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Environmental Leapfrogging in Kenya:

The Role of Human Capital, Wealth and Institutions for the Adoption of Solar Energy

by

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Abstract: While developing countries are faced with pressing socio-economic challenges, they are also increasingly vulnerable to the impacts of environmental degradation. Starting from this double challenge, current research has been focusing on the synergies between economic development and environmental protection. Within the field, the concept of environmental leapfrogging has emerged, referring to the possibility for developing countries to skip the dirty stages of development of the early industrializers by leapfrogging to the adoption of clean technologies. This thesis analyses the case study of the adoption of solar energy in Kenya, which, by contributing to doubling the electrification rate of the country, represents a successful case of environmental leapfrogging. Specifically, the thesis investigates the effect of human capital, wealth and the institutional environment on the adoption of solar energy in the past two decades in Kenya. Using the Kenya Integrated Household Budget Surveys of 2005/06 and 2015/16, the thesis finds a statistically significant association between the level of human capital and the adoption of solar energy, while it does not find it for wealth. Additionally, a qualitative analysis reveals the importance of the institutional environment as a driving factor for the adoption of solar energy. The results highlight the importance of investing in human capital development and creating an institutional environment conducive to sustainable development.

Keywords: Environmental Leapfrogging, Sustainable Development, Human Capital, Institutional Environment, Solar Energy, Kenya

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“*Conventional wisdom states that economic growth should be roughly proportional to increasing consumption of raw materials and energy. But if this relationship was to hold for many more decades, the consequences would be disastrous. There is thus a basic potential conflict between environmental well-being and economic development*”

(Goldemberg, 1998, p.730)

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List of Abbreviations

ASAL	Arid and Semi-Arid Lands
BLUE	Best Linear Unbiased Estimator
CBS	Central Bureau of Statistics
DRE	Decentralized Renewable Energy
EKC	Environmental Kuznets Curve
FIT	Feed-in-Tariff
FPE	Feminist Political Ecology
ERC	Energy Regulatory Commission
GCP	Gross County Product
GDP	Gross Domestic Product
HDI	Human Development Index
ICT	Information and Communication Technology
IEA	International Energy Agency
IPP	Independent Power Producers
IRENA	International Renewable Energy Agency
ISIC	International Standard Industrial Classification of all Economic Activities
KANU	Kenya African National Union
KIHBS	Kenya Integrated Household Budget Survey
KNBS	Kenya National Bureau of Statistics
LSMS	Living Standard Measurement Survey
NAFTA	North American Free Trade Agreement
OECD	Organization for Economic Cooperation and Development
OLS	Ordinary Least Squares
OWD	Our World in Data

PAYG	Pay-as-you-go
PV	Photovoltaics
RCRC CC	Red Cross Red Crescent Climate Centre
R&D	Research and Development
REA	Rural Electrification Authority
REP	Rural Electrification Programme
RERAC	Renewable Energy Resources Advisory Committee
REREC	Renewable Energy Corporation
RSS	Residual Sum of Squares
SDG	Sustainable Development Goals
SHS	Solar Home Systems
SSA	Sub-Saharan Africa
S&T	Science and Technology
UN	United Nations
UNDP	United Nations Development Programme
UNIDO	United Nations Industrial Development Organization
VAT	Value Added Tax
WB	World Bank

1 Introduction

"Since the Industrial Revolution, the world economy has grown at the expense of the environment" (Altenburg & Rodrik, 2017, p.5). The path of the early industrializers can no longer be emulated by today's developing countries. The approach of "growing first and cleaning up later" is not a plausible option because it ignores the irreversibility of some environmental damages and their consequent impairment of future economic development (Fay, 2012). Besides, it is economically inefficient given that the costs of switching to sustainable consumption patterns later are higher when countries are already locked into a well-developed infrastructure and institutional system built on unsustainable practices (Altenburg & Rodrik, 2017). In this sense, developing countries have the advantage of allocating their investments directly to sustainable infrastructure (Altenburg & Rodrik, 2017).

Improvements in energy efficiency, which refers to a reduction in the amount of energy needed to produce the same unit of output, were accelerated by the 1973 oil crisis (International Energy Agency [IEA] & Organization for Economic Cooperation and Development [OECD], 2004). Yet, this is a necessary but not sufficient condition to offset the effects of building modern industrial infrastructure, far-reaching transportation systems and the urbanization trends that the economic development of countries involves (Goldemberg, 1998). Therefore, while low-income countries are faced with pressing socio-economic challenges, they cannot afford to follow a growth path as the one undertaken by the early industrializers, disregarding the planetary limits (OECD, 2012). Starting from this double challenge, research is increasingly focusing on the potential synergies between economic development and environmental protection (Pedercini et al. 2019).

Within the field, the concept of environmental leapfrogging has emerged. This refers to the possibility for developing countries to avoid adopting the dirty technologies of past industrializers and to leapfrog to the clean ones (Perkins, 2003). An example of this is leapfrogging to the adoption of renewable energies. The deployment of solar photovoltaics (PV) in developing countries can strongly benefit rural communities, that often lack access to electricity or use unhealthy and unsustainable lighting methods, such as firewood or kerosene lamps (Goldemberg, 1998; Murphy, 2001). However, there is no consensus yet in the literature on whether energy leapfrogging is possible, given that renewable energies are not yet commercialized on a large-scale in industrialized economies (Unruh & Carrillo-Hermosilla, 2006). However, among those who argue that it is possible, there is agreement that a set of conditions needs to be met. Goldemberg's words (1998) sum this up: "such 'hard' technologies can only be successfully absorbed and developed if complementary 'soft' technologies […] are in place" (739). Three factors stand out among the most cited driving factors of environmental leapfrogging: 1) human capital, namely the capacity to absorb the new technologies; 2) wealth, i.e. the capacity to afford the new technology; 3) the institutional environment, which refers to the enabling incentive structure that stimulates the adoption of a new technology (El Fadel et al., 2013; Fay, 2012; Gallagher, 2006; OECD, 2012; Sauter & Watson, 2008; Simelane & Abdel-Rahman, 2011).

Zooming on the case of solar PV, between 2009 and 2019 the prices declined by 89 percent (Our World in Data [OWD], 2020). The question is then "why the solar revolution has failed to take off in a significant way in Africa" (Amankwah-Amoah, 2015, p.16). This is particularly surprising in the context of Sub-Saharan Africa, where the rate of rural electrification in 2020 still stands at 28.7 percent (World Bank Data, 2022a). It is within this context that it becomes urgent to understand what are the factors that have contributed to the adoption of solar energy in Kenya, a leader in solar rural electrification in Africa (IEA, 2019). While some scholars have analysed what has been the cause of such success, the body of literature has in large part used qualitative methods. Furthermore, studies that have analysed it from a quantitative perspective have used data not more recent than 2005 (Lay, Ondraczek & Stoever, 2013), when the prices of solar PV were still not competitive and its adoption was therefore rather limited. Emerging from this research gap, the following research question has been formulated:

To what extent have human capital, wealth and the institutional environment been associated with the adoption of solar energy by Kenyan households in the past two decades?

1.1 Aim and Scope

The purpose of the research is to contribute to the understanding of the driving factors of environmental leapfrogging. More specifically, the research focuses on the case of Kenya which, thanks to the adoption of solar PV, has managed to almost triple its electrification rate in only a decade (World Bank Data, 2022b). The aim is thus to understand to what extent human capital, wealth and the institutional environment have been related to the adoption of solar energy by Kenyan households in the past two decades. This contributes and expands the current literature on whether and how it is possible to undertake a process of economic development that is also environmentally sustainable. In fact, despite being one of the biggest challenges of our time, there is a concerning gap regarding the concrete policies that would enable to combine socio-economic development objectives with the protection of the environment. While the issues of climate change and environmental degradation are increasingly on the agenda of industrialized countries, little focus is dedicated to developing countries which will soon be the source of increasing global CO^2 emissions, as the case of China exemplifies (OWD, 2020).

More specifically, the focus on human capital, wealth and the institutional environment is a crucial area of study, given that these represent factors that are usually lacking in developing countries. As a matter of fact, while skills and capital are required for the adoption of green technologies, the comparative advantage of developing countries lies in neither of them, but rather in a large supply of cheap unskilled labour (Rodrik, 2014). Likewise, while an enabling regulatory environment is needed to channel investments to the development of both the educational and the financial system, this is often lacking in pre-industrial societies (Kizilcec & Parikh, 2020).

Understanding the driving factors of solar electrification in Kenya has a direct social impact on similar contexts that are characterized by low access to electricity, a crucial obstacle to education and economic activities. While solar PV represents an adequate solution to electrification in decentralized remote areas, where connecting to an electric grid would require a large amount of capital, two thirds of the African rural population still lack access to electricity (World Bank Data, 2022a). It is therefore urgent to understand what are the policies that enable to accelerate electrification, which in turn increases information, education, economic activity, entertainment and connectivity (Rahut et al., 2018), thus contributing to a process of poverty reduction that avoids environmental degradation.

1.2 Outline of the Thesis

The thesis is structured along eight sections. After the introduction, Section 2 digs into the theory that guides the research question, analysing the concept of environmental leapfrogging, its emergence and its challenges. Section 3 provides some context on the case study of Kenya, in order to inform the reader about the structure of the economy, the state of its energy transition and the current development of solar energy in the country. Section 4 reviews the literature on the topic, highlighting where the research frontier stands and how this thesis contributes to it. Section 5 presents the data sources of the analysis, both quantitative and qualitative together with their respective limitations. Section 6 presents the mixed methods approach, introduces the variables included in the analysis and the models. Section 7 presents the results of the analysis and discusses them in relation to the theory. Finally, Section 8 provides an analytical conclusion, draws practical implications and highlights further areas of research.

2 Theoretical Approach

While the term “sustainable” applied to ecosystems goes back a long way, the concept of “sustainable development” emerged for the first time in the Brundtland Report of 1987 *Our Common Future*, defined as development that “meets the needs of the present without compromising the ability of future generations to meet their own needs” (Harlem, 1987, p.16). Two years later, the International Society for Ecological Economics was founded, signalling the emergence of a new strand of the economic discipline that considers the economy and the environment as a joint interdependent system that needs to be analysed through a transdisciplinary approach (Common & Stagl 2005, p.4).

However, the environmental factor was already reintroduced in the economic discipline in the 1970s, when neoclassical economics was challenged by the emergence of environmental economics and natural resources economics. During the same period, in 1972 the United Nations (UN) Conference on Human Environment was held in Stockholm, emphasizing for the very first time the importance of including the environment in the development agenda (Rogers et al. 2008, p.9). Fifty years have passed since then, and yet we are far from mainstreaming the environment in the development discipline. While the adoption of Agenda 2030 Sustainable Development Goals (SDGs) has attracted much attention, these are targets often void of practical policy recommendations of how developing countries can reach them jointly (Hickel, 2019).

2.1 The Environmental Kuznets Curve

The question of how countries can develop sustainably, by ensuring both poverty reduction and environmental protection, was answered by the proposition of a simple and reassuring solution in the 1990s: continuous economic growth will eventually be the means to environmental improvement (Stern, 2004). With a study on the effect of the North American Free Trade Agreement (NAFTA) on pollution in Mexico and the surrounding area, Grossman and Krueger

(1991) introduced the idea that "environmental degradation and income have an inverted U-shaped relationship, with pollution increasing with income at low levels of income and decreasing with income at high levels of income" (Grossman & Krueger 1995, p.2). Such view was soon adopted by the World Bank (1992) and renamed as the Environmental Kuznets Curve (EKC), given the analogous U-shaped relationship between inequality and economic growth advanced by Kuznets (1955) some decades before (Panayotou, 1993). In line with this, the United Nations Industrial Development Organization (UNIDO) report of 2011 attributes the current decline in global energy intensity to the reaching of a turning point, where high income economies have undergone structural shifts from industrial to service economies, following a natural "dematerialisation of the economy", determined by shifts to more capital-, skills- and technology-intensive sectors (UNIDO, 2011).

However, the evidence proving the existence of the EKC on a systematic level is debated. First, contrary to the UNIDO 2011 Report, Henriques and Kander (2010) and Kander et al. (2013, p.434) argue that the recent reduction in energy intensity is due to developments in Information and Communication Technology (ICT), which substantially improved the energy efficiency of capital, and more specifically machinery. Furthermore, Henriques and Kander (2010) point out that even when only post-industrial economies are considered, only Germany and the United Kingdom show an inverted U-shaped EKC curve. Nevertheless, even if the transition to service economies was truly responsible for the reduction of environmental degradation, the EKC disregards the effect of emissions outsourcing and thus presents a logical problem: "in our finite world the poor countries of today would be unable to find further countries from which to import resource-intensive products as they, themselves, become wealthy" (Stern 2004, p.1427).

Additionally, the EKC has never been demonstrated to be applicable to all environmental impacts, rather has been limited to the analysis of local problems, such as air and water pollution, with less relevance for global environmental issues, such as global warming (Fay, 2012; Stern, 2004). Finally, what is completely disregarded by the model is the effect of environmental damage on economic production (Stern, 2004). The argument of "grow now and clean up later" ignores the fact that some environmental damages are irreversible and thus inevitably undermine the possibility of future economic development (Altenburg & Rodrik, 2017; Fay, 2012; Pezzey & Burke, 2014).

2.2 Environmental Leapfrogging and Its Challenges

Given the multiple issues identified above of the EKC "grow now clean up later" approach, the concept of environmental leapfrogging has recently emerged in the literature (Goldemberg, 1998). This refers to the argument that "developing countries [do not] need [to] adopt the dirty technologies of the past. Rather, they might well be able to 'leapfrog' over them, opting instead for modern, clean technologies" (Perkins 2003, p.177) (Figure 1).

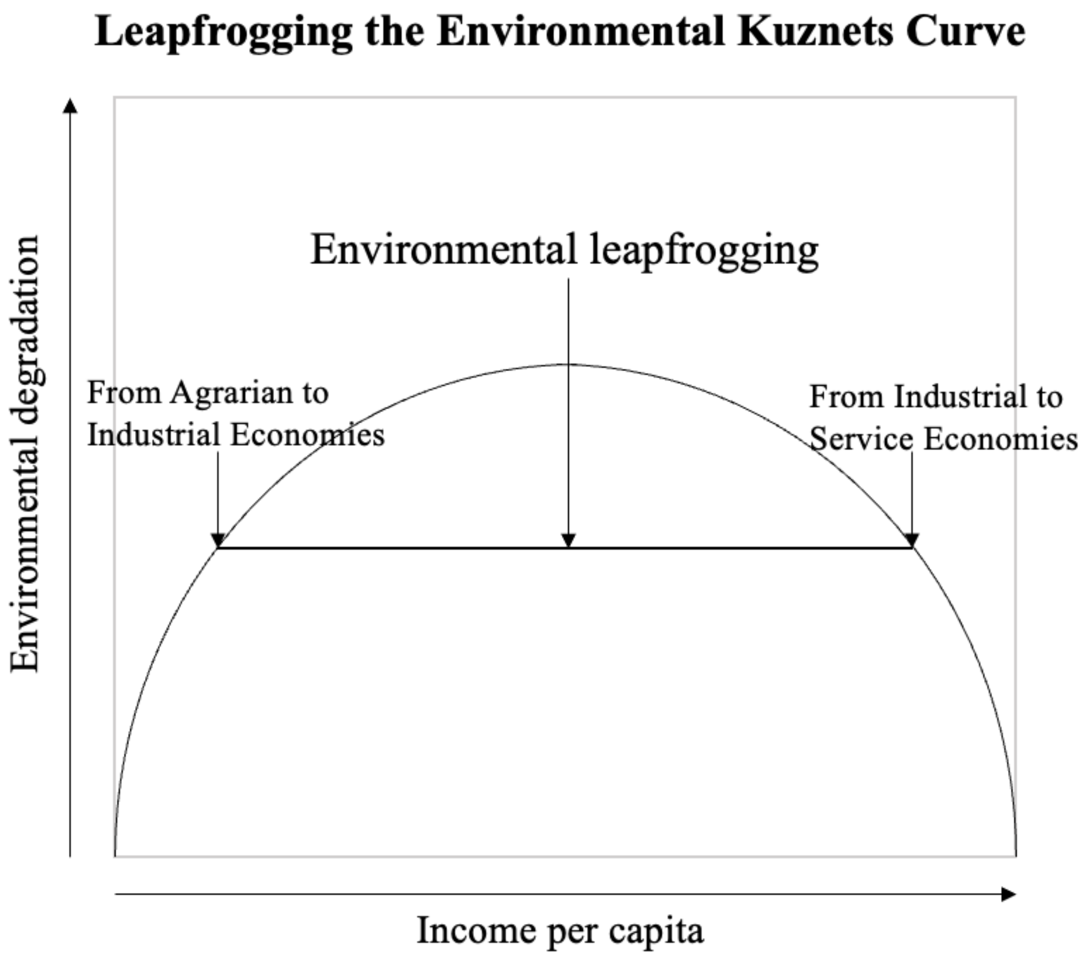


Figure 1. Visual representation of environmental leapfrogging, based on Goldemberg (2011) – Author's own elaboration

The possibility that developing countries can skip the dirty development stages of industrialized countries deserves serious attention for a number of reasons. First, as aforementioned, this may be the only way possible for countries today to become affluent, given that the usual growth path if undertaken by today's developing countries would most likely cause irreversible environmental damages, from which there is simply no way out (Fay, 2012; Intergovernmental Panel on Climate Change, 2022).

Second, the costs of adopting clean technologies straight away are much lower than switching to them later (Altenburg & Rodrik, 2017; OECD, 2012; Smil, 2016). This is explained by what Unruh (2000) defined as a situation of “carbon lock-in”, referring to the path-dependent infrastructural and institutional lock-in that makes it extremely challenging for industrialized countries to undertake the next energy transition. Having a well-developed institutional and infrastructure system makes it costly and lengthy to replace it with another one (Sovacool, 2016; Unruh, 2000). Technologies should not be treated as single replaceable items, but rather as part of larger interdependent systems, whose social, economic, technological and institutional aspects are constantly reinforced by positive feedbacks mechanisms (Unruh, 2000).

However, there is no consensus in the literature about whether and how is it possible for developing countries to leapfrog to the adoption of clean technologies. Unruh & Carrillo-Hermosilla (2006) argue that while developing countries are not locked-in yet in the techno-institutional complex described above, they are unlikely to leapfrog given the current state of art. While analogies with successes of technological leapfrogging with mobile phones, for instance, have happened when the new technologies were already developed on a large-scale in affluent countries, renewable energies “have not yet experienced large-scale adoption or commercialization and are a long way from becoming mature commodity products” (Unruh & Carrillo-Hermosilla 2006, p.1187). On the contrary, drawing from historical experiences in Latin America, Rubio and Folchi (2012) provide evidence that countries such as Costa Rica, with lower energy consumption levels, have undertaken earlier and faster energy transitions than more advanced economies. They conclude, in fact, that the replacement cost of factories and machines is the biggest obstacle of switching to different sources of energy (Rubio & Folchi, 2012).

Finally, among those who believe it is possible to leapfrog to renewable energies, there is consensus across the literature that a set of conditions needs to be fulfilled in order to be able to do so. Three of the main requirements most commonly identified are 1) the role of human capital, 2) the role of wealth and 3) the role of an enabling institutional environment (El Fadel et al., 2013; Fay, 2012; Gallagher, 2006; OECD, 2012; Sauter & Watson, 2008; Simelane & Abdel-Rahman, 2011).

2.2.1 The Role of Human Capital

There is general consensus (El Fadel et al., 2013; Fay, 2012; Gallagher, 2006; OECD, 2012; Simelane & Abdel-Rahman, 2011) that a "sufficient level of absorptive capacity – i.e. the ability to adopt new technologies – is a core condition for successful leapfrogging. This capacity includes technological capabilities, knowledge and skills, as well as supportive institutions" (Sauter & Watson 2008, p.3). Technological capabilities refer to the ability to maintain and operate clean technologies (Sauter & Watson, 2008). In this regard, Simelane and Abdel-Rahman claim that it is "poor technical and imported equipment maintenance skills and after-sales service in Africa [that] affect the development of all renewable technologies" (2011, p.84). This is crucial in order to ensure the long-term sustainability of newly installed energy systems, and avoid their abandonment after the short-term.

Human capital development is needed at all levels, from policy-makers to scientists to entrepreneurs to end-users (OECD, 2012; Sauter & Watson, 2008; Simelane & Abdel-Rahman, 2011). The development of the educational system should therefore be broad-based, including professional education and trainings, such as universities, as well as technical and vocational trainings programmes (OECD, 2012; Simelane & Abdel-Rahman, 2011). Additionally, knowledge exchange should be encouraged outside of the formal educational system through good practices dissemination, such as workshops, exchange visits and community demonstrations (Simelane & Abdel-Rahman 2011; El Fadel et al. 2013). In fact, while technologies can be easily transferred, the capabilities to manage them cannot (Perkins, 2003). To conclude, broad-based human capital investment from the government tailored to the new renewable technologies is considered as a necessary prerequisite for a country to leapfrog to the adoption of such technologies.

2.2.2 The Role of Wealth

Next to the need to scale-up the skilled workforce, an important requirement identified in the literature is the need to develop the financial system, in order to unlock the necessary risk capital for the high initial investments needed for renewable energies (Fay, 2012; Sauter & Watson, 2008; Simelane & Abdel-Rahman, 2011). While the costs of renewable energies, such as solar PV, have declined by as much as 80 percent (OWD, 2020) and their maintenance presents low costs, high up-front investment costs remain a challenge for less affluent households compared to conventional energy (Simelane & Abdel-Rahman 2011; El Fadel et al. 2013). This needs particular attention, given that developing countries are, on average, characterised by a lack of capital. In fact, together with the requirement of skills development, the financial system development is a particularly challenging condition for developing countries, whose comparative advantage is naturally the opposite of skills and capital and rather lies in the large unskilled labour force (Rodrik, 2014). In relation to this, an enabling institutional environment is crucial to both channel funds to human capital development and to make the new technologies affordable.

2.2.3 The Role of the Institutional Environment

As defined by North, “institutions are the humanly devised constraints that structure political, economic and social interaction. […] Institutions provide the incentive structure of an economy” (1991, p.97). In the case of renewable energies in developing countries, institutions are crucial to create the enabling environment for investment and innovation in the technologies of interest. A comprehensive framework of policies, regulations, subsidies, tax credits and certificates is necessary for renewable energies investments even in affluent countries, given that they have not yet been adopted on a large scale at the global level (Sauter & Watson, 2008; Simelane & Abdel-Rahman, 2011)

Furthermore, a set of institutional organisations, ranging from specialized local and national authorities to universities and research centres are needed in order to build the so-called “national system of innovation” (Perkins, 2003; Sauter & Watson, 2008). Broadly advocated for in the technological upgrading literature, this refers to a network that enables systemic relationships between public policy, firms and knowledge institutions, such as Research and Development (R&D) and Science and Technology (S&T) organizations, including universities (Johnson, Edquist & Lundvall, 2004). In conclusion, a strong regulatory framework that facilitates and encourages investments in renewable energies, as well as the complementary educational system development and technology and skills transfers is deemed as the necessary incentive structure for environmental leapfrogging in developing countries.

3 Kenya: Country Profile

Located on the eastern cost of Africa, Kenya shares borders with Somalia, Ethiopia, South Sudan, Uganda and Tanzania. It is classified as a lower-middle income country (Kimenyi et al. 2016) and it is the sixth largest economy in Africa in terms of GDP (Statista, 2021). In line with the "Africa Rising" narrative (The Economist, 2011), Kenya has experienced substantial economic growth in the past two decades, reaching a GDP per capita of 1,912.648 current US$ in 2019 (World Bank Data, 2022c). At the same time, its Human Development Index (HDI) increased from 0.482 in 1990 to 0.601 in 2019 (United Nations Development Programme [UNDP], 2020). With access to the seaside, Kenya holds a strategic position relative to five resource-rich landlocked neighbouring countries (Kimenyi et al. 2016). It also plays a leading role in ICT development, especially thanks to the successful large-scale adoption of mobile phone-based financial services, which helped to strengthen financial inclusion in the country (Kimenyi et al. 2016).

Kenya's economy was liberalized in the 1990s (Kimenyi et al. 2016). Its growth is still largely reliant on the agricultural sector, including an important share of pastoralist activity, while services and industry remain underdeveloped (African Development Bank, 2021). The agricultural sector accounts for 26 percent of GDP, provides the livelihood for 80 percent of the Kenyan population and accounts for 65 percent of the export earnings (Food and Agriculture Organization, 2022). Kenya's major agricultural exports are tea, coffee, cut flowers and vegetables (OEC, 2020). Furthermore, Kenya is an important producer of milk in Africa, given its large livestock sector, that spreads all the way to the arid and semi-arid lands of the country (Nyariki & Amwata, 2019). Finally, Kenya's labour force is dominated by the informal sector (Kimenyi et al. 2016).

Formerly part of the British empire, Kenya gained independence in 1963. Dominated for about 30 years by the Kenyan African National Union (KANU), Kenya was a one-party state until the 1990s, when it held its first multiparty elections (Ajulu, 2002). When compared to its neighbours the country presents a post-independence history of relative peace and stability, holding elections regularly and without resorting to military governments (Sayer, 2004).

Nevertheless, Kenya is characterized by a long history of ethnic violence that dates back to the colonial time (Ajulu, 2002), and more specifically to the “divide and rule” British strategy (Morrock, 1973). In this regard, Sayer writes: “the politicisation of ethnicity has a long history in Kenya. During the period of British rule, under the patronage of the colonial authorities, indigenous political activity was restricted to local rather than national interests” (2004, p.23). Ethnic conflict is then strongly reflected in regional inequalities, with uneven development across the country, dependent on the ethnicity of who holds power, consequently determining the distribution of resources (Ajulu, 2002).

The last ethnically-driven violence episode was sparked by the 2007 elections, following a dispute over flawed presidential vote count (Kanyinga & Long, 2012), which culminated into 1,300 deaths and 600,000 displaced (Kimenyi et al. 2016). Yet, this ended with a power-sharing agreement that later led to the promulgation of a new constitution. The Constitution of 2010 signals a leap forward for Kenya in terms of democracy and civil liberties. Countering the post-independence tendency of continuously increased concentration of power in the presidency, the new Constitution kick-started a process of devolution of power (Kanyinga & Long, 2012), besides introducing a bill of rights and a land reform (Government of the Republic of Kenya, 2010). Previously divided into eight provinces, the new administrative division of Kenya counts 47 counties (Government of the Republic of Kenya, 2010). Devolution has been considered as beneficial in Kenya because “it provides for individual counties to deliver specific services and also design policies to promote growth” (Kimenyi et al. 2016, p.26) tailored to the local context-specific needs.

3.1 Energy Transition in Kenya

According to the Notre Dame Global Adaptation Initiative, “Kenya is the 31st most vulnerable country and the 37th least ready country – meaning that it is very vulnerable to, yet unready to combat climate change effects” (Red Cross Red Crescent Climate Centre [RCRC CC], 2021, p.3). Particularly at risk are the Arid and Semi-Arid Lands (ASALs) in the northern part of the country, which constitute 80 percent of the national territory (RCRC CC, 2021). The effects of climate change are expected to increase and intensify the already frequent droughts and floods in these areas of the country (RCRC CC, 2021). Furthermore, despite the staggering progress of the past five years, about 30 percent of the country still lacks access to electricity (World

Bank Data, 2022b). The country is also still characterized by a large rural-urban divide, with 90.8 percent of the urban population having access to electricity in 2019, in contrast to a percentage of 61.7 of the rural population (World Bank Data, 2022b). A process of economic development that is also environmentally sustainable therefore results as the inevitable and most promising path for the country's poverty alleviation.

In the past two decades, Kenya has become a leading African country in the renewable energies sector which, as mentioned above, spilled over to major improvements in terms of access to electricity in the country, going from a rate of 20 percent in 2010 to over 70 percent in 2020 (World Bank Data, 2022b) (Figure 2).

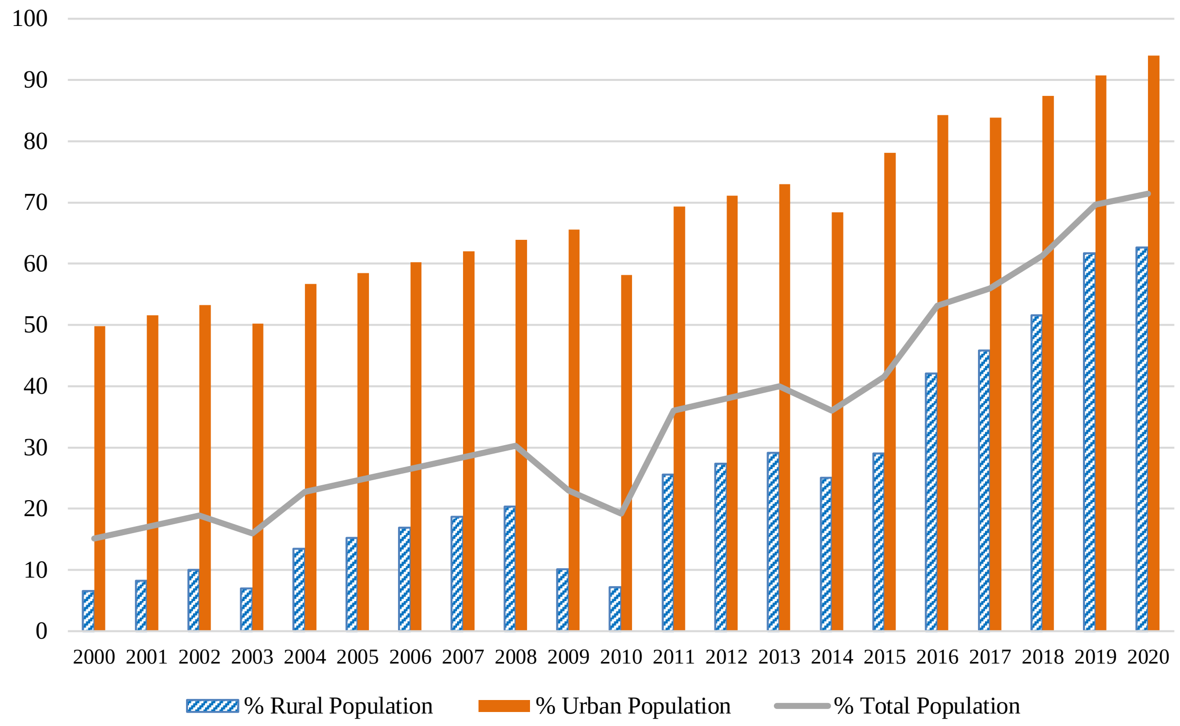


Figure 2. Access to Electricity in Kenya (% of Population) (World Bank Data, 2022b) – Author's own elaboration

In 2008, Kenya Vision 2030 was launched, with the aim of providing a long-term national plan that would transform Kenya into a "newly industrializing, upper middle-income country providing a high quality of life to all citizens by 2030 in a clean and secure environment" (Government of the Republic of Kenya, 2007). The Vision recognizes energy as the driver of all development activities, indicates a drop in prices due to big investments in renewables and includes sustainable waste management (Newell et al. 2014).

Kenya, together with South Africa, Morocco and Egypt, attracted 75 percent of all investments in renewables in Africa between 2010 and 2020 (International Renewable Energy Agency [IRENA], 2022). It is the largest geothermal producer in Africa (IRENA, 2019) and presents a large capacity in terms of hydropower (IRENA, 2022). However, Kenyan energy supply does not strongly rely on hydropower, and is even more unlikely to do so in the future, given the expected increasing frequency of droughts which will constrain water availability even further (Newell et al., 2014; RCRC CC, 2021). In addition to geothermal, a large share of Kenya's energy supply comes from bio-energy (IRENA, 2022): the majority of the urban poor and rural areas basic needs, such as cooking and heating, are met by biomass fuel, namely wood and charcoal (George et al. 2019). Finally, although they constitute a still very small part of the country's energy matrix, Kenya is a leading market in Africa in terms of solar and wind power (IEA, 2019). However, it is important to note that the recent discovery of oil bears the risk of offsetting the efforts of reducing the country's carbon footprint through electricity generation from renewables (Newell et al. 2014).

3.2 Solar Energy in Kenya

Kenya presents particularly favourable conditions for solar energy. Divided by the equator in almost two equal parts, it has abundant solar irradiance for most regions, reaching a peak of over 1000 W/m^2 (George et al. 2019). A majority of the regions have a tropical climate with a yearly average temperature of 22°C and with an average of 5-7 peak sun hours; the coast is hot and humid, the inland is moderate and the north is extremely dry (Takase et al. 2021). Taking advantage of this potential, Kenya is a leading African country in the deployment of solar energy (Amankwah-Amoah, 2015). Solar energy is seen as particularly beneficial in terms of rural electrification, which often implies decentralised application given the lack of connection to the grid in remote rural areas (Mokveld & von Eije, 2018). It is, in fact, the wide-spread deployment of off-grid energy systems that contributed to Kenya's striking electrification progress (IRENA, 2022).

In this regard, Mokveld and Eije write: "Kenya has become one of the best-served off-grid populations in the world, featuring some of the most advanced pay-as-you-go solar home system companies and innovative business models for mini-grid development" (2018, p.6). Solar home systems (SHS) are energy systems that convert solar energy into electricity through a PV module. The electricity can be used instantly or stored for later use in various appliances, such as lighting during the night hours, television, radio and phone charging, thus contributing to an increase in entertainment, information and communication (George et al. 2019). Alternatively, the most common sources of light are kerosene (or paraffin) lamps and firewood, both detrimental in terms of deforestation and indoor pollution, which have negative environmental and health effects (Kimutai, 2019).

The development of the Kenyan SHS market in the past decade has occurred also thanks to the advanced development of the mobile payment industry, which in Kenya counts a percentage of 96 adult population with access to mobile money (Mokveld & von Eije, 2018). Mobile-based payments are a crucial development, especially in lower income countries, because they enable financial transactions also for those who do not have a formal bank account (Mokveld & von Eije, 2018). This was functional to the adoption of the Pay-as-you-go (PAYG) scheme (IRENA, 2022). PAYG refers to a system of purchasing SHS by households through monthly payments, instead of the full upfront investment (Mokveld & von Eije, 2018), substantially widening the accessibility of renewable electricity also to less affluent households.

4 Previous Research

Given the accelerating development of renewable energies, coupled with their decrease in prices (Figure 3), international organizations as well as academia are dedicating increasing attention to the possibility for developing countries to leapfrog to the adoption of clean technologies. A substantial number of publications are increasingly focused on the conditions that influence the adoption of renewable energies by governments, firms and households.

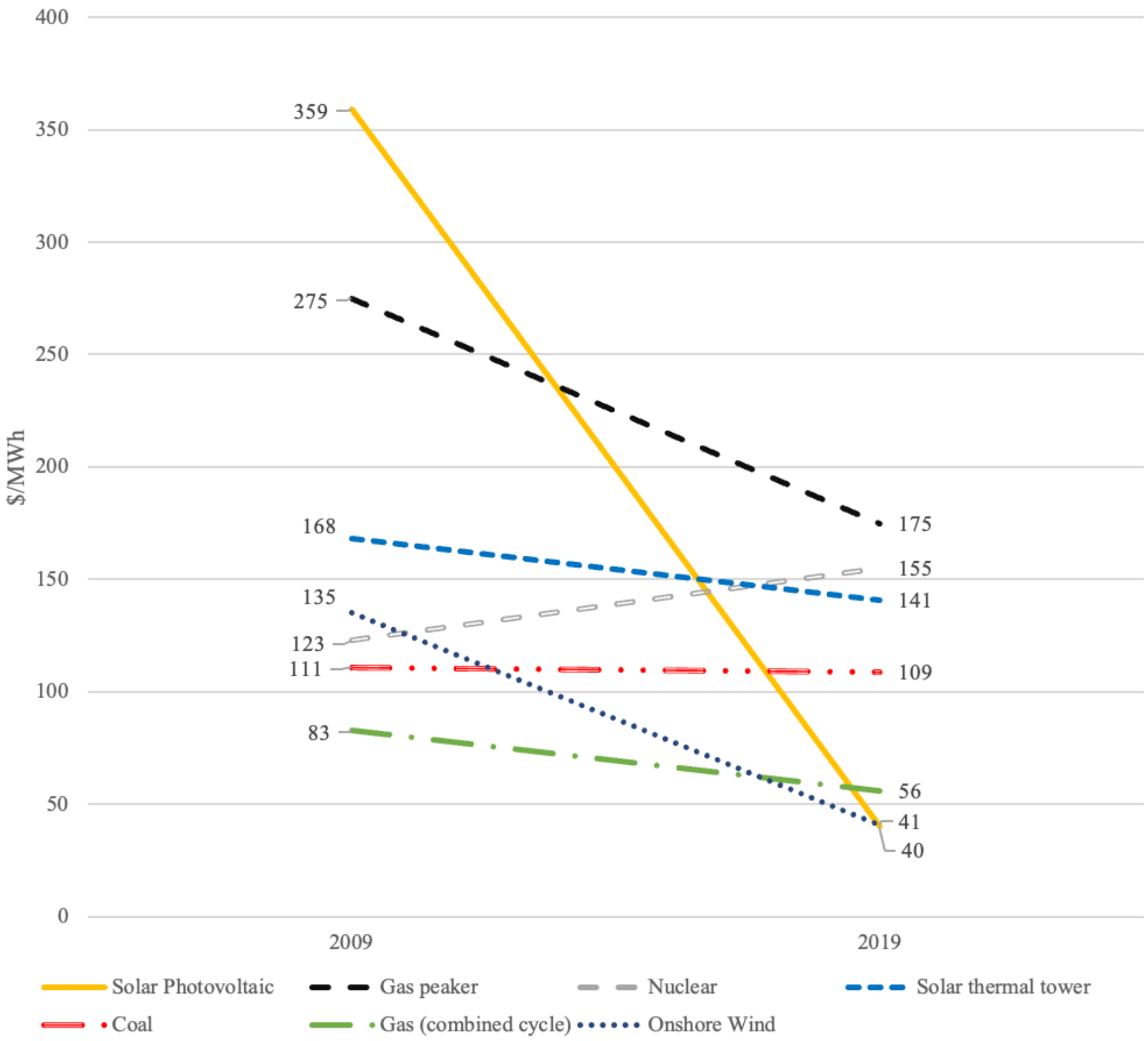


Figure 3. Price decline of electricity from renewable sources (OWD, 2020) – Author's own elaboration

4.1 Renewable Energy Adoption in the Developing World

Beyond the case study of Kenya, other African countries as well as emerging economies in other continents have been studied in relation to the adoption of solar or wind energy at the household and firm level. The findings differ to some extent. However, most studies point to the significance of the effects of education, affordability and the regulatory environment.

Human capital emerges as a common driving factor in studies on technology adoption in Sub-Saharan Africa (SSA). Using panel data from a sample of 45 SSA countries from 1960 to 2010, Danquah and Amankwah-Amoah (2017) find a statistically significant positive effect of human capital on the adoption of technology, while they find it insignificant on the level of innovation capacity. They highlight the novelty of their results, given that similar studies are often focused on industrialized countries, where the institutional enabling environment is already well-developed (Danquah & Amankwah-Amoah, 2017). In relation to this, Kizilcec and Parikh (2020) identify the need for more research on the institutional barriers of the adoption of SHSs in SSA. Simelane & Abdel-Rahman (2011) also emphasize the importance of human capital development in Africa for the adoption of renewable energy, listing a number of policy areas, such as financial and project management, maintenance of and repairs of renewable energy equipment, infrastructure and operations and monitoring and evaluations (Simelane & Abdel-Rahman, 2011). Finally, from a feminist political ecology (FPE) perspective, Ojong's (2021) findings indicate the relevance of gender and its intersections with age, geography and other inequalities in affecting the adoption of SHSs in SSA, resulting in the reinforcement of existing inequalities.

Several case studies on the adoption of solar energy have been carried out on the Eastern African region. Analysing a sample of two kebeles (districts) in the Oromia regional state in Ethiopia, Guta (2018) finds that wealthier and more educated households are more likely to adopt solar energy. Contrary to this, Ojong (2021) finds that male-headed households are less likely to adopt it, probably because of women being the usual responsible for households chores. With a study on the Uganda's National Electrification Survey of 2018, Aarakit et al. (2021) bring back to the attention the importance of affordability, which they found to be the main determinant of the adoption of solar PV type in Uganda, praising flexible payment mechanisms as a policy option to counter the trend. Besides the effects of income and education, Rahut et al. (2018) also find a significant effect of different demographic profiles, such as the household size and their composition. Their study is based on the Living Standard Measurement Survey (LSMS) of Ethiopia, Tanzania and Uganda (Rahut et al. 2018). Other studies on SSA countries with similar results on the effect of income and education include Ghana (Mensah & McWilson, 2021) or also lower income countries such as Zambia and Burkina Faso, besides Rwanda (Klein et al., 2015).

With similar results, studies on the topic include emerging economies from both Latin America and Asia. Rebane and Barham's (2011) study demonstrates the effect of knowledge, i.e. familiarity with the technology, on the adoption of SHSs in rural Nicaragua. Lewis (2007) studies the potential of technological leapfrogging, by analysing the development of wind turbines in China and India. She finds that, besides technology transfers, national innovation systems and learning networks are key facilitating elements of energy leapfrogging (Lewis, 2007). Another study on energy leapfrogging in China highlights the importance of technological capabilities for the adoption of advanced technologies (Gallagher, 2006).

4.2 Solar Energy Development in Kenya

Research on solar energy development in Kenya addresses a variety of aspects that range from the synergies of renewable energy deployment and socio-economic development to the role of the government, the effect on the environment, specific policies analyses, and the reasons for Kenya's solar market success compared to neighbouring countries. Synergies and trade-offs between the energy transition and economic development are addressed by Roche and Blanchard (2018), Pahle, Pachauri and Steinbacher (2016) and Pueyo (2015), among others. Roche and Blanchard (2018) paint a quite positive picture: drawing from the analysis of a solar centre in a rural village of Kenya, they conclude that renewable energy allows the community to develop economically, providing power to income-generating activities, basic lighting and mobile phone charging. On the other hand, Pahle, Pachauri and Steinbacher (2016) and Pueyo (2015) call for the need of government intervention embracing a pro-poor electrification strategy, addressing challenges such as affordability that currently reduce the potential of solar energy to actually reduce poverty.

This is in contrast with Ondraczek's (2013) study that mentions the private-led development of Kenyan solar market as a reason for its success, in contrast with the Tanzanian one, which has always been more dependent on government and donor support. Coupled with the historically higher inequality rate of Kenya compared to its neighbours, this allowed it to have a "vast number of rural middle and upper class households that proved important for the initial demand for solar power systems in Kenya" (Ondraczek, 2013, p.413). This is in line with some of the main findings of Hansen, Pedersen and Nygaard (2014) and Jacobson (2007) that indicate that the benefits of solar electrification are mostly captured by the rural middle class in Kenya, thus neither benefiting the elite nor the rural poor. Jacobson (2007) also points out that what the solar home systems are mostly producing is an increased use of television use, thus having a larger role on "connective" appliances, rather than education-related activities.

Other areas of study include analyses of the political economy and of the power actors in the renewable energy sector in Kenya (Newell et al., 2014) or of specific policies, such as the drivers and challenges of the Feed-in-Tariff introduced in 2008 (Ndiritu & Engola, 2020). Others point out technical challenges, such as the low product quality of solar systems as an obstacle to a sustainable development of solar energy in Kenya (Kammen & Jacobson, 2014); social and cultural challenges such as awareness of the health and environmental effects of traditional cooking and lighting fuels; and physical challenges, such as distance from the fuel market (Kimutai, 2019). Finally, Shirley et al. (2019) carry out the first analysis on the job creation potential of the decentralized renewable energy (DRE) sector in Kenya and Nigeria, looking again at synergies between economic and environmental SDG targets. Their results are promising, indicating that an already big workforce, both formal and informal, is finding employment in the DRE sector (Shirley et al., 2019). Yet, they also identify "many challenges for scaling the DRE sector, including access to a skilled workforce" (Shirley et al., 2019, p.3), which leads us to the discussion in the next section.

4.3 Solar Energy Adoption in Kenya

One of the pioneer studies that specifically focuses on the potential of environmental leapfrogging in rural Eastern Africa, by analysing households adoption of solar energy is the one from Murphy (2001). With a multidimensional perspective, he concludes that "the rural energy technologies […] face numerous capability limitations preventing their rapid dissemination in East Africa – technically, organizationally and institutionally" (Murphy, 2001, p.189). With "technically" he refers to the challenges of manufacturing, purchasing, operating and maintaining solar energy systems; with "organizationally" he indicates the dependence on external sources for funding and technical assistance; and with "institutionally" he refers to the social acceptability by households of adapting to a new solar technology (Murphy, 2001). A number of studies then later analysed one or more of these aspects from different angles and methodologies.

Social challenges in terms of public awareness have been identified by Adwek et al. (2020) and Opiyo (2019). Adwek et al. (2020) mention geographical distance from the local market and education as contributing factors to public awareness. Carrying out a survey in the Kendy Bay area of Kenya, Opiyo (2019) confirms the relevance of public awareness, by highlighting the influence of neighbouring households that have already adopted solar systems on the likelihood of adopting solar energy. Similarly, Gitone's (2014) policy implications point to raising awareness among those with a higher educational level, in order to increase adoption of solar energy. This follows his findings of a negative association between secondary and post-secondary education with the adoption of solar energy (Gitone, 2014). These findings are in contrast with most studies that identify higher educational level as being positively associated with the adoption of solar energy by rural households.

Adwek et al. (2020) indicate the importance of the institutional environment and affordability as determinants for the successful deployment of solar energy, indicating the PAYG system in Kenya as a tool to expand affordability to poor households. Through a literature review and expert interviews in Kenya, besides South Africa and Ghana, Adenle (2020) also reports that financial constraints, technical problems and weak government policy in all three countries are the major barriers in the solar energy market. These results recall those of George et al. literature review's main point, which is that "Kenya is still faced with a number of technical, regulatory, institutional and financial challenges in her quest to develop and deploy solar electrification" (2019, p.123). More specifically, they point out the high capital and installation costs of solar systems, the difficulty in accessing finance, the lack of decentralized energy policy, and the lack of local technicians with the adequate building and maintenance skills for solar infrastructure (George et al., 2019). Accordingly, Amankwah-Amoah's feature article on the challenges of technological leapfrogging in the solar sector, identifies the need to develop the necessary skills of local support, to address the high up-front costs and a facilitating institutional environment as the reasons for why “the solar revolution has failed to take off in a significant way in Africa” (2015, p.16).

Finally, Lay, Ondraczek and Stover’s (2013) research is the only quantitative study looking into these variables. Using the Kenya Integrated Household Budget Survey (KIHBS) of 2005/06, they carry out a multinomial logistic regression (Lay, Ondraczek & Stoever, 2013). They find income and education to be the key determinants of adoption of SHSs by households. In terms of income, their results are in line with Jacobson’s (2007) rural middle class being the main purchasing group. However, they acknowledge that “prices for SHS are much lower today than they were at the time of the survey, meaning that SHS have become more competitive alternatives to traditional and transitional fuels even without any government intervention” (Lay, Ondraczek & Stoever, 2013, p.358), and predict that this is likely to continue in the future, with the development of business models, such as the PAYG scheme.

This thesis adds to the literature by filling the gap of scarcity of quantitative studies on the drivers of adoption of solar energy by households in Kenya. It also contributes with the first cross-regional analysis on this matter, which has usually been analysed only using households as the unit of analysis. The use of regions as the unit of analysis results appropriate because of the large regional inequalities present in Kenya discussed in the country profile section, which make them fit for comparison. Furthermore, analysing the effect of education, wealth and the institutional environment on solar energy adoption is particularly relevant at this time, given that after the 2005/06 KIHBS, there has been the most significant institutional change in Kenya in terms of renewable energy promotion, which therefore needs to be analysed. As well, variables such as education and wealth, which have been consistently found to be relevant across the literature in the past years, need to be analysed again within the new institutional and regulatory framework of solar energy. Finally, the decline in prices of solar PV of the past decade (OWD, 2020) makes it relevant to carry out an updated analysis on the drivers of solar energy adoption. Therefore, the research aims at investigating to what extent have human capital, wealth and the institutional environment been associated with the adoption of solar energy by Kenyan households in the past two decades.

5 Data

The analysis uses both quantitative and qualitative data sources in a complementary way in order to answer the overarching research question. While the effect of human capital and wealth are studied using quantitative data, the analysis of the institutional environment is based on qualitative data. The body of data sources selected together with their strengths and weaknesses will be discussed in the following sections.

5.1 Quantitative Data

The analysis investigating the effects of education and wealth on the adoption of solar energy by Kenyan households is based on the two most recent Kenya Integrated Household Budget Surveys (KIHBS), of 2005/06 and of 2015/16. The KIHBS are designed to collect and update information on a range of socio-economic aspects which include education, health, energy, housing, water and sanitation, agriculture and livestock, expenditure and consumption among others (Central Bureau of Statistics [CBS], 2007; Kenya National Bureau of Statistics [KNBS], 2018). Additionally, they contribute to the national statistical database providing updated consumer price indexes, poverty and inequality indicators and the new national account information (CBS, 2007; KNBS, 2018).

The **KIHBS 2005/06** was the first integrated year-long household survey carried out in Kenya, signalling a substantial improvement in data collection in the country since the previous 1997 Welfare Monitoring Survey (WMS III) (CBS, 2007). The process of data collection lasted 12 months, starting in mid-May 2005 and covered all districts of Kenya (CBS, 2007). The survey consists of a total sample size of 13,430 households, of which 8,610 are rural and 4,820 are urban. The survey was coordinated by a national management team from the Central Bureau of Statistics (CBS) (CBS, 2007). The **KIHBS 2015/16** was funded by The Government of Kenya and the World Bank (WB) (KNBS, 2018). This was the second KIHBS, but the first to be collecting data on the 47 counties created by the 2010 Constitution that substituted the eight provinces and 70 districts (KNBS, 2018). The survey was conducted between May 2015 and September 2016 (KNBS, 2018). The sample size consists of 24,000 households, of which 14,120 rural and 9,880 urban (KNBS, 2018). The survey was coordinated by a steering committee from the renamed Kenya National Bureau of Statistics (KNBS) (KNBS, 2018).

The 2015/16 database is then complemented with data from the **Gross County Product 2019** (KNBS, 2019). The Gross County Product (GCP) is a geographic breakdown of Kenya's GDP that provides estimates of the size and structure of the counties' economies. As a response to the devolution of power that followed the 2010 Constitution and the creation of counties, this is the first publication of this kind and covers estimates from 2013, when the counties started operating, up to 2017. This is also supported by the KNBS and the WB (KNBS, 2019).

5.2 Qualitative Data

Qualitative data are used to analyse the influence of the institutional environment on the adoption of solar energy. The reason for this part of the analysis being qualitative is that, while the quantitative analysis uses regions (districts first and counties later) as the unit of analysis, policies and institutions regulating the energy sector are national, and therefore no regional data could be analysed quantitatively for the purpose of this analysis. Furthermore, the use of qualitative data is particularly beneficial for the analysis of complex topics, such as the study of institutions and their interactions, that require a holistic account to allow the researcher to avoid oversimplifying them (Creswell, 2014, p.235).

Related to this, it is particularly challenging to measure institutional environments and institutional quality in a quantitative way. In fact, despite the existence of various indicators, it is often not clear what they measure and they tend to miss out the complete picture, by prioritizing one aspect over others, such as the level of corruption, the ease of doing business or property rights enforcement (Samadi & Alipourian, 2021, pp.143–144). The qualitative data consist of both primary and secondary data. Primary data include policy documents, regulations, plans and visions related to the energy sector. Secondary data include reports by research institutes and international organizations, as well as academic articles analysing the regulatory and institutional environment of the Kenyan solar energy sector.

5.3 Limitations

The data limitations are analysed in terms of reliability, representativity and validity. Reliability refers to the consistency of measurement of the data across observations and across time, which determines whether a replication of the analysis would be likely to produce the same results (Creswell, 2014, p.295). Although the quantitative data are secondary data, they can still be considered strong in terms of reliability, given that they have been collected by the same official institute, which contributes to high consistency across measurements. Additionally, even though the data for the 2015/16 analysis are collected from two different datasets, namely from the KIHBS 2015/16 and the GCP 2019, they do not threaten consistency across time, given that the GGP 2019 presents yearly county data of most of the variables selected for the analysis. However, a limitation in this regard is still present, given that the county data on agriculture, manufacturing and services value added are only available for 2017, not exactly matching the time-frame of the KIHBS 2015/16. The qualitative data are gathered from different sources, thus possibly representing a weakness in terms of consistency across the data, but also representing a strength in terms of triangulation.

Representativity refers to whether the sample is generalizable to the population (Creswell, 2014, p.204). As mentioned above, the quantitative data cover a sample, randomly selected, of over 10,000 households in 2005 and over 20,000 households in 2015 (Central Bureau of Statistics, 2007; Kenya National Bureau of Statistics, 2018), which can be considered as a fairly large sample. However, in terms of time-frame, the only years covered by the surveys are 2005 and 2015, therefore presenting limitations in terms of representativeness during time. In this regard, further research should be carried out to investigate the drivers of solar energy adoption with time-series analyses. The reason for the choice of a cross-sectional analysis was due to data availability constraints, given that regional data for the variables of interest are only available for the two years chosen. However, the two years represent two very different points in time in terms of solar energy development in the country, which contributes towards higher representativity. The qualitative data do not show weaknesses in terms of representativity, given that all available and relevant policy documents and institutional developments regarding the solar energy sector are analysed.

In research methods, validity is sub-divided into internal and external validity. Internal validity refers to the ability to draw correct relationships and causal inferences about the findings

(Creswell, 2014, p.223). External validity refers to the generalizability of the analysis and therefore to whether the findings provide implications to other cases (e.g. countries, areas of study, settings, time-frames) (Creswell, 2014, p.224). In terms of internal validity, limitations such as the testing threat, namely the risk that participants become familiar with the matter and remember responses for later testing (Creswell, 2014, p.223), are ruled out. This is because the surveyed households are asked only once and the questions are about facts and not about perceptions of respondents. However, given that the surveys were carried out during a period of time of 12 months, the data are limited in terms of the history threat, which refers to the risk that the survey's responses vary as a natural result of events occurring through time (Creswell, 2014, p.223).

When dealing with qualitative data instead, one of the ways to ensure the internal validity or accuracy of the findings is to triangulate different data sources, in order to cross-check the validity of the different data (Creswell, 2014, p.251). This is already addressed in the sample selection of the qualitative data, which draws from a range of different sources. Finally, in terms of external validity, both quantitative and qualitative data cover a case study, which therefore is limited in terms of generalizability of the results to different contexts. However, the selection of the case follows the typical case sampling, which makes it easier to allow drawing implications to other contexts. This will be further discussed in the case selection part of the methods section.

6 Methods

The choice of the case study research design and of the mixed methods approach are elaborated in the following sections. Additionally, the quantitative part of the method is discussed in more detail, with a presentation of the econometric method of analysis and its limitations, the variables chosen, the process of data management and finally the models with the related sub-research questions and hypotheses. Likewise, the qualitative method of analysis, the corresponding sub-research question and hypothesis are presented.

6.1 Research Design

A case study research design was chosen as the most appropriate for the purpose of this study. Given the scarce literature on environmental leapfrogging and more generally on concrete policies for the energy transition in developing countries, digging into a single case seems more appropriate to start to understand the dynamics of a research field that has been understudied. In this sense, a case study results as beneficial because it allows an in-depth understanding of the phenomenon of study together with its important contextual conditions (Yin, 2018, pp.45–46). Furthermore, a case study results the appropriate choice when the aim of the research is to provide a detailed, comprehensive and nuanced understanding of the analysis (Yin, 2018, p.45).

The choice of Kenya was based on the "typical case" selection method. A typical case refers to a case that can be considered representative of the relationship that the research aims at exploring (Seawright & Gerring, 2008). This allows the researcher to understand the dynamics of the case in depth and to have a substantial degree of external validity, being able to generalize the results to a wider sample of similar contexts (Seawright & Gerring, 2008). Kenya was deemed as an appropriate typical case because it is a lower-middle income country, that has been leading the energy transition in Sub-Saharan Africa, and in the Global South at large (IEA, 2019). Furthermore, it represents one of the most successful solar markets in Africa, where the deployment of SHSs has contributed to a massive increase in access to energy (IRENA, 2022), making it a successful, and therefore "typical" case to investigate the nascent concept of environmental leapfrogging and the drivers of solar energy adoption.

6.2 The Mixed Methods Approach

The method of analysis is a mixed methods approach. For the purpose of this research the quantitative and the qualitative analyses answer two different parts of the research question. The reason for this is data availability. The relationships between human capital and wealth with the adoption of solar energy are tested through an econometric analysis, using the regions of Kenya as the unit of analysis. On the other hand, the influence of the institutional environment is analysed through qualitative analysis, given that regional data on institutions are not available, since the energy sector is managed nationally and policies and institutions are better understood in a qualitative manner, with an in-depth analysis.

6.2.1 Quantitative

The quantitative analysis is carried out through the Ordinary Least Squares (OLS) method, which is suitable for the linear regression analysis. This is based on the Least Squares Principle, which refers to the fact that the parameters of the model are estimated through the minimization of the Residual Sum of Squares (RSS) (Gujarati & Porter, 2010, p.34), meaning that what we cannot explain will be as small as possible. According to the Gauss-Markov Theorem, an OLS model should be BLUE (Best Linear Unbiased Estimator) (Gujarati & Porter, 2010, p.60). This means that: 1) the parameters are a linear function of the outcome, 2) the paraments and the error variance are unbiased, i.e. on average they coincide with the respective population parameters and error variance, 3) the parameters are efficient estimators, i.e. they have minimum variance (Gujarati & Porter, 2010, pp.60–61).

The multiple linear regression model, which is essentially a linear regression model with more than one explanatory variable, is also dependent on a series of assumptions. First, the model should be linear in the parameters, even though it could also be nonlinear in the variables. Second, the explanatory variables should be uncorrelated with the error term. Third, the error term should have a mean equal to zero. Fourth, the variance of the error terms should be constant, or homoscedastic. Fifth, there should be no correlation between the error terms (autocorrelation). Sixth, there should be no high collinearity or multicollinearity between the explanatory variables. Seventh, the error is normally distributed with a mean of zero (Gujarati & Porter, 2010, pp.97–99).

However, even when all the assumptions are met, the OLS presents some important limitations. First, it can only establish associations and not causation (Smith, 2015, p.263). Yet, the support of theory can increase the confidence towards the establishment of causal relationships, which the OLS alone cannot do. Second, the establishment of correlations presents the issue of reverse causality, which means that the opposite direction of the investigated relationship cannot be easily ruled out (Smith, 2015, p.264). Here again, the use of theory and literature can help to reduce the problem. While these issues will be addressed in the presentation of results and discussion, the following paragraphs present and justify the variables selected for the 2005/06 analysis. The same will follow for the variables included in the 2015/16 analysis.

2005/06 Analysis: Variables of interest

Solar (Dependent variable): From the KIHBS 2005/06, the variable is part of the sub-section of the survey "Sources of lighting fuel". It refers to the percentage distribution of households, for each district, that use solar energy as their main source of lighting fuel. Even though this only captures solar as a lighting source, it was considered as the best variable available to measure the adoption of solar energy by households, because no other data exists at the household level in terms of adoption of solar energy.

Attended (Independent variable): From the KIHBS 2005/06, the variable is part of the sub-section "School attendance". This refers to the percentage distribution of population (6-17 years), by districts, that has ever attended school. Although other variables such as type of school attended or literacy were available from the household survey, the attendance rate was chosen as the most appropriate given that it measures an average education level in each district. It is, therefore, limited in the sense that it loses the detailed information, but on the other hand it is an adequate proxy for the purpose of the analysis to compare the average level of human capital across districts.

Owner (Independent variable): From the KIHBS 2005/06, the variable is part of the sub-section "Housing acquisition". It refers to the percentage distribution of households, by districts, that are owners of the house they occupy. This variable was chosen in absence of a macro-economic variable such as the GCP for this year of study. Alternatively, house tenure was considered as the best proxy to capture the effect of wealth at the household level.

2005/06 Analysis: Control variables

A set of control variables have been selected in order to avoid spurious relationships due to omitted variables. Variables such as access to credit and loss due to shocks have been included because they are expected to influence the wealth level of the districts besides the variable of housing tenure, used as a proxy for wealth. Corruption level has been included because it is the most closely available variable to institutional quality, which is expected to influence the real overall development of a district, including the adoption of new technologies, such as solar energy. The sex of the household head has been included to capture the gender dimension which is expected to possibly have an effect on the adoption of solar energy, given that females are traditionally the ones taking care of the household's chores. Distance from the nearest phone facility has been included as a proxy for the level of technological development of districts, which may be correlated to the level of adoption of solar energy, this also being a new technology. Finally, the shares of agriculture, manufacturing and services have been included as representatives of the basic structure of the economy of each district, which is also expected to influence the adoption of solar energy, being a proxy for whether a district is more rural or urban in its economic activities. A table summarizing the discussed control variables included in the 2005/06 analysis can be found in Appendix A.

2015/16 Analysis: Variables of interest

Solar (Dependent variable)*:* From the KIHBS 2015/2016, the variable solar was extracted from the sub-section "Main source of lighting". It refers to the percentage distribution of households, by counties, that use solar energy as their main source of lighting fuel. Even though it only captures solar as a lighting source, this was considered as the best variable available to measure the adoption of solar energy by households, because no other data exist at the household level in terms of adoption of solar energy.

Attended (Independent variable)*:* From the KIHBS 2015/16, the variable is part of the sub-section "School attendance". It represents the percentage distribution of population 3 years and above that have ever attended school, by county. Although other variables such as educational attainment or literacy were available from the household survey, the attendance rate was chosen as the most appropriate given that it measures an average education level in each county. It is, therefore, limited in the sense that it loses the detailed information, but on the other hand it is ad adequate proxy for the purpose of the analysis to compare the average level of human capital across counties.

***GCPperc (Independent variable)*:** From the GCP 2019, this variable refers to the Gross County Product per capita in constant prices (Ksh). As mentioned above, this is a regionally disaggregated measure of the national GDP. The data available are yearly data from 2013 to 2017. The variable data included in the analysis are the mean of the 2015 and 2016 data. This variable was deemed as the most appropriate to capture the wealth level of each county. Especially, being a per capita measure, it results as better than other variables, such as the county share of GDP, because it allows to capture the average wealth of households by county.

2015/16 Analysis: Control variables

In the same way as for 2005/06, also for the 2015/16 dataset a set of control variables have been selected to better isolate the relationship of interest. Access to credit, incidence of shocks, household headship, ICT development and structural change variables have been included in this dataset as well, for the same reasons as the ones discussed in relation to the previous dataset. Furthermore, the tenure status has been included as a control variable that might have an effect on the level of wealth, given that here GCP per capita was chosen as the variable of interest, deemed as a better proxy for counties' wealth. Besides, in absence of a variable that could capture the level of local institutional quality, the variable capturing the level of disputes was included in this dataset, given that disputes in a country like Kenya with recurrent ethnic violence, represent an important factor, that may hamper overall development, including renewable energy adoption. A table summarizing the control variables of the 2015/16 analysis can be found in Appendix A.

6.2.1.1. Data Management

Most of the variables included in the analysis were already available in their final form in the datasets, meaning that the majority of the data did not need to be transformed. In both the 2005/06 and the 2015/16 datasets, only the variables concerning structural change are the result of the assembling of multiple variables into the three main sectors of the economy, namely agriculture, industry and services. For 2005/06, all the variables were retrieved from the KIHBS 2005/06. The variables originally included data on seven economic sub-sectors by district. For

2015/2016 instead, the variables used were collected from the GCP 2019. In the original dataset the categorization by economic activity included 17 economic sub-sectors. The assembling of the various economic sectors into the three main ones for both years was carried out following the International Standard Industrial Classification of all Economic Activities (ISIC) (ILOSTAT, 2022). Furthermore, the *GCP per capita* variable of the 2015/16 analysis, was calculated as the mean of the GCP per capita data by county of 2015 and 2016, given that the KIHBS, from which the other variables originate from, was conducted between 2015 and 2016.

Finally, the dependent variable *Solar* was transformed for both the 2005/06 and the 2015/16 analysis. For 2005/06, the plotting of a histogram of the variable's observations revealed a positive right-skewedness, indicating an abundance of low values. This needed to be solved given that otherwise it would have caused the residuals to not be normally distributed, thus violating the seventh assumption of the multiple linear regression, as discussed above. For this reason, a log transformation of the variable was carried out, which allowed to transform the variable into a normally distributed one. For the 2015/16 analysis, the dependent variable *Solar* was again right-skewed. However, this time the log transformation did not solve the problem, but only transformed the right-skewedness into a left-skewedness. The reason for this is that here the problem was the presence of an outlier, i.e. a value that substantially differs from the rest of the observations (Smith, 2015, p.38). This was a value of 62.6 percent of the population of the county of Bomet using solar energy as a source of lighting, compared to an average of 17.7 percent. After dropping this value from the variable, *Solar* became normally distributed.

6.2.1.2. The Model

Following the discussion above, two sub-research questions can be formulated for the purpose of this analysis:

1. *To what extent are the levels of human capital and wealth associated with the adoption of solar energy by Kenyan households in 2005/06?*
2. *To what extent are the levels of human capital and wealth associated with the adoption of solar energy by Kenyan households in 2015/16?*

Based on this, two corresponding models are constructed as follows:

Model 1, 2005/06:

$$Y_{ln\_Solar_i} = \beta_1 + \beta_2 * Attended + \beta_3 * Owner + \beta_4 * Credit + \beta_5 * Shocks + \beta_6 * Corruption + \beta_7 * Femalehead + \beta_8 * Phone + \beta_9 * Agriculture + \beta_{10} * Manufacturing + \beta_{11} * Services + u_i$$

Model 2, 2015/16:

$$Y_{Solar_i} = \beta_1 + \beta_2 * Attended + \beta_3 * GCPperc + \beta_4 * Credit + \beta_5 * Shocks + \beta_6 * Grievances + \beta_7 * Femalehead + \beta_8 * Phone + \beta_9 * Owner + \beta_{10} * Agriculture + \beta_{11} * Manufacturing + \beta_{12} * Services + u_i$$

The hypotheses for both analyses are that both human capital and wealth are positively associated with the adoption of solar energy. The reasons for these expectations are widely discussed in the theoretical framework and literature review sections. These hypotheses and the expected relationships for the control variables, are summarized in Appendix B.

6.2.2 Qualitative

The theoretical framework discussed above will function as the guiding principle for the qualitative analysis. Both primary and secondary data will be reviewed in order to answer to the third sub-research question:

3. *To what extent has the institutional environment influenced the adoption of solar energy by Kenyan households in the past two decades?*

The corresponding hypothesis here is that the institutional environment in Kenya has contributed to the increased adoption of solar energy in the country. The motivation for the hypothesis reflects the discussion in the theoretical framework and the literature review sections.

7 Empirical Analysis

The section presents both the quantitative and qualitative findings of the analysis. The quantitative findings are preceded by the main descriptive statistics of the analysis and followed by a sensitivity analysis of the results. All results are summarized in tables and in some cases displayed on maps and then followed by a narrative explanation. An overall discussion of the results concludes the section.

7.1 Quantitative Results

Tables 1 and 2 display the summary of the main descriptive statistics of all the variables included in the analysis.

Table 1. Summary descriptive statistics 2005/06 analysis – Author's own computation

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Solar[1]	51	2.145	1.875	.4	8.2
Attended	51	93.939	8.630	52.1	100
Owner	51	73.647	22.086	7.6	94.9
Credit	51	27.882	14.679	1.8	64
Shocks	51	33525.12	22091.5	7466	84976
Corruption	34	14.018	12.483	.5	44.5
Femalehead	51	29.963	11.237	10.8	79.1
Phone	47	62.491	23.267	12.7	100
Agriculture	50	80.848	17.959	14.4	100
Manufacturing	51	2.892	4.745	0	19.1
Services	51	12.220	14.537	0	70.9

[1] Included in the analysis as a log

Table 2. Summary descriptive statistics 2015/16 analysis – Author's own computation

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Solar[2]	47	16.836	12.468	.2	62.6
Attended	47	85.291	15.871	37.6	97.5
GCPperc	47	70670.19	32639.9	27627.5	209894
Credit	47	33.083	16.187	5.5	66.1
Shocks	47	62.843	21.125	16.8	96
Grievances	47	15.398	9.021	.6	38.8
Femalehead	47	33.872	7.093	20.3	52.1
Phone	47	72.264	11.338	42.8	94
Owner	47	69.898	18.257	8.1	94.6
Agriculture	47	2.134	1.953	.1	10.6
Manufacturing	47	10.628	21.009	.6	136.4
Services	47	25.536	57.996	3.4	403.2

First, from the 2005/06 table, it is noticeable that the number of observations is not constant across all variables, besides not coinciding with the number of districts of Kenya at the time, which was 70, including Nairobi. The reason for this is that a number of observations for the dependent variable *Solar* were missing. Furthermore, the control variables *Corruption*, *Phone* and *Agriculture* have fewer observations than the rest because they had additional missing values. On the other hand, in the 2015/16 analysis the number of observations is consistent across all variable and corresponds to the number of Kenyan counties since 2010, namely 47.

Second, we can see that in both tables some variables are more clustered around the mean, while others present a larger standard deviation, meaning that in these cases the mean becomes a less representative value for the sample. *Solar* in 2005/06 results as the variable with the smallest standard deviation of just 1.875. This is remarkable especially in comparison to 2015/16, where the standard deviation is 12.468, representing larger differences in adoption of solar energy across different areas of Kenya. As well, it is important to already notice how much solar energy as a source of lighting has increased in only a decade: while in 2005/06 the mean was 2.145, this is equal to 16.836 in 2015/16. In the same way the maximum value of percentage of solar as a source of lighting by district/county increases from 8.2 to 62.6 in the

[2] Included in the analysis without the outlier of 62.6

same period. Finally, we can notice that other indicators have had a positive increase in the decade of study. Out of the variables that are comparable across the two tables, access to credit has increased from a mean of 27 to 33 percent; female headed households have increased from a mean of 30 to 34 percent; while the mean level of agricultural activities has decreased, the one of manufacturing and services has, on average, increased.

7.1.1 Findings

Table 3 reports the findings of the 2005/06 analysis. Additionally, Figure 4 and 5 provide a visual representation of the most relevant results.

Table 3. 2005/06 results – Author's own computation

Variable	ln_Solar		
	(1)	**(2)**	**(3)**
Attended	**.0273961***	**.0645515****	**.0646343*****
	(.0141554)	(.0227114)	(.0220426)
Owner	.0013702	5.74e-06	-.000192
	(.0055312)	(.0066941)	(.0064957)
Credit		-.0145773	**-.0145759***
		(.0086191)	(.0064957)
Shocks		**.0000133***	**.0000134****
		(6.50e-06)	(6.03e-06)
Corruption		.0026473	.0026085
		(.0092787)	(.0089933)
Femalehead		.0097903	.0095803
		(.0110256)	(.0094131)
Phone		-.0072293	-.0072092
		(.0050532)	(.0049004)
Agriculture		.0249453	.0240418
		(.0269874)	(.0139348)
Manufacturing		.0355337	.034815
		(.0397175)	(.0344051)
Services		-.0012439	
		(.0315147)	
Constant	-2.22286	**-7.719801****	**-7.632514*****
	(1.198776)	(3.503394)	(2.64847)
Observations	51	30	30
Adjusted R-Squared	0.0647	0.1707	0.2121

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

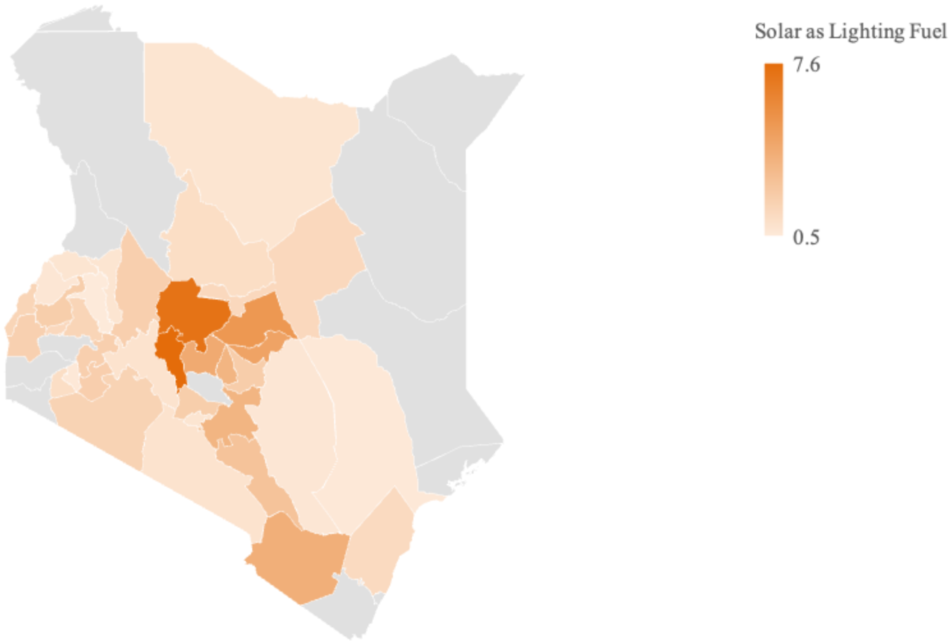


Figure 4. Mapping of solar adoption by counties[3] 2005/06 (CBS, 2007) – Author's own elaboration

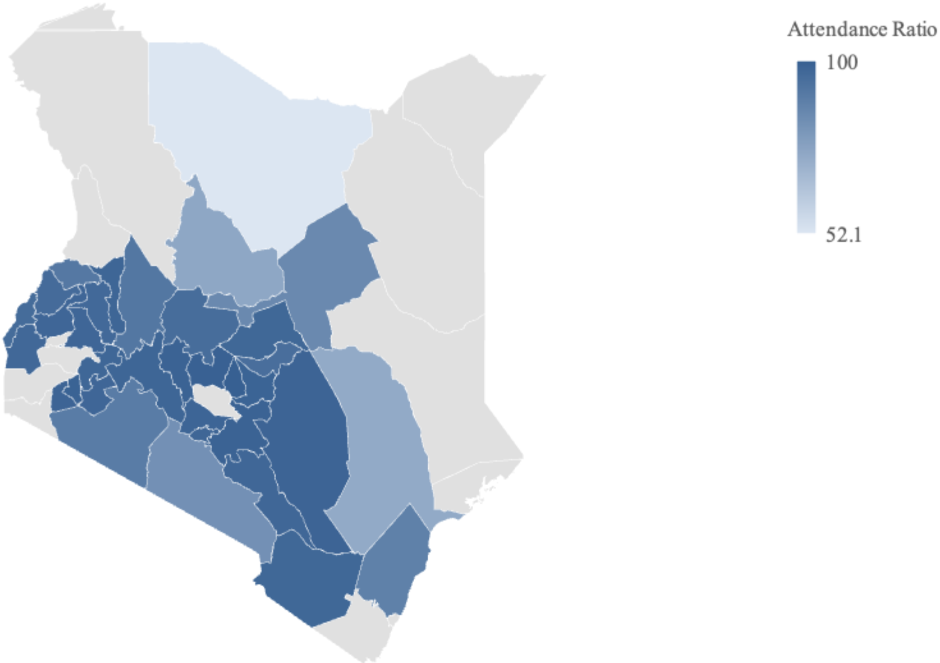


Figure 5. Mapping of school attendance by counties[3] 2005/06 (CBS, 2007) – Author's own elaboration

[3] For the purpose of creating the maps, original districts data have been recoded into the corresponding counties created by the 2010 Constitution.

As shown in Table 3, two sub-models were run before arriving to the final one. The first one only analyses the relationship between the main independent variables and the dependent variable. The independent are *Attended* and *Owner,* which are proxies for human capital and wealth as discussed above. The dependent variable is the log of *Solar,* which was obtained for the purpose of having normally distributed residuals. While the effect of *Owner* is not significant, the effect for *Attended* is significant, even though only at the 10 percent level. Given that that the dependent variable is logarithmic and the independent variable is linear, this is what is called a log-lin model and it requires a specific interpretation formula. This corresponds to 100 x (e^{β}- 1), where β is the coefficient of the independent variable. This means that a one unit increase in the percentage of the population (6-17 years old) that has ever attended school is associated with a 2,8 percent increase in the percentage distribution of households that use solar energy as their main source of lighting. Figure 4 and 5 visualize this correlation, showing similarities across regions in terms of degree of school attendance and solar energy adoption, indicated by the intensity of colouring.

In the second model, the control variables were included in the analysis, in order to better isolate the desired effect. Here, the independent variable *Attended,* representing the level of human capital in the district, becomes significant at the 5 percent level and presents a more relevant effect size: a one unit increase in the school attendance ratio is now associated with a 6,7 percent increase in the percentage of households using solar energy as their main source of lighting (Figure 4 and 5). Yet, the effect for *Owner,* as a proxy of wealth, remains insignificant. The effects of the control variables included are also not significant, except for the variable *Shocks* which, contrary to expectations, shows a positive relationship between the loss due to shocks and adoption of solar energy, even though the size of the effect is very small. Nonetheless, the explanatory power of the model has more than doubled from the previous one, now indicating that 17 percent of the variance of the use of solar energy as the main source of lighting fuel can be explained by the independent variables. Finally, the number of observations dropped to 30, because of the exclusion of missing values of some control variables.

Finally, the third model represents the final one. The difference from the second model here is that when checking whether the OLS assumptions were met, the multicollinearity assumption was violated: *Agriculture* and *Services* were highly correlated, which is not too surprising given that they represent complementary parts of an economy, together with *Manufacturing.* The variable *Agriculture* was therefore dropped. At this point all assumptions were met, as shown in Appendix C. Here the variable referring to human capital (*Attended*) becomes significant at the 1 percent level. The coefficient is similar in size to the one of Model 2, and therefore should be interpreted again as: one unit increase in the percentage of the population (6-17 years old) that has ever attended school is associated with a 6,7 percent increase in the proportion of households that use solar energy as lighting fuel (Figures 4 and 5). The effect of *Owner* is again not significant and it even changes sign, which shows the weakness of it. The effect of shocks remains significant, this time at the 5 percent level, and the effect of *Credit* becomes significant, indicating that access to credit is negatively associated with the adoption of solar energy, again contrary to expectations. Yet, these two results should not attract too much attention, given that their size is relatively small. Finally, the adjusted R^2 here has further increased, indicating that 21 percent of the use of solar as lighting fuel is explained by the independent variables. Table 4, Figure 6 and Figure 7 show the results for the 2015/16 analysis.

Table 4. 2015/16 results

Variable	Solar		
	(1)	**(2)**	**(3)**
Attended	**.3119402*** **	**.276863** **	**.2884873** **
	(.0998944)	(.1189072)	(.1272558)
GCPperc	**-.0000868***	**.0002287** **	**.0001528***
	(.0000484)	(.000087)	(.0000846)
Credit		.0262081	-.0136234
		(.1019096)	(.0964395)
Shocks		0.1452958	.1206533
		(.0893473)	(.0955068)
Grievances		-.0845886	-.1028752
		(.2166558)	(.2162011)
Femalehead		-.1355371	-.208205
		(.2026076)	(.2106088)
Phone		**-.4407881** **	**-.5141707*** **
		(.1843645)	(.1731225)
Owner		.0475378	
		(.1385474)	
Agriculture		**1.445065***	1.006903
		(.7214764)	(.7236877)
Manufacturing		**-.6141209** **	
		(.2405604)	
Services		.1023401	**-.0885705** **
		(.0799442)	(.0354999)
Constant	-4.56339	1.491236	16.16472
	(7.842068)	(19.52756)	(12.89459)
Observations	46	46	46
Adjusted R-Squared	0.1513	0.4449	0.3586

*** p < 0.01; ** p < 0.05; * p < 0.1

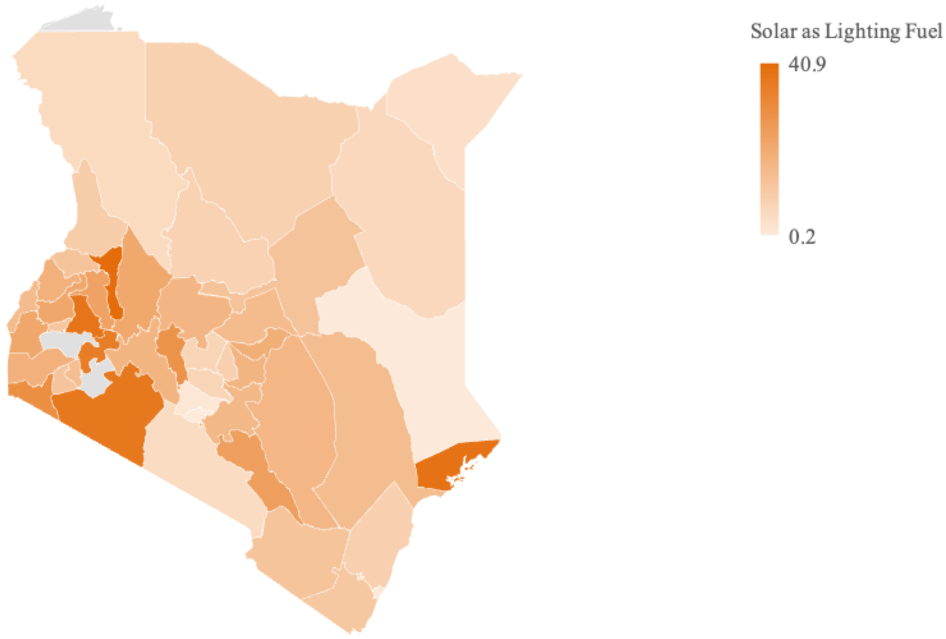


Figure 6. Mapping of solar adoption by counties 2015/16 (KNBS, 2018) – Author's own elaboration

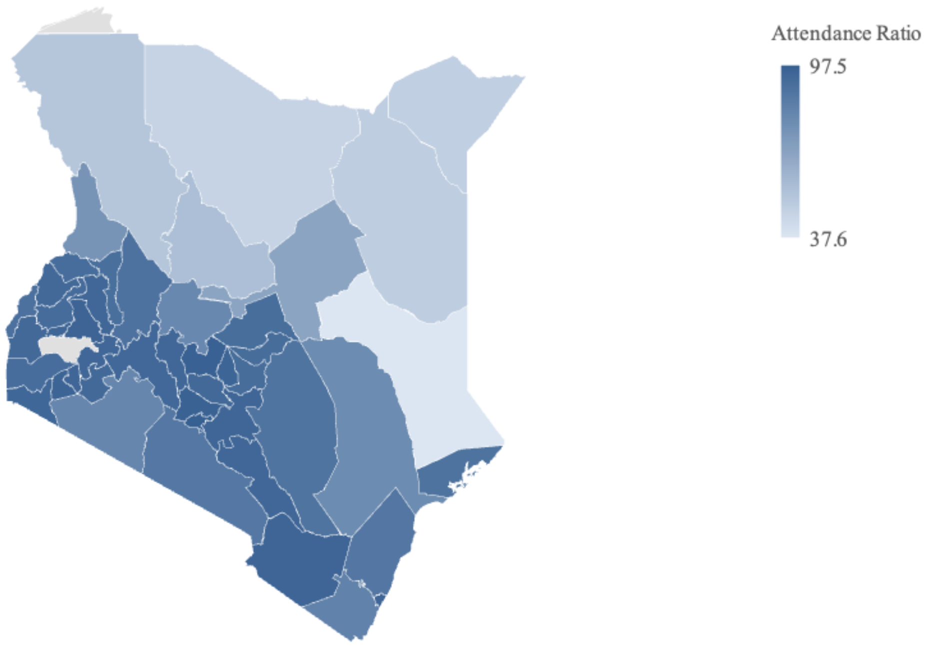


Figure 7. Mapping of school attendance by counties 2015/16 (KNBS, 2018) – Author's own elaboration

As in the previous analysis, two sub-models were tried out before getting to the final one. In all models the number of observations corresponds to 46, given that the outlier of the variable *Solar* was dropped from the analysis, as it was biasing the results. The first model only includes the analysis of the relationships between *Attended* and *GCPperc* with *Solar*. The attendance ratio, functioning as a proxy for the educational level in each county, is significant at the 1 percent level. More specifically, a 1-unit increase in the percentage of population 3 years and above that has ever attended school is associated with a 0.31 increase in the percentage of households that use solar energy as their main source of lighting fuel. With more complete data, the association is visible in Figures 6 and 7, highlighted by the intensity of colours across counties. Contrary to the previous analysis, here also the effect of *GCPperc*, representing the counties wealth, is significant. However, this is only significant at the 10 percent level, the size of the effect is extremely small (β = -0.0000868) and, more crucially, it shows the opposite sign as the one expected.

The second model, which includes the set of control variables, represents a significant improvement from the first one. First, the adjusted R^2 presents a very high value, indicating that the independent variables can explain 44 percent of the variance of the dependent variable. Then, the effect of *Attended* remains significant, even though now at the 5 percent level (Figure 6 And 7). The size of the effect also shrinks compared to the previous model, indicating that some explanatory power is now captured by some of the control variables, thus avoiding a spurious relationship. Here a one unit increase in the percentage of population 3 years and above that has attended school is associated with a 0.28 increase in the percentage of households that use solar energy as their main source of lighting fuel. *GCPperc* becomes significant at the 5 percent level, now also reflecting the expected relationship, that in wealthier counties more households adopt solar energy. However, the effect of it is still very small (β = 0.0002287).

Among the control variables, the effect of *Phone, Agriculture* and *Manufacturing* are significant. They are striking given that they are all quite large in size (β = -0.4407881, β = 1.445065 and β = -0.6141209). *Phone* goes in the opposite direction to the one expected. A larger proportion of the population 18 years and above owning a phone was expected to be positively associated with the adoption of solar energy for two reasons: first, it shows a high level of technological leapfrogging; second, it would imply a high deployment of mobile payment systems, which would be expected to facilitate the purchase of solar systems. On the other hand, the reason for this result could be that more urbanized counties have a higher percentage of mobile phones, while the deployment of solar electrification is mainly happening in rural areas, because of the benefits of being decentralized. Related to this, *Agriculture* and *Manufacturing* reflect the expected relationship that more rural areas have higher adoption of solar and that vice versa more urban areas, where usually more manufacturing capacity is concentrated, have better connection to the electrical grid and, thus, less solar energy adoption.

Finally, the third model differs from the second because it excludes the variables *Owner* and *Manufacturing,* since they had high multicollinearity with *GCPperc* and *Services,* respectively. After this step, all assumptions of the OLS method were met as shown in Appendix D. Here, the adjusted R^2 decreased from the previous model, yet still indicating a high explanatory power: 36 percent of the variance of the percentage of households that use solar energy as the main source of light is explained by the independent variables. *Attended* is still significant, and indicates that a 1 unit increase in the percentage of population 3 years and above that has attended school is associated with a 0.29 increase in the percentage of households that use solar energy as the main source of light (Figure 6 And 7). *GCPperc* becomes again significant at the 10 percent level, but still with a very small size effect. The effect of phone corresponds to the one in Model 2, it is significant, now also at the 1 percent level and the size of the effect is large, yet it goes in the opposite direction as the one expected. *Services* as well is significant and in line with the expected relationship: a one unit increase in the county share of gross value added by services is associated with a 0.08 decrease in the percentage of households using solar as the main source of lighting. The reason for this expectation corresponds to the one related to *Manufacturing* that urban areas, where usually more services value added is concentrated, have better connection to the electrical grid and thus less solar energy adoption.

7.1.2 Sensitivity Analysis

The robustness of the results was checked first by running all the necessary tests, in order to check whether the OLS assumptions were met and, as discussed in the sections above, despite initial problems of multicollinearity, eventually all assumptions were met. Second, running the models in two different steps, by first analysing only whether there was a correlation between the main independent and dependent variables and then only after adding the set of control variables, allowed to better control the fitness of the model, in terms of how relevant the addition of controls was. Third, an alternative model was run for both analyses. The model remained unchanged in terms of variables, but Nairobi was excluded from the observations, because even though it was counted as a district in 2005/06 and as a county in 2015/16, being the capital of the country, it presents several characteristics that make it a deviant case compared to the rest of the observations, therefore representing a potential bias for the results. The results from these analyses are reported in Appendix E and are overall in line with the ones of the original analyses, further confirming the robustness of results. The effect of human capital is confirmed as significant across all models in both analyses, while the effect of wealth again cannot be proved, being very small and not always significant.

Nonetheless, given that the OLS method only establishes correlations and not causation, the results should only be interpreted as associations between the variables and not as causal effects. This could potentially create a problem of reverse causality, given that solar energy is also largely contributing to the electrification of schools and health centres in rural areas (World Bank Group, 2020). The issue is reduced in this analysis, given that the variable *Solar* here only represents solar powered lighting for households and not for schools or other facilities. Additionally, the support of theory further reduces the issue. Yet, it cannot be completely ruled out, given that other less evident mechanisms might be at play between the increased adoption of solar energy and education. An example of this are households previously dependent on the collection of firewood having more time to study as a result of the reduced time needed to produce lighting.

7.2 Qualitative Results

Tables 5 and 6 summarize the main actors that make up the institutional environment of the energy sector in Kenya, as well as the main policies and regulations that define the regulatory environment of it.

Table 5. Institutional environment of the Kenyan energy sector – Authors' own elaboration

Institutions	**Time-Frame**	**Description**
Ministry of Energy	/	Oversees policy and strategy development for the entire energy sector. It is in charge of creating energy policies and steering the mobilization of resources in the sector.
Rural Electrification Authority (REA)	2007-2019	Special purpose agency that promotes and accelerates the electrification of all Kenyan households, through the promotion of renewable energies. It implements the Rural Electrification Programme (REP), which is aimed at promoting off grid renewable energy generation for in rural areas.
Energy Regulatory Commission (ERC)	2006-2019	An independent regulator for the sector. Its role includes the approval of Power Purchase Agreements and the preparation of national energy plans.
Kenya Power	1922, 2008	Main power company of Kenya. Reformed in 2008: the functions of generation, transmission and distribution of

		power were separated and assigned to KenGen, Ketraco and the KPLC respectively. Signs PPAs with KenGen and all IPPs. 50% state-owned.
Kenya Electricity Generating Company (KenGen)	2008	Largest Kenya's power producer. 70% state-owned.
Kenya Electricity Transmission Company (Ketraco)	2008	Government-owned transmission company in charge of all new transmission lines.
Independent Power Producers (IPPs)	2008	Private investors involved in generation under Kenya's feed-in-tariff.
Rural Electrification and Renewable Energy Corporation (REREC)	2019	Replaced the REA. Mandated to promote Kenya's energy green drive and to implement rural electrification projects. Has a wider mandate than REA.
Renewable Energy Resources Advisory Committee (RERAC)	2019	Replaced the REA. Regulates the development of the renewable energy policy.
Energy and Petroleum Regulatory Authority	2019	Replaced the ERC, with an expanded mandate of regulating also upstream petroleum and coal.

Table 6. Regulatory environment of the Kenyan energy sector – Authors' own elaboration

Policies, Regulations, Visions and Plans	**Time-frame**	**Description**
Kenya Vision 2030	2008-2030	Set long-term objectives. Identifies energy as a key driver to all development activities.
Kenya National Adaptation Plan	2015-2030	First adaptation plan, designed to help to move towards the attainment of Vision 2030.
National Climate Change Action Plan	2013, 2018	Designed to complement Vision 2030, which did not address climate change issues.
Energy Act	2006, 2019	The 2006 set up the ERC and the REA. Created the REP. Provided several incentives to increase the use of renewables, such as tax exemptions for imports of renewables equipment. The 2019 adopted a net-metering system. It dissolved the REA and replaced it with the REREC and the RERAC. It dissolved the ERC and replaced it with the EPRA.
Feed-in-Tariff	2008, 2010, 2012	Offers less risk to investors (IPPs) by ensuring them set prices through 20 years contracts, that can only be adjusted to inflation. Tariffs are technology and capacity-specific.
Energy (Solar Photovoltaic Systems) Regulations	2012	Provides rules and standards for the installation of PV in Kenya.
Value Added Tax (VAT) Act and Amended VAT Act	2013, 2014	Exemption from import duties and VAT for supplies or purchases of equipment and materials for the construction of renewable energy projects.

National Energy Policy	Last version 2018	Comprehensive description of the current state of the energy sector and of its policy framework. Includes policy recommendations for the different sub-sectors.
National Electrification Strategy	Last version 2018	The roadmap to achieve universal access to electricity.
Least Cost Power Development Plan	annual	Lays out the Government's medium to long term planning of the energy sector. It is updated annually.

As it is evident from the tables, a very significative institutional change has happened in the past two decades, which explains the mean of the adoption of solar energy by households skyrocketing from 2.145 to 16.836. More specifically, between 2005/06 and 2015/16, namely the years investigated through quantitative analysis, renewable energies have been strongly promoted as key factors for the achievement of socio-economic development goals, such as universal electrification. In 2008, Kenya Vision 2030 was developed as the first long-term plan that goes beyond electoral cycles, aimed at promoting industrialization while also protecting the environment (Newell et al., 2014). While this recognized the importance of maintaining "a clean and secure environment" (Government of the Republic of Kenya, 2007, p.19), it did not directly address the issue of climate change. For this reason, it was later complemented by the Kenya National Adaptation Plan in 2015 and a National Climate Change Action Plan in 2013, updated five years later in 2018.

A milestone signalling the strong promotion of rural electrification is represented by the promulgation of the Energy Act no. 12 in 2006, which created the Rural Electrification Authority (REA) and the Energy Regulatory Commission (ERC). The REA in particular was an agency specifically mandated to implement the Rural Electrification Programme (REP), aimed at the provision of off-grid renewable energy to rural areas, for the purpose of accelerating the pace of rural electrification for households and income-generating activities (Boampong & Phillips, 2016; Mokveld & von Eije, 2018). Recalling what has been discussed in the context sector, this has shown important results, with the rural electrification rate increasing from 16.9 percent in 2006 to 61.7 percent in 2019 (World Bank Data, 2022b). The 2006 Act has been now substituted by the Energy Act 2019, which has replaced the REA with the Rural Electrification and Renewable Energy Corporation (REREC) and the Renewable Energy Resources Advisory Committee (RERAC). The REREC has a wider mandate than REA, charged with "spearheading Kenya's green energy drive in addition to implementing rural electrification projects" (REREC, 2022).

Another major institutional change that happened after 2005 is the introduction of a Feed-in-Tariff (FiT) in 2008, which was then revised in 2010 and in 2012. A FiT is designed to ensure investors, also known as Independent Power Producers (IPPs), to buy renewable energy generated electricity at a price that is fixed for a relatively long period of time and that can only be adjusted to inflation (George et al., 2019). The 2012 FiT in Kenya ensures 20 years contracts at a fixed price and includes solar, wind, biomass, small hydro, biogas and geothermal (Ministry of Energy, 2012). FiT are the most used policies for renewable energy promotion around the world because they reduce the investment risk guaranteeing a stable return over a certain period of time, which is especially beneficial for renewable energies, whose prices still suffer from high instability, also due to their intermittency (Janho, 2020).

Also in 2012, the Energy Solar Photovoltaic System Regulation has been issued, namely a specific policy on solar PV, contributing to the clarity and standardization of the sector's procedures. This sets the rules for the licensing and registration requirements of solar PV system stakeholders, besides outlining all procedures of the phases of production and post-production from the design and installation to the maintenance of the PV systems (Brückner, 2015). Finally, solar equipment and accessories have been also exempted from Value Added Tax (VAT) and import taxes thanks to the VAT Act of 2013 and Amendment Act of 2014 (Janho, 2020).

7.3 Discussion

At this point, it is important to locate the results of the analysis into the body of literature analysed in the theory and literature review sections. Recalling the research purpose, the aim of the analysis was to investigate the association between human capital, wealth and the institutional environment with the adoption of solar systems by Kenyan households in the past two decades.

Starting with human capital, the quantitative analyses yield strong results supporting a positive relationship between the level of education, here measured as the attendance ratio to school, and the adoption of solar energy. Districts and counties with higher attendance ratios present a higher level of solar energy use as a source of lighting fuel, which confirms the hypothesized relationship. This is in line with the theoretical expectations that "in order to contribute to sustainable renewable energy development [in Africa], human capital development at all levels – from scientists and policy makers to entrepreneurs and end-users – is crucial" (Simelane & Abdel-Rahman, 2011, p.127). As well, it confirms previous studies on the subject (Amankwah-Amoah, 2015; George et al., 2019; Lay, Ondraczek & Stoever, 2013; Murphy, 2001). This indicates that investing in education is crucial for a country to leapfrog to the adoption of new technologies.

While from the results we can only conclude that there is a correlation between the attendance ratio to school and the adoption of solar systems, the theory suggests more detailed mechanisms behind it. Investments in education are needed both on the supply and on the demand side. In terms of supply, professional education and trainings need to be scaled up in order to create a skilled labour force of technicians and professionals that can support and make the PV value chain more efficient at all levels in Kenya (Rencon Associates Ltd, 2018). In terms of demand, research has shown the relevance of awareness creation among end-users for the adoption of PV (Adwek et al., 2020; Opiyo, 2019). Households need to be informed about how to use a PV system and about the benefits of solar electrification, in terms of health, reducing the air pollution from kerosene and firewood; information and entertainment, enabling the connection of connective appliances, such as phone and televisions; light, which can improve the conditions for working and studying in the evenings; and finally in relation to the environment (Rahut et al., 2018).

Moving on to the effect of wealth on the adoption of solar energy, the results are inconclusive. The 2005/06 analysis does not find any statistically significant relationship between the percentage of households owning the house they live in, which was chosen as the most appropriate available proxy for wealth, and the adoption of solar energy. On the other hand, the 2015/16 analysis finds a statistically significant association between the level of GCP per capita, which refers to the level of GDP per single counties, and the use of solar as the main source of lighting. However, the results here are extremely weak, given that the coefficient is negative in the first model and becomes positive in the second and third model, besides being very small in terms of size effect. This disconfirms the expected hypothesis and is in contrast with the literature reviewed (Adenle, 2020; Adwek et al., 2020; Amankwah-Amoah, 2015; George et al., 2019; Lay, Ondraczek & Stoever, 2013). The reasons for this could be that the variable *Owner* in 2005/06 did not represent well enough the effect that the analysis aimed to capture, given that owning a house instead of renting it is not necessarily a synonym for being richer.

Regarding the 2015/16 analysis instead the explanation for the small effect of wealth is more complex. While the variable *GCPperc* here seems an adequate proxy of the financial capability of a region, as shown in Figure 3 in the past ten years the price of solar PV has declined by 89 percent, probably contributing to expand the affordability of solar systems also to less affluent households.

Furthermore, the development of the PAYG scheme is likely to have contributed to limiting the obstacle of the still high upfront cost for poor households. “SHSs in the past consisted mainly of hire purchase, microfinance and cash payment models […] [which] attained little success in promoting electricity access for rural households” (Adwek et al., 2020, p.3901). PAYG is a business model where customers “pay-as-they-use” solar systems, facilitated by the widespread use of mobile payment systems in Kenya (Adwek et al., 2020). Finally, the development of the regulatory environment of the past two decades, which strongly promoted and lowered the costs of deploying solar energy in Kenya is likely to have contributed to limiting the effect of wealth on the adoption of solar energy, analysed on the 2015/16 data.

Indeed, it emerges from the qualitative analysis that the institutional environment has resulted as a crucial enabling factor in accelerating the adoption of SHSs by Kenyan households. This confirms the theoretical expectations (Perkins, 2003; Sauter & Watson, 2008; Simelane & Abdel-Rahman, 2011) that a targeted incentive structure, made up of policies, regulations and tax credits is fundamental to leapfrog to the newer technologies, in this case renewable energies. The decline of solar PV prices, in fact, cannot be the only explanation for the staggering expansion of SHSs in Kenya, given that the solar revolution has not reached many other countries where, similarly to Kenya, decentralized electrification through solar would be extremely beneficial for the socio-economic development of the country. Only Kenya, together with South Africa, Ghana and a few other Eastern African countries, has been taking advantage of its solar potential and the decline in prices (IRENA, 2022), while still only 28.7 percent of the rural population of Sub-Saharan Africa has access to electricity in 2020 (World Bank Data 2022).

The findings about the relevance of the regulatory and institutional environment are also in line with previous studies on the topic (Adenle, 2020; Adwek et al., 2020; Amankwah-Amoah, 2015; George et al., 2019). Its importance is already visible from the descriptive statists (Tables 1 And 2) which show a massive increase in the adoption of solar energy as the main source of lighting across the country. The institution of the REA, a special agency targeted at the electrification of off-grid rural areas, as well as the enactment of the feed-in-tariff, a targeted regulation for solar PV (Energy Solar Photovoltaic Systems Regulations 2012) and tax exemptions for solar equipment have created the necessary incentives to attract investments and adoption of solar energy in Kenya. However, while this seems to have limited the effect of wealth itself, assuming the case that this is not due to data limitations, the level of education remains an important factor for the adoption of solar energy, independently from how well-developed the institutional and regulatory environment for renewable energies is.

8 Conclusion

This research aimed at contributing to the environmental leapfrogging literature, by analysing the case of solar energy adoption by Kenyan households. Solar PV represents an optimal case study of sustainable development in Kenya, where socio-economic objectives are reached without compromising the future well-being of the environment: the use of solar home systems as a source of lighting contributed to more than doubling the electrification rate of Kenya in the past two decades (World Bank Data, 2022b). The results of both the 2005/06 and 2015/16 analyses show a statistically significant positive relationship between the level of human capital, measured as the attendance ratio to school, and the adoption of solar systems, measured as the percentage of households that use solar as the main source of lighting. Although the method of analysis only allows to establish relationships and not causation, all the assumptions of the method were met and the effect size of the results were quite large.

On the other hand, the results for the effect of the level of wealth, measured as households that owned the house that they lived in for the 2005/06 dataset and as Gross County Product for the 2015/16 dataset, produced inconclusive results. While for the first analysis the effect of housing tenure was not statistically significant, in the second analysis the effect of Gross County Product, which is a decomposed regional measure of GDP, was statistically significant. However, also here the effect is extremely small in size and not robust, given that the sign of the coefficient changes when control variables are added to the model. Finally, the institutional and regulatory environment of Kenya in the past two decades, which instead was analysed qualitatively, reveals a clear promotion of solar energy by the government, through the creation of special agencies charged with the mandate of solar electrification, the enactment of a feed-in-tariff, solar specific regulations and tax credits for solar materials. Therefore, besides the decline in prices of solar PV, the large increase in solar energy adoption has been influenced by the nation-wide promotion of it, through policies, regulations and dedicated institutions.

Overall, the analysis shows that the institutional environment is the crucial enabling factor for being able to leapfrog to new technologies, such as renewable energies in this case. Technology transfers from advanced countries are unlikely to be able to stimulate alone the diffusion of a new technology: the government needs to take an active role in the promotion of it, even in private-led markets as the solar energy sector of Kenya. Regarding the effect of wealth, which refers to the capability to afford the high costs of new technologies, the insignificant results of 2005/06 might have been due to data limitations, with the proxy variable of housing tenure not being the most adequate to measure to what extent can a household afford solar home systems.

On the other hand, the very small size effects of wealth for 2015/16 might indicate that the promotion of solar energy through tax credits and feed-in-tariffs, together with the downward trend in solar prices of the past decade, might have contributed to partially offsetting the obstacle of the still high up-front costs of solar. It is important to notice, instead, that the effect of human capital remains strongly correlated with the adoption of solar energy both before and after the regulatory environment promoting solar energy was put in place by the government. This indicates that, in contrast with affordability, human capital is a crucial driving factor of environmental leapfrogging, independently from the institutional environment's influence. The ability to absorb a new technology through appropriate skills from both technicians and professionals employed in the solar value chain, as well as from the end-users is essential for the transition to renewable energies.

8.1 Practical Implications

The paper calls for some important policy implications. The results indicate the need for developing countries to heavily invest in human capital, to build a skilled labour force that is able to make the best use of renewable energy technologies, thus contributing to job creation, converging with one of the most important socio-economic objectives of a country. Besides, it is crucial to raise awareness among end-users, through formal or informal knowledge practices disseminations, such as workshops or experiences exchanges. In this way, households will be more socially prone to accept the new technology, once they learn about the benefits of it and how to use it. Furthermore, an institutional enabling environment results as a crucial factor to scale-up the deployment of renewable energies in developing countries. Given that these are not even adopted on a large-scale in industrialized countries, policies such as feed-in-tariffs, tax exemptions and targeted agencies can contribute to overcome the obstacle of affordability, typical of several renewable energy technologies.

8.2 Future Research

Future research is needed on the effect of wealth on the adoption of solar energy, as the results of this analysis were inconclusive and they contradict a large body of literature reviewed. Furthermore, more detailed analysis, both through more advanced quantitative methods and through qualitative methods, are needed to dig deeper into what specific areas of human capital investments should be directed to, for instance if more towards universities or to vocational trainings institutes. Moreover, comparative case studies will benefit the field, by allowing to compare what works best and what does not. Finally, solar PV adoption represents one small fraction of what sustainable development entails, and more research should be directed to analyse other cases of environmental leapfrogging, in order to enrich the existing literature and to contribute to the formulation of concrete policy recommendations for the joint achievement of poverty reduction and environmental protection.

References

Aarakit, S. M., Ntayi, J. M., Wasswa, F., Adaramola, M. S. & Ssennono, V. F. (2021). Adoption of Solar Photovoltaic Systems in Households: Evidence from Uganda, *Journal of Cleaner Production*, vol. 329, pp.1–12.

Adenle, A. A. (2020). Assessment of Solar Energy Technologies in Africa-Opportunities and Challenges in Meeting the 2030 Agenda and Sustainable Development Goals, *Energy Policy*, vol. 137, pp.1–16.

Adwek, G., Boxiong, S., Ndolo, P. O., Siagi, Z. O., Chepsaigutt, C., Kemunto, C. M., Arowo, M., Shimmon, J., Simiyu, P. & Yabo, A. C. (2020). The Solar Energy Access in Kenya: A Review Focusing on Pay-As-You-Go Solar Home System, *Environment, Development and Sustainability*, vol. 22, no. 5, pp.3897–3938.

African Development Bank. (2021). African Economic Outlook, From Debt Resolution to Growth: The Road Ahead for Africa, Available Online: https://www.afdb.org/en/documents/african-economic-outlook-2021.

Ajulu, R. (2002). Politicised Ethnicity, Competitive Politics and Conflict in Kenya: A Historical Perspective, *African Studies*, vol. 61, no. 2, pp.251–268.

Altenburg, T. & Rodrik, D. (2017). Green Industrial Policy: Accelerating Structural Change Towards Wealthy Green Economies, in *Green Industrial Policy: Concept, Policies, Country Experiences*, Geneva, Bonn: UN Environment, pp.1–20.

Amankwah-Amoah, J. (2015). Solar Energy in Sub-Saharan Africa: The Challenges and Opportunities of Technological Leapfrogging, *Thunderbird International Business Review*, vol. 57, no. 1, pp.15–31.

Boampong, R. & Phillips, A. (2016). Renewable Energies Incentives in Kenya: Feed-in Tariffs and Rural Expansion, *National Science Foundation's Sustainable Energy Pathways Initiative*, pp.1–31.

Brückner, U. (2015). Kenya's PV Regulatory Framework, *Financial and Legal Affairs*, Available Online: https://www.roedl.de:10006/de-DE/de/medien/publikationen/fachaufsaetze/erneuerbare-energie/Documents/Kenya-article.pdf.

Central Bureau of Statistics. (2007). Kenya Integrated Household Budget Survey, Available Online: https://catalog.ihsn.org/index.php/catalog/1472.

Common, M. & Stagl, S. (2005). Ecological Economics: An Introduction, New York: Cambridge University Press.

Creswell, J. W. (2014). Research Design: Qualitative, Quantitative, and Mixed Methods

Approaches, 4th edn, Los Angeles: SAGE Publications Inc.

Danquah, M. & Amankwah-Amoah, J. (2017). Assessing the Relationships between Human Capital, Innovation and Technology Adoption: Evidence from Sub-Saharan Africa, *Technological Forecasting and Social Change*, vol. 122, pp.24–33.

El Fadel, M., Rachid, G., El-Samra, R., Boutros, G. B. & Hashisho, J. (2013). Knowledge Management Mapping and Gap Analysis in Renewable Energy: Towards a Sustainable Framework in Developing Countries, *Renewable and sustainable energy reviews*, vol. 20, pp.576–584.

Fay, M. (2012). Inclusive Green Growth: The Pathway to Sustainable Development, World Bank Publications.

Food and Agriculture Organization. (2022). FAO in Kenya: Kenya at a Glance, Available Online: https://www.fao.org/kenya/fao-in-kenya/kenya-at-a-glance/en/.

Gallagher, K. S. (2006). Limits to Leapfrogging in Energy Technologies? Evidence from the Chinese Automobile Industry, *Energy policy*, vol. 34, no. 4, pp.383–394.

George, A., Boxiong, S., Arowo, M., Ndolo, P. & Shimmon, J. (2019). Review of Solar Energy Development in Kenya: Opportunities and Challenges, *Renewable Energy Focus*, vol. 29, pp.123–140.

Gitone, I. (2014). Determinants of Adoption of Renewable Energy in Kenya.

Goldemberg, J. (1998). Leapfrog Energy Technologies, *Energy Policy*, vol. 26, no. 10, pp.729–741.

Goldemberg, J. (2011). Technological Leapfrogging in the Developing World, *Georgetown Journal of International Affairs*, vol. 12, no. 1, pp.135–141.

Government of the Republic of Kenya. (2007). Kenya Vision 2030, Available Online: https://vision2030.go.ke/.

Government of the Republic of Kenya. (2010). The Constitution of Kenya.

Grossman, G. M. & Krueger, A. B. (1991). Environmental Impacts of a North American Free Trade Agreement.

Grossman, G. M. & Krueger, A. B. (1995). Economic Growth and the Environment, *The quarterly journal of economics*, vol. 110, no. 2, pp.353–377.

Gujarati, D. N. & Porter, D. C. (2010). Essentials of Econometrics, 4th edn, New York: McGraw-Hill Companies.

Guta, D. D. (2018). Determinants of Household Adoption of Solar Energy Technology in Rural Ethiopia, *Journal of Cleaner Production*, vol. 204, pp.193–204.

Hansen, U. E., Pedersen, M. B. & Nygaard, I. (2014). Review of Solar PV Market Development in East Africa, *UNEP Risø Centre, Technical University of Denmark: Kongens Lyngby, Denmark.*

Harlem, B. G. (1987). Our Common Future, World Commission on Environment and Development, Available Online: https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf.

Henriques, S. T. & Kander, A. (2010). The Modest Environmental Relief Resulting from the Transition to a Service Economy, *Ecological Economics*, vol. 70, no. 2, pp.271–282.

Hickel, J. (2019). The Contradiction of the Sustainable Development Goals: Growth versus Ecology on a Finite Planet, *Sustainable Development*, vol. 27, no. 5, pp.873–884.

ILOSTAT. (2022). International Standard Industrial Classification of All Economic Activities (ISIC), Available Online: https://ilostat.ilo.org/resources/concepts-and-definitions/classification-economic-activities/.

Intergovernmental Panel on Climate Change. (2022). Climate Change 2022: Mitigation of Climate Change, Available Online: https://journeytozerostories.neste.com/sustainability/ipcc-report-analysis-top-five-measures-halve-emissions-2030?gclid=Cj0KCQjwhLKUBhDiARIsAMaTLnHDitJhWXH0gOC8Z_DPFOkWfldJ9zwAaCK9PBboLNJ-dKOAvfMbq0IaAlxtEALw_wcB#b5065ed3.

International Energy Agency. (2019). Africa Energy Outlook 2019, Overview: Kenya, Available Online: https://www.iea.org/reports/africa-energy-outlook-2019.

International Energy Agency & Organization for Economic Cooperation and Development. (2004). Oil Crises & Climate Challenges: 30 Years of Energy Use in IEA Countries, Available Online: https://www.iea.org/reports/oil-crises-and-climate-challenges-30-years-of-energy-use-in-iea-countries.

International Renewable Energy Agency. (2022). Renewable Energy Market Analysis: Africa and Its Regions, Available Online: https://www.irena.org/publications/2022/Jan/Renewable-Energy-Market-Analysis-Africa.

Jacobson, A. (2007). Connective Power: Solar Electrification and Social Change in Kenya, *World Development*, vol. 35, no. 1, pp.144–162.

Janho, R. (2020). Renewable Energy in Kenya: An Examination of the Legal Instruments and Institutional Changes That Successfully Attracted Foreign Investment, *Energy Central*, Available Online: https://energycentral.com/c/pip/renewable-energy-kenya-examination-legal-instruments-and-institutional-changes.

Johnson, B., Edquist, C. & Lundvall, B.-Å. (2004). Economic Development and the National System of Innovation Approach, 2004, Georgia Institute of Technology.

Kammen, D. M. & Jacobson, A. (2014). Solar Innovation and Market Feedback: Solar Photovoltaics in Rural Kenya, in *Energy Technology Innovation: Learning from Historical Successes and Failures*, New York: Cambridge University Press, pp.244–256.

Kander, A., Malanima, P. & Warde, P. (2013). Power to the People. Energy in Europe over the Last Five Centuries, New Jersey: Princeton University Press.

Kanyinga, K. & Long, J. D. (2012). The Political Economy of Reforms in Kenya: The Post-2007 Election Violence and a New Constitution, *African Studies Review*, vol. 55, no. 1, pp.31–51.

Kenya National Bureau of Statistics. (2018). Kenya Integrated Household Budget Survey, Available Online: https://statistics.knbs.or.ke/nada/index.php/catalog/13.

Kenya National Bureau of Statistics. (2019). Gross County Product 2019, Available Online: https://www.knbs.or.ke/download/gross-county-product-2019/.

Kimenyi, M. S., Mwega, F. M. & Ndung'u, N. S. (2016). The African Lions: Kenya Country Case Study, UNU-WIDER, Available Online: https://www.brookings.edu/research/african-lions-kenya-country-case-study/.

Kimutai, K. S. (2019). Effects of Renewable Energy and Accessibility on Household's Fuel Choices: A Case Study in Kenya, *Journal of Energy Technologies and Policy*, vol. 9, no. 7, pp.29–34.

Kizilcec, V. & Parikh, P. (2020). Solar Home Systems: A Comprehensive Literature Review for Sub-Saharan Africa, *Energy for Sustainable Development*, vol. 58, pp.78–89.

Klein, J., Jochaud, P., Casado, F. & Perez, J. (2015). Green Growth and Human Capital Development in Africa: Economic Sector Working Paper, African Development Bank, Available Online: https://globalcad.org/wp-content/uploads/2018/04/Green-Growth-Human-Capital-Development_Final-Report.pdf.

Kuznets, S. (1955). Economic Growth and Income Inequality, *The American economic review*, vol. 45, no. 1, pp.1–28.

Lay, J., Ondraczek, J. & Stoever, J. (2013). Renewables in the Energy Transition: Evidence on Solar Home Systems and Lighting Fuel Choice in Kenya, *Energy Economics*, vol. 40, pp.350–359.

Lewis, J. I. (2007). Technology Acquisition and Innovation in the Developing World: Wind Turbine Development in China and India, *Studies in comparative international development*, vol. 42, no. 3, pp.208–232.

Mensah, G. & McWilson, W. K. (2021). The Dynamics of Households' Adoption Behaviour of Solar Home Systems (SHSS) in Ashongman Estate in the Greater Accra Region of Ghana, *Ghana Journal of Geography*, vol. 13, no. 1, pp.235–259.

Ministry of Energy. (2012). Feed-in-Tariff Policy on Wind, Biomass, Small-Hydro, Geothermal, Biogas and Solar Resource Generated Electricity.

Mokveld, K. & von Eije, S. (2018). Final Energy Report Kenya, Netherlands Enterprise Agency, Available Online: https://www.rvo.nl/sites/default/files/2019/01/Final-Energy-report-Kenya.pdf.

Morrock, R. (1973). Heritage of Strife: The Effects of Colonialist" Divide and Rule" Strategy upon the Colonized Peoples, *Science & Society*, pp.129–151.

Murphy, J. T. (2001). Making the Energy Transition in Rural East Africa: Is Leapfrogging an Alternative?, *Technological Forecasting and Social Change*, vol. 68, no. 2, pp.173–193.

Ndiritu, S. W. & Engola, M. K. (2020). The Effectiveness of Feed-in-Tariff Policy in Promoting Power Generation from Renewable Energy in Kenya, *Renewable Energy*, vol. 161, pp.593–605.

Newell, P., Phillips, J., Pueyo, A., Kirumba, E., Ozor, N. & Urama, K. (2014). The Political Economy of Low Carbon Energy in Kenya, *IDS Working Papers*, vol. 2014, no. 445, pp.1–38.

North, D. C. (1991). Institutions, *The Journal of Economic Perspectives*, vol. 5, no. 1, pp.97–112.

Nyariki, D. M. & Amwata, D. A. (2019). The Value of Pastoralism in Kenya: Application of Total Economic Value Approach, *Pastoralism*, vol. 9, no. 1, pp.1–13.

OEC. (2020). Kenya, Available Online: https://oec.world/en/profile/country/ken#:~:text=Exports%20The%20top%20exports%20of,and%20United%20Kingdom%20(%24435M).

Ojong, N. (2021). The Rise of Solar Home Systems in Sub-Saharan Africa: Examining Gender, Class, and Sustainability, *Energy Research & Social Science*, vol. 75, p.102011.

Ondraczek, J. (2013). The Sun Rises in the East (of Africa): A Comparison of the Development and Status of Solar Energy Markets in Kenya and Tanzania, *Energy Policy*, vol. 56, pp.407–417.

Opiyo, N. N. (2019). Impacts of Neighbourhood Influence on Social Acceptance of Small Solar Home Systems in Rural Western Kenya, *Energy Research & Social Science*, vol. 52, pp.91–98.

Organization for Economic Cooperation and Development. (2012). Green Growth and Developing Countries: A Summary for Policy Makers, Available Online: https://www.oecd.org/dac/50526354.pdf.

Our World in Data. (2020a). Why Did Renewables Become So Cheap So Fast?

Our World in Data. (2020b). China: CO2 Country Profile, Available Online: https://ourworldindata.org/co2/country/china.

Pahle, M., Pachauri, S. & Steinbacher, K. (2016). Can the Green Economy Deliver It All? Experiences of Renewable Energy Policies with Socio-Economic Objectives, *Applied Energy*, vol. 179, pp.1331–1341.

Panayotou, T. (1993). Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Economic Development, International Labour Organization.

Pedercini, M., Arquitt, S., Collste, D. & Herren, H. (2019). Harvesting Synergy from Sustainable Development Goal Interactions, *Proceedings of the National Academy of Sciences*, vol. 116, no. 46, pp.23021–23028.

Perkins, R. (2003). Environmental Leapfrogging in Developing Countries: A Critical Assessment and Reconstruction, Vol. 27, Natural Resources Forum, 2003, Wiley Online Library, pp.177–188.

Pezzey, J. C. & Burke, P. J. (2014). Towards a More Inclusive and Precautionary Indicator of Global Sustainability, *Ecological Economics*, vol. 106, pp.141–154.

Pueyo, A. (2015). Pro-Poor Access to Green Electricity in Kenya, Institute of Development Studies, Available Online: https://opendocs.ids.ac.uk/opendocs/handle/20.500.12413/6165.

Rahut, D. B., Mottaleb, K. A., Ali, A. & Aryal, J. (2018). The Use and Determinants of Solar Energy by Sub-Saharan African Households, *International Journal of Sustainable Energy*, vol. 37, no. 8, pp.718–735.

Rebane, K. L. & Barham, B. L. (2011). Knowledge and Adoption of Solar Home Systems in Rural Nicaragua, *Energy policy*, vol. 39, no. 6, pp.3064–3075.

Red Cross Red Crescent Climate Centre. (2021). Country Level, Climate Factsheet: Kenya, Available Online: https://www.climatecentre.org/publications/5549/country-factsheet-kenya/.

Rencon Associates Ltd. (2018). Consultancy Services for a Study on Solar Photovoltaic Industry in Kenya, Draft Final Report.

Roche, O. M. & Blanchard, R. E. (2018). Design of a Solar Energy Centre for Providing Lighting and Income-Generating Activities for off-Grid Rural Communities in Kenya, *Renewable Energy*, vol. 118, pp.685–694.

Rodrik, D. (2014). The Past, Present, and Future of Economic Growth, *Challenge*, vol. 57, no. 3, pp.5–39.

Rogers, P. P., Jalal, K. F. & Boyd, J. A. (2008). An Introduction to Sustainable Development, London: Glen Educational Foundation, Inc.

Rubio, M. M. & Folchi, M. (2012). Will Small Energy Consumers Be Faster in Transition? Evidence from the Early Shift from Coal to Oil in Latin America, *Energy Policy*, vol. 50, pp.50–61.

Rural Electrification and Renewable Energy Corporation. (2022). About Us, Who We Are, Available Online: https://www.rerec.co.ke/about-us.php.

Samadi, A. H. & Alipourian, M. (2021). Measuring Institutional Quality: A Review, *Dynamics of Institutional Change in Emerging Market Economies*, pp.143–171.

Sauter, R. & Watson, J. (2008). Technology Leapfrogging: A Review of the Evidence A Report for DFID, *Sussex Energy Group SPRU (Science and Technology Policy Research), University of Sussex*.

Sayer, G. (2004). Independence and After, in *Kenya: Promised Land?*, Oxfam GB.

Seawright, J. & Gerring, J. (2008). Case Selection Techniques in Case Study Research: A Menu of Qualitative and Quantitative Options, *Political research quarterly*, vol. 61, no. 2, pp.294–308.

Shirley, R., Lee, C.-J., Njoroge, H. N., Odera, S., Mwanzia, P. K., Malo, I. & Dipo-Salami, Y. (2019). Powering Jobs: The Employment Footprint of Decentralized Renewable Energy Technologies in Sub Saharan Africa, *Journal of Sustainability Research*, vol. 2, no. 1.

Simelane, T. & Abdel-Rahman, M. (2011). Energy Transition in Africa, Pretoria: Africa Institute of South Africa.

Smil, V. (2016). Energy Transitions: Global and National Perspectives, Santa Barbara: ABC-CLIO.

Smith, G. (2015). Essential Statistics, Regressions and Econometrics, 2nd edn, London: Elsevier Inc.

Sovacool, B. K. (2016). How Long Will It Take? Conceptualizing the Temporal Dynamics of Energy Transitions, *Energy Research & Social Science*, vol. 13, pp.202–215.

Statista. (2021). African Countries with the Highest Gross Domestic Product (GDP) in 2021 (in Billion U.S. Dollars), Available Online: https://www.statista.com/statistics/1120999/gdp-of-african-countries-by-country/.

Stern, D. I. (2004). The Rise and Fall of the Environmental Kuznets Curve, *World development*, vol. 32, no. 8, pp.1419–1439.

Takase, M., Kipkoech, R. & Essandoh, P. K. (2021). A Comprehensive Review of Energy Scenario and Sustainable Energy in Kenya, *Fuel Communications*, vol. 7, p.100015.

The Economist. (2011). Africa Rising, Available Online: https://www.economist.com/leaders/2011/12/03/africa-rising.

United Nations Development Programme. (2020). The Next Frontier: Human Development and the Anthropocene, Kenya, Human Development Report 2020, Available Online: https://hdr.undp.org/en/countries/profiles/KEN.

United Nations Industrial Development Organization. (2011). Industrial Energy Efficiency for Sustainable Wealth Creation: Capturing Environmental, Economic and Social Dividends, [e-journal], Available Online: https://www.unido.org/sites/default/files/2012-01/UNIDO_FULL_REPORT_EBOOK_0.pdf.

Unruh, G. C. (2000). Understanding Carbon Lock-In, *Energy policy*, vol. 28, no. 12, pp.817–830.

Unruh, G. C. & Carrillo-Hermosilla, J. (2006). Globalizing Carbon Lock-In, *Energy Policy*, vol. 34, no. 10, pp.1185–1197.

World Bank. (1992). World Development Report 1992: Development and the Environment, The World Bank.

World Bank Data. (2022a). Access to Electricity, Rural (% of Rural Population) - Sub-Saharan Africa, Available Online: https://data.worldbank.org/indicator/EG.ELC.ACCS.RU.ZS?locations=ZG.

World Bank Data. (2022b). Access to Electricity (% of Population) - Kenya, Available Online: https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=KE.

World Bank Data. (2022c). GDP per Capita (Current US$) - Kenya, Available Online: https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=KE.

World Bank Group. (2020). Increasing Human Capital by Electrifying Health Centres and Schools Through Off-Grid Solar Solutions, Available Online: https://openknowledge.worldbank.org/handle/10986/33276.

Yin, R. K. (2018). Case Study Research and Applications, Design and Mehods, 6th edn, California: SAGE Publications, Inc.

Appendix A

a. Control variables of 2005/06 analysis

Variable Name	Variable Label	Variable Description	Time-frame	Source
Credit	Access to credit	Proportion of households that sought credit, by regions and districts.	2005/06	KIHBS
Shocks	Loss due to shocks	Estimated value of loss due to shocks by severity (Ksh), by regions and districts	2005/06	KIHBS
Corruption	Corruption	Percentage distribution of communities by corruption involving public servants, by regions and districts.	2005/06	KIHBS
Femalehead	Household headship	Percentage distribution of households by sex of head of the household, per region and district.	2005/06	KIHBS
Phone	ICT	Percentage of the population that is 5 or more kms distant from the nearest telephone facility, by regions and districts.	2005/06	KIHBS
Agriculture	Structural change - Agriculture	Percentage distribution of communities by main economic activities - Agriculture	2005/06	KIHBS
Manufacturing	Structural change - Manufacturing	Percentage distribution of communities by main economic activities - Manufacturing	2005/06	KIHBS
Services	Structural change - Services	Percentage distribution of communities by main economic activities - Services	2005/06	KIHBS

b. Control variables of 2015/16 analysis

Variable Name	Variable Label	Variable Description	Time-frame	Source
Credit	Access to credit	Proportion of households, by county, that sought credit.	2015/16	KIHBS
Shocks	Incidence of shocks	Percentage of households reporting any shock, by county.	2015/16	KIHBS

Grievances	Grievances/Disputes	Proportion of households reporting grievances, by county	2015/16	KIHBS
Femalehead	Household headship	Percentage distribution of households by sex of household head, by county.	2015/16	KIHBS
Phone	ICT	Proportion of population aged 18 years and above that have a mobile phone.	2015/16	KIHBS
Owner	Tenure status	Percentage distribution of households that own the house they occupy.	2015/16	KIHBS
Agriculture	Structural change - Agriculture	County share of gross value added and gross county product by economic activity – Agriculture.	2017	GCP
Manufacturing	Structural change - Manufacturing	County share of gross value added and gross county product by economic activity – Manufacturing.	2017	GCP
Services	Structural change - Services	County share of gross value added and gross county product by economic activity – Services.	2017	GCP

Appendix B

Summary of hypotheses and expected relationships for 2005/06 and 2015/16 analyses

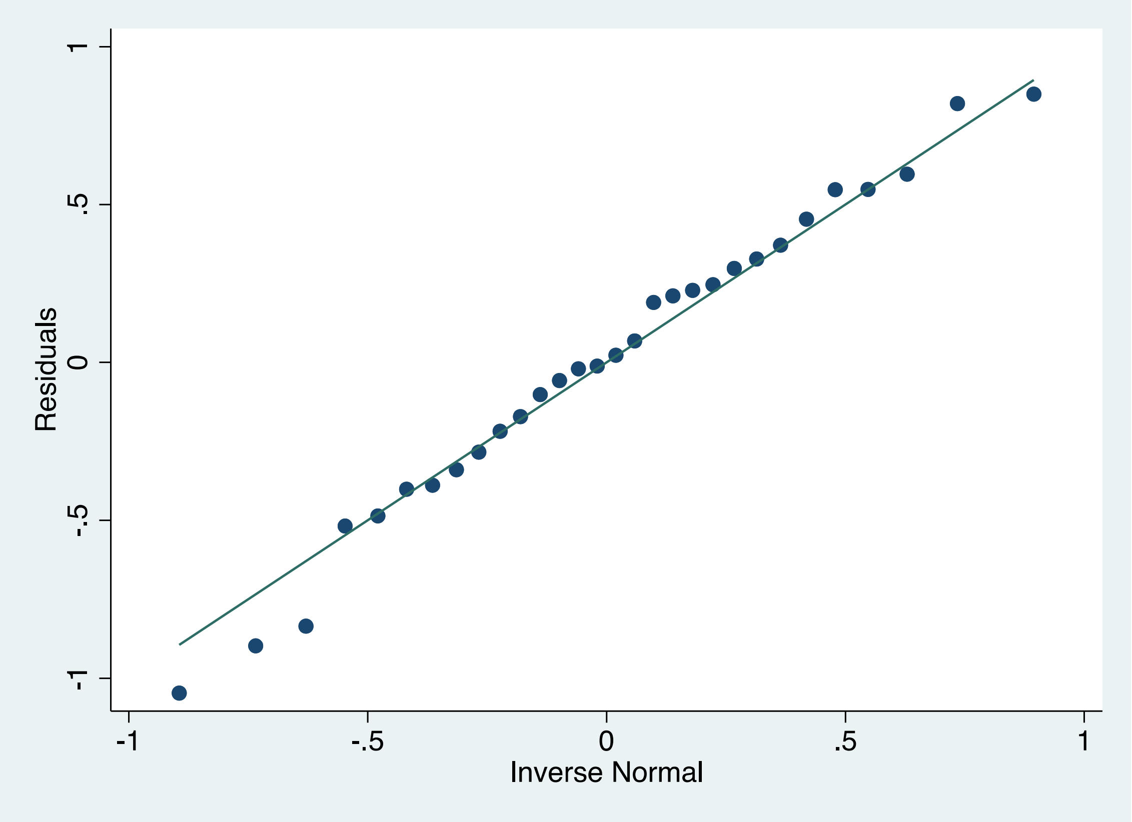
Variable Name (2005/06)	**Expected relationship (2005/06)**	**Variable Name (2015/16)**	**Expected relationship (2015/16)**
Attended	+	Attended	+
Owner	+	GCPperc	+
Credit	+	Credit	+
Shocks	-	Shocks	-
Corruption	-	Grievances	-
Femalehead	-	Femalehead	-
Phone	-	Phone	+
Agriculture	+	Owner	+
Manufacturing	-	Agriculture	+
Services	-	Manufacturing	-
		Services	-

Appendix C

a. Normality of residuals, Analysis 2005/06

Skewness and kurtosis tests for normality

Variable	Obs	Pr(skewness)	Pr(kurtosis)	Joint test chi2(2)	Joint test Prob>chi2
e2	**30**	**0.4442**	**0.8232**	**0.64**	**0.7279**



b. Homoscedasticity, Analysis 2005/06

```
Breusch–Pagan/Cook–Weisberg test for heteroskedasticity
Assumption: Normal error terms
Variable: Fitted values of ln_Solar

H0: Constant variance

    chi2(1) =   0.10
Prob > chi2 = 0.7562
```

```
White's test
H0: Homoskedasticity
Ha: Unrestricted heteroskedasticity

   chi2(29) =  30.00
Prob > chi2 = 0.4140

Cameron & Trivedi's decomposition of IM-test
```

Source	chi2	df	p
Heteroskedasticity	30.00	29	0.4140
Skewness	4.40	9	0.8831
Kurtosis	0.70	1	0.4040
Total	35.10	39	0.6485

c. Multicollinearity, Analysis 2005/06

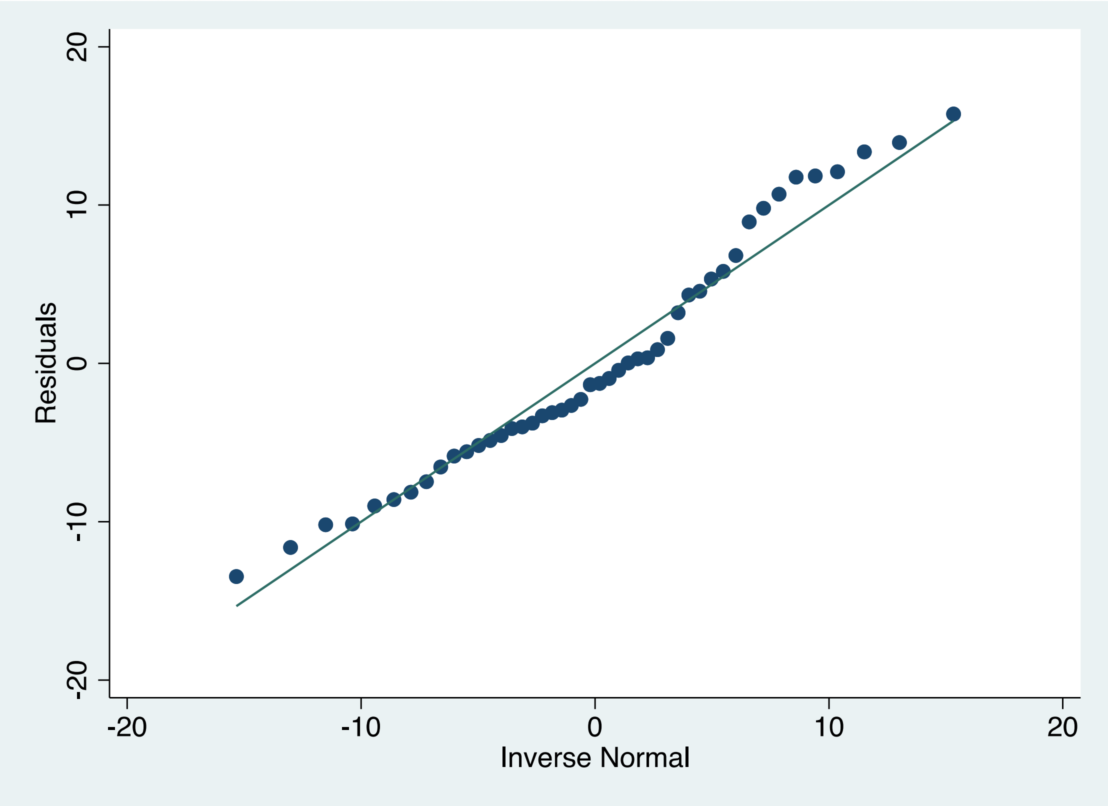
Variable	VIF	1/VIF
Agriculture	3.33	0.300316
Manufactur~g	2.62	0.381517
Attended	2.35	0.425046
Owner	1.90	0.526734
Shocks	1.68	0.596945
Credit	1.57	0.636384
Phone	1.29	0.776450
Femalehead	1.26	0.792729
Corruption	1.14	0.878962
Mean VIF	1.90	

Appendix D

a. Normality of residuals, Analysis 2015/16

Skewness and kurtosis tests for normality

Variable	Obs	Pr(skewness)	Pr(kurtosis)	Joint test chi2(2)	Joint test Prob>chi2
e2	**46**	**0.2034**	**0.2233**	**3.10**	**0.2122**



b. Homoscedasticity, Analysis 2015/16

```
Breusch–Pagan/Cook–Weisberg test for heteroskedasticity
Assumption: Normal error terms
Variable: Fitted values of Solar

H0: Constant variance

    chi2(1) =   2.17
Prob > chi2 = 0.1403
```

```
White's test
H0: Homoskedasticity
Ha: Unrestricted heteroskedasticity

   chi2(45) =  46.00
Prob > chi2 = 0.4306

Cameron & Trivedi's decomposition of IM-test
```

Source	chi2	df	p
Heteroskedasticity	**46.00**	**45**	**0.4306**
Skewness	**9.14**	**9**	**0.4249**
Kurtosis	**2.34**	**1**	**0.1262**
Total	**57.47**	**55**	**0.3837**

c. Multicollinearity, Analysis 2015/16

Variable	VIF	1/VIF
GCPperc	**4.91**	**0.203736**
Services	**2.73**	**0.366759**
Attended	**2.61**	**0.382765**
Shocks	**2.46**	**0.406074**
Phone	**2.44**	**0.409540**
Grievances	**2.30**	**0.434043**
Credit	**1.55**	**0.647172**
Femalehead	**1.40**	**0.713254**
Agriculture	**1.26**	**0.793666**
Mean VIF	**2.41**	

Appendix E

a. Regression analysis 2005/06 without the observation of Nairobi

Variable	ln_Solar		
	(1)	**(2)**	**(3)**
Attended	**.0327158****	**.0645515****	**.0646343*****
	(.0149783)	(.0227114)	(.0220426)
Owner	-.0022239	5.74e-06	-.000192
	(.0064597)	(.0066941)	(.0064957)
Credit		-.0145773	**-.0145759***
		(.0086191)	(.0064957)
Shocks		**.0000133***	**.0000134****
		(6.50e-06)	(6.03e-06)
Corruption		.0026473	.0026085
		(.0092787)	(.0089933)
Femalehead		.0097903	.0095803
		(.0110256)	(.0094131)
Phone		-.0072293	-.0072092
		(.0050532)	(.0049004)
Agriculture		.0249453	.0240418
		(.0269874)	(.0139348)
Manufacturing		.0355337	.034815
		(.0397175)	(.0344051)
Services		-.0012439	
		(.0315147)	
Constant	-2.438937	**-7.719801****	**-7.632514*****
	(1.213738)	(3.503394)	(2.64847)
Observations	50	30	30
Adjusted R-Squared	0.0724	0.1707	0.2121

*** p < 0.01; ** p < 0.05; * p < 0.1

b. Regression analysis 2015/16 without the observation of Nairobi

Variable	Solar		
	(1)	**(2)**	**(3)**
Attended	**.2892436*****	**.3299125*****	**.3319217*****
	(.1022634)	(.1155864)	(.1163616)
GCPperc	-.0000443	**.0001907****	**.0001726***
	(.0000638)	(.0000845)	(.000077)
Credit		.0224128	-.0507129
		(.0968235)	(.0883725)
Shocks		0.1046996	.0892955
		(.0869248)	(.0872787)
Grievances		-.0037181	.1642658
		(.2098196)	(.1972074)

Femalehead		-.150791	-.2411361
		(.1925934)	(.191364)
Phone		**-.4548718****	**-.4009468****
		(.1752554)	(.1616328)
Owner		-.1062184	
		(.1495824)	
Agriculture		**1.76917****	**1.350731***
		(.7015461)	(.6666539)
Manufacturing		**-.4522737***	
		(.2404563)	
Services		-.2282754	**-.4007651*****
		(.1706814)	(.1103274)
Constant	-5.354447	17.07902	11.01354
	(7.87542)	(19.90071)	(11.82536)
Observations	45	45	45
Adjusted R-Squared	0.1276	0.4845	0.4569

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$