorised under the conservation hypothesis is observed. This observed relationship demonstrates that in the short run, household the use of solid fuels is strongly influenced by the economic state of the region. In the long run, the bi-directional causal relationship obtained in the causality test, demonstrate that in the case of the east Asian region, there exists a feedback relationship between the use of solid fuels and economic development. This indicates that the use of solid fuels has a significant impact on economic growth within the region and vice versa. Simply put, in the case of east Asia, household use of solid fuels and economic growth influence each other. This can also be interpreted that since wealthier countries have the chance of having better infrastructures, this could facilitate better access to clean cooking fuels which in turn could aid higher productivity levels feeding back to economic development. Therefore, it can be anticipated that as some east Asian countries such as Cambodia and Mongolia develop, there is the possibility of a loop which feeds into the development of better energy infrastructures and back into economic advancement.

From a policy perspective, these findings imply that in the short-run, for the east Asian region, changes in the economic state of the region would have a significant impact on the energy profiles of household. As such, to address the issue of household utilisation of solid fuels, broader policies aimed at economic development need to be

considered alongside energy policies. In fact, these broader policies might be more impactful in addressing the issue. In the long run, considering that both factors mutually affect one another, energy conservation policies such as reduction of household consumption of solid fuels as well as economic and energy development policies which would facilitate improved household income and improved household accessibility to clean fuels, etc., need to be simultaneously implemented for effective outcomes. On the whole, it can be inferred that east Asian countries should strive towards implementation of cleaner energy (for cooking and/or heating) and broader economic policies as this would reinforce economic development. Furthermore, policies designed to in-cooperate accessibility barriers would aid in the alleviation of the issue.
Lastly, similar to sub-Saharan Africa, better data collection practices are needed to aid improved analyses and thus, improve the understanding of the issue.

Finally, for south Asia, the conflicting cointegration results would suggest that generally speaking, across the region, there is a potential relationship between the household use of solid fuels and economic development. However, there is also a possibility of the existence of extreme non-cointegration properties within some countries or vice versa. Nonetheless, the obtained causality results confirm no causal relationship between the variables in the long run. This implies that the household use of solid fuels does not have a significant impact on the economic development within the region/or and vice versa. As such, it can be anticipated that although income poverty [5] could generally speaking, be a contributing factor to the issue, in the case of south Asia, in comparison to other factors, it might not be such a strong determinant of the problem. To this effect, the studies by Rosenbaum et al.; Jeuland et al.; amongst others could provide plausible explanations to these outcome. In their study which investigated factors affecting transition to cleaner cooking fuels and/or technologies, they highlighted that in the south Asian region, other factors such as cultural beliefs or behaviours, taste preferences, amongst others, play a significant role in households' decision on continued use of solid fuels - even in cases where households have access to cleaner cooking alternatives (See [184]–[188]).

[5] In the forms of economic elements: at both national and household levels

Looking at the short run causal relationship, a reverse growth hypothesis is observed, with the causal relationship running from household use of solid fuels to economic development. Thus implying that in the short run, the use of solid fuels has a negative impact on economic development in the region.

From a policy perspective, although policies similar to those proposed in the case of sub-Saharan Africa can be adopted, considering the economic state within the region and the nature of the causal relationship reported for the region, it would be beneficial when designing policy solutions for the region to consider and incorporate consumer behaviour policies. These policies should be incorporated in addition to solid fuels conserving measures and broader poverty policies.

To summarise, based on the results from Sections 4.4.1 to 4.4.3, the posed research questions can be answered as such: in the context of sub-Saharan Africa, enhanced economic development might play a role influencing the nature of household use of solid fuels but ultimately, a reduction in the household use of solid fuels plays a crucial role in achieving said enhanced economic development. For east Asia, economic development and household use of solid fuels would significantly impact one another, in the long run. However, in the short run, the significance of economic development becomes more significant in the dynamic of this relationship: in that economic development would influence the nature of household use of solid fuels. For the south Asian region, household use of solid fuels and economic development appear exclusively related in the long-run. Although in the short run, household use of solid fuels would significantly impact on economic development.

To conclude, the results in this Chapter have provided an insight into the dynamics of household use of solid fuels and economic development at regional levels for sub-Saharan Africa, east Asia and south Asia - in both the long run and short run. Although the nature of the causal relationship between the two variables varied across the examined regions, the results provide evidence that there exists a strong relationship between the household use of solid fuels and economic development. In addition, causes for the varying outcomes observed between the regions can be reasoned to be two-fold: 1) each region has varying contributing factors (or barriers) to access (or lack of) to modern cooking alternatives; 2) the distribution of economic development is uneven across the regions.

Finally, following these findings, in the next chapter, the barriers to household accessibility to cleaner cooking alternatives is investigated for the regions explored within this chapter.

4.6 Summary of key findings

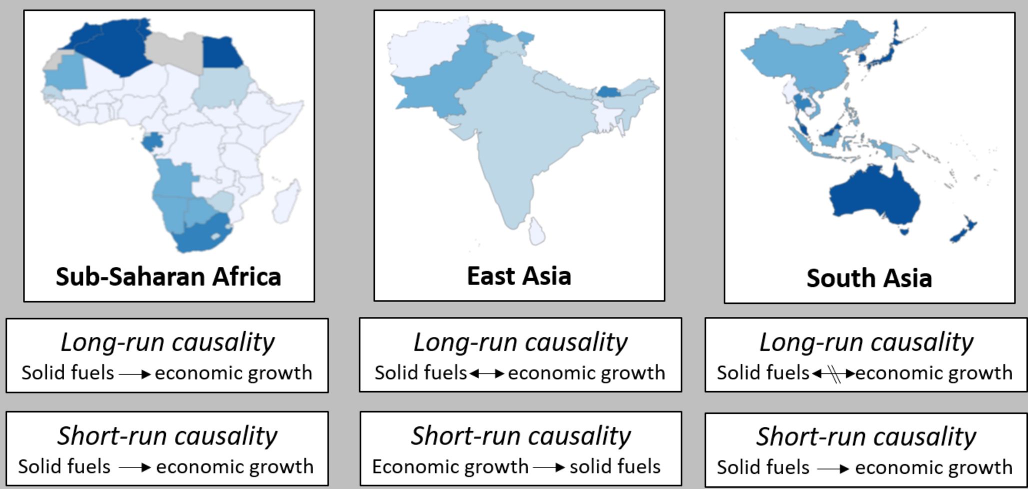


Figure 4.2: Summary of observed causal relationships between household use of solid fuels and economic development

In SSA, in both the long-run and short-run, a negative causality is observed and seen to run from household use of solid fuels to GDP per Capita. In other words, higher rates of solid fuel use tend to lead to lower GDP per Capita in the SSA region. Thus, for policy purposes, in both the long-run and short-run, the household solid fuels - GDP per capita relationship for SSA falls under a negative-growth hypothesis: implying that household solid fuels conservative policies would be favourable in the region.

In EA, in the long run, causality is also observed and seen to run in both directions .i.e. a bi-directional causal relationship between household use of solid fuels and GDP per capita is seen. This implies that household use of solid fuels and GDP per Capita influence one another in the long run. In the short run, the causality is observed to flow from GDP per Capita to household use of solid fuels. Thus, for policy purposes, in the long run, the household solid fuels - GDP per capita relationship for EA falls under the feedback hypothesis while in the short-run, the relationship falls under the conservation hypothesis: implying that household solid fuels conservative policies would also be favourable in the region.

Finally, in SA, no causal relationship is observed in the long-run. However, in the short-run, the causality is observed to flow from household use of solid fuels to GDP per Capita - implying that household use of solid fuels influence GDP per Capita. Thus, for policy purpose, in the long run, solid fuels expansive or conservative policies would not significantly impact the economy of the region. However, in the short-run, solid fuels conservative policies would be favourable in the region.

Chapter 5

Barriers to modern cooking fuels

This chapter aims to answer question 'Q5' of the research sub-questions outlined in section 1.1: "what are the obstacles to accessibility of cleaner cooking fuel alternatives for households in these impoverished regions". It reviews and discusses the current barriers to household accessibility to cleaner cooking fuel alternatives from both the supply and demand perspective. In so doing, this Chapter determines the contributing factors to the continued use of household solid fuels - with the aim of understanding and highlighting the implications of these barriers on the impacts observed in Chapters 3 and 4, as well as determining if current government policies and interventions effectively address the issue.

5.1 Introduction

As highlighted in Chapter 2, despite the long-standing efforts of many national and international organisations to improve the accessibility of the poor to modern energy services, the progress of accessibility to modern cooking alternatives has been slow. In Chapters 3 and 4, the impacts of household use of solid fuels on social and economic development, respectively, were analysed and established, for the three most impoverished regions: sub-Saharan Africa, east Asia and south Asia. Motivated by the recognition of the significance of household use of solid fuels on social and economic development, this Chapter reviews the barriers to accessibility to, and adoption of modern cooking alternatives. It contributes to the body of existing literature through examining the current situations of households in the three regions, and outlining the obstacles to households obtaining and adopting modern cooking alternatives. The review in this Chapter is performed in order to answer the following question:

- *"What are the major barriers to the adoption of modern cooking services among the world's poorest population"*

In this chapter, adoption implies not only purchase or acquisition of different forms of modern cooking provisions through any possible channel, but also the sustained use of modern cooking alternatives over time.

The findings from the review show the deficiency of infrastructures; deficiency of policies; financial barriers (at national and households levels), as well as a prevailing deficiency in information and/or attention at household and national levels, to be the ubiquitous contributing barriers across the impoverished regions [14], [27], [39]. Although behavioural and/or cultural components undoubtedly contribute to the energy issues, here, we concentrate primarily on the factors external to households and thus, are outside their control. In addition, this review is conducted from the perspective of households willing to adopt modern cooking fuels and as such, does not address barriers that could be specific to households unwilling to adopt modern cooking alternatives. Lastly, it is worth noting that even though these barriers are discussed separately, they are undeniably, quite interconnected.

The outline of this chapter is as follows: in Section 5.2, the role of economic barriers in accessibility to modern cooking alternatives is reviewed. Section 5.3 discusses the issue in terms of technical barriers and/or infrastructure barriers while section 5.4 discusses the role of institutional barriers in accessibility to modern cooking alternatives.

5.2 Economic Barriers

The different factors associated with the ability to afford the installation, sustainment and operation of the provisions that aid the utilisation of modern cooking alternatives are referred to as economic barriers. Broadly speaking, these barriers can be grouped into two categories:

- Demand-side barriers: These include high costs of provisions such as high capital (stove) costs and high operational (fuel) costs; complexity of financial flow; and lack of access to finance;
- Supply-side barriers: These include the high costs associated with infrastructure; low capacity for cost recovery; as well as lack of finance

The demand-side economic barriers are normally related to lack of access to finance at various levels. Several studies have reported that poor households especially those residing in poor rural communities tend to be unable to access credit. This alongside unreliable or non-existent government subsidies strongly impede households from pursuing modern cooking alternatives. What's more, studies in literature confirm the vital role played by prices and financial liquidity constraints on the decisions of households to purchase, utilise and maintain, modern cooking alternatives. The evidence of this effects of high investment and fuel costs on households' decisions on shifting to modern forms of cooking energy can be clearly seen in the study by Jeuland et.al. In their study which explored the demand for Improved Cook Stoves (ICS) and the preferences of households using the data from 2120 households in north India, Jeuland et al., reported that the cost of the ICS was a strong determinant in the decisions of households [186].

Several other studies such as, the study by Puzzolo which investigated the factors influening the up-take of modern cooking alternatives by households [189]; the study by Rehfuess et al., which examined the enablers and barriers to uptake of improved solid fuel stoves [190]; and the work by Beltramo which examined the effects of finance payment options on households' decisions to shift to cleaner cooking stoves [191]; to name a few, have all reported the effect of costs on households' decisions to adopt modern cooking provisions.

By means of illustratation, adapted from the study by Jeuland et.al [192], Table 5.1 shows the various costs related to different cooking forms. The 'investment costs' are illustrated using the estimated mid-values whilst the 'fuel costs' and 'consumption per household' are presented using the ranging estimates.

Table 5.1: Costs associated with various cooking options [186]

	Investment cost ($)	Fuel cost ($/kg)	Consumption per household (toe/year)
Traditional cookstoves			
Charcoal	3 - 6	0.1 - 0.8	0.5 - 1.9
Fuelwood, straw	0 - 2	0.03 - 0.2	1.0 - 3.7
Improved cookstoves			
Charcoal	14	0.1 - 0.8	0.4 - 1.5
Fuelwood	15	0.03 - 0.2	0.5 - 1.6
Alternative cookstoves			
Kerosene	30	0.3 - 0.7	0.1 - 0.2
LPG	60	0.4 - 1.0	0.08 - 0.15
Electricity	300	0.03 - 0.10	0.07 - 0.13
Biogas digester	600 - 1,500		0.07 - 0.14

toe = Tonne of oil equivalent;

Looking at investment costs, it can be seen that the traditional fuelwood and biogas digester options, have the lowest and highest investment costs, respectively and whilst households might not have to pay for fuels for the biogas digester, for households using traditional woodfuel, it has been hypothesised that these households can either gather woodfuel at no cost or purchase woodfuel at very low costs - in addition to not requiring any special cookstoves [18]. Therefore, although in the long run, the traditional woodfuel is the most inefficient form of fuel and thus requires the highest amount of fuel; based on a present-day cost viewpoint, the low fuel prices as well as low investment costs, make traditional or modern 'fuelwood', an appealing option for many households in the developing regions [18]. Excluding 'LPG' and 'Kerosene' which have relatively lower costs, the high investment costs associated with the modern alternatives such as electrical cookstoves, is suggested to be play vital a role in hindering attainability of households switching to these options. In addition to the high investment costs, high fuel prices for modern alternatives such as LPG and Electricity, can also be anticipated to further deter households wanting to move onto these options.

The effect of financial barriers is further evidenced in the results obtained from the household survey conducted by Energy Sector Management Assistance Program

(ESMAP). Their report stated that due to high costs, approximately 60% of willing households in sub-Saharan Africa cannot afford to change from traditional fuel forms to modern cooking alternatives[18]. These results further suggest that given that poverty rates are high across these regions, the implications of these high costs become further heightened .i.e. modern cooking alterntives are less affordable [1].

From a supply perspective, the low population densities and high poverty levels usually associated with impoverished areas (especially rural areas), tend to make for unattractive markets for investors. The resulting low energy demands is generally anticipated to result in difficult cost recovery: depicting such projects commercially non-viable investments for investors. It can therefore be anticipated that the lack of working capital and financing options for investors and utilities, even where there appears to be high willingness to pay, act as barriers to supply possibilities. Furthermore, as a result of the general notions which consider these supply projects in impoverished areas to be loss-making investments, such projects are generally left for finance by governments and the donor community (foreign aid). Therefore, in most cases, supply remains unavailable to these population until governments or the donor community intervene. Therefore, it can furthermore be assumed that investment restrictions impact on the potentialities of infrastructure development - infrastructures necessary for adequate energy supply.

5.3 Technical barriers

Factors attributable to technical barriers vary from the quality and performance of infrastructures, to the capability to install, utilise and maintain the modern cooking alternatives at different scales (households, service providers, regulators, etc.) Generally speaking, the rudimentary or in some cases, completely absent nature of infrastructures constituting the energy systems in developing regions, can be termed a principal barrier to the distribution of modern energy forms for cooking and/or heating in these regions [193]. At national levels, the significance of the inadequacy in energy system infrastructures become more evident - particularly in rural areas. For most developing countries, the pervasive absence of distribution networks contributes to the high levels of inaccessibility to modern energy alternatives in both urban and rural areas [25]. This is particularly true in rural areas where there is an extensive lack of distribution network and as such, a higher rate of inaccessibility to modern alternatives [193], [194].

From a supply perspective, issues of the capabilities to design, install and utilise advanced cooking energy systems have been extensively discussed in literature[195]. Studies such as the report by ESMAP and the study by Rosenbaum et al, have referred to the low technical capacity in rural communities as a barrier to the operation and maintenance of advanced cooking alternatives such as the biogas digester, ICS, or electrical cookstoves [18], [188]. An example of the case of technical barrier is given by the study by Hanna et al., which showed that stove defects/damages in combination with inadequate investments in maintenance, inappropriate use and cleaning practices, impeded the prolonged usage of modern stoves in households in India [196]. However, for simpler technologies, this problem appears to be less acute. For example, for cookstoves involving kerosene, local networks exist which aid in the maintenance of these appliances. However, generally speaking, in the most affected areas, the technical capabilities are limited such that advanced cooking systems are inadequately supported and in cases where technical capabilities are developed, due to the better standards of life, the skilled people are often attracted to urban areas.

From a demand perspective, the barriers involving infrastructure failures or poor infrastructure performances, result in direct problems in terms of the use of the services as well as indirect problems in terms of instigating perceptions of risks of use. In some cases, the low quality of the modern cooking appliances available to households constitute a problem [194]. For example, in their study which investigated the major barriers faced by households in rural Kenya, Duke et al., reported that due to the inability to discern the relative quality of appliance brands, some households in Kenya suffered major financal losses which in turn caused reduced confidence in modern stoves, creating market failure, as well as, generating operation and maintenance issues [197].

Furthermore, inadequate basic infrastructures; such as the lack of or poor transport infrastructures, particularly roads, have been shown to hinder accessibility to modern fuel alternatives in some developing countries [198]. However, from a demand perspective, the implication of inadequate transport infrastructures goes well beyond inaccessibility. Inadequacy, unreliability and high costs of fuel supply, are further implications of the lack of basic infrastructure(s) [198]. For example, in sub-Saharan Africa, reports show that just over 10% of roads in rural areas are paved. Thus, transportation costs of goods to rural areas are high and transportation can be unreliable in certain periods of the year [199]. The study by Fukubayashi and Kimura further supports this information. In their study, Fukubayashi and Kimura reported that in most rural areas in sub-Saharan Africa, during rainy season, the areas become inaccessible as a result of the poor roads [200]. Hence, during these seasons, supply of modern fuels can become unreliable [201]. The effects of unreliability of cooking fuels on households have been extensively analysed in literature [47], [202]. The evidences presented by these studies indicate that reliability of energy supply acts as a determinant of the decisions households make regarding cooking fuel adoption [203], [204]. Therefore, from the demand perspective, unreliability and insecurity of modern cooking fuels can be seen to discourage households from converting to modern alternatives.

Finally, the significance of inadequate basic infrastructures goes beyond the inaccessibility and unreliability elements of the problem. As previously stated, the lack of basic infrastructure contributes to high costs of fuel supply. To clarify, due to the high transportation costs associated with delivery of goods in rural areas, it can be anticipated that even with the provision of modern fuel alternatives, these high costs would remain significant and thus, would inevitably be passed onto the consumers (households) - creating further barriers.

5.4 Policies and Governance

The politicisation of energy service delivery in most developing countries and the impacts on energy supply, are discussed in literature. Studies such as the work by Barnes [205] and the study by Rehman et al., [206] discuss the effects of political interference on energy services whilst other studies such as the work by D'sa and Murthy [207], mention corruption issues and behaviours of vested interests. For example, the study by Mulder which investigated the barriers to modern energy services in Mozambique highlights the effect of vested interests within the government on the difficulties in implementing institutional changes which could reform the energy services within the country [85]. One of the key points highlighted in their study was the fact that in areas with low voting population, such as sparsely populated areas, there are possibilities of little to no political incentives and thus, little desire to instigate modern energy provisions - including modern cooking services. Furthermore, studies such as the study by Schlag and Zuzarte, which examined the market barriers to clean cooking fuels in sub-Saharan Africa, amongst several others studies, have reported politics and conflicts at local levels as barriers to modern cooking services [27], [208].

Furthermore, literature suggests that these barriers translate directly to issues at technical levels. Most of the reported issues caused by the institutional weaknesses and/or dysfunctional hindrances, translate into either technical capability issues or weak policy implementation, interactions, unstable policy environments, amongst others [208]. For example, the study by Lee et al., found that in the case of Nigeria, even where available, firms are highly restricted by rigid regulations that do not allow private provision of energy services or permit the provision of infrastructural services [208].

Lastly in terms of direct policies, the IEA reports that whilst half of the developing countries have adapted some form of targets to improve access to electricity, only a few countries are addressing the need for improved cooking stoves and/or access to modern fuels for cooking. Furthermore, even now, energy for cooking continues to receive limited funding and/or political backing from the governments across the globe.

5.5 Lack of attention and information

The lack of adequate information can also be viewed as a barrier to the adoption of modern cooking fuels from both the supply and demand perspectives. Starting with the supply perspective; it can be anticipated that the lack of adequate information on household energy consumption levels and patterns, would result in difficulties in the estimation of modern cooking fuels demand as well as difficulties in the estimation of the potentiality for modern cooking energy programmes in the affected areas. This could in turn result in issues in determining the commercial viability of different types of fuels thus potentially discouraging interventions and/or investments. This case is exemplified in the study by Christian Aid which reviewed the barriers to the adoption of modern cooking provisions in south Asia [41]. The findings from the review suggested that the lack of adequate information strongly discouraged the establishment of modern energy programmes and interventions in rural areas of the region [41]. Therefore, it can be anticipated that this could be a recurring barrier in other developing regions.

From the demand (household) standpoint, lack of adequate information implies that households would have limited knowledge of the disadvantages of the use of solid fuels; the alternative cooking provisions available; as well as the benefits associated with the use of modern cooking fuels or technology. The evidence of the effects of the lack of adequate information on households can be clearly seen in the study by ESMAP. In their study, ESMAP reported that once educated about the benefits of modern cooking stoves, households were willing to pay for the stoves and the adoption rates of the stoves significantly increased [18]. As such, this could suggest that the provision of adequate information about different cooking fuels and technologies; the effects of the use of solid fuels (especially health effects), as well as the environmental consequences, could encourage fuel and/or technology switching in households.

Finally, as stated in chapter 2, in comparison to access to electricity, access to clean fuels for cooking and/or heating has received much less attention from international, regional and national governments [27]. Further research which can provide comprehensive information that would facilitate the adoption of clean cooking fuels are needed to increase access to clean fuels and technologies for cooking and heating.

5.6 Discussion and conclusions

The most dominant barriers to household accessibility to cleaner cooking alternatives, in the most impoverished regions have been reviewed in this chapter. Although one could argue that the economic (financial) barriers are most pervasive or important and that the presented barriers have been found prevalent across all the impoverished regions; it is worth noting that some barriers are more dominant in some regions than others. For example, in the case of sub-Saharan Africa, the inaccessibility to modern cooking provision issue within the region is mostly attributable to a complete absence or inadequacy in modern cooking system infrastructures, as well as the dominant, substantial governance and policy problems within the region.

In the case of south Asia, the issue within the region has been noted by previous studies, to be attributable to lack of and/or failing infrastructures (particularly in rural and/or remote areas) and more importantly, limited energy resources which lead to high levels of fuel imports causing high prices of modern fuel alternatives [30], [41].

For east Asia, similar to south Asia, limited energy resources results in the heavy reliance on fossil fuel such as coal within the region, as well as the heavy reliance on energy importation, which causes the high costs associated with modern energy alternatives available within the region.

With regard to the pacific islands, the issue of accessibility to modern cooking provisions are principally attributable to lack of infrastructure mainly because of the topography of the islands; high costs of modern fuels due to high importation practices; and lack of institutional capacity and/or framework(s). To clarify: with regards to institutions[1], across the region, with the exception of Fiji, lack of institutions focusing on general energy access appears to be a common situation [126], [209], [210]. Across most islands, specific governmental departments dedicated to energy matters appear to be far and few between and in islands where such departments exist, they tend to have limited capacities: in terms of staff and budget. For instance, the energy department in Tokelau

[1] In this regard, we refer to governmental organizations

has been reported to have only one member of staff [211].

Lastly, as can be observed above and as mentioned in section 5.1, although the barriers have been presented separately, the evidence show that these barriers are inter-related. For instance, the provision and maintenance of infrastructures are often dependent on political and institutional context in developing regions; just as much as the economic of new energy systems would also be contingent upon the political and institutional context.

Firstly, the implications of these findings on the results observed in Chapters 3 and 4 are considered. The knowledge of the dynamics between the household use of solid fuels and development could help in designing systematic approaches that could address aspects of these dominant barriers, and vice versa. To exemplify; in Chapter 4, in the east Asian region, the household use of solid fuels and economic growth are seen to mutually influence each other in the long-run, while in the short-run, economic growth is observed to influence household use of solid fuels. Now, given that this review observed financial barriers to be dominant within the region; it can be anticipated that for the east Asian region, policies which tackle financial issues at household levels (such as subsidies for cleaner stoves), might be effective in addressing this barrier - from the demand-side standpoint. What's more, through addressing the financial barrier from the demand or household perspective, one could speculate that the demand for cleaner alternatives might increase, and thus, some of the supply-side barriers discussed in section 5.2 are addressed. Conversely, in the case of south Asia where no causal relationship was observed in the long run (Chapter 4), it can be speculated that policies addressing the other barriers (such as lack of information and cultural barriers), might be more effective in tackling the issue within the region - in comparison to dominantly finance-related policies.

Therefore, to summarise: the implications of the outcomes of this brief review can be viewed as two-fold: policy implications and research implications. Starting with the policy implications. In addition to the implications highlighted above, the outcomes of the review have implied that it is important when evaluating the barriers from a policy perspective to consider the inter-related nature of barriers. Therefore, policies and interventions would benefit from undertaking an integrated approach to addressing the barriers and resolving the issues.

Within the context of economic (financial) barriers, from both the supply and demand perspectives, the upfront and maintenance costs of new energy systems are found to be a consistent problem while access to finance which could aid affordability for users is found to be limited due to political/institutional barriers. As such, policies which effectively and comprehensively address these barriers might provide a step towards resolving the issue.

Lastly, in the context of the technical barriers, from both the supply and demand perspectives, the outcomes suggest that while the absence of infrastructures/appliances clearly constitute a barrier, the maintenance of available infrastructures/appliances is another (overlooked) barrier. Therefore, from a policy and intervention perspective, installation policies and/or interventions should be accompanied by policies and/or interventions which promote sustainability over time. Hence, policies and/or strategies encompassing skills and capabilities for installation, operation and maintenance should be considered.

Finally, from a research implication perspective, there are several specific areas that require further research. To name a few, more studies are required on the subjects of household financing; impacts of political barriers; interaction between the barriers, etc. For example, studies on the impacts of availability of credit schemes on clean cooking alternative uptakes; amongst other studies, might be beneficial in tackling this problem.

As a final point, it is worth highlighting some of the limitations in this review. Firstly, this review has been limited in some ways owing to the wide scope of the question, the breadth of literature and some resource constraints. For example, during the review process, some evidence and analysis from the private sector were obtained, but could not be shared in the review. This appears to be a somewhat common issue. Some studies have mentioned the availability of tacit knowledge isolated by professionals in specific locations. Nonetheless, this review gives a much needed concise yet inclusive representation of prevalent barriers faced across the impoverished regions.

Chapter 6

Impact of non-energy policies

This chapter answers question 'Q6' of the research sub-questions outlined in section 1.1: "how effective have current interventions and/or policies been in addressing the issue". Using data from the recent MVP in Northern Ghana, the effectiveness of current international sustainable development policies and interventions are examined. The MVP are projects designed by the UN across the world in an attempt to accomplish the SDG. As such, by utilising data from one of the project sites, it is possible to test how current international policies and interventions impact the issue - in the context of rural northern Ghana. This Chapter examines how household cooking fuel patterns and/or experiences are influenced as a result of the implementation of the SDG interventions.

6.1 Introduction

The social and economic impacts of household use of solid fuels have been investigated and established in Chapters 3 and 4, respectively. The findings from these Chapters varied across the examined variables and across the explored regions. However, overall, the outcomes from these Chapters have demonstrated that household use of solid fuels has statistically significant impacts on measures of social development, as well as, economic development. Considering the significance of these findings, in Chapter 5, the most prevalent barriers to household accessibility to modern cooking alternatives, and factors contributing to continued household reliance on solid fuels, were reviewed and discussed.

From Chapters 3 to 5, the absence of energy specific policies has been established, and observed as an important, contributing factor of the issue. Up-to-date, to address the household energy issue(s), most governments and organisations within the most affected regions continue to focus primarily on non-energy policies - with the notion that these policies would inclusively address the household energy poverty issue.

Motivated by the discovery of the significant impacts of household use of solid fuels on dimensions of sustainable development, as well as, the obvious lack of improvement in this issue over the years (as established in Chapter 2), this Chapter investigates if non-energy policies indeed impact on household use of solid fuels. As will be shown in this Chapter, this is a significant gap in the current literature on this subject, and the analyses in this Chapter address this significant research gap. The work in this Chapter contributes to the body of existing literature by answering the following question:

How do non-energy policies and/or interventions impact on household use of solid fuels?

For this purpose, using the data collected during the Millennium Village Project (MVP) in northern Ghana, and applying the Difference-in-Difference (DD) methodology, we examine what impacts the Millennium Village Project (MVP) non-energy policies and socio-economic interventions had on household use of solid cooking fuels, in the area.

The results obtained from the analyses can be summarised to imply that whilst the non-energy related policies applied in the Millennium Village Project (MVP) in northern Ghana have some effect, they do not have any statistically significant effect on elements of household use of solid fuels - in the Millennium Village Project (MVP) in northern Ghana. The findings from this Chapter contribute to the body of existing literature in two-fold. Firstly, it establishes that the MVP non-energy policies (at least in the context of rural Northern Ghana) do not contribute to the accessibility to modern cooking fuels, as well as, do not cause a change/shift in the types of cooking fuels used within households. Secondly, it establishes that these MVP policies and/or interventions do not have a significant impact on the seasonal unavailability of solid fuels and/or other difficulties experienced by households in obtaining these solid fuels - in the context of the Millennium Village Project (MVP) in northern Ghana.

The outline of this Chapter is as follows: Section 6.2 presents the background of the MVP as well as existing literature on the subject of the relationship between non-energy policies and energy. The data and methodologies used for the analyses in this Chapter are discussed in Section 6.3. Section 6.4 presents the results of the analyses while Section 6.5 discusses the wider significance, implications and conclusions deduced from the results. Finally, Section 6.6 provides a summary of the Chapter with emphasis being placed on the significant findings.

6.2 Background

In this section, a background of the MVP is presented and previous studies which have examined the impact of non-energy related policies on energy are explored. In addition, considering the diversification of the MVP project, we investigate current, existing studies examining the impacts of policies within the sectors addressed by the MVP intervention, on energy - examining the existing methodologies and conclusions from these studies.

6.2.1 The Millennium Village Project (MVP)

The Millennium Village Project (MVP), funded by the UK Department for International Development (DFID) and led by the Earth Institute (EI) at Columbia University, is an intervention designed to aid the attainment of the MDG in villages with extreme levels of poverty [212]. The MDG, now replaced by the SDG, were goals set in 2000, by world leaders, in hopes of reducing extreme poverty whilst bettering conditions such as: health, sanitation, water access, gender equality, amongst others. Accordingly, to accomplish these goals, a multi-sector, community-led, development approach was proposed and implemented in the form of the MVP interventions. These interventions designed for the MVP were based on the recommendations of the United Nations Millennium Project (UNMP). The recommendations proposed a holistic strategy which involved directing an integrated set of investments towards the coordinated promotion and delivery of services across multiple sectors including agriculture and business development, education, infrastructure and health [212].

Employing this approach, the MVP was designed to be implemented in eighty villages, comprising of approximately five hundred thousand people, clustered into fourteen groups, across ten sub-Saharan African countries: Ethiopia, Ghana, Kenya, Malawi, Mali, Nigeria, Rwanda, Senegal, Tanzania, and Uganda. To demonstrate how tailored approaches can be used to overcome development challenges, the villages were selected from varying agro-ecological zones. These selected villages had diverse agricultural, water, and disease obstacles to income, food production, service delivery and health system development. The MVP was initiated in the villages of Sauri (Kenya) and Koraro (Ethiopia) in 2005 but was launched at scale in 2006. With a principal aim to reduce poverty and hunger, the project targeted reducing the share of the population in the villages living on less than one dollar a day, by fifty percent[1]. The interventions are estimated at a cost of approximately $120 per person per year and covers agricultural production, nutrition, education, health services, roads, energy, communications, water, sanitation, enterprise diversification, environmental management and business development. To determine the precedence as well as the appropriate sequence and timing of interventions in different sites, community-based assessments and interactive sessions are used. Some of the solutions provided include high-yield seeds, fertilizers, medicines, building materials for schools and clinics, amongst others.

Nonetheless, the MVP implementation framework is not based on a stratified set of fixed interventions across every community. Instead, it adapts a flexible and coherent plan which considers implementations based off of village-level and multi-sector budgeting. This ensures that communities gain access to the basic set of goods and services which are most relevant to them.

The study used in this Chapter is the MVP study in Northern Ghana, which ran over the period of five years, comprised of approximately 30,000 people, in a cluster of thirty-four communities.

[1] Using the population between 1990 and 2015, as reference

Table 6.1: Summary of the MVP interventions

Sector	Quick wins	Long-term wins
Agriculture and environment	Provision of fertiliser and improved seeds for basic staples Training of extension agents in soil and water conservation Training of extension agents in use of improved crop varieties	Construction of local grain storage facilities Promotion of community forestry
Health and nutrition	Provision of insecticide-impregnated mosquito bednets Basic health care for common diseases Provision of ARV therapy Provision of voluntary AIDS counselling and testing Provision of school feeding programmes Provision of multi-nutrient supplementation for pregnant and lactating mothers	Improved access to drinking water Rehabilitation of health facilities
Education and training	Training for all primary school children in the use of computer and internet Training activities in agriculture, health, etc. Training of local facilitators	Establishment of secondary school scholarships Rehabilitation of education facilities
Infrastructure, energy and communication	Improved solar lanterns VSAT equipment to provide internet access Access to mobile phones Provision of a generator Provision of modified vehicle for ambulance services and cargo transportation	Provision of health facilities and equipment Provision of education facilities and equipment

Twenty-three of these communities are located in the Builsa District which is located in the Upper East region whilst the other eleven are located in the West Mamprusi District located in the Northern region. Although these two districts are contiguous, they are inhabited by two different ethnic groups: the Builsa and the Mamprusi. The Millennium Villages (MVs) were chosen based on the following criteria:

- The sites must be based in a minimum of two of the Northern regions: Upper East, Upper West, Northern, where the degree of poverty is most apparent
- The sites must be archetypally one of three broader systems present in the North: agro-forestry; river-based; or growth pole
- The sites must be located in the Northern Savannah Ecological Zone
- The sites must be exemplary of a typical rural community in the North and make a cluster of a maximum of 30,000 individuals
- There must be a strong commitment from the local and regional governments

A matched group of Control Villages (CVs) were selected from the same region/district as the MVs and stratified by distance to the project site.

The MVP implementation began in June 2012, with three rounds of data collection: baseline in 2012, mid-line in 2014 and end-line in 2016. The project utilised the systems approach, placing emphasis on delivering vital services through three major programs: Lead Farmer Program (LFP), Community Health Worker (CHW) program, and Community Education Worker (CEW) program. The activities of these programs are summarised in Table 6.1.

The first phase of the project, which lasted about 12–18 months involved the first set of interventions, termed 'quick wins' were aimed at increasing agricultural productivity and attaining disease control. These 'quick wins' consisted of free distribution of improved seeds, fertilisers and mosquito nets; followed by immunisations, Vitamin A campaigns and community de-worming. The 'quick wins' were then accompanied by 'long-term wins' which involved long-term investments in education, health and agricultural production. In addition, infrastructural development and/or improvements were included to aid structures such as buildings, roads, water and sanitation. These were deemed vital to the betterment of the primary health care and education services, as well as the development of agricultural markets and businesses. These 'long-term wins' consisted of water, education and health infrastructures being rehabilitated or built anew, properly equipped and staffed. Programme activities over the years included nutrition education; growth monitoring and promotion; training of health professionals; school feeding; teachers' training; scholarships for secondary education; agricultural extension; supply chain facilitation; cooperatives formation; rehabilitation of granaries; developing early warning systems; and increasing access to roads, electricity, mobile phone network and internet [212]. Further elements within the MVP approach included the restoration and reinforcement of community institutions and strategies that promote leadership and participation of women.

The second phase of the project involved ongoing improvements to local service delivery systems which support the local scale-up of the project, as well as the commercialisation of agricultural gains.

In terms of how the interventions were implemented, by utilising the Theory of Change (TOC) approach, the implementation of the interventions were grouped by considering and incorporating the inter-relationships between the intended outputs and the planned activities. With the exception of the Agriculture, Hunger and Nutrition Sectors, where only the horizontal (intended outputs) inter-relationships were considered, across all sectors, the vertical (planned activities) and horizontal (intended outputs) inter-relationships between each anticipated sectoral outputs and activities determined the timing and manner of implementation.

6.2.2 Non-energy policies and energy consumption

Despite the evidence that energy services and/or systems are not affected solely by energy policies but a broad range of various policies, there has been little analysis of the matter. A thorough review of the existing literature shows that the existence of studies exploring the link between non-energy policy and energy systems or services is largely absent. It appears rather uncommon for studies to focus on the connection between non-energy policies and energy systems or services. What's more, there appears to be an apparent disregard for non-energy policies in most studies which claim to take holistic or comprehensive approaches on reviewing the issues on energy systems or services.

Consequently, to illustrate this link, a different approach is taken in this section. The various sectors of the MVP intervention are considered and studies reviewing the link between the individual sectors and energy services or systems are reviewed. The sectoral policies considered in this section are: Agricultural, Education, Economic and Governance. Although a part of the MVP intervention sectors, transport, communication and environmental policies have been excluded from this review.

6.2.2.1 Agricultural policies and energy

In the agricultural sector, there are various studies which explore the impact of agricultural policies on energy in general. For example, the studies by Kalaba et al., [213] and Lockeretz [214] suggest that the implementation of agricultural policies such as Root And Tuber Expansion Programme (RTEP) in Nigeria [215]; and the Accelerated Agricultural Growth and Development Strategy (AAGDS) in Ghana [216], influence

general energy consumption. Despite these, most studies found on the topic appear to focus explicitly on impacts on electricity consumption. For example, the study by Sutherland et al., which analyses the link between agriculture and electricity regimes and opines that both sectors are characterised by policy interventions addressing food and energy security, respectively, ensuing competition for resources, between both sectors [217]; the study by Rounsevell and Reay [218] and the report by Swain and Mehta [219], all review the subject with varying opinions.
Yet, whilst it appears that there is a considerable amount of literature examining the impact of various food and farming policies on energy (mainly electricity) and emissions, a closer investigation would suggest that there is a shortage of studies considering the issue in developing countries and more so, much of these studies examine the inverse impact.

When biomass is considered, the study by Alexander et al [220]; Manning et al. [221], and the Environmental Audit Committee report are amongst the noteworthy studies on the impacts of agricultural policies on biomass. Although, most discussed agricultural policies in these studies are specific to energy crops and to developed countries, these studies observed that in most cases, agricultural policies influenced energy demand and/or supply. For instance, the 'Single Farm Payment' which obligates farmers to leave some land uncultivated but permits the cultivation of non-food energy crops like Miscanthus on such land, gives an initiative for the cultivation of energy crops. Thus, indirectly, influences energy supply.

6.2.2.2 Education policies and energy

In the education sector, very few relevant studies were found on the impacts of education policies on energy. The studies found can be broadly categorised under three main concepts: impact on the energy consumption of educational institutions; impacts on transport and impact on producing skilled employees for the sector. However, overall, these studies focused on the impacts of these policies on energy demand, with few considering the supply aspect. Furthermore, although studies such as [222], [223] and [224] present interesting discussions on education policies acting as mechanisms for development of energy systems: through the development of skilled workers required for the building; maintaining; and operating of energy system infrastructures, these do not seem substantive in the context of this Chapter.

6.2.2.3 Economic/Fiscal policies and energy

The economic sector appears to be perhaps the most complex sector considering that fiscal, monetary and other economic policies generally impact many (if not all) sectors. In the existing literature, the main concepts addressed appear to be the impact of taxation and exchange rates on rates (and thus demand and supply) of energy services. In terms of studies looking into the impacts from government interventions and policies directly on energy, much of the existing studies such as the study by Adom et al., which investigated the impact of policy changes on electricity demand in Ghana [225]; the work by Abbasi amd Riaz which examined the impact of financial policies on energy consumption using Carbon Dioxide (CO2) as an instrument [226]; and the work by Henisz et al., which examines the effect of policies on electricity provision in Southeast Asia [227]; tend to view these interventions and policies as overarching processes rather than policies.

Nonetheless, the conclusions from these studies tend to infer that these interventions have impacts on many sectors; including energy and further studies such as [228]–[230] have reported increase in general energy consumption following implementations of these policies. Considering biomass, existing studies appear to consider only the effects of biomass on economic growth and thus, are not policy related. Yet, even then, these studies refer to biomass power plants and not biomass consumption at household levels.

6.2.2.4 Governance and energy

Lastly, studies on the impacts of governance processes and structures, are considered. Studies found on this topic encompass several, various issues around policy-making practices, organisations and capacities. Still, the adverse effects of the lack of effective governance on general development - across several sectors in developing countries:

especially in the sub-Saharan African region, is widely acknowledged in existing literature [231]–[233]. The study by Claude, which examines the impact of participatory governance on the reduction of poverty [234]; the work by Fayissa and Nsiah, which discusses the impact of governance on the economic growth in Africa [235]; and the study by Gray et al., which reviews the effects of good governance across sectors in Tanzania [236]; are amongst studies that have discussed the significant impacts of ineffective governance across multiple sectors - including energy.
Considering the impacts on solely energy; generally, the studies found on this subject focused primarily on the impacts on development and/or deployment of energy infrastructures while others focused on impacts of energy governance [237]–[239]. Few studies are found examining the impacts of non-energy governance on energy consumption. Amongst these are the study by Menegaki and Ozturk which methodically analysed the impact of political stability on energy consumption [240]; the study by Cubbin and Stern which examines the effects of good governance on electricity capacity and efficiency [241]; and the study by Baker et al., which reviews the impact of new governance on energy transitions in South Africa [242]. Across these studies, correlations between capital and governance stability; and between governance stability and energy consumption, are observed. However, once again, most of these studies do not centre around household energy consumption and/or household use of solid fuels.

Overall, the review of existing literature has unveiled the relative absence of studies focusing explicitly on the link between non-energy policies and general energy services (or consumption). With the exception of studies investigating the link between environmental policies and energy services (or consumption), studies examining impacts of other non-energy policies, are largely invisible. Although several studies exist when considering the impacts of energy policies[2] on various sectors, there is a staggering lack of literature on the impacts of these sectoral policies on energy services (or consumption).
What's more, when considering the subject in the context of developing countries, very few studies exist, and even fewer studies exist when considering this in the context

[2]However, it is observed that many of these studies tend to consider energy policies nested in non-energy policies

of household cooking energy forms. Nonetheless, by reason of the findings in the aforementioned studies, there are reasons to presume that the implementation of the MVP could have some effects on household energy consumption.

6.2.3 The Millennium Village Project (MVP) and energy

Considering the existing literature on the MVPs, there are very limited studies which evaluate or analyse the impacts of established MVPs. The study by Remans et al., which utilises Nutritional functional diversity (FD) metrics to calculate nutritional diversity in farming systems using data collected from three MVPs in sub-Sahara Africa [243] and the work by Pronyk et al., which investigates the impacts of the MVP on health-related outcomes including child mortality [244], are amongst the few existing studies on the subject.

Table 6.2: Summary of studies on MVP interventions

Authors	Countries	Measure	Methods	Conclusions
Bendavid, E (2010)	Malawi	Energy - Solar LED lighting	Market-based model	High satisfaction levels with the LED lanterns Savings in annual kerosene expenditure
Michelson and Tully (2018)	Kenya	Land value	Hedonic analysis	No increase in land prices
Michelson et al. (2013)	Ghana, Malawi, Mali and Tanzania	Poverty rates	Livelihood-weighted Structural Income Asset Index; PCA, factor analysis and DHS asset indices	Inconclusive
Masibo, Peninah Kinya (2013)	Kenya	Nutrition - Children	ANOVA; multivariate logistic regression models	Improved growth, gain in lean body mass and reduced anaemia prevalence in MV
Ninsiima (2010)	Uganda	Environment	Correlation tests	Significant correlation between MVP activities and environmental sustainability interventions
Nuwagira (2013)	Rwanda	Education	Descriptive statistics	Increase in school enrollment, completion rates, pupil-teacher ratio; improved performance
Puri (2010)	Ghana, Kenya, Nigeria and Tanzania	Telecommunication	Survey	Mobile phone network influences human development in remote villages
Remans et al. (2011)	Malawi, Kenya, Uganda	Agriculture - progress monitoring	Functional diversity (FD)	Nutritional FD metrics would optimise agricultural interventions
Nerubucha (2013)	Kenya	Water	Linear regression	MVP influences water access; which further influences overall poverty

Table 6.2 presents a summary of studies found on the MVPs. Due to the multifaceted nature of the project, various methodologies and conclusions exist across these studies. However, the study by Bump et al., expressed doubts about the validity of the findings in some existing studies [245]. Two principal concerns were expressed by Bump et al. Firstly, Bump et al. reveal that findings from some studies were not at the relevant 95%

Confidence Interval, yet, these studies did not state that their findings were statistically insignificant. Secondly, it was indicated that some existing studies used datasets with structural break in the time series of the variables: implying unbalanced baseline and follow-up data. However, the studies failed to use the appropriate analytical methods to compensate for these unbalanced datasets. As a result, some studies, including the study by Whanjala and Muradian were retracted from literature.

In addition, although there are existing valid studies which have investigated the impacts of the MVP interventions, most of these studies have done so using approaches which do not compare the before and after effects of the projects. Hence, although these studies have investigated the impacts of the MVP on various outcomes, they have failed to take into account differences in the explanatory variables - as a result of the MVP. So far, only the reports by Masset et al.,[246] have analysed variable outcomes using data obtained before and after the MVP interventions. Yet, even the reports from Masset et al., have not analysed the impacts of the MVP in the energy context. In relation to the energy sector, currently, only the study by Adkins et al., which summarises the household energy use across approximately 3000 households in 10 millennium villages in sub-Saharan Africa [247] appears to be available on the subject. However, the study only provides a synopsis of the energy profiles of households but does not analyse the impact of the MVPs. Finally, considering the Northern Ghana MVP outcomes and the analyses of the project impacts, so far, upon thorough review of existing literature, only the evaluations and reports by the Earth Institute (EI) [246] was found.

Therefore, the evaluations conducted in this Chapter differ from existing literature in three ways. Firstly, unlike the studies by Remans et al.[243] and Pronyk et al.[244], the data used in the analyses are from sizeable treatment and control groups and incorporates the before and after of the MVP interventions. Secondly, the analyses are carried out using panel data: meaning only the households and individuals present over the three survey periods are included in the analyses. Thirdly, unlike the work by Adkins [247], it quantifies the impact of the MVP on households.

Lastly, in contrast to the works by Masset et al.[246], [248] and Sanchez et al.[212], it investigates the impacts of the MVP on household energy use: centring on household energy use for cooking.

6.2.4 Review of methodologies

Taking into account the absence of studies on the subject, to investigate the impact of non-energy policies on household energy consumption, methodologies which have been applied in general development studies, as well as, the MVP studies highlighted in Table 6.2, are considered.
From these studies, five main methodologies appeared prominent. The strengths and weaknesses of these methodologies are summarised in Table 6.3.

Table 6.3: Summary of methods

Methods	Strengths	Weakness	Studies	Notes
Difference-in-Difference	Accounts for changes due to factors other than intervention	Cannnot be used if intervention allocation determined by baseline outcome	Athey and Imbens (2017) [249]; Buckley and shang (2003) [250]	Violation of parallel trend assumption would lead to biased estimation of the causal effect.
	Individual and/or group level data can be used in model	Cannot be used if comparison groups have different outcome trend	Dimick and Ryan (2014) [251]; Cameron and Alatas [252]	
		Cannot be used if composition of groups pre/post change are not stable	Reinikka and Svensson (2005) [253]; Handa (2002) [254]	
Instrumental Variables	Widely known for its ability to address endogeneity problems	Only identifies causal effects based on only the group whose behaviour is influenced by the instrument	Adams et al. (2008) [255]; Isaac and Samwel (2012) [256]	IV heavily relies on having valid instruments. However, selection of instrument is subjective
		Use of variables which are weakly correlated with treatment and/or with residuals in the outcome equation could lead to larger bias problems	Makki and Somwaru (2004) [257]	
Propensity score	Allows for inclusion of interaction terms in calculation	Accounts for only measured covariates	Chirwa (2010) [258]; Titus (2007) [259]	Sensitivity analyses are recommended to determine consistency or results
	Uses only one score in estimations. Thus, multiple covariates can be used in estimations	Missing data results in missing propensity score	Imbens (2004) [260]	
	Can be used for dichotomous or continuous variables	Does not account for clustering	Frölich et al. (2017) [261]	
		To ensure appropriate matching, groups must significantly overlap		
Regression	Very effective in explaining relationships	Not easy to determine if model is adequately specified	Takeshima et al. (2012) [262]; Gilbert et al. (2012) [263]	Traditionally used in the estimation of treatment effects
		Observed relationships do not imply necessarily causality		

The first method involves a single equation model which statistically controls for the observed variable(s) which could impact on household energy consumption as well as are correlated with the MVP intervention. This is done by adding these observed variables in the equation that is being used to determine the household energy consumption. Due to its effectiveness especially in cases such as the MVP, when there is data on several variables which are correlated with the project and could potentially impact the outcome of interest, this approach is deemed useful.

However, on account of this, although the approach is deemed the most effective in reducing of bias in project impact estimations [264], the approach has a drawback of assuming that the effect on the outcome of interest is already known. As a result of this assumption, the interactive term by which the observed variable(s) impact the outcome, is assumed to be known. Considering the nature of the MVP data and the fact that the interactive term in this case, is unknown, this approach is deemed unsuitable for the intended analyses in this Chapter.

The second method, following the work by Murnane et al. [265], is similar to a structural equation model using the decomposition method to estimate treatment effect(s). It involves modelling three estimation equations. In the case of the MVP, for example, the first equation would have been modelled to demonstrate the outcome for the MV group while the second equation would demonstrate the outcome for the CV group. The coefficients from each equation demonstrate the relationship between the explanatory and outcome variables for each group. However, the third equation determines if a household belongs to the MV or CV group. The estimation obtained from this third equation enables for a selection bias correction term to be added to the two preceding equations. Thus, in theory, correcting for the bias attributable to unobserved variables that are correlated with the MVP and could affect the outcome of household energy consumption.

However, a few of the model assumptions make this method unsuitable for the intended analyses. These include the assumption that the variables and interaction terms for all three equations have been accurately specified and the assumption of a specific statistical distribution for the unobserved factors i.e. error terms, present in the three equations [266].

Thirdly, the instrumental variable (IV) method is considered. Under this approach, instrumental variables which are uncorrelated with other unobserved variables which could impact household energy consumption while indicating MVP involvement, are utilised in the model. With this method, changes in household energy consumption are observed through only the statistically changes in the assigned instrumental variable that can be attributed to changes in the MVP.

The concept behind this approach is that the impacts observed in the outcome of interest through the changes in project captured by the instrumental variables, demonstrate the actual impacts of the project. The reasoning being that these changes in project would be uncorrelated with the unobserved variables that are influencing the outcome because these changes are produced by the instrumental variables which are uncorrelated to the unobserved variables that are affecting the outcome.

However, there are considerable drawbacks to utilising this approach. Firstly, as above stated, the variable must have little-to-no correlation with unobserved variables which could affect the outcome, yet, must adequately explain project involvement. Else, the estimation would omit valuable information. However, testing the assumptions of correlation between a proposed instrument and unobserved variables, can be challenging. Secondly, as the selection of instrument(s) can be somewhat subjective, the suitability of the instrument(s) for the model, can be debated.

Utilised in the MVP to select matching district villages to project villages [248], the fourth method is based on the propensity score approach. In the case of the MVP, the method would involve the matching of treatment (MV) households with control (CV) households that are comparable in characteristics .i.e. would focus on finding households with very close propensity scores. The propensity score would represent an estimated probability based on the observed variable(s), that a household benefits from the project [267]. The propensity score can be estimated by utilising variables which indicate MVP participation and independent of the MVP, have a correlation with household energy consumption.

Assuming there is data consisting of variables which are correlated with non-MVP factors that impact household energy consumption and also, can be used to determine involvement in the MVP, the propensity score approach is deemed an excellent approach [267].

However, although the obtained data consists of reasonably close MV to CV matches, the propensity score approach would in this case suffer from inefficiency, due to the presence of many unobserved variables which are correlated with household energy consumption and could determine MVP involvement.

Lastly, the Difference-in-Difference (DD) approach is considered. Fundamentally a variant of panel fixed effects, the DD method evaluates the differences in outcomes before and after a project, between the control and treatment groups. Thus, eliminating selection bias and group specific time effects (see Table 6.4).

Table 6.4: DD illustration

Group	Period	Outcome	$D_1 = (e_a - e_b)$	D_2
MV	Before	$e_b = F_{mv}$		
	After	$e_a = F_{mv} + T + I$	$T + I$	
				I
CV	Before	$e_b = F_{cv}$		
	After	$e_a = F_{cv} + T$	T	

eh is energy consumed by households; I is MVP intervention; T is time effect; F_{mv} is unobserved fixed effects of MV group; F_{cv} is unobserved fixed effects of CV group

One of the key advantages of the DD method is its implication that the other factors affecting the outcome variable can be controlled for, by considering the effects of the time period as well as if the individual belongs to the control or treatment group. However, this can also be seen as a limitation of the DD method. There is the possibility that other variables; observed and/or unobserved, which are correlated to the project, might be contributing to the outcome.

However, the DD method has amongst others, two principal assumptions.

The first assumption is the exclusion restriction, which requires that there is no time-variant group specific unobserved variables.

The second assumption, which is deemed as the most important, is the 'parallel trend assumption' [268]. The parallel trend assumption specifies that without the treatment, the difference between the control and treatment group must be constant over time

[268]. Although there are no statistical test for the parallel trend assumption, the study by Abadie proposed that the smaller the time period tested, the more likely the assumption is to hold [269].
As such, reviewing the MVP data used in this Chapter, these assumptions are deemed fulfilled.

Overall, considering the strengths and drawbacks of the various methods (summary presented in Table 6.3), as well as the nature of the MVP data, the DD method is considered the most appropriate for the evaluation of the impacts of the MVP intervention on household energy consumption. Hence, we evaluate the impact of the MVP intervention on household energy consumption, by estimating the differences in household energy consumption over time, in the average outcomes between the MV and CV groups.

6.3 Data and Methodology

As previously mentioned, for the analyses in this Chapter, we draw upon the data from the MVP in northern Ghana. The Difference-in-Difference (DD) model is applied to the obtained data for the analyses within this Chapter.

6.3.1 Methodology

Firstly, let 0 and 1 represent the periods before and after treatment, respectively for any household, while g represents the group that the household belongs: either the MV or CV group. Therefore, generally speaking, the household energy consumption in the absence of treatment is expressed as equation 6.1,

$$E\left[e_{hgt}^{0} \mid g, t\right] = \gamma_g + \tau_t \tag{6.1}$$

and the dummy variable for a household, post-treatment is expressed as D_{gt}. As such, the average treatment impact on household energy consumption, using DD can be modelled as:

$$E\left[e_{hgt}^{1} - e_{hgt}^{0} \mid g, t\right] = \delta_{DD} \tag{6.2}$$

where, γ_g is the sum of the time-variant group fixed effect; τ_t is time effect; t is time (either pre or post treatment); h is household and δ is average treatment effect.

Following this, the observed household energy consumption can be written as:

$$e_{hgt} = \gamma_g + \tau_t + \delta_{DD} D_{gt} + \varepsilon_{hgt} \tag{6.3}$$

Accordingly, for the MVP, equation 6.2 which represents the DD for household energy consumption can be derived as follows:
For the CV group, household energy consumption pre-treatment period can be defined as:

$$E\left(e_{hgt} \mid g = CV, t = 2012\right) = \gamma_{cv} + \tau_{2012} \tag{6.4}$$

Household energy consumption post-treatment period for CV can be defined as:

$$E\left(e_{hgt} \mid g = CV, t = 2014\right) = \gamma_{cv} + \tau_{2014} \tag{6.5}$$

Difference between post and pre-treatment periods for CV is obtained by:

$$E\left(e_{hgt} \mid g = CV, t = 2014\right) - E\left(e_{hgt} \mid g = CV, t = 2012\right) = \tau_{2014} - \tau_{2012} \tag{6.6}$$

For the MV group, household energy consumption pre-treatment period can be defined as:

$$E\left(e_{hgt} \mid g = MV, t = 2012\right) = \gamma_{mv} + \tau_{2012} \tag{6.7}$$

Household energy consumption post-treatment period for MV can be defined as:

$$E\left(e_{hgt} \mid g = MV, t = 2014\right) = \gamma_{mv} + \tau_{2014} + \delta \tag{6.8}$$

Difference between post and pre-treatment periods for MV is obtained by:

$$E\left(e_{hgt} \mid g = MV, t = 2014\right) - E\left(e_{hgt} \mid g = MV, t = 2012\right) = \tau_{2014} - \tau_{2012} + \delta \tag{6.9}$$

Therefore, differencing the two differences in equations 6.6 and 6.9, the overall MVP impact .i.e. the household energy consumption DD effect, can be calculated as:

$$\begin{aligned}\hat{\delta} &= \Big(E\left(e_{hgt} \mid g = MV, t = 2014\right) - E\left(e_{hgt} \mid g = MV, t = 2012\right)\Big) \\ &- \Big(E\left(e_{hgt} \mid g = CV, t = 2014\right) - E\left(e_{hgt} \mid g = CV, t = 2012\right)\Big) \\ &= \left(\tau_{2014} - \tau_{2012} + \delta\right) - \left(\tau_{2014} - \tau_{2012}\right) \\ &= \delta\end{aligned} \tag{6.10}$$

We also evaluate the DD effect using a regression framework approach. The regression model is defined as:

$$y_{ht} = \alpha + \beta_1 T_t + \beta_2 D_h + \delta \left(D \times T\right)_{ht} + \tau_t + \sigma_g + \varepsilon_{gt} \qquad (t = 0, 1) \tag{6.11}$$

where, y_{ht} is the outcome for household h; β_1 is the time-trend obtained from the difference in outcomes between the before (2012) and after (2014) treatment periods; T is post treatment dummy variable equal to 0 for 2012 and equal to 1 for 2014; β_2 is the difference between MV and CV, after treatment (in 2014); D is the dummy variable equal to 0 if the household is in CV and equal to 1 if household is in MV; δ is the DD effect of the MVP while $\boldsymbol{\delta\left(D \times T\right)_{ht}}$ is the interaction and is the DD coefficient of interest.

Finally, the regression model evaluating the MVP impact on household energy consumption can be defined by re-writing equation 6.3 as:

$$y_{hgt} = \alpha + \gamma D_h + \tau T_t + \delta \left(D \times T\right)_{ht} + \varepsilon_{hgt} \tag{6.12}$$

Following the study by Bertrand et al., which suggests the possibility of biased standard errors in DD regression models [270], in addition to the already aggregated treatment periods, two method were implemented to ensure robustness of the model. Bootstrapping of the standard error and the clustering of standard errors at group level.

Nonetheless, to ensure the validity of the methodology, the principal threats to the validity of the method: non-parallel trends, compositional differences, long-term effects vs reliability and functional form dependence; were reviewed and considered. With regard to non parallel trends, these are mostly attributable to instances of endogenous treatments and/or regional targeting. In these cases, the treatment and control groups have been selected based on pre-existing differences in outcomes (in the case of endogenous treatments) or based on pre-defined initial group conditions (in the case of regional targeting) which thus result in the trends of the groups moving in different, non-parallel directions. Compositional differences is mainly probable in projects or studies with long, repeated cross-sectional data where the nature or attributes of the sample population changes between the observed pre and post treatment periods. As a result of these time-variant unobservables, the changes in composition becomes a form of omitted variable bias which invalidates the effectiveness of the DD methodology. Similar to the parallel trend assumption, reliability of the DD is likely to hold true over shorter time periods in comparison to long time periods. Finally, in cases where the average outcomes for the groups are very different at baseline, it is probable that the size and/or sign of the DD coefficients would be sensitive to the functional form. These threats have been considered to ensure the validity of the DD analyses and the possibility of their existence, investigated in Section 6.3.2. Following the analyses in Section 6.3.2, these threats are deemed absent.

6.3.2 Data

The project comprised of a target of 755 Millennium Village (hereafter 'MV') households and 1496 Control Village (hereafter 'CV') households. The survey effort encompasses baseline and follow-up surveys. To capture the composition of the households, a demographic survey and population census were initially conducted at the project design stage. Following these, at the baseline year *(year 0)*, second *(year 2)* and last *(year 4)* follow-up years, more comprehensive surveys: comprising of several interviews and the full household surveys, were conducted. However, the data obtained from the last follow-up year *(year 4)* remains unavailable. Meanwhile, in the first follow-up year

(year 1) and third follow-up year *(year 3)*, reduced household surveys were conducted. As a result, only the data from the baseline and the second follow-up surveys are used in the analyses in this Chapter. In addition, only the data collected from the household surveys are used in our models.

In terms of the sample sizes, data from the baseline survey shows that from the 755 MV and 1496 CV households that were targeted, the household samples obtained for the MV and CV sites were 711 and 1461 households respectively. For *Year 2*, only 735 MV and 1456 CV households from the targeted households were reported to have completed the interviews.

Table 6.5: Household sample sizes - targeted vs obtained

Sample	Target	Year 0	Year 2
MV interviews	755	711	735
CV interviews	1496	1461	1456
Total interviews	2251	2172	2191

A breakdown of the reasons for the differences in sample sizes over the years is presented in Table 6.6. It is important to note that due to the inaccessibility to the dataset at the project design stage , the reasons reported for *Year 0* are based on the information provided by Masset et al., [248]. However, the reasons reported for Year 2 are based on our analyses of the dataset.

Table 6.6: Reasons for differences in sample sizes

Reason	Year 0	Year 2
No competent household member at home	21	8
Entire household absent	22	11
Dwelling vacant or destroyed	···	2
Dwelling not found	19	13
Household relocated	···	15
Deceased	···	3
Household dissolved	···	3
Interview refused	1	···
Duplicate household	···	4
Interview postponed	10	···
Other	6	···
Total	79	59

To accurately estimate the impacts, only households interviewed in both years (termed panel households) - a total of 4289 households across both sites and periods, are included in the DD models. The reason for this decision is that in using only panel households, it can be anticipated that the actual impact of the interventions, on households can be more precisely identified. A breakdown of these panel households is presented in Table 6.7.

Table 6.7: Panel household sample sizes

Sample	Year 0	Year 2
Panel MV households	711	697
Panel CV households	1461	1420
Total panel households	2172	2117

From Table 6.7, a slight attrition is observed in the panel household sample sizes. As such, we examine the average household sizes over the years, to ensure there are no compositional differences in household sizes. The average household sizes of the panel households are calculated at year 0, year 1 and year 2 as well as the changes between these periods. The average household sizes obtained for years 0 and 1 were fairly stable at 7.147 and 7.400 respectively. However, although a larger attrition of household sample size is observed in year 2, the average household size obtained is significantly larger than preceding years: at 8.179. Figures 6.1 and 6.2 illustrate the distributions of the changes in average household sizes over the two years.

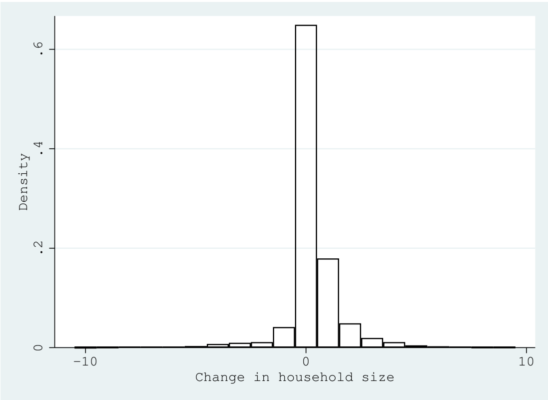


Figure 6.1: Change in average household size: Year 0 to Year 1

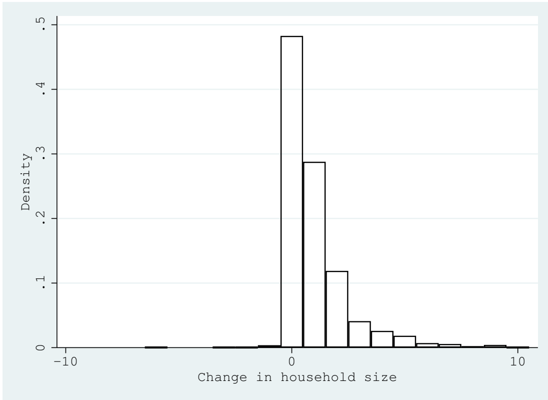


Figure 6.2: Change in average household size: Year 0 to Year 2

As shown in Figure 6.1, the difference in household sizes between the baseline year (Year 0) and Year 1, is observed to be minimal. It is seen that the largest proportion of households had no changes in household sizes. This distribution is followed by changes of one to three additional household members. However, in Figure 6.2, it is seen that in Year 2, whilst households with no changes remain the largest proportion, increase in household members are observed in majority of the households: with some households reporting extreme[3] household size changes.

In terms of the demographics of the population, at baseline (Year 0), in the MVs, 49.84% and 50.16% of the population are male and female respectively, whilst 49.80% of the overall population are observed to be under the age of 18. In the case of the CVs, 50.39% and 49.61% are male and female, respectively, while 50.59% of the total population are seen to be under the age of 18.

In Year 2, no substantial changes were observed in the composition of the population: with the ratio of adults to minors (under 18), remaining fairly similar, across both groups.

[3]Up to ten additional household members

To further capture the nature of the households, the levels of education and nature of employment, across the CVs and MVs were reviewed. The details of the levels of education for the CVs and MVs, across both periods, are presented in Tables 6.8 and 6.9 respectively.

Table 6.8: Levels of education of population in CVs

	CV	
Level of education	Year 0 (%)	Year 2 (%)
None	56.63	49.32
Pre-school	10.72	11.96
Primary	22.63	26.25
JSS/JHS	6.29	6.86
SSS/SHS	3.16	4.42
Vocational/technical school (post primary)	0.06	0.06
Vocational/technical school (post secondary)	0.12	0.19
University/College	0.37	0.43
Religious school	···	0.38
Adult literacy school	0.02	0.1
Adult Vocational/Technical training	···	0.03

Table 6.9: Levels of education of population in MVs

	MV	
Level of education	Year 0 (%)	Year 2 (%)
None	53.61	44.73
Pre-school	11.86	14.71
Primary	25.73	27.90
JSS/JHS	5.91	7.57
SSS/SHS	2.54	4.08
Vocational/technical school (post primary)	0.06	···
Vocational/technical school (post secondary)	0.13	0.10
University/College	0.13	0.41
Religious school	···	0.22
Adult literacy school	0.02	0.14
Adult Vocational/Technical training	···	0.14

Overall, considering the breakdown of education across the population in both CVs and MVs, at baseline, it is observed that more than half of the population across both groups, do not have any form of education. When examining all levels of education, it is observed that the levels of education across the populations are similar: with primary education being the dominant highest level of education across both CVs and MVs. Post-treatment, whilst the share of the population with no education appear to decrease comparably across both CVs and MVs; with the exception of the vocational and religious schools, there appears to be higher rates of enrolment across the various levels of education, in MVs.

When employment statistics are considered, at baseline, the percentage of the total population employed in the CVs and MVs areas were 61.49% and 60.57% respectively. Post treatment, in Year 2, the difference in figures observed in the employed population in CVs is minute: the recorded employed population increased to 61.78%. By contrast, in MVs, a higher increment is observed. The proportion of employed population is observed to have increased to 61.21%.

Tables 6.10 and 6.11 present the breakdown of the sources of employment across CVs and MVs, respectively. The dominant sector of employment in both CVs and MVs is observed to be Agriculture: with less than 2% of the population (overall or employed), working in other sectors.

Table 6.10: Sources of Employment in CVs

	Year 0		Year 2	
Occupation	(%) of TP	(%) of EMP	(%) of TP	(%) of EMP
Farmer (Own farm)	58.77	95.54	59.95	96.24
Livestock/Animal husbandry	0.24	0.39	0.19	0.31
Fisherman	0.08	0.14	0.21	0.33
Self employed	0.49	0.8	0.91	1.46
Farm labour (not own farm)	1.19	1.94	0.09	0.14
Non-farm labour	0.2	0.33	0.36	0.58
Salaried	0.41	0.67	0.45	0.72
Other	0.12	0.2	0.13	0.21

TP = Total Population; EMP = Employed population

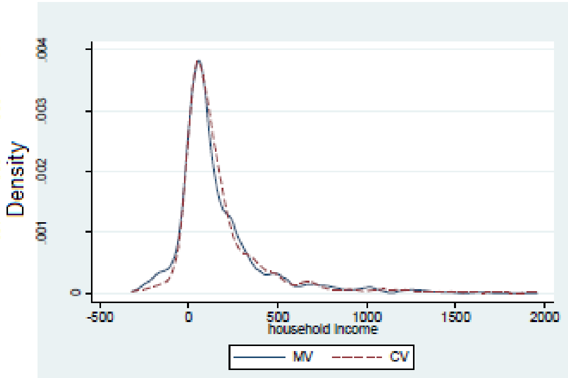
Here, the share of the total and employed population are presented to illustrate the distribution of employment in CVs and MVs, before and after treatment.

Table 6.11: Sources of Employment in MVs

	Year 0		Year 2	
Occupation	(%) of TP	(%) of EMP	(%) of TP	(%) of EMP
Farmer (Own farm)	54.86	90.58	60.04	97.50
Livestock/Animal husbandry	0.5	0.82	0.14	0.23
Fisherman	...	...	0.05	0.09
Self employed	1.3	2.14	0.66	1.08
Farm labour (not own farm)	2.71	4.48	0.02	0.03
Non-farm labour	0.38	0.62	0.16	0.26
Salaried	0.5	0.82	0.37	0.60
Other	0.33	0.55	0.14	0.23

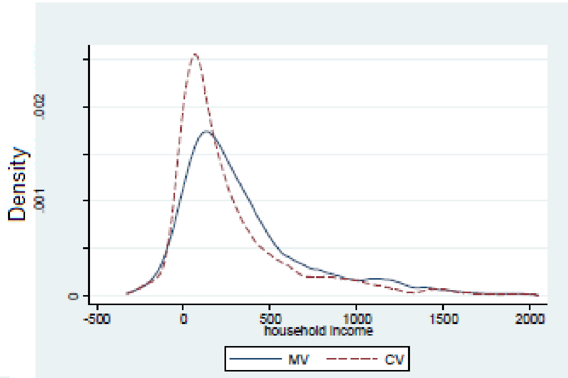
TP = Total Population; EMP = Employed population

From Table 6.10, post-treatment, a significant increase in the share of the self employed population is observed. This expansion is followed by the shares of the population working in fishery and non-farm related labour. Although, there appears to be a general inclination across the various occupations, a significant decline is observed in the share of population working in non-owned farms.
Conversely, in the MVs, as shown in Table 6.11, post-treatment, significant declines are observed across almost all the occupations: with the exception of farmers working on own-farms and fishery.



Source: Masset et al. [248]

Figure 6.3: Household income in Year 0



Source: Masset et al. [248]

Figure 6.4: Household income in Year 2

Looking at household incomes, Figure 6.3 and 6.4 illustrate the densities of household incomes in CVs and MVs, in the two periods.
Figure 6.3 shows that at baseline (Year 0), there are no significant differences in the shapes of income distributions in households in the CVs and MVs.
However, in Year 2, a significant change in the shapes of the distributions of household incomes is observed - especially in the MVs. Figure 6.4 shows an evident shift to the right of the MVs income distribution and a less dense distribution in household incomes in CVs. The changes in household income distributions appear to be more pronounced in the middle and upper end of the income distributions. *Households are getting more income in MV, post-treatment*

Regarding energy consumption, the breakdown of household energy profile is presented and discussed in Section 6.4. Lastly, with regards to the threats to DD validity discussed in Section 6.3.1, the nature of the project, as well as the obtained figures presented in Table 6.5 to 6.11, demonstrate the absence of the aforementioned threats.

A final note on the datasets: Not all households and individuals in the CVs and MVs have been utilised or presented in this section and/or in the analyses within this Chapter. Households and individuals have been included depending on if they are amongst the panel observations or not. Thus, households and individuals which have not been enumerated across both periods have been removed from the dataset used in this Chapter.

6.4 Results

The primary energy services required and used by households in rural areas of developing countries, can generally be classified into three main types: lighting; agro-processing and/or pumping; cooking and heating.

When considering the first category of services: lighting; in our study, across both the CVs and MVs, our data show that in Year 0, households had no access to either grid or non-grid electricity connections. When other alternative forms of modern supply were considered, only electrical generators were reported. However, only 27 households in the CVs and 18 households in the MVs reported owning generators for lighting purposes. Even then, the households reported seldom using them for the household lighting needs. The ownership of generators was observed predominantly amongst households with small enterprises which generally utilised these for their businesses as well as charging mobile phones, amongst others.

Table 6.12: Sources of lighting - Year 0

Lighting sources	CV (%)	MV (%)
Kerosene	9.51	5.62
Dry cell (E-B)	82.34	84.55
Rechargeable (E-B)	2.26	4.07
Solar PV	1.44	0.56
Others (electricity-based)	1.16	0.14
Others (non-electricity based)	0.75	0.42
None	2.53	4.63

E-B = Electricity-batteries; PV = photovoltaic

Excluding these households, as shown in Table 6.12, it is observed that the lighting needs amongst other households are predominantly met by Electricity-battery dry cells and kerosene lamps.

With regard to the second category of energy services, although this category which consists of agro-processing and pumping is not focused upon or addressed in this study, it was observed that these services were generally met by small engine machineries -

mostly, at community levels.

Finally, turning to the third category of services which is the focus of this study, the importance of this service to households within the CVs and MVs becomes apparent. Across the CVs and MVs, approximately 99.72% of households report preparing meals at home.

The primary fuel resource for this service in households across both the CVs and MVs is observed to be firewood, with households rarely reporting the use of other fuels - including other biomass forms, such as wastes from farms, etc. A breakdown of the sources of fuels used for this service is presented in Table 6.13.

Table 6.13: Sources of fuels used for cooking

	CV		MV	
	Year 0 (%)	Year 2 (%)	Year 0 (%)	Year 2 (%)
Owned fallow land	22.45	8.73	24.02	9.04
Other owned land/fields	13.07	8.45	8.01	2.58
Roadside/community land/ forest	60.57	79.23	65.45	87.09
Someone else's land/field	1.44	0.56	1.54	...
Purchased	1.85	2.75	0.7	0.72
Gifted	0.07	0.07	...	...
Produced by HH	...	0.07	...	...
HH storage/reserve	0.07	...	...	...
Other	0.48	0.14	0.28	0.57

HH = Household

From Table 6.13, it is observed that a vast amount of fuels used by the households in both the CVs and MVs, are collected from roadsides, community lands and/or forests. Following this, the next major means of obtaining fuels appears to be through the collection of fuels from owned farms and/or lands. Overall, it appears that very few households obtain fuels through external means such as purchasing or being gifted.

However, a few things are worth noting from Table 6.13. Across both the CVs and MVs, post-treatment (Year 2), a significant reduction in the share of households that collect fuels from owned lands and/or farms is observed whilst there appears to be significantly more households collecting fuels from the roadside, community lands and/or forests. A plausible explanation to this might be the agricultural interventions (Table 6.1) which have increased owned farming activities as shown in Tables 6.10 and 6.11.

Consequently, the fuel gathering factors and/or experiences across the CVs and MVs are examined: to observe the people responsible for the fuel-gathering task; how this affects the duration of fuel-gathering trips; hours spent gathering fuels as well as the number of fuel-gathering trips taken per week.
Firstly, the people within the households who are responsible for gathering the fuels are considered and the results presented in Figure 6.5.

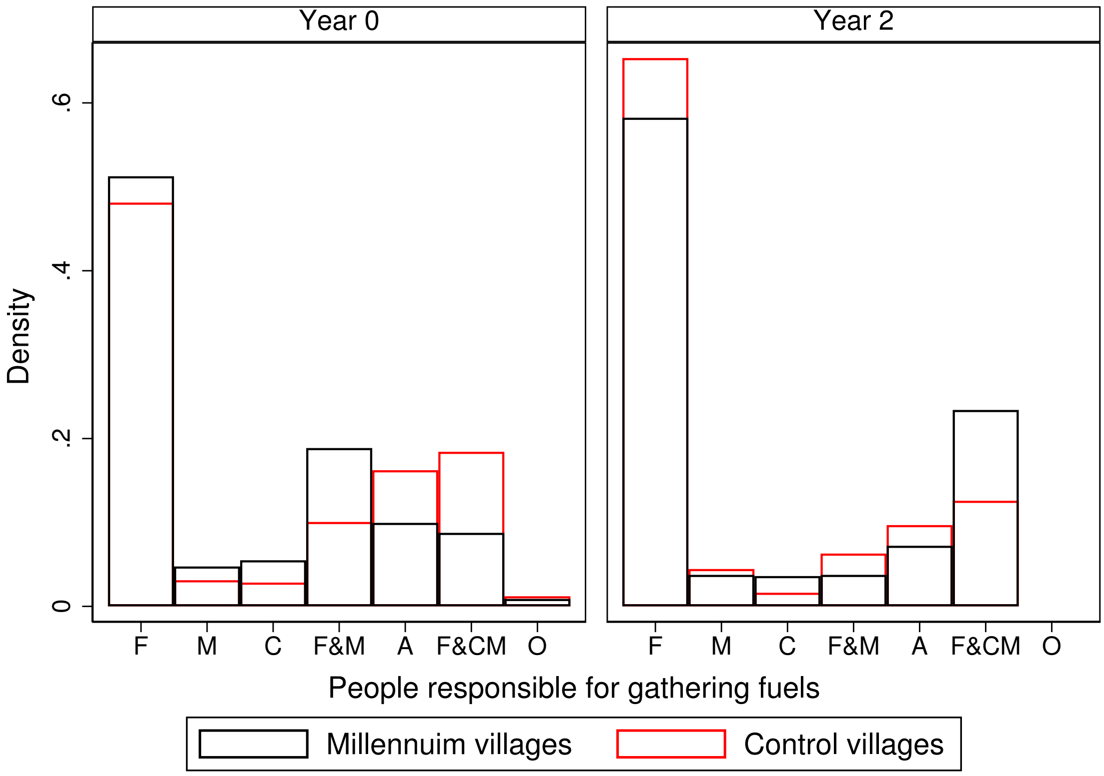


Figure 6.5: People responsible for gathering fuel

As shown in Figure 6.5, across both the CVs and MVs, the adult females within the households are observed to be predominantly responsible for the task of gathering fuels for the households.

In Year 2, starting with the CVs, it is observed that the share of adult females responsible for gathering fuels within households considerably increased and the share of adult males slightly increased whilst the share of children and other combinations of people, either remained the same over the periods or reduced.
In the MVs, the share of adult females responsible for gathering fuels within households was also observed to increase considerably, as well as, the share of adult females and child males, whilst the share of other groups slightly reduced.

Following this, the time spent gathering fuels is considered. Figure 6.6 shows the distribution of the hours spent on gathering fuels in both CVs and MVs, across both periods.

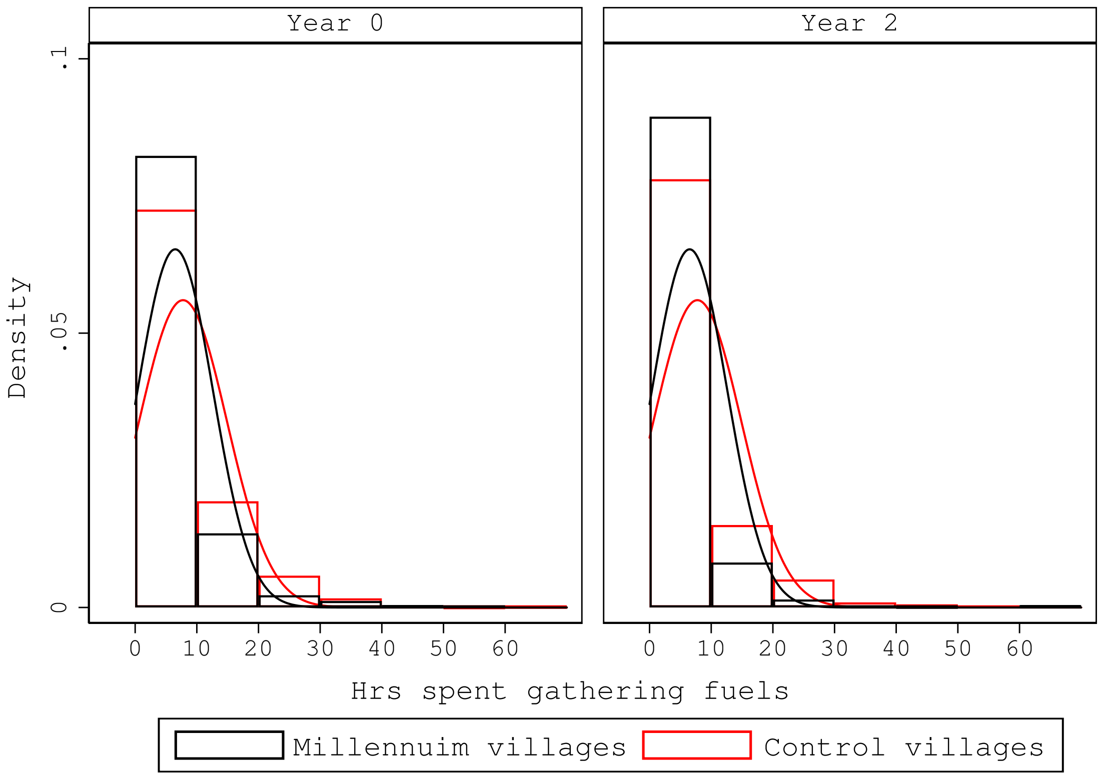


Figure 6.6: Hours spent gathering fuels

From Figure 6.6, it is readily apparent that on average, households in MVs spend more hours gathering fuels than households in the CVs. Generally, across both the CVs

and MVs, it is observable that households predominantly spend between one to ten hours gathering fuels whilst the next considerable share of households appear to spend between ten to twenty hours gathering fuels.
Evaluating the graphs further, it is observed that across both periods, whilst there appears to be more households in the MVs than in the CVs that spend between one to ten hours gathering fuel; more households in the CVs than in MVs spend over ten hours on fuel gathering. Furthermore, in year 2, whilst there appears to be a considerable decline in the share of households in MVs that spend over ten hours on gathering fuels, there seems to be no substantial change in the share of households in CVs that spend over ten hours on gathering fuels.
Due to more households in CV spending larger amounts of time, overall, households in CV spend more time gathering fuels than households in MV. This is the case pre and post treatment.

Next, the entire duration of the trip is considered. That is, the amount of time it takes for the household member(s) to travel to the gathering site and back home.
To clarify the difference between Figure 6.6 above and Figure 6.7 below, a household member collecting fuels from a forest or community land is used as an example.
Using this example, Figure 6.6 above illustrates the time it takes the household member(s) to gather the fuels in the forest site, whilst Figure 6.7 below, illustrates the time it takes the household member to travel to that forest and back.

The results obtained and illustrated in Figure 6.7 show that households in the MVs spend on average, more time travelling to and from fuel collection sites, than households in the CVs.
Although the pre and post-treatment distributions seem similar, there appears to be significant differences in the reported trip durations across the CVs and MVs.

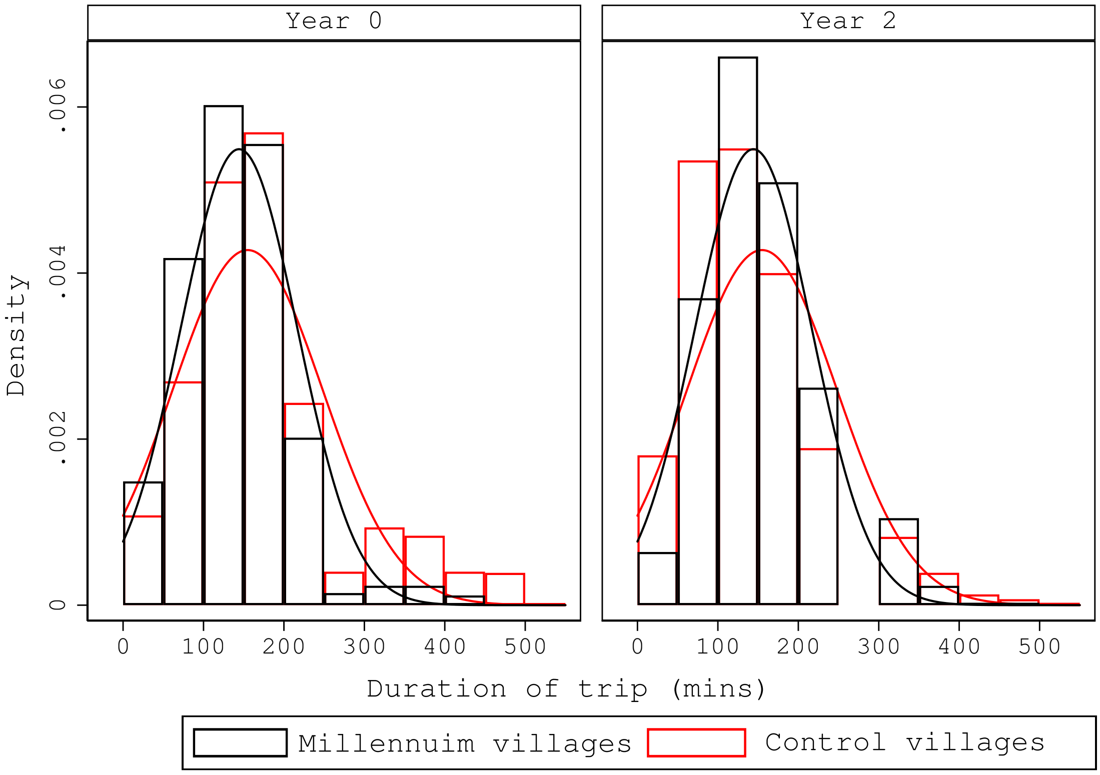


Figure 6.7: Duration of fuel-gathering trips

In the MVs, post-treatment, whilst the share of households spending on average between 0 and 100 minutes travelling to and from collection sites reduced, the share of households with average trip duration ranging between 100 to 350 minutes, significantly increased. Moreover, although little, the share of households spending over 350 minutes on average on fuel-gathering trips, reduced post-treatment.

In the CVs, the share of households spending on average over 200 minutes travelling to and from the fuel collection sites significantly reduced in Year 2, whilst the share of households spending on average between 0 and 200 minutes on the trips, significantly increased in Year 2. *Post-treatment, in the MVs, most households are spending between 100 and 350 minutes on trips while most households in the CVs are spending between 0 and 200 minutes on the trips. Therefore, households in MV are spending more time on fuel collecting trips than households in the CVs - pre and post treatment. This might mean that households in MVs generally had to travel further to gather fuel than households in the CVs.*

Subsequently, the average number of weekly trip per week is examined and reported in Figure 6.8.

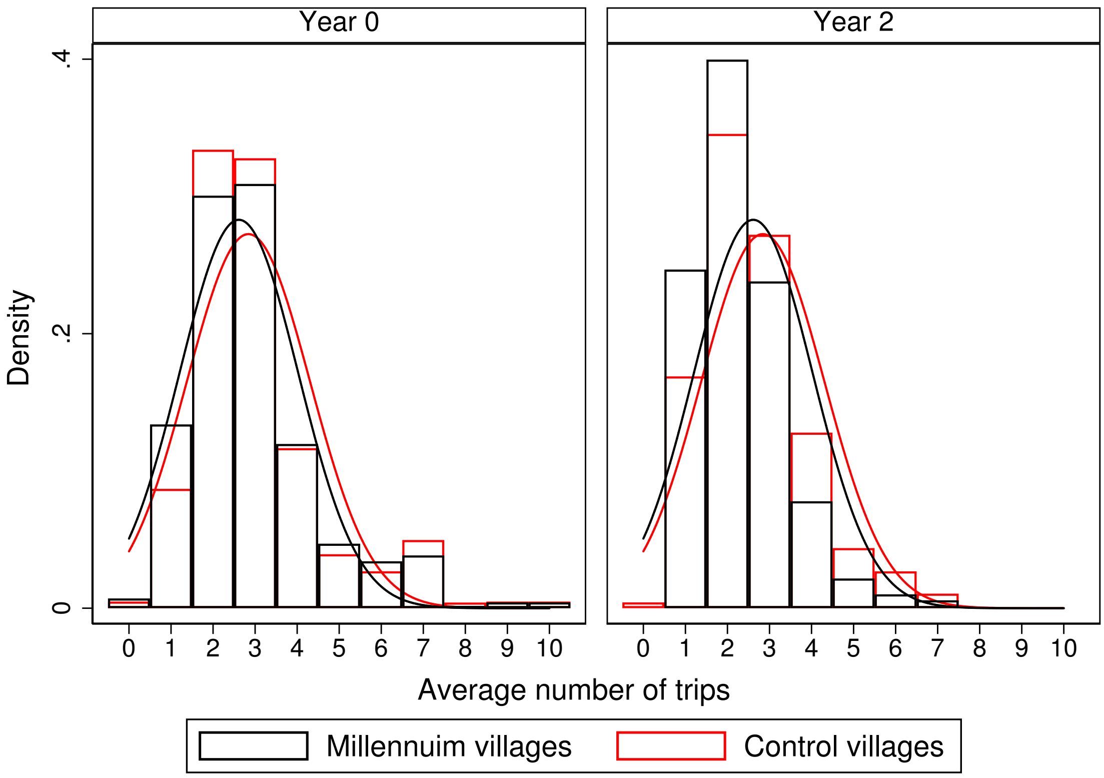


Figure 6.8: Average number of trips - per week

At both baseline and post-treatment, the vast majority of households in the CVs and MVs reported taking between one to four fuel-gathering trips weekly. However, yet again, although the obtained distributions pre and post-treatment appear similar, there magnitudes of the distribution components are distinctive.

Starting with households in the CVs: in Year 2, the share of households reporting over 6 weekly trips on average, considerably reduced. In comparison to Year 0, where over 10% of CVs households reported taking more than 7 trips per week on average, by Year 2, 99.80% of households reported taking between one to six trips per week on average - with approximately 92% reporting taking between one to four trips per week on average.

In the MVs, a similar pattern is observed. Pre-treatment, approximately 7% of households reported taking over 7 trips per week on average whilst post-treatment, 100% of the households reported taking between one and seven trips per week on average: with approximately 97% taking between one to four trips per week on average. *Meaning that households in MVs are taking fewer trips to gather fuel than households in CVs.*

Overall, across the CVs and MVs, households that use fuel-wood report using it practically every day for cooking. Yet, a range of social, environmental and climatic factors such as population density; traditions and choices of farming, forestry and other land use; rainfall patterns, amongst others, are reported to affect the availability, affordability and usability of these fuels.
Therefore, following the observations in Figures 6.5 to 6.8, the difficulty of households in obtaining fuels is investigated. In so doing, it can be determined if the interventions of the MVP have any impacts on the experiences of households in obtaining fuels.

Table 6.14 presents the results obtained from the DD analysis which was carried out to examine if the MVP had any effect(s) on the households' difficulty in obtaining fuels in Year 1 - the year succeeding the commencement of the interventions but preceding Year 2.

Table 6.14: Difficulty in obtaining fuel - Annual

Period	Outcome variable	ep	S. Error	t	P > |t|
Baseline	Control Treated	0.398 [1461] 0.364 [712]			
	Diff (T-C)	-0.034	0.021	-1.40	0.098^{-}
Follow-up	Control Treated	0.233 [1420] 0.162 [697]			
	Diff (T-C)	-0.071	0.017	-4.12	0.000*
	DD	-0.037	0.029	-1.24	0.204

ep = Difficulty obtaining fuel variable; S.error = Standard error; t = t statistics; P> |t| = p-values; [] = no of observations; * = 5% significance; $^{-}$ = 10% significance.

From Table 6.14, a negative impact is observed following the intervention. This result implies that the project could have had a negative impact on households difficulty obtaining fuels. This negative impact observed in the results is to be interpreted that result of the MVP, households could have less difficulties obtaining fuels. However, upon consideration of the probability of the effect being as a result of the project (by means of the p-value obtained from the results), it becomes apparent that the obtained result from the DD analysis can not be deemed statistically significant.

Thus, the result can be interpreted to mean that the MVP interventions have no statistically significant impact or effect on the difficulty experienced by households in obtaining fuels.

Nonetheless, considering other obtained coefficients such as the standard error, the results obtained in Table 6.14 suggest that there may exist some implied effects resulting from the intervention. As such, monthly analyses are performed and the results are presented in Table 6.15.

Table 6.15: Difficulty in obtaining fuel - Monthly breakdown

Period	ep	S. Error	t	P > |t|
January	-0.006	0.004	-1.27	0.204
February	-0.005	0.004	-1.15	0.25
March	-0.007	0.006	-1.24	0.214
April	0.005	0.009	0.62	0.535
May	0.007	0.01	0.74	0.457
June	-0.026	0.012	-2.19	0.028*
July	-0.012	0.013	-0.93	0.035*
August	0.01	0.023	0.42	0.677
September	0.032	0.027	1.2	0.23
October	-0.022	0.02	-1.11	0.265
November	-0.042	0.013	-3.26	0.001*
December	-0.007	0.005	-1.43	0.153

ep = Difficulty obtaining fuel variable; S.error = Standard error; t = t statistics; P> |t| = p-values; * = 5% significance.

Table 6.15 presents the DD results on difficulties experienced by households in obtaining fuel for every month of the year. From Table 6.15, mixed effects of the MVP are observed: some months indicate positive impacts of the MVP whilst the majority of the months indicate negative impacts. Nonetheless, the effect of the MVP is seen to be particularly larger between the months of June and November - the rainy season within the region. However, again considering the p-value of the obtained results, the MVP can be said to have had significant impacts across only a few months: June, July and November.

On a whole, the results in Table 6.15 indicates that as a result of the MVP, in the months of June, July and November, between 1% to 4% of panel MVs households experienced no or lesser difficulties in obtaining fuels for cooking.

Table 6.16: Hours spent gathering fuel

Period	Outcome variable	hgf	S. Error	P > |t|
Baseline	Control	0.937	0.050	0.000
	Treated	1.164	0.076	0.019
	Diff (T-C)	0.226	0.091	0.013
Follow-up	Control	0.714	0.049	0.000
	Treated	1.070	0.074	0.000
	Diff (T-C)	0.356	0.027	0.000
	DD	0.129	0.045	0.004

hgf = Hours gathering fuels; S.error = Standard error; t = t statistics; P> |t| = p-values.

Table 6.16 presents the DD results on hours spent gathering fuels. For both the CVs and MVs households, in the follow-up period, in comparison to the baseline period, a slight decline in the average hours spent gathering fuels was observed. These results are in agreement with initial observations made in figure 6.6.

However, the DD coefficient obtained is positive and significant. Therefore, considering the results from both the CVs and MVs groups, the obtained results suggest that the decline in hours gathering fuels is greater in the CVs villages than in the MVs villages. *Thus, overall, as a result of the MVP, the panel MVs households can be deemed as spending more hours gathering fuels in comparison to the CVs households.*

Table 6.17: Average number of trips - per week

Group	anot	S. Error	P > |t|
Control	-0.155	0.018	0.000
Treated	-0.301	0.032	0.000
DD	-0.146	0.038	0.000

anot = Average number of trips; S.error = Standard error; t = t statistics; P> |t| = p-values.

The DD results on the average number of trips per week is presented in Table 6.17. The results obtained show that post treatment, households in both CVs and MVs, on average, travelled less times a week to gather fuels. Again, these results are in agreement with the initial results presented in figure 6.8. However, the overall DD results obtained indicates that the MVP had a greater significant impact on the MVs households' average number of fuel-gathering trips. Therefore, this suggests that as a result of the MVP, panel households in the MVs travelled on average, less times a week, to gather fuels.

Table 6.18: Duration of fuel-gathering trips

Period	Outcome variable	dot	S. Error	P > |t|
Baseline	Control	1.149	0.039	0.000
	Treated	1.084	0.555	0.000
	Diff (T-C)	-0.065	0.068	0.000
Follow-up	Control	1.214	0.038	0.000
	Treated	0.919	0.055	0.000
	Diff (T-C)	-0.295	0.022	0.000
	DD	-0.359	0.036	0.000

dot = Duration of trips; S.error = Standard error; t = t statistics; P> |t| = p-values.

In Table 6.18, the DD results on the overall duration of the fuel-gathering trips is presented. Similar to Table 6.17, the results obtained show that the MVP had a negative effect on the overall duration of fuel-gathering trips. The magnitude of this effect in observed to be greater in households in the MVs. In substantive terms, these results show that panel MVs households spent less time on fuel-gathering trip, post-treatment, in comparison to CVs households.

To summarise the DD results on fuel gathering trips, the results obtained from Tables 6.16 to 6.18 can be interpreted as follows: the panel households in MVs spend more time gathering fuel (presumably locally) but are less likely to need to travel to access fuel, and when they do, they spend less time on the trips in comparison to the CVs households.

Lastly, Tables 6.19 to 6.21 present the DD results on the impacts of the MVP on people responsible for fuel gathering within households.

Table 6.19: DD results on people responsible for fuel gathering - Children

	CV group	MV group	Diff (M-C)
Baseline	0.012	0.009	-0.003 (0.004)
Follow-up	-0.000	-0.000	-0.000
DD			0.003 (0.004)

(a) Children under age of 15

	CV group	MV group	Diff (M-C)
Baseline	0.028	0.055	0.027*** (0.010)
Follow-up	0.016	0.036	0.020** (0.008)
DD			-0.007 (0.014)

(b) Mix of male and female children

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

Starting with the children, Table 6.19a shows that when considering children under 15 years of age. Although a slight reduction can be observed; overall, a slight positive effect is observed in the number of households where this group within the household are responsible for gathering fuels. When considering the overall mix of children, as shown in Table 6.19b, across both groups, a slight reduction is observed in children responsible for obtaining fuel - post treatment. In addition, when considering the actual MVP effect, the obtained DD results show that post MVP, there is a slight decrease in the number of households where children are responsible for fuels gathering. However, although these effects are observed, across both tables, the obtained DD coefficients do not show statistical significance.

These results can be interpreted to mean that the MVP had no effect on the amount of children *being responsible for gathering fuels in both the CVs and MVs sites.*

Table 6.20: DD results on people responsible for fuel gathering - Adults

	CV group	MV group	Diff (M-C)
Baseline	0.031	0.048	0.016* (0.009)
Follow-up	0.045	0.038	-0.007 (0.009)
DD			-0.023* (0.013)

(a) Adult male

	CV group	MV group	Diff (M-C)
Baseline	0.481	0.513	0.032 (0.019)
Follow-up	0.653	0.582	-0.071*** (0.027)
DD			-0.103*** (0.033)

(b) Adult female

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

Tables 6.20 shows the DD results for the adults responsible for gathering fuels. The MVP impact on male adults responsible for gathering fuels is shown in Table 6.20a. The results obtained showed that post MVP, the number of households where adult males were responsible for gathering fuels decreased by over 2% but only at a statistical significance level of 10%. However, when considering female adults, as shown in Table 6.20b, the portion of adult female responsible for gathering fuel increased across both group - post treatment. However, when considering the actual MVP effect, the DD coefficient obtained shows a considerable reduction of over 10% - at a statistically significant level of 1%. This implies that as a result of the MVP, there are 10% less households in the MVs group, where adult females are responsible for gathering fuels. Taken together, these results suggest that the MVP significantly reduced the portion of households where adults were responsible for the gathering of fuels.

Table 6.21: DD results on people responsible for fuel gathering - Mix of household members

	CV group	MV group	Diff (M-C)
Baseline	0.028	0.055	0.027***
			(0.010)
Follow-up	0.016	0.036	0.020**
			(0.008)
Diff-in-Diff			-0.007
			(0.014)

(a) Adult female and male children

	CV group	MV group	Diff (M-C)
Baseline	0.100	0.189	0.088***
			(0.015)
Follow-up	0.063	0.038	-0.025***
			(0.009)
Diff-in-Diff			-0.114***
			(0.015)

(b) Mix of adults

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

Finally, Table 6.21 shows the result for households where a mix of household members are responsible for gathering fuels. Table 6.21a shows the results for households where a mix of adult females and male children were responsible for gathering fuels. It is observed that post MVP, across both groups, there is a slight decrease and overall, as a result of the MVP, there is a decrease in the number of households where this group were responsible for fuel gathering. In the case of mix adults, as shown in Table 6.21b, the results obtained showed that post MVP, the number of households where a mix of adult males and females were responsible for gathering fuels drastically reduced by over 11% - as a result of the MVP.

Therefore, taken together, the DD results obtained on the impacts of the MVP on the people responsible for fuel gathering shows that the the project had a greater statistical impact on households where adults (especially female adults) were responsible for gathering fuels for cooking.

It can be speculated that the reduction observed in adults responsible for fuels gathering might be as a result of higher employment rates in the MVs villages, post-treatment.

6.5 Discussion

The issue of inaccessibility to clean, modern fuels for basic daily activities such as lighting and cooking, remains a reality in many developing countries. Using Northern Ghana as a case study, this Chapter shows and adds quantitative findings to some aspects of energy use, including the heavy dependence on solid fuels as cooking fuel, the dominant use of dry-cell batteries for household lighting, and the near absent rate of household connections to electricity grid. An ongoing actuality in many rural areas of sub-Saharan Africa.

Firstly, it is worth mentioning the limitation of the dataset utilised in this Chapter. The lack of data on what specific interventions were implemented in each village serves as a shortcoming. It would perhaps have been helpful to understand what mechanisms (intermittent) contributed to the changes/patterns observed in the analyses. By way of example, by identifying what interventions were implemented in what villages, it might be easier to identify the causes/drivers of the observed changes. However, the principal attribute of the DD methodology makes up for this shortcoming. Due to the fact the DD methodology accounts for changes due to factors including the unobserved and/or undeclared variables, the effects of the overall intervention on the outcomes of interest have been accurately captured.

Regardless, from a policy perspective, considering the negative impacts of using solid fuels - the stress on local biomass resources, health problems caused by indoor pollution, social impacts discussed in Chapter 3, economic impacts discussed in Chapter 4, as well as the difficulties of obtaining fuels discussed in this Chapter, it becomes apparent that movement towards modern, more efficient and cleaner sources of cooking fuels is critical in this area of the world. This issue is likely to be best addressed through policies and practices aimed directly at modern energy provision: which till date, appear to be lacking. The prevailing notion for this has been that broader, poverty policies and programmes such as the MVP would address the issue. However, our results for the MVP in northern Ghana show that the MVP policy measures deployed have not been successful in addressing the issue. Thus, proving this notion to be inaccu-

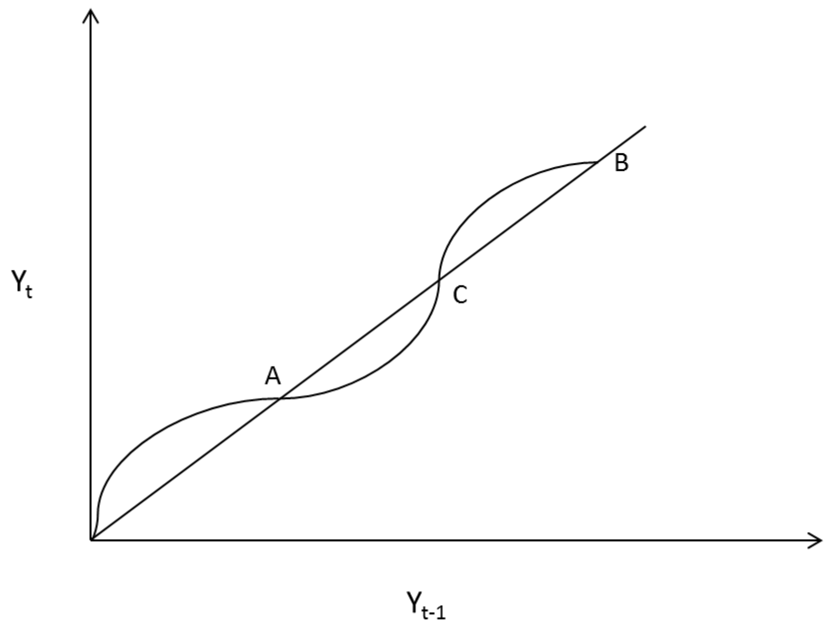


Figure 6.9: The canonical poverty trap model

rate - at least, in the context of the MVP in northern Ghana. Although it is worth stating that studies covering a wider set of policy measures, communities and countries would be necessary in order to draw wider conclusions as to the efficacy of such policies.

Following on the topic of poverty, the MVP is an experimental application of the poverty trap model which has implemented development interventions to address multiple aspects of development issues in developing countries - following the poverty trap theory. Therefore, assuming the con census definition of poverty, the issue of lack of modern, cleaner sources of cooking fuels, can be argued to be a constituent of energy poverty and a form of overall poverty.

As such, the canonical threshold poverty trap theory (Figure 6.9) can be applied to demonstrate the persistence of this component of energy poverty. Following this theory, there exists three inter-temporal equilibrium points, two of which are stable (points A and B) and one is unstable (C). The energy poverty path can be hypothesised as follows: at the immediate right and left of point A, access converges to the equilibrium point A. By contrast, the equilibrium point C is unstable, and any movement from this point brings access either to point A or B. Point A is a poverty trap: small access increases beyond A lead access to converge again to point A. The intersection of the phase line with the 45 degrees line at point C is the poverty trap threshold. Movements of access beyond this point should push a country or household permanently from one equilibrium state to the other. The implication of this model can be interpreted as such: temporary events such as the MVP could have permanent consequences on the issue. So, although situations such as unsound policies may compromise any progress or contribute to the continued impoverishment, this phenomenon can also be advantageous in addressing the problem. In addition, as a result of this behaviour of the model, a 'big push' such as a massive energy-aid programme, may stimulate an onset onto a sustainable progress path.

To illustrate this model: let us assume point A on figure 6.9 represents household use of solid fuels while point C represents household continued use of cleaner alternatives. Using the same MVP area in northern Ghana, let us assume three different policies/interventions: 1, 2 and 3 are implemented in the villages. Intervention 1 addresses only electrification access to the community; intervention 2 addresses electrification, as well as provision of kerosene stoves to the community; while intervention 3, provides a more holistic set of policies which address multiple aspects of the energy poverty issue. In the case of intervention 1, the community gets access to electricity and therefore, move from point A (use of solid fuels) in Figure 6.9 towards point C. Now, let us assume the electricity access is unreliable due to power shortages (an established issue in developing countries), the canonical theory implies that these households which now use electricity for cooking will have to return to the use of solid fuels (point A), remaining trapped in the issue.

In the case of intervention 2, for the community which gets access to electricity, as well as kerosene stoves, in the case of power shortages, this community remains at point C - since households are able to utilise kerosene stoves for their cooking needs. However, considering the fact that the MVP area consists of poor households, these households will still not be above the poverty trap threshold because other issues such as affordability of kerosene have not been addressed by the implemented intervention. Lastly, in the case of intervention 3, the community gets electricity access, kerosene stoves, as well as other interventions addressing reliability of supply and affordability (through interventions that holistically address income poverty). In this scenario, the households would be expected to push beyond point C, towards point B, due to the holistic and substantial nature of the intervention.

Finally, to answer the posed questions at the beginning of the Chapter, the results obtained in this Chapter show that some energy-related conditions of households such as hours spent gathering fuels remained the same post-treatment while some factors such as duration of fuel-gathering trips, and average number of trips, improved (reduced) post-treatment in the MVP area. However, considering the absence of significant changes and/or differences in the households difficulties in obtaining fuels, post-treatment, it can be reasoned that the non-energy-related interventions interventions applied in the MVP in Northern Ghana, might not be significantly contributing to the alleviation of the issue. Bold, considerable, energy-directed policies may be more effectual and beneficial in resolving this issue. However, as previously stated, additional study is needed as regards the potential for complementary non-energy policies to enhance positive impacts

6.6 Summary of key findings

The results obtained from the analyses within these chapter have shown that the MVP non-energy policies and interventions, applied in northern Ghana had the following effects on the following aspects of household use of solid fuels:

In the context of difficulty obtaining cooking fuels, for households in the MVs, post-treatment, no difference was observed in the difficulty in obtaining cooking fuels on an annual basis.

Considering the different months in the year, a significant reduction in difficulties obtaining fuels was observed in only three months across the year: June, July and November.

With regard to hours spent gathering fuels, the results show that households in the MVs spent more hours gathering fuel, post-treatment.

However, in terms of average number of weekly fuel-gathering trips and overall duration of the trips, the results obtained show that MVs households had less average weekly fuel-gathering trips and spent less hours overall on fuel-gathering trips.

This implies that households in MVs spend more time gathering fuel (presumably locally) but are less likely to need to travel to access fuel, and when they do, they spend less time on the trips in comparison to the CVs households.

Lastly, results obtained on people responsible for gathering fuels show that the most significant impact is observed in the number of households where female adults are responsible for gathering fuels. Post MVP, the number of households where female adults gathered the fuels reduced significantly.

Chapter 7

Conclusion and future work

7.1 Conclusion

A review of the energy access situation across the globe was conducted. The findings unearthed that approximately 1.2 billion people lack access to electricity while over a third of the global population (over 2.8 billion people) lack access to modern energy for cooking and thus, have to rely on traditional cooking methods based on the use of solid fuels. The geographical distribution of this phenomena was observed to be uneven across the globe. The majority of the affected population was observed to be concentrated in developing Asia and sub-Saharan Africa.

Motivated by the realization that more people across the globe lack access to modern cooking services, further investigation on this phenomenon were conducted. The outcomes of the investigations indicated that despite strong praise for action and the deployment of electrification programs, little attention has been placed on the aspect of modern cooking services. What's more, a further review of literature showed that very few studies have shed light on the barriers to, the enablers of, and, the impacts of access to modern cooking sources on development outcomes, using rigorous methodologies. This thesis addresses this recent strand of research. It tries to fill some of the gaps in existing literature and asks the key research question:

To what degree does the household use of solid fuels in developing countries impact on sustainable development?

To answer this principal research question, further sub-questions as outlined in Section 1.1, were investigated.

Sub-questions 'Q1' and 'Q2' were explored and answered in Chapter 2. The proportion and distribution of the global population relying on solid fuels for cooking due to lack of access to modern, cleaner alternatives were established. It was observed that over 30% of the global population lack access to clean cooking fuels for cooking and/or heating. In addition, it was observed that the distribution of the situation is uneven across the globe: the most impoverished regions were established to be the sub-Saharan African, east Asian and south Asia regions.

Following this, the impacts of this phenomenon (household use of solid fuels) on measures of social development (Q3) was successfully analysed and established for the three most impoverished regions: sub-Saharan Africa, east Asia and south Asia. Based on existing literature on social development, enrolment in primary and secondary education; life expectancy; employment rates and labour force participation were selected as indicators for social development. The fixed and random effects models were then applied for analyses. These analyses were performed at global, regional and country-levels.

The most significant effect of household use of solid fuels has been found to be on life expectancy. At both the global and regional levels, the results obtained showed that the household use of solid fuels had statistically significant negative associations to life expectancy. However, more importantly, the country-level analyses results show that across all countries examined, a significantly negative relationship exists between life expectancy and household use of solid fuels: implying that the household use of solid fuels could significantly reduce the life expectancy of solid fuels users. The degree of effects observed across the examined countries varied with some countries having very high elasticity effects. However, taken together, the results demonstrated that across the countries, the levels of effects were directly related to the percentages of the households utilising solid fuels for cooking.

In the case of education, a widely-acknowledged essential component to development, the impacts of the phenomenon on rates of enrolment to primary and secondary education, have been examined.

At the global level, the household use of solid fuels was observed to have a strong negative association with primary enrolment rates, while at the regional-levels, similar outcomes were observed. At country-level, the results from the investigation on primary education enrolment reflected mix outcomes. Some countries showed no statistically significant effects whilst others exhibited statistically significant effects. Looking at the countries with statistically significant effects, the observed effects are seen to be largely negative. Thus suggesting that the household use of solid fuels does reduce the likelihood of enrolment of school-aged children to primary education.

When considering enrolment into secondary education, at all levels (global, regional and country-level), the effects were observed to be greater. At the global and regional levels, the obtained elasticities are observed to be up to three times the elasticities obtained for impact on primary enrolment; whilst at country-level, in some cases, the effects have been observed to be more than three times the impact on primary education.

In the case of labour force participation and employment rate, the results obtained for the global level analysis show that the household use of solid fuels is strongly, negatively, associated with employment rate, but is not significantly associated with labour force participation. When considering the regional-level results, the outcomes observed are diversified. To clarify: for the sub-Saharan Africa and south Asian region, statistically significant, negative associations are observed when considering impact on employment rates; whilst no association is observed for the east Asian region. Furthermore, when considering labour force participation, a negative, statistically significant, association is observed only in the case of south Asia, while no associations are observed in the cases of sub-Saharan Africa and east Asia. Similarly, at country level, the results from the labour force participation and employment rate analyses were very diversified. Similar to the case of education, some countries exhibited non-significant effects whilst others showed statistically significant effects of solid fuels use on the variables. However, amongst the significantly impacted countries, the nature of the effects varied from positive to negative effects, across the countries. A plausible explanation to the positive effects observed for some countries such as Vietnam, could be the creation of unskilled labour jobs associated with the collection and/or processing of solid fuels such as coal, animal dung, amongst others. Conversely, the negative effects observed for some countries indicate that the household use of solid fuels does hamper employment rates and labour force participation. The implication of these findings are in agreement with the recent reports from the World Bank which suggest that the household use of solid fuels hampers free-time which could otherwise be used for productive purposes.

The effects of the household use of solid fuels on life expectancy, employment rates and labour force participation rates, in the context of the female population were also analysed. At the global level, across all examined variables, statistically significant, negative associations are observed between the household use of solid fuels and the aforementioned variables. What's more, compared to the results obtained for the general population, the obtained elasticities are observed to be higher when considering the female population only. These observed results imply that globally, the female population are more likely to experience the effects of household use of solid fuels.
At the regional-levels, the results obtained varied. Starting with the life expectancy variable. As a whole, across the east and south Asian regions, the effects on the female population were found to be significantly negative and compared to the general population, higher. While on the other hand, in sub-Saharan Africa, although a strongly significant negative association is also observed, in comparison to the general population, there was no significant difference observed in the magnitude of the effects on the female only population. These results can thus be interpreted as follows: in the east and south Asian regions, the household use of solid fuels is likely to have a larger effect on reducing the life expectancy of the female population within the regions; while in the sub-Saharan region, the effects are likely to be similar across the entire population.
In the case of labour force participation; across sub-Saharan Africa and south Asia, similar to the results obtained for life expectancy, the results obtained showed strongly significant, negative, associations (with higher elasticities) with household use of solid fuels. Whilst in east Asia, no statistically significant relationship is observed between

the household use of solid fuels and labour force participation. However, the results from the employment rate for the female population show that across the three regions, the effects on the female population were significantly higher. These results imply that within these regions, as the rates of household use of solid fuels grow, the employment rates and labour force participation of the female proportion of the population decreases: with the exception of female labour force participation in east Asia. For the country-level analyses, similar to the results obtained at regional level, the results obtained from the country-level analyses showed varying outcomes.

In Chapter 4, the impacts are investigated in the context of economic development. Using the panel cointegration and causality methods, these impacts were investigated in the short-run and long-run.

The results from the short-run causal analyses show that in the cases of south Asia and sub-Saharan Africa, the household use of solid fuels strongly negatively influences the economic growth within the regions; while in the case of east Asia, economic development is observed to influence the household use of solid fuels. The implications of these results can thus be translated as follows: in the short term, for south Asia and sub-Saharan Africa, an increase in the household use of solid fuels such as coal, animal dung, dried crops, etc., for cooking and/or heating, negatively impacts on the GDP per capita of the regions.

In terms of the long-run, no causal relationship was observed in south Asia, implying that the household use of solid fuels did not play a statistically significant role on the economy within the region, just as economic development within the region plays no significant role on household use of solid fuels. For sub-Saharan Africa, the relationship observed showed that the household use of solid fuels negatively influenced the economic growth of the region; implying that in the long term, the household use of solid fuels for cooking and/or heating acts as an inhibitor to economic development within the region. Lastly, for east Asia, the obtained results showed that the household use of solid fuels and economic growth mutually influenced one another.

A cause for the variances observed between the short-run and long-run results can be speculated to be due to the differences in which countries respond to economic shocks in the short-run and the long-run. The short-run denotes a period of six months following the initial shock to the economy, while the long-run denotes a period following this. As such, it can be reasoned that the impacts on economies might defer with times. In addition, the causes for the varying outcomes observed between the regions can be reasoned to be two-fold: 1) each region has varying contributing factors (or barriers) to access (or lack of) to modern cooking alternatives; 2) the distribution of economic development is uneven across the regions.

Inspired by these findings, the barriers to household accessibility to and adoption of modern cooking fuels was reviewed in Chapter 5. The review was conducted from both the demand and supply perspectives. The outcomes of the review suggested that the main ubiquitous barriers can be categorised into three main categories: technical (infrastructure), economic (finance), and governance barriers. The lack of adequate energy infrastructure and resources, as well as basic infrastructures such as good roads, needed to facilitate accessibility and reliability; the issue of affordability due to low income (at both national and household levels); and the lack of efficient policies which address these obstacles, were found to be dominant factors across the regions. The implications of these review findings on the results observed in Chapters 3 and 4 were firstly considered. In addition, broader implications of the review findings were considered and viewed as two-fold: policy implications and research implications. Due to these findings and the implications, it was observed that current interventions and policies might be ineffective in addressing the issue of household accessibility to, and adoption of modern cooking fuels. To exemplify, many current policies fail to take into account the inter-related nature of the various barriers. In addition, although crucial in formulating appropriate solutions, the knowledge of the dynamics between the household use of solid fuels and development is lacking in current interventions and policies.

Based on these review findings, the effects of current sustainable development interventions and policies on household use of solid fuels were analysed in Chapter 6 - to test if current approaches do address the issue. For this purpose, the data from the MVP in Northern Ghana was utilised and the DD methodology applied. The results showed that although some impacts were observed in some factors associated with household use of solid fuels, overall, current MVP non-energy policies and interventions, did not have significant impacts on the difficulties experienced by households in obtaining necessary fuels for cooking - in the case of the Millennium Village Project (MVP) in northern Ghana.

From these results, the answer to the posed key research question can be stated as such:

The dynamic between household use of solid fuels and sustainable development is complex, and varies from country to country. However, on a whole, it can be stated that in most developing countries where sustainable development is most needed, household use of solid fuels does have statistically significant effects on some measures of social development, and influences economic development.

Lastly, in addition to answering the research questions, the results from this thesis provide a quantitative complement to the embryonic, mostly qualitative contributions in the literature. The current approaches in energy poverty literature, policies and interventions, which focus only on accessibility to electricity, without incorporating measures for accessibility to modern cooking services are insufficient to address the issue of energy poverty. Widening the scope and increasing the pace of modern cooking alternative, however, would require in general, better institutional arrangements than currently are in place in developing regions. More attention for and a better understanding of the dynamics of the phenomenon in developing countries constitute essential components for strategies to increase access to modern cooking services for the impoverished. Adequate, multifaceted policies and interventions would ultimately determine the effectiveness of available economic and technical solutions, and hence, are a fundamental in bringing about the needed change — a general conclusion that is not less true for modern cooking alternatives.

7.2 Limitations

The limitations of the variables used as indicators, as well as the various models applied in the analyses performed within this thesis, have been extensively discussed in Chapters 3 to 6. These limitations can be summarised to be predominantly data-related limitations. To clarify, given the limited available data, the definition of energy poverty had to be restricted to the accessibility element of the phenomenon only. So other important elements of energy poverty, such as reliability, affordability, and availability, etc., have been bypassed in the analyses. The inclusion of these elements might give a more comprehensive picture of the phenomenon. Nonetheless, focusing on accessibility only has an interest in itself given the importance that energy accessibility studies have generally played in the design of international policies and interventions.

7.3 Future work

For effective policy-making at national levels, the dynamics and heterogeneity within the countries should be considered at national and sub-national levels. Although, the dearth of data prevents to follow this research path, this thesis provides a base for future study of impacts of household use of solid fuels.

For Chapter 3, subject to the availability of data, future work could include further variables of education such as attendance rates, student performance measures like grades, as well as further employment and/or income variables.

In addition, considering that the majority of the population lacking modern cooking services reside in rural areas, future works on Chapters 3 and 4, should analyse these impacts in the context of rural areas.

Lastly, for the analyses performed in Chapter 6, it would have been advantageous to have the breakdown of the near-control and far-control villages. Such information could have helped estimate which villages had the most impacts - the near project or far project villages. In addition, subject to the availability of data on a wider range of policy interventions in a wider range of countries, this type of analyses could be considered in future works.

Appendix A

Appendix: Chapter 2

This is the Appendix for Chapter 2

A.1 Coding for literature

Table A.1: Coding labels for literature

Keywords	Code	Description
Energy poverty	EP	Lack access to modern energy services
Energy and sustainable development	ESP	Energy and sustainable development
Energy security	ES	Ensuring continued access to energy carriers
Energy & indirect use	EU	Energy used indirectly through services, food, public transport, etcetera
Energy & health	EH	Energy's connections with human health
Energy & education	EE	Energy's connections with education
Energy & climate	EC	Energy's connections with climate change
Energy & resources	ER	Energy's connections with limits on resources
Energy & employment	EM	Energy's connections with Employment
Energy & Developing countries	ED	Energy in connection with developing countries
Foundation	F	Foundational reading: poverty, inequality, needs, development, etcetera

Table A.1 shows the some keywords and codes used to search for articles focused on energy and sustainable development, in Journals and databases. In cases where the literature was deemed foundational reading for the review but did not fit under chosen keywords, the study was coded as “Foundation”.

Table A.2: Results of the database query for the keywords shown in Table A.1

Terms searched	Code	Hits in entire SD database all years (to 2017)	Hits in SD energy focused journals all years (to 2017)	% Hits in energy focused journals published since 2018
Energy poverty	EP	212 (82)	187 (75)	60%
Energy and sustainable development	ESP	134 (74)	115 (62)	46%
Energy security	ES	1233 (834)	1013 (687)	32%
Energy & indirect use	EU	18 (13)	12 (8)	33%
Energy & health	EH	7,268 (4,973)	1,206 (732)	40%
Energy & education	EE	1,689 (1,260)	532 (387)	27%
Energy & climate	EC	11,660 (7,651)	7,344 (4,696)	36%
Energy & resources	ER	156 (103)	112 (70)	38%
Energy & Employment	EM	27 (19)	13 (10)	23%
Energy & Developing countries	EF	18 (9)	7 (2)	71%
Total		22,415 (15,081)	10,541 (6,729)	36%

Table A.2 shows the results of the database query for the keywords shown in Table A.1. This database searched were conducted between 2016 and 2017 and once in early 2018 and again in mid-2018. Examples of Journals reviewed include “Energy Policy”, “Energy for Sustainable Development”, ”Applied Energy”, ”Energy Economics”, ”American journal of Energy Economics”, ”World Development”, “Renewable and Sustainable Energy Reviews”, amongst others.

In addition, Grey literature was retrieved through searches conducted in the following non-subscription databases and websites of key stakeholder organisations: (a) the International Energy Agency (b) United Nations databases, Organisation for Economic Cooperation and Development (c) the World Health Organisation (d) the World Bank (e) the African Development Bank (f) the Renewable Energy and Energy Efficiency Partnership (g) the Global Village Energy Partnership (h) and the African Energy Policy Network. Similar search terms to those used in the subscription databases were applied to the internet search, although depending on the database we were often limited in our ability to apply all the search terms.

Table A.3: Categorized and coded journal articles included in the review

Author, date	Study category	Citations
Banki, S. (2009)	F	11
Barnes, D. F., et al. (2011)	EP, ESP	38
Bazilian, M., et al. (2014)	EP	10
Bell, M. L., et al. (2004)	EH	716
Bhattacharyya, S. C. (2012)	EP	33
Boardman, B. (2012)	F, EP	7
Bouzarovski, S., et al. (2012)	FP	30
Brees, I. (2010)	F	23
Bullard III, C. W. and R. A. Herendeen (1975)	EU	384
Cabraal, R. A., et al. (2005)	EP, EH, EE	123
Cardis, E., et al. (2005)	EH	438
Casillas, C. E. and D. M. Kammen (2010)	EC, EP	69
Chakravarty, S., et al. (2009)	EC, EP, EC	169
Chester, L. (2014)	ESP	1
Davis, L. W. (2010)	F	61
Dietz, T., et al. (2009)	F	86
Dolly Kyaw and J. K. Routray (2006)	F	3
Donoghue, A. (2004)	EH	95
Epstein, P. R., et al. (2011)	EH	148
Fankhauser, S. and S. Tepic (2007)	F	112
Goldemberg, J., et al. (1985)	EP	104

Continued on next page

Author, date	Study category	Citations
Goldthau, A. and B. K. Sovacool (2012)	ER, ES, EC	29
Groh, S. (2014)	EP	6
Grubler, A. (2012)	F	40
Haas, R., et al. (2008)	EU	62
Healy, J. D. and J. P. Clinch (2004)	F	69
Heltberg, R. (2004)	EP	133
Hull, S. (2009)	F	4
Jackson, S. and A. Sleigh (2000)	EH	95
Li, K., et al. (2014)	EP, ESP	4
Liddell, C. and C. Morris (2010)	EH, ESP	75
Lovins, A. B. (1976)	ES, ER	507
Mainali, B., et al. (2014)	EP, EC, ER	5
Maslow, A. H. (1943)	F	12,731
McMichael, A. J. and E. Lindgren (2011)	EH, EC	71
McMichael, A. J., et al. (2008)	F	189
Moll, H. C., et al. (2005)	EU	122
Nussbaumer, P., et al. (2012)	EP, ESP	75
Nussbaumer, P., et al. (2013)	EP, ESP	-
Nussbaumer, P., et al. (2013)	EP, ESP	3
Pachauri, S. (2011)	EP, ESP	17
Pachauri, S. and D. Spreng (2002)	EU	172
Pachauri, S. and D. Spreng (2011)	EP	29
Pachauri, S., et al. (2004)	EP	100
Palmer, I. (1977)	F	75
Pascale, A., et al. (2016)	EM, EP	-
Reinders, A., et al. (2003)	EU	161
Rogers, C., et al. (2013)	EF	2
Sen, A. (2001)	F	2,859
Sher, F., et al. (2014)	EP	1
Shyu, C.-W. (2014)	EP	2
Smith, M. F. and N. Htoo (2008)	EM, ES, EF, ESP	14

Continued on next page

Author, date	Study category	Citations
Sovacool, B. (2012)	EM, EC, ER, ESP	3

Table A.3 lists some of the journal articles included in the literature review for Chapter 2.

Appendix B

Appendix: Chapter 3

This is the appendix for Chapter 3

B.1 Method

B.1.1 Fixed Effects model

For the unobserved effects model expressed in equation 3.4, the first stage of the FE transformation involves first averaging equation 3.4 over $t = 1, \ldots, T$ to obtain:

$$\bar{Y}_c = \beta \bar{X}_c + u_c + \bar{\varepsilon}_c \tag{B.1}$$

where,

$$\bar{Y} = \frac{1}{T} \sum_{t=1}^{T} Y_{ct}; \qquad \bar{X} = \frac{1}{T} \sum_{t=1}^{T} X_{ct}; \qquad \bar{u}_c = \frac{1}{T} \sum_{t=1}^{T} u_{ct};$$

Following this, equation B.1 time demeaned by subtracting it from equation 3.4 for each t, to obtain the FE transformed equation:

$$\left(Y_{ct} - \bar{Y}_c\right) = \left(\beta \left(X_{ct} - \bar{X}_c\right)\right) + \left(u_c - u_c\right) + \left(\varepsilon_{ct} - \bar{\varepsilon}_c\right) \tag{B.2}$$

Rewriting equation B.2 above,

$$\ddot{Y}_{ct} = \beta \ddot{X}_{ct} + \ddot{\varepsilon}_{ct} \tag{B.3}$$

Equation equation B.2 above is numerically equivalent to the regression of Y_{ct} on X_{ct}. Hence the term *within* or *fixed* effect estimator.

B.1.2 Random Effects model

Starting with the unobserved effects equation 3.4, assuming the first assumption in section 3.4.1.2, (RE1), we introduce a composite error term ψ_{ct} where $\psi_{ct} = u_c + \varepsilon_{ct}$. Since u_c now becomes the composite error in each period, ψ_{ct} is serially correlated across time. That is, ψ_{ct} and $\psi_{ct} - \psi_{ct-1}$ are not random and are related.
Therefore, equation 3.4 can be written as equation 3.13.

Now, under the second assumption (RE2) in section 3.4.1.2, the correlation between the error terms can be viewed as:

$$corr\left(\psi_{ct}, \psi_{cs}\right) = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_\varepsilon^2}, \qquad t \neq s \tag{B.4}$$

where, $\sigma_u^2 = var(u_c)$ and $\sigma_\varepsilon^2 = var(\varepsilon_{ct})$. $'var'$ stand for variance

With equation B.4 in mind, we can transform the equation to obtain the demeaned data to eliminate the serial correlation. From equation B.4, for period, T, renaming $corr(\psi_{ct}, \psi_{cs})$ as φ^2;

$$\varphi^2 = \left[\frac{\sigma_u^2}{\sigma_u^2 + T\sigma_\varepsilon^2}\right] \tag{B.5}$$

therefore,

$$\varphi = \sqrt{\varphi} = 1 - \left[\frac{\sigma_u^2}{\sigma_u^2 + T\sigma_\varepsilon^2}\right]^{\frac{1}{2}} \tag{B.6}$$

Therefore, the transformed equation B.2 equivalent RE equation becomes:

$$y_{ct} - \varphi\bar{y}_c = \beta_0\left(1-\varphi\right) + \beta_1\left(x_{ct1} - \varphi\bar{x}_{ct1}\right) + \ldots + \beta_k\left(x_{ctk} - \varphi\bar{x}_{ctk}\right) + \left(_psict - \bar{\psi}_c\right) \tag{B.7}$$

Derivation of Variance Matrix To derive the unconditional variance matrix of ψ_c, (ϱ) which is defined in equation 3.14, with the second assumption (RE2a) expressed in equation 3.16 in mind:

$$E\left(\psi_{ct}^2\right) = E\left(u_c^2\right) + 2E\left(u_c\varepsilon_{ct}\right) + E\left(\varepsilon_{ct}^2\right) = \sigma_u^2 + \sigma_\varepsilon^2 \tag{B.8}$$

However, with second, second RE assumption (RE2b) represented in equation 3.17, for all $t \neq s$,

$$E\left(\psi_{ct}\psi_{cs}\right) = E\left[\left(u_c^2 + \varepsilon_{ct}\right)\left(u_c + \varepsilon_{cs}\right)\right] = \sigma_u^2 \tag{B.9}$$

Therefore, the variance matrix of ψ becomes:

$$E\left(\psi_c\psi_c'\right) = \begin{pmatrix} \sigma_u^2 + \sigma_\varepsilon^2 & \sigma_u^2 & \dots & \sigma_u^2 \\ \sigma_u^2 & \sigma_u^2 + \sigma_\varepsilon^2 & \dots & \vdots \\ \vdots & & \ddots & \sigma_u^2 \\ \sigma_u^2 & & & \sigma_u^2 + \sigma_\varepsilon^2 \end{pmatrix} = \boldsymbol{\varrho} \tag{B.10}$$

For ease of representation, this can be rewritten as:

$$\boldsymbol{\varrho} = \sigma_\varepsilon^2 \mathbf{I}_T + \sigma_u^2 \mathbf{j}_T \mathbf{j}_T'$$

where, $\mathbf{j}_T$ $\mathbf{j}_T'$ are $T \times T$ matrix with unity in each element. From here, the demeaned variance matrix becomes:

$$\hat{\boldsymbol{\varrho}} = \hat{\sigma}_\varepsilon^2 \mathbf{I}_T + \hat{\sigma}_u^2 \mathbf{j}_T \mathbf{j}_T'$$

which is then applied in the RE estimator as shown in equation 3.15

B.2 Data

Note on Data

China: Two Special Administrative Regions – Hong Kong and Macao – are reported separately from data for China.

Singapore: Education data starting in 2016 refer to residents (citizens and permanent residents) with local addresses and who were away from Singapore for a cumulative period of below 6 months in the past 12 months prior to the reference date (end-June each year). The data should only be used for the purpose of computing education indicators and should not be compared against other sets of population data published by the Singapore Government.

Summary tables of variables for Regions

Table B.1 presents the variables utilised in the global, regional aggregate panel analyses while Table B.2 presents the variables utilised in the global, regional aggregate panel analyses which examines the gender impact - specifically, to investigate the way solid fuels impact females across these indicators of interes

Table B.1: Descriptive summary of variables - Regional

Region	Variables	Min	Max	Mean	Std.Dev
East Asia & Pacific	Penr	94.70973	97.49242	96.02216	0.783669
Europe & Central Asia	Penr	96.64809	97.97246	97.20874	0.375388
Latin America & Caribbean	Penr	93.97533	96.11617	95.16358	0.651166
Middle East & North Africa	Penr	84.58186	95.74418	92.07207	3.265788
North America	Penr	93.32284	97.82759	95.78219	1.37459
South Asia	Penr	79.41564	93.53793	88.8121	5.259682
Sub-Saharan Africa	Penr	60.23151	78.76731	71.45812	6.23957
East Asia & Pacific	Emp	66.60179	70.47947	67.82913	1.309118
Europe & Central Asia	Emp	51.95744	54.00197	52.79076	0.662342
Latin America & Caribbean	Emp	57.18912	61.01698	59.55151	1.382647
Middle East & North Africa	Emp	40.87347	43.44304	42.40821	0.875157
North America	Emp	57.87441	63.48531	60.56931	2.00315
South Asia	Emp	52.75673	57.70488	55.59744	1.933637
Sub-Saharan Africa	Emp	63.03895	64.18782	63.51463	0.317907
East Asia & Pacific	Life	71.58823	75.10255	73.60058	1.113696
Europe & Central Asia	Life	73.06551	77.20708	75.00006	1.397519
Latin America & Caribbean	Life	71.49049	75.06372	73.38391	1.132068
Middle East & North Africa	Life	69.80253	73.12388	71.55991	1.060926
North America	Life	76.89243	79.06415	78.13341	0.771975
South Asia	Life	62.87669	68.20917	65.62335	1.731259
Sub-Saharan Africa	Life	50.5125	59.39988	54.72765	3.038752
East Asia & Pacific	Seced	65.7937	77.17284	70.1338	3.091131
Europe & Central Asia	Seced	84.00036	90.34275	86.80438	1.706013
Latin America & Caribbean	Seced	65.4912	75.85851	70.15757	3.420344
Middle East & North Africa	Seced	61.18883	72.50917	66.57835	3.579315
North America	Seced	85.77491	90.84785	88.77106	1.440048
South Asia	Seced	39.18943	58.47898	48.54108	6.665451
Sub-Saharan Africa	Seced	20.70127	33.37505	27.47901	4.498501
East Asia & Pacific	Lforce	69.62429	73.88811	71.04965	1.496754
Europe & Central Asia	Lforce	57.08402	58.59619	57.8538	0.538534
Latin America & Caribbean	Lforce	64.19136	65.85046	65.20142	0.526923
Middle East & North Africa	Lforce	47.02069	48.91485	47.93266	0.556629
North America	Lforce	62.59666	66.32353	64.73194	1.18087
South Asia	Lforce	54.88391	60.56274	58.03248	2.145766
Sub-Saharan Africa	Lforce	68.6984	69.15908	68.97462	0.118162

$Penr$ = Enrolment in primary education; $Seced$ = Enrolment in Secondary education; Emp = Proportion of population employed (aged 15+) (%); $Force$ = Proportion of population in labour force (%); $Life$ = Life expectancy at birth

Table B.2: Descriptive summary of variables for female population - Regional

Region	Variables	Min	Max	Mean	Std. Dev
East Asia & Pacific	Penr	94.40989	97.3136	95.9496	0.895708
Europe & Central Asia	Penr	96.25444	97.57091	97.01695	0.363073
Latin America & Caribbean	Penr	94.19831	95.81923	95.21477	0.532993
Middle East & North Africa	Penr	81.11229	94.07565	89.77274	3.916682
North America	Penr	93.19438	98.17882	96.32025	1.520859
South Asia	Penr	71.97429	92.97762	86.57702	7.72684
Sub-Saharan Africa	Penr	56.56621	76.7036	68.66488	6.736962
East Asia & Pacific	Emp	58.69448	62.68852	59.9281	1.342498
Europe & Central Asia	Emp	43.45402	46.28131	45.16522	1.005879
Latin America & Caribbean	Emp	41.46642	48.46844	45.64545	2.280502
Middle East & North Africa	Emp	14.89863	17.31208	16.35212	0.804372
North America	Emp	52.69926	56.43174	54.67212	1.388139
South Asia	Emp	27.45733	34.54018	31.29529	2.815029
Sub-Saharan Africa	Emp	55.29557	57.4143	56.4847	0.641272
East Asia & Pacific	Life	73.78508	77.2454	75.75224	1.110558
Europe & Central Asia	Life	77.1801	80.70016	78.8303	1.184995
Latin America & Caribbean	Life	74.82784	78.3369	76.7095	1.1091
Middle East & North Africa	Life	71.52769	74.94696	73.38897	1.101607
North America	Life	79.55436	81.47912	80.67448	0.676939
South Asia	Life	63.73018	69.71367	66.71866	1.950558
Sub-Saharan Africa	Life	52.03801	61.09384	56.21782	3.111796
East Asia & Pacific	Seced	63.68071	78.88088	70.63722	4.211724
Europe & Central Asia	Seced	83.91965	90	86.7623	1.666387
Latin America & Caribbean	Seced	67.65878	78.00299	72.697	3.407037
Middle East & North Africa	Seced	58.04208	70.2738	63.96674	3.894752
North America	Seced	85.98243	92.05659	89.75258	1.635444
South Asia	Seced	33.66145	58.18392	45.66998	8.217383
Sub-Saharan Africa	Seced	18.8675	31.30706	25.23268	4.453563
East Asia & Pacific	Lforce	61.04177	65.4029	62.5149	1.533437
Europe & Central Asia	Lforce	48.22509	50.81219	49.57187	0.877788
Latin America & Caribbean	Lforce	48.10113	52.63633	51.16004	1.434696
Middle East & North Africa	Lforce	19.0709	21.30147	20.41483	0.764705
North America	Lforce	56.6377	59.01982	58.23811	0.792361
South Asia	Lforce	28.82714	36.62291	32.88383	2.966661
Sub-Saharan Africa	Lforce	61.11045	62.59617	62.12713	0.425884

$Penr$ = Enrolment in primary education; $Seced$ = Enrolment in Secondary education; Emp = Proportion of population employed (aged 15+) (%); $Force$ = Proportion of population in labour force (%); $Life$ = Life expectancy at birth

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