LUND UNIVERSITY
SCHOOL OF
ECONOMICS AND
MANAGEMENT

Master's Programme in Innovation and Global Sustainable Development

Renewable Energy Sources and Energy Poverty

A Global Empirical Analysis of Renewable Energy's Effects on Energy Poverty

by

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The availability of energy is an overarching measure connected to various aspects of poverty. Energy Poverty, as a concept, captures the deprivation of access to energy, clean and safe fuels and end-appliances. While measures to reduce energy poverty increase the demand for energy, greenhouse gas emissions must decrease to mitigate the worst impacts of climate change, rendering renewable energy sources (RES) the predominantly applied measure. As varying effects for different RES can be expected, understanding the interconnection of RES and energy poverty among the background of different levels of institutional quality (IQ) is crucial to give sound policy advice. Applying a dual analysis of static (GLS) and dynamic (GMM) panel regression models, these effects were explored. It can be concluded that: (1) RES have a positive effect on energy poverty reduction, with solar energy obtaining the largest effects, (2) however, these effects are relatively small, ranging from 0,1 to 0,4 percent decreases in energy poverty, and (3) IQ shows to have a promoting effect on RES' energy-poverty-reducing effects. From these results, it can be deduced that there are no counter-effects between the goals of energy poverty reduction and the transition to renewable energies; in fact, RES seem to have a positive impact on both goals.

Keywords: Energy Poverty, Renewables, Institutional Quality, GLS, GMM

EKHS34
Master's Thesis (15 credits ECTS)
May 2022
Supervisor: Alexandra Nikoleris
Examiner: Jutta Bolt
Word Count: 15,941

Acknowledgements

I would like to state my gratitude for the support from my supervisor in this process. Additionally, I am thankful for being surrounded by wonderful friends and - even if only digitally - by my family.

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List of Abbreviations

AB	Arellano-Bond	OECD	Organisation for Economic Co-operation and Development
AR(1)	First Order Auto-Regressive	OLS	Ordinary Least Squares
bp	British Petroleum	PV	Photovoltaic
EER	European Electricity Review 2022	RE	Random-Effects
EPI	Energy Poverty Indicator	RES	Renewable Energy Sources
FE	Fixed-Effects	SDG	Sustainable Development Goals
GDP	Gross Domestic Product	SE4ALL	Sustainable Energy for All Data Bank from World Bank
GLS	Generalized Least Squares	SSA	Sub-Saharan Africa
GMM	Generalized Method of Moments	UNDP	United Nations Development Programme
IEA	International Energy Agency	UNPD	United Nation Population Division
IQ	Institutional Quality	USD PPP	United States Dollar Purchasing Power Parity
IRENA	International Renewable Energy Agency	VIF	Variance Inflation Factor
ITU	International Telecommunication Union	WB	World Bank
kWh	Kilowatt-hour	WDI	World Development Indicator databank
MEPI	Multi-Dimensional-Energy-Poverty Index	WGI	Worldwide Governance Indicator databank
MJ	Megajoule	WHO	World Health Organisation

1 Introduction

In 2015, still 10 percent of the global population lived in extreme poverty (United Nations, 2015c). Poverty can interplay, affect, and manifest in almost every aspect of living, from a ”lack of income and productive resources to ensure sustainable livelihoods [to] hunger and malnutrition, [a] limited access to education and other basic services, social discrimination and exclusion, as well as the lack of participation in decision-making” (United Nations, 2015a, n.p.). There are rarely universal solutions to multidimensional problems, which complicates the search for and use of appropriate measures. However, an overarching measure connected to all aspects of poverty is the availability of energy. In the words of González-Eguino (2015, p. 379), “energy consumption is necessary, but not sufficient in itself, for development”. González-Eguino (2015) found a close relation between development indicators, like the Human Development Index, life expectancy or economic performance and per capita energy consumption of a country. This gives a first indication of the enabling impacts which energy access can have on a population. On the other side, the deprivation of access to safe energy sources, or any form of energy source, has devastating effects on the development of populations and individuals, in terms of the Millennium Development Goals (Bhide & Monroy, 2011). This type of deprivation is called energy poverty and in this analysis it will be defined as *an insufficient level of access to clean and safe energy sources as well as end-use appliances to access existing energy for the fulfilment of basic living conditions (heating, cooking, lighting) and development activities (e.g internet).*

While energy poverty hampers development opportunities, it is also largely a health issue. It is estimated that in 2021, still, approximately 2.6 billion people used solid cooking and heating fuels, like wood, kerosene, biomass and coal (World Health Organization, 2021). The use of biomass in indoor facilities leads to great health burdens due to indoor pollution. In India, for example, the impact of this was estimated to be a loss of 1,6 to 2,0 billion days of work annually (Bhide & Monroy, 2011). The World Health Organisation states that indoor pollution, from unsafe cooking fuels and technologies, leads to around 3.8 million premature deaths per year (World Health Organization, 2021). Moreover, the implications of energy poverty are not evenly distributed across low-income household members. Women and children are disproportionately exposed to the risks and negative impacts of solid fuels as they are still the primary caretakers of cooking and household chores and therefore spend more time indoors (González-Eguino, 2015).

Economic sectors are also affected by energy poverty. Garba and Bellingham (2021) found significant evidence that the reliance on solid fuels has a negative, short- and long-term impact on economic development. González-Eguino adds to this that “energy poverty affects all production sectors and limits [the] potential for development” (González-Eguino, 2015, p. 382).

Through the above-mentioned chains of effects, it becomes visible that energy poverty itself has far-reaching and negative effects on development outcomes, and can lead to poverty traps where chances of development reduce with increasing levels of energy deprivation. However, this also stresses the potential poverty-alleviating effects of increased access to safe energy sources, enabling widespread sustainable development and calls for rapid action. While progress has already been made, today still 770 million people do not have access to electricity and around 3 billion have no access to clean and safe fuels for cooking and heating (IEA, 2022c; Roser, 2021).

The close connection of energy and poverty, as explained above, emphasizes that measures to address energy poverty must be taken immediately to enable sustainable development for all. However, an increase in energy access implies an increase in energy usage. The question arises as to how meeting the world's growing energy demand can be in harmony with the global energy transition towards renewable energies. The provision of energy services is a major contributor of greenhouse gas (GHG) emissions and a severe cause of climate change (Moomaw, Yamba, Kamimoto, Maurice, Nyboer, Urama & Weir, 2011). This stresses the need for emission-free energy sources. As a possible solution to decoupling the energy sector from GHG emissions renewable energy sources (RES) have been proposed and widely accepted (Moomaw et al. 2011). Increasing the share of RES and alleviating energy poverty appear to be connected goals. This perception is also supported by the United Nations. They define both goals as sub-goals of the Sustainable Development Goal (SDG) 7, which aims to "[e]nsure access to affordable, reliable, sustainable and modern energy for all" (United Nations, 2015b, n.p.). Sub-goal 7.1 addresses energy poverty by setting the goal of ensuring "universal access to affordable, reliable and modern energy services", while sub-goal 7.2 aims to further expand renewable energies in terms of their share in the global energy mix (United Nations, 2015b, n.p.).

1.1 Research Problem

A two-sided problem unfolds. Energy poverty must be addressed and effectively decreased, due to its immediate impact on several development aspects and health impacts for the affected individuals, as addressed above. These measures increase access to electricity and safe fuels, which translates into higher demand for these goods. In parallel, the energy transition toward reducing GHG emissions must progress rapidly to mitigate the worst impacts of climate change, making renewable energy sources the most appropriate measure to achieve this goal (Moomaw et al. 2011). In addition, when addressing a multidimensional issue, it can be assumed that there is no one-size-fits-all solution, and the respective institutional context of a region might have an impact on the effects of renewable energies on energy poverty. In order to successfully pursue both goals, possible interrelationships must be understood against the backdrop of diverse institutional settings. Could RES be used as a tool to address energy poverty? Or does the implementation of RES trigger counter-effects? Could achieving the transition to "green" energy possibly leave people behind, stuck in energy poverty spirals? Furthermore, do these effects vary for different RES and levels of institutional quality of the country? These are the broad questions this analysis aims to answer, and to give some indications of correlations and possible counter-effects between RES and energy poverty.

Recent research aimed to understand the relation between renewable energy and energy poverty but so far differentiations between types of RES, like solar, wind or hydro power have been missing. Due to different characteristics of energy sources, which will be elaborated on later, it can be expected that their effects on energy poverty vary. To draw more concrete and useful conclusions, it is important to differentiate between the different forms of renewable energies. Additionally, there has been a lack of consideration of the influences of institutional quality in the location of RES implementations. To address these issues, this study aims to answer the following research question and sub-research questions:

(1) Do renewable energy sources influence the issue of energy poverty?

(1.1) Do effects vary for different renewable energy sources, like solar, wind or hydro power?

(1.2) At last, does the context, in the form of institutional quality, influence these effects?

1.2 Aim and Scope

The aim of this study is to understand the influences of RES on energy poverty, as well as further investigate these effects in different institutional quality contexts of countries. To achieve this, an empirical approach is applied, using country-level data from 167 countries covering the timespan from 2000 to 2019. The country sample was purposefully not limited to developing or developed countries to give a truly global understanding and include emerging countries too. The most heavily affected area of energy poverty is Sub-Saharan Africa (SSA), as can be seen in Figure 1.1 below (UNDP & World Health Organization, 2009). Therefore, all SSA countries are included in this sample to ensure this is appropriately covered. Country-level data is, however, not available for all observed years. Research has often focused either on developed or developing countries separately, which ignores a more holistic perspective on the subject by the use of a global sample (Zhao, Dong, Dong & Shahbaz, 2022). To capture the multidimensionality and enable a wide coverage of country-years, a composite indicator is generated for energy poverty. The global distribution of energy poverty, as measured by the composite indicator for the year 2019, can be seen in Figure 1.1 below.

For the methodological approach, a dual analysis has been conducted by calculating the effects through a static and a dynamic panel regression model, to assure a level of robustness of the results. After the generation of a composite indicator for institutional quality, a sub-analysis is calculated based on four groups of institutional quality, from low to high. Through these analyses, an improved source- and context-specific understanding of the impacts of RES on energy poverty is gained. This type of knowledge is relevant for policy advice to avoid countereffects between actions addressing renewable energy implementation and energy poverty alleviation, as only when both issues are addressed adequately true sustainable development is possible.

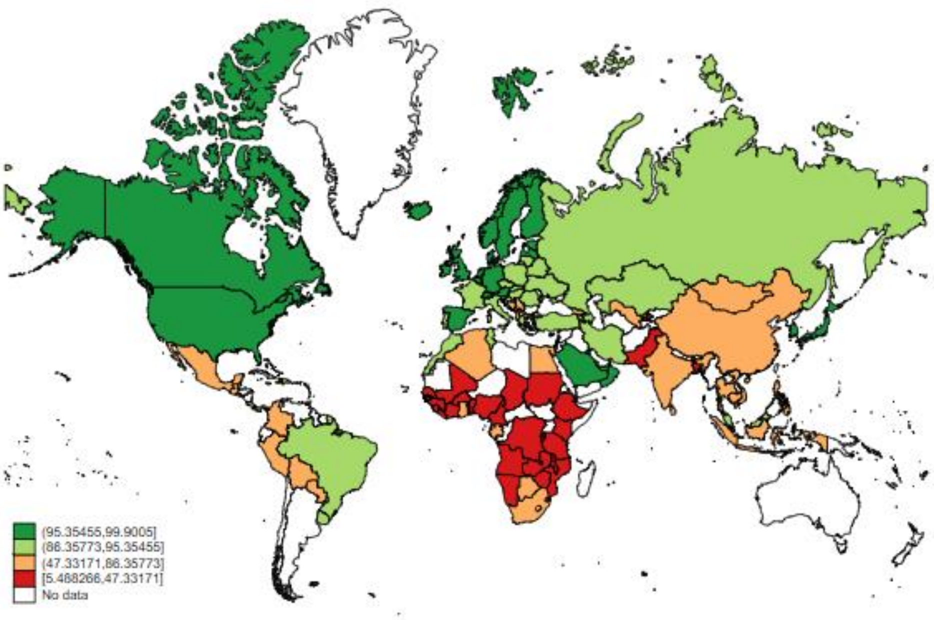

Figure 1.1 Energy Poverty in 2019 (author's elaboration based on (The World Bank, 2022)

Note: Based on the composite indicator for energy poverty (addindex_ep) on a scale from 0 (no access to electricity, safe and clean cooking fuels and technologies and the internet) to 100 (full population has access to all three categories), not all in the analysis included countries are visible in this figure

1.3 Outline of the Thesis

After explaining the need for an improved knowledge base on the effects of RES on energy poverty and defining the aim and scope in chapter one, chapter two will provide an overview of the previously published literature and define gaps. In the following, chapter three will explain the theoretical background and give definitions of energy poverty and institutional quality. The methodology, including the empirical strategy as well as the choice and sources of variables, will be described in chapter four. Followed by the empirical analysis, including the display of the results, their discussion, as well as a test of their robustness and a discussion of the limitations of this study in chapter five. Finally, chapter six concludes the main findings of this study.

2 Literature

In the following chapter, an overview of previously conducted research will be presented. This overview will be covering the concept and definition of energy poverty, the diverse angles that have been applied to analyse the topic of energy poverty and its connection to renewable energy. In addition, existing research concentrations concerning the location, sample size and type of renewable energy resource are identified. To assure a level of quality, the literature ranking was validated using the Norwegian Register for Scientific Journals, Series and Publishers and literature that was published in journals ranking lower than rank one was excluded from this overview (Norwegian Directorate for Higher Education and Skills, 2019).

The topic of energy poverty has gained much interest in recent years. However, the difficulty surrounding this topic begins with a missing common understanding of the term itself. Energy poverty, like poverty, is a multidimensional concept. Its development and sustainment are influenced by multiple aspects, such as energy costs, household income as well as the available energy infrastructure and energy efficiency (Henry, Baker, Shaw, Kondash, Leiva, Castellanos, Wade, Lord, van Houtven & Redmon, 2021). This characteristic led to various definitions being used across the literature, but at their core, all definitions aim to capture aspects concerning an *insufficient satisfaction of energy needs* for basic living conditions, such as heating, lighting, and cooking. Different definitions are also used in relation to different contexts. The EU defines it as a situation in which households are unable to meet domestic energy needs (European Commission, Directorate-General for Energy, Bouzarovski, Thomson, Cornelis & et al. 2020). The United Nations' definition, in the context of developing countries, is a lack of access to electricity and clean cooking fuels and technologies (United Nations, 2018). This definition is shared by the International Energy Agency (2010). In developed countries "fuel poverty" is often added to this, referring to the inability to adequately heat one's home (Boardman, 2012). Clear benefits of these types of definitions are the concreteness and separability of the included dimensions, which increases the availability of data and therefore enables a higher coverage of country-year observations. Nevertheless, these definitions have strong limitations in covering the whole concept of energy poverty, as not only insufficient access contributes to it. To address these limitations more nuanced definitions were developed. A widely used definition of energy poverty has been brought forward by Reddy (2000, p. 57) and defines energy poverty as the "absence of sufficient choice in assessing adequate, affordable, reliable, high-quality, safe, and environmentally benign energy services to support economic and human development".

As a consequence of the lack of a common understanding of the concept of energy poverty, there is also no universally accepted approach to measuring energy poverty in the current literature. Often, one-dimensional indicators, like the percentage of the population with access to electricity or access to clean and safe cooking fuels, are used (Bhide & Monroy, 2011; Garba & Bellingham, 2021; González-Eguino, 2015). However, due to this lack of agreement, it became a more common practice to develop indicators and proxies that best fit the individual analysis and research question. Zhao et al. (2022), for example, applied an approach similar to this study, by generating a composite indicator prior to the analysis in order to have a comparable indicator for their global sample. To accommodate the multidimensional characteristics of energy poverty, indicators like the Multi-Dimensional-Energy-Poverty Index (MEPI) by Nussbaumer, Bazilian and Modi (2012) are applied. The MEPI captures a "set of energy deprivations that may affect a person" (Nussbaumer, Bazilian & Modi, 2012, p. 235). While other indicators focus on accessibility aspects of energy the MEPI places a focus on the "deprivation of access to modern energy services" (Nussbaumer, Bazilian & Modi, 2012, p.231). The services referred to are categorized in five dimensions: cooking, lighting, services provided by means of household appliances, entertainment and communication. Wang, Wang, Li and Wei (2015) give another example for the case of China, where they developed an index tailored to the circumstances and context of the region. One disadvantage of this inconsistent application of indicators, is that the comparability between the existing research findings is difficult, if not impossible.

As this topic is highly multidimensional, there are a myriad of perspectives on it. The literature often focuses on the impact of energy poverty on general development outcomes, which leads to the well-understood positive effects of energy poverty reduction on outcomes like GDP (Garba & Bellingham, 2021), income inequality (Nguyen & Nasir, 2021), health or education (Oum, 2019) that exist today. Electrification, regardless of its origin, has been found to have positive effects on economic growth, income inequality and the labour market. In the case of SSA, Chirambo (2018) found that an increased level of electrification has led to improved levels of economic growth and reduced inequality as well as poverty. This relation stresses the multiplicator effect electricity access, and energy access, have on other SDGs.

Nonetheless, regarding the impact of renewable energy on energy poverty, the literature is still divided and requires more attention. Two perspectives have been represented among scholars. One side found that renewable energy is conducive to moving away from energy poverty (Adom, Amuakwa-Mensah, Agradi & Nsabimana, 2021; Chirambo, 2018; Hamed & Peric, 2020; Liu, Huang, Wang & Shuai, 2021; Pereira, Marques & Fuinhas, 2019). The other side raised arguments to the contrary (Bhide & Monroy, 2011; Henry et al. 2021; Mastropietro, 2019; Stram, 2016).

The strand of literature that points to the countereffects of RES on energy poverty identifies the aspect of higher costs associated with the installation and maintenance of renewable energy systems, which has been shown to have a countereffect and increase energy poverty in certain households (Bhide & Monroy, 2011; Henry et al. 2021; Mastropietro, 2019; Stram, 2016). Bhide and Monroy (2011) addressed the economic barriers of using RES as a tool to decrease energy poverty, in the case of India. They further manifested the counter-effective mechanism of RES if a lack of subsidies is present. Together with high initial investment costs and "high transaction costs from small decentralized systems" that RES entail, the positive impacts of renewables are prevented from unfolding, which mitigates or even reverses their potential impact on poverty reduction (Bhide & Monroy, 2011, p. 1061). Henry et al. (2021) analyzed the effects of renewable energies on energy poverty in Guatemala and found a negative correlation. They concluded that a transfer of one percent of the additional generation costs associated with RES to the consumer, through a tariff, would lead to a two to three percent increase in energy poverty on a household level. In cases of developed countries, these negative effects of cost transfer were also observable. In Germany and Denmark, an increase in energy prices followed the integration of RES into the grid, which triggered counter-productive effects in terms of energy poverty reduction (Stram, 2016). From this divide in the literature, it certainly becomes clear that the connection and interaction between renewable energy and energy poverty is not straightforward or universal. The context of implementation, the type of RES, and the framework of provision play with a high likelihood a grand role in its final effect.

This question of what role concrete types of RES play in alleviating energy poverty has been a more recent one (Hamed & Peric, 2020; Henry et al. 2021; Liu et al. 2021). Up to now, only a few quantitative studies have addressed this topic (Atems & Hotaling, 2018; Baurzhan & Jenkins, 2016; Henry et al. 2021; Liu et al. 2021; Zhao et al. 2022), and studies using qualitative methods are even sparser (Hamed & Peric, 2020). Solar, wind and hydro power technologies all have different characteristics, prerequisites and benefits. Therefore, it can likewise be assumed that they could differ in their effects on energy poverty, which stresses the importance of understanding their varying effects to adequately implement RES. This differentiation between these sources of renewable energy has been lacking in the literature. When RES are addressed, the focus is most often placed on solar photovoltaic (PV) (Baurzhan & Jenkins, 2016; Liu et al. 2021). Liu et al. (2021) quantified the poverty-reducing effects of solar PV projects in rural China through a quasi-natural experiment and a Difference-in-Difference analysis. Baurzhan and Jenkins (2016) analysed the feasibility of off-grid solar PV in SSA, in terms of their impact on costs, the environment and in their abilities to reduce poverty. Furthermore, Pagliaro and Meneguzzo (2020) gave an overview of the developments of distributed electricity generation from solar PV in a selected sample of developing countries and elaborated on their potential for reducing poverty. This gravity of the literature on solar energy is also mentioned by Zhao et al. (2022), but despite their acknowledgement of this deficit, they also did not address this needed differentiation in their quantitative analysis of RES on energy poverty, hence, still leaving this gap open for further research.

From a geographic perspective, the focus is often laid on both extremes of the spectrum of energy poverty – either on countries suffering most severely from energy poverty, often developing countries, where one would talk about absolute energy poverty or countries where one would talk about relative energy poverty or fuel poverty. This led to a majority of research addressing SSA, (Adom et al. 2021; Chirambo, 2018; Crentsil, Asuman & Fenny, 2019; Garba & Bellingham, 2021), as well as parts of Asia (Bhide & Monroy, 2011; Hamed & Peric, 2020; Liu et al. 2021) or OECD countries (Topcu & Tugcu, 2020; Mastropietro, 2019). A consequence of this is that emerging economies were disproportionately left out of the analyses. As developing countries are continuously aiming to develop sustainable and viable economies, this group of countries is increasing and is already playing an important role in terms of its energy requirements and climate goals (Muhammad, 2019). With a growing economy, an increase in emissions is also expected and should be addressed by the use of renewables (Cantarero, 2020). This stresses the need for a thorough understanding of the effects RES can have on a society and especially on other development outcomes than GDP growth – like energy poverty – using more diverse country-group samples.

While a more diversified sample group is needed, the sample size should also be increased in order to get a more holistic understanding of the interactions between RES and energy poverty and to be able to differentiate and compare differences in impacts. Three fairly recent examples of an approach like this are McGee and Greiner (2019), Atems and Hotaling (2018), and Zhao et al. (2022). McGee and Greiner (2019) investigated the effects of renewable energy consumption on income inequality and afterwards its environmental impacts, by conducting fixed-effects panel regression models including 175 nations over the time span from 1990 to 2014. Another example of a broader coverage is the study by Atems and Hotaling (2018) where a sample of 174 countries from 1980 to 2012 is used. Employing a system Generalized Method of Moments they contrasted the influences of non-renewable sources on economic growth against renewable sources and found positive effects from both. Using the same methodological approach as Atems and Hotaling (2018), Zhao et al. (2022) estimated the dynamic impact of renewable energy on poverty reduction using a smaller sample of 64 countries for the time span from 2000 to 2014. While some examples of a broader analysis are present, many questions remain unanswered when it comes to global estimates, as the majority of research focuses on single country analysis (Zhao et al. 2022).

Whereas differentiation between degrees of economic development of countries has been done in previous literature, still a stronger acknowledgement of the institutional context and environment is missing (Zhao et al. 2022). Sparsely covered in the literature is the role of the government influencing the effect of RES on energy poverty. Using total final government consumption expenditures and a proxy for institutional quality in a global panel analysis, Nguyen and Su (2022) analysed the effects of government spending in relation to energy poverty. They found that institutional quality serves as a “critical catalyst for the effects of government spending”, stressing the importance of taking the institutional context into consideration for future analyses (Nguyen & Su, 2022, p. 7). Hamed and Peric (2020) chose a qualitative approach by reviewing energy reports, political concepts, and peer-reviewed journals to better understand the status-quo, mechanisms and obstacles of addressing energy poverty via the employment of RES in Palestine. They focused on the influence of political stability within Palestine and its dependence on Israel, in the context of RES’ energy-poverty-reducing capabilities. Moreover, a widely recognised crucial intervention by governments is subsidies to address the aspect of energy affordability, which is closely linked to the extent of energy poverty. To estimate the trade-offs of reaching renewable energy goals and alleviating energy poverty in Guatemala, Henry et al. (2021) applied a spatial analysis of the cost developments of RES, as well as an empirical analysis of household attributes based on survey data from 2014. While most of the above-mentioned analyses conclude and advise differentiated action by governments to account for income-level differences of households, the institutional quality, with possible influencing effects, is hardly ever taken into consideration. This suggests the necessity to adopt a more nuanced view on the effects of RES on energy poverty. A list of comparable studies can be found in Appendix A.

This analysis aims to contribute to the field in three ways: (1) by applying a global perspective and including not only developed or developing but also emerging countries, to have a holistic sample, (2) by differentiating between types of RES, namely solar, wind and hydro energy sources, which appears to have not been done previously, and (3) by giving a better understanding of the influence of the institutional environment of a country on the poverty-alleviating effects of RES. For this, a proxy of institutional quality will enable a sub-sample analysis of the different quarters of countries, rating in the first, second, third and fourth quarter, ranging from low to high institutional quality.

3 Theoretical Background

To give context to the addressed research question, this chapter will establish the theoretical background. The chosen definition and the measurement approach for energy poverty will be explained. Mechanisms and influences between RES and energy poverty will be highlighted, this includes general beneficial and counter-effects, as well as the specific effects of solar, wind and hydro power. At last, the theoretical relation between the selected control variables of the model and energy poverty will be explained.

3.1 Energy Poverty

In this analysis, the term energy poverty describes *an insufficient level of access to clean and safe energy sources as well as end-use appliances to access existing energy for the fulfilment of basic living conditions (heating, cooking, lighting) and development activities (e.g internet)*. This definition of energy poverty is a combination of the European Commission et al.'s (2020) and the United Nations' (2018) definitions with an addition regarding the usage possibilities of electricity, which is inspired by the approach applied by Nussbaumer, Bazilian and Modi (2012). The here taken definition covers dimensions of *accessibility* of energy, *quality* of the source as well as *usability* of the energy, in terms of its usability through energy end-use appliances.

To take the complexity of energy poverty into consideration, a multidimensional approach is taken in this analysis. As Nussbaumer, Bazilian and Modi (2012, p.232) explained, "single indicators are often unsuitable for less tangible issues". The MEPI by Nussbaumer, Bazilian and Modi (2012) would have been interesting to use as a proxy for energy poverty but it is based on survey data and therefore limits the time continuity of the variable, which makes it less fitting for a global scope. Therefore, a composite indicator covering the percentage of the population with access to electricity (*accessibility)*, with access to clean and safe cooking fuels (*quality of source)*, as well as the percentage of population with access to the internet (*usability)*, is chosen here as a proxy for energy poverty on an annual country-level. The first two indicators are widely applied as proxies for energy poverty (Nguyen & Su, 2022). However, to measure energy usability, no common practice has been found in previous studies. Capturing this dimension of energy poverty is crucial, as the sole electrification of a region does not immediately lead to an increase in usable energy (Lee, Miguel & Wolfram, 2020). The reasons for including internet access as a proxy for energy usability are three-fold. First, end-use appliances that give access to the internet must be powered by electricity and therefore have a direct connection to energy access. Second, the variable used does not indicate that the person accessing the internet has ownership over the end-use appliance. Therefore, both sides of consumers, private owners and users of public devices are taken into consideration, as the actual ownership does not matter for the purpose of alleviating energy poverty, as long as access is provided. Third, appliances that provide internet access have a higher attractiveness compared to other appliances, as the internet provides access to various educational materials, communication channels and so on. Therefore, it can be assumed that if a household or individual has usable energy access, it will use such a device. This assures an appropriateness of this measure to proxy if energy is usable.

3.2 Institutional Quality

This analysis aims to fill an existing gap in the literature, as pointed out in chapter two, by focusing on the context of different levels of institutional quality of countries, in the light of the effects of RES on energy poverty. The influence of the institutional environment on the energy sector as well as on poverty-reducing measures has been proven before and that governments have a crucial role in this has already been identified (Hamed & Peric, 2020). Particularly, institutional quality has already been established as a "critical catalyst for the effect of government spendings on energy poverty" (Nguyen & Su, 2022, p. 7). High institutional quality provides incentives for investments in RES installations, such as wind or solar plants. It guarantees a level of safety and security for the business and its infrastructure, as unrest in a country can be a threat to this (Adesanya & Pearce, 2019). This connection led to the hypothesis that in relation to the impact of renewable energies on energy poverty, institutional quality must also play a formative role. Following Nguyen and Su (2022) the World Bank's Worldwide Governance Indicator databank is used to measure the institutional quality of a country on an annual basis (Kaufmann, Aart & Massimo, 2010b). A composite indicator using an additive mean approach was employed to condense the six available indicators from the databank into one proxy for institutional quality. These indicators were control of corruption (*ccor*), government effectiveness (*gef*), political stability and absence of violence/terrorism (*ps*), regulatory quality (*regq*), rule of law (*rol*) and voice and accountability (*vaa*) (Kaufmann, Aart & Massimo, 2010a).

3.3 Renewable Energy and Energy Poverty

While it can be assumed that non-renewable energy sources can also improve access to electricity and energy, they differ from RES in essential core elements. As non-renewables are not compatible with a climate-friendly energy system and the transformation of it, they are not treated as an energy-poverty-reducing option in this study. The focus lies on those energy sources that are compatible with climate goals. As these are the only long-term sustainable and thus relevant option to achieve both goals of reducing energy poverty and developing a climate-friendly energy system. RES possess some specific characteristics which clearly differentiate them from their counterparts – non-renewable sources, like fossil fuels. These characteristics are formative for the impact that renewable energy can have on energy poverty and will therefore be discussed in the following paragraphs.

First, RES are characterised by their *independence* on multiple levels. They are not reliant on fuels that have to be rebought. RES can therefore be operated without the reliance on the availability of fuels on the market, which makes them more resilient to price shocks and enables implementation in rural areas. With energy costs becoming more predictable, renewable energy improves the affordability and availability of energy in rural areas (Duarte, García-Riazuelo, Sáez & Sarasa, 2022). Furthermore, unlike fossil fuels, RES are more flexible concerning the location and scale of implementation, as they are not as bound to factor endowments and can be implemented in decentralized off-grid locations (Goldemberg, 2000). The construction of microgrids based on local sources enables faster access to energy, which helps to reduce energy poverty (Stram, 2016). Although less formative than for fossil fuels, factor endowment matters because the availability of sunlight, wind and suitable water flows is necessary for the efficient operation of RES and can make a significant difference in terms of the efficiency and cost-effectiveness of RES (Akpinar & Akpinar, 2005). The difference to fossil fuels is that these factors are largely available but so far untapped in rural areas of developing countries (Letcher, 2018b). At last, RES do not rely on pre-existing electricity grids and due to their local implacability can generate independence from a political standpoint. Hamed and Peric (2020) showed the advantages of this independence for Palestine, which is still heavily dependent on Israel for their energy access and therefore greatly vulnerable. RES can help countries become more resilient and independent regarding their energy supply. Recent developments in the context of the Russian-Ukrainian war have highlighted the importance of preserving a nation's political sovereignty, decision-making space and freedom of intervention that stems from its energy system (Tollefson, 2022).

Second, RES differentiate themselves from other energy sources through a better *health impact* (Hamed & Peric, 2020). In the short-term, this implies better health conditions due to the use of safer fuels, in comparison to solid fuels, that in the long-term can provide a lever out of potential poverty traps. Büchs, Bahaj, Blunden, Bourikas, Falkingham, James, Kamanda and Wu (2018) established two hypotheses, which could both be addressed through an improvement of the health implication of energy sources. The mobility hypothesis states that, due to poor health, people stay inside more, which leads them to use more electricity. The second hypothesis, the income hypothesis, on the other hand, refers to a spiral, where poorer health is the reason for a lower income. Due to this lower income, less energy can be used in the household. Both hypotheses leave the person vulnerable to energy price increases and therefore prone to energy poverty (Büchs et al. 2018). By enabling a safer and healthier life, RES can alleviate poverty, which concludes from these two types of poverty cycles, and have positive effects on a range of development outcomes, like life expectancy or employment (Adom et al. 2021; Hamed & Peric, 2020).

Third, in terms of *costs,* an advantage of RES is that they are available at a small scale which decreases the initial investment costs, making them more affordable (Stram, 2016). In areas with a relative abundance of required resources, like wind speed, land space, water streams or sun intensity, Henry et al. (2021) found that the implementation of RES could lead to a decrease in energy expenditures. The advantage of RES is that, while initial investment costs are large, the maintenance and operating costs are competitively low and have decreased significantly over the last decade (IRENA, 2020). Furthermore, this argument is supported by Adom et al. (2021), who point out that the levelized costs of RES are competitive and that increased affordability enables improved access which itself decreases energy poverty. This financial advantage is also present in the case of developing countries, as Adesanya and Pearce (2019) show in the case of Nigeria.

While positive effects of the implementation of renewable energy have been identified, there are also countervailing effects. As it has been pointed out in chapter two, these are primarily related to the monetary plan of the roll-out, i.e. where the additional costs are incurred and whether they are passed on to consumers through tariffs (Henry et al. 2021; Mastropietro, 2019). While in the long-term RES have shown to be less cost intense, the initial set-up costs represent one of the largest obstacles for poverty-reducing deployment of them (IEA, 2021b; Sovacool, Dhakal, Gippner & Bambawale, 2011). It is a common practice for energy sectors, in countries which incentivise RES deployment, to transfer the additional costs that are assigned to the energy sector, to the consumer via tariffs (Mastropietro, 2019). These additional costs are associated with the distribution networks and higher initial costs for small and decentralized systems (Bhide & Monroy, 2011). Pereira, Marques and Fuinhas (2019, p. 801) analysed the effects of RES on income distribution and energy poverty and found that the "costs of generation, transportation, and RES surcharges" are being paid for by the consumer and will keep increasing, which in turn increases the risk of energy poverty. A troubling mechanism of these tariffs is that a proportional increase in them, in terms of energy consumption, does not rise at the same rate through household income levels as income does (Mastropietro, 2019). Therefore, tariffs are having a financially more devastating impact on lower-income households and possibly generate counter-productive effects in terms of energy poverty alleviation. A trend becomes clear that where resources for renewable energy generation are abundant the generation costs can be low and competitive with other forms of energy sources. But not always do low-generation cost areas overlap with low-income areas. In overlapping cases, RES can be effective in alleviating energy poverty. If this is not the case, the benefits of RES are not reaching those that are in most desperate need of them (Henry et al. 2021).

3.4 Renewable Energy Sources

To better understand the effects different RES possibly have on energy poverty, the independent variables included in this model represent generated electricity from three RES: solar, wind, and hydro power. Each source inhibits its own characteristics bringing benefits and obstacles which leads to the hypothesis, that each source has individual specific effects on energy poverty and must therefore be analysed separately. By this differentiation, more concrete insights can be gained. To understand in what ways these RES differ from each other, a closer look will be placed on the individual effects of solar, wind, and hydro sources on energy poverty within this chapter.

Solar

Solar energy refers to the "conversion of sunlight into usable energy forms" and entails some individual characteristics, which will be elaborated on in the following (IEA, 2022a, n.p.). It is the fastest growing RES and fourfolded its capacity from 2011 to 2016 (Letcher, 2018b). Solar photovoltaic (PV) is one of the most commonly available and well-established technologies and often used in analyses concerning renewable energies' effects on energy poverty (IEA, 2022; Liu et al. 2021; Baurzhan 2016). One of solar energy's main benefits stems from its financial perks.The International Energy Agency estimated that despite currently rising prices, solar photovoltaic is still the "least costly option for adding new electricity capacity" for most countries across the world (IEA, 2022a). Great increases in capacity expansion between 2007 and 2011 led to a decrease of the prices of PV materials, like solar wafers, cells and modules (Jäger-Waldau, 2017). The prices of solar PV continued to decrease, making them competitive to other energy sources. The magnitude of the decrease since 2008 is estimated to be over 85 percent (Jäger-Waldau, 2017). This price competitiveness makes solar PV a suitable energy source to tackle energy poverty in many locations, as often the price is a determining factor making potentially available energy unaffordable for the low-income population. However, the initial capital investments necessary for solar energy are immense and estimated to make up 80 to 90 percent of the levelized costs of electricity generation (IEA, 2021b). For solar PV special equipment is necessary to convert the power to a usable form (Stram, 2016). These upfront costs present an obstacle in the poverty-alleviating mechanism of solar energy if they are transferred to consumers via feed-in-tariffs, which first and foremost harm the lower-income households (Pereira, Marques & Fuinhas, 2019).

Nevertheless, solar energy also brings a multitude of benefits and positive effects for poverty reduction. Advantages of solar PV cells, as mentioned by Letcher (2018) and Hamed & Peric (2020) are their modularity in production, which enables small and large-scale implementation, retrofitting as well as the independence from electricity grids. Liu et al. (2021) analyzed the effect of solar photovoltaic poverty-alleviating projects in China and found a positive effect for rural households, reducing poverty and increasing their economic conditions. Moreover, the energy from solar PV is versatile. It can be used in heating, cooking, lighting and more. At last, Letcher (2018a) states that especially in countries with a hot climate, where energy is required for air-conditioning during the day, the daytime peak of solar energy is conveniently lining up with the demand peak. Large potentials for solar energy remain "untapped" in Africa and the Middle East, where resource abundance of sunlight and land space is present but solar energy technologies still only in small concentrations (Letcher, 2018b, p. 11). This shows the high potential of solar energy in reducing energy poverty in developing countries. Electricity generated by solar PV is also safer and can be used on-site, which decreases transmission costs (Letcher, 2018b). Another benefit of this type of energy, as well as other RES, is the creation of local jobs, development and investments, which are built for the long-term as resources, in this case the sun, cannot be depleted. Therefore, solar energy development can create a safe and stable job market in local regions (Letcher, 2018b). Furthermore, in energy systems, dependencies are always a big topic. From this perspective solar PV might be able to change the position of the consumer. Consumers could become part of "Demand-Side Management (DSM) programs" by small-scale implementations of RES (Pereira, Marques & Fuinhas, 2019, p. 792). Thereby, RES are able to improve living conditions and hence tackle poverty.

Wind

The term wind energy is used to refer to both onshore and offshore wind turbines. Many benefits from wind power come from the matureness of the technologies utilizing wind power (IEA, 2022b). Nonetheless, there are also some obstacles involved in its implementation. Wind energy is more limited than solar energy due to a more uneven distribution of resources (Bhide & Monroy, 2011). It is characterized by a high volatility regarding its production capacity depending on its location and the local wind conditions (Comakli, Kaya & Sahin, 2008). Bhide and Monroy (2011, p. 1065) state that for small-scale wind farms, finding "perfect isolated locations with the current wind speeds" is an obstacle. With the height of the windmill ground the power generated increases, which indicates that the geographical conditions of a region can be a significant limitation to the possibilities of efficiently generating wind power (Akpinar & Akpinar, 2005). Regarding the costs, wind energy, like solar energy, requires high initial capital investments, which places a financial burden on the cost takers, be it a firm, the government or the consumer (Stram, 2016). Maintenance and operation costs, however, became with increasing scale and maturity of the technology competitive with other energy sources (IRENA, 2020). Prices hit a peak from 2007 to 2010 but have since then steadily decreased. Some reasons for this are technological advancements in production, increased market competitiveness, and economies of scale (IRENA, 2022). Furthermore, the costs of wind power are expected to continue on this trend and decrease to a range of 4.2 - 4.5 cents per kWh until 2030, which gives wind energy a competitive advantage in comparison to other fuels, like coal and natural gas (Williams, Hittinger, Carvalho & Williams, 2017). This cost level makes them attractive for investments and increases their potential of decreasing energy poverty by providing access. Additionally, the scale of on-shore wind projects which were tendered by governments increased by around 50 percent, making projects viable and therefore attractive for companies (IEA, 2018).

Hydro

Hydro power is defined as "a source of renewable energy obtained from flowing water" (Yıldız, 2018, p. 1221). The plants can be placed along rivers and streams but most often dams are built to regulate the water flow. This makes hydro power the "most reliable, technically exploitable, and environmentally friendly renewable energy alternative" (Yıldız, 2018, p. 1221). Hydro power is the most deployed RES today, while still leaving large amounts of its full potential untapped (Hussain, Sarangi, Pandit, Ishaq, Mamnun, Ahmad & Jamil, 2019). In 2019, hydro power was estimated to produce 16 percent of the global electricity and more than 80 percent of the global electricity stemming from renewables (Hussain et al. 2019). In addition, it also brings advantages for water storage in agriculture (Hussain et al. 2019).

It has been addressed before, that for rural areas with low population density, off-grid energy solutions are the most suitable and financially viable energy sources, and mini-hydro plants are one of these possible sources (Szabó, Bódis, Huld & Moner-Girona, 2013). Bhide and Monroy (2011) validated the financial viability of hydro power projects for the case of India, and declared that hydro energy sources proved to be very successful and efficient, as they can use indigenous technologies produced in India, which plays a role in its low maintenance and generation costs. A hypothesis can be made from this stating that those countries with technological capabilities regarding hydro energy sources, or any other RES, have a competitive advantage over other countries and are therefore more successful in harnessing the benefits of RES deployment.

Nonetheless, economic and social barriers do exist to the successful set-up and maintenance of hydro power plants. In terms of the financing of these projects, some obstacles occur for regions with low income. In a case concerning hydro power plants in Nepal, the local banks did not even have the required amounts of funding available which would be necessary for these projects making them impossible to fund (Sovacool et al. 2011). Furthermore, Sovacool et al. (2011) brought the obstacle of long lead times forward. Gaining approval and mastering all steps of construction until a project can start generating electricity hinders the positive effects that could come from hydro power (Sovacool et al. 2011). Additionally, the maintenance of these systems is highly complex and requires special training, which is often missing in developing countries and has to be imported, further increasing the costs (Sovacool et al. 2011). There are also social barriers to hydro projects, as they have been identified in the project placed in Nepal. Villages based up- or down-stream from the hydro power plant have problems finding agreements on how water resources, the costs of the plant or the electricity itself should be distributed (Sovacool et al. 2011). As hydro power implementation requires significant land changes, local communities often experience the immediate negative consequences of these projects, namely, the displacement of houses and livelihoods (Hussain et al. 2019).

3.5 Further Determinants

The applied model integrates a selection of control variables to give a more complete simulation of energy poverty. These control variables are government spending, energy intensity, GDP per capita and the level of urbanization. The theoretical background behind the inclusion decision of every variable will be stated in the following paragraphs.

Government Spending

Nguyen and Su (2022) conducted a panel analysis based on 56 developing countries for the years between 2000 and 2015 to understand the influences government spending has on energy poverty. They found an inverted U-shaped relation, meaning that government spending reduces energy poverty up to a certain level. After this threshold has been reached additional expenditures increase energy poverty. An explanation for this is that high amounts of public spending can have a crowding-out effect which is an obstacle to the effectiveness of fiscal policies (Kandil, 2017). Due to this shaping role of government spending, it is included in this model as the general government final consumption expenditure. The unit of measurement is the percentage of government expenditure compared to the country's GDP on an annual basis. The expected direction of the coefficient of government spending is positive, therefore energy-poverty-reducing.

Energy Intensity

Energy intensity expresses how much energy is necessary to produce a unit of economic output. It, therefore, has an important function for energy poverty on a household level, as a higher intensity can lead to large losses of energy, hence increasing the costs (Li, Chien, Hsu, Zhang, Nawaz, Iqbal & Mohsin, 2021). The hypothesis can be made that lower intensity comes from a more efficient generation or usage of energy, which enables need satisfaction with fewer resources and therefore decreases energy poverty. RES are a possible tool to reduce the energy intensity, as they have shown a promising path of development towards reduced energy intensity, or energy efficiency, so far and are expected to continue on this path (IRENA, 2017). Increased efficiency leads to a smaller amount of energy being necessary to fulfil the same needs. Zhao et al. (2022) conclude in their work that this will lead to a decrease in energy consumption. More precisely, they state that a one percent increase in RES leads to a 0.007 percent increase in efficiency and an increase of one percent in efficiency leads to a 0.036 percent decrease in energy poverty (Zhao et al. 2022). However, they also disclaim that this effect is mostly present in European countries and that it is not transferable to other areas (Zhao et al. 2022). Based on this, a negative effect on energy poverty is assumed, meaning that a reduced intensity leads to a decrease in energy poverty. Energy intensity is included as the energy intensity level of primary energy in megajoule (MJ) per 2011 USD PPP.

GDP per capita

Economic wealth and growth enable investments into energy projects and generate access to safer and cleaner energy sources. In a country with a higher GDP per capita, more energy consumption can be expected, which functions as an incentive for firms to establish themselves and commit to long-term projects like energy plants (Komal & Abbas, 2015). Financial ability of households enables them to make a choice regarding energy consumption and the type of fuel they use. This illustrates that GDP and energy consumption are closely connected (González-Eguino, 2015; Yu & Choi, 1985). Causality is difficult to predict here, as electrification also has positive effects on the economy. RES, in specific, make it possible to achieve positive economic effects in the longevity, as they are essentially designed for the long term and the necessary resources for energy production do not run out. A more stable labour market can thus be created, possibly increasing a country’s GDP per capita, as the industry of renewable energy plants and projects have long lifetimes (Letcher, 2018b). This leads to the conclusion, that a positive direction of the GDP per capita estimates is assumed, indicating an energy-poverty-reducing effect.

Urbanization

The relation between urbanization and energy poverty has not been studied to a high extent as research tends to focus on one of these two dimensions instead of on its interconnection. However, in general terms, energy poverty, captured in the amount of consumed energy, has been seen to decrease with rising urbanization (Mahumane & Mulder, 2022). Additionally, a common agreement in the findings is that in rural areas, in comparison to urban areas, energy poverty is more present, as grid connections are more difficult to establish (Liu et al. 2021). This is one reason why urbanization is accompanied by more sophisticated infrastructure systems, such as energy grids. A higher population density additionally works as an incentive for investment due to higher present demand, in comparison to rural areas (Besley, 1995). This leads to the assumption of a positive effect of increasing urbanization on energy poverty.

Institutional Quality

Institutions are "the implicit and explicit rules by which the members of society interact, [they] shape the economic behaviour of agents and help explain the economic performance of countries" (Chong & Calderón, 2000, p. 761). Problems with IQ can express themselves in the form of uncertainties which lead to instability and then unproductiveness in the market. Due to this, the IQ of a country is crucial for its economic performance (Chong & Calderón, 2000). Likewise, it is connected to poverty and energy poverty. High IQ gives a level of security to investors and therefore works as an incentive for them to set up an energy plant or even a whole grid. Without this level of security, the risk and the indirect costs of the transaction are often regarded as too high for such long-term projects like energy development (Cuervo-Cazurra, Silva-Rêgo & Figueira, 2022). Therefore, the assumption is placed that with increasing IQ the magnitudes of the effects of RES on energy poverty increase.

4 Methodology

The chosen methodological approach, to address the proposed research questions, will be explained in the following chapter, including the model specification. A dual analysis of both a static and a dynamic panel regression model are applied to gain relatively robust insights into the influences of specific RES on energy poverty. In the subchapter 4.1, the specifications of both models are elaborated and the results of diagnostic tests are presented. This is followed by chapter 4.2, in which the selection of variables, the generation of the energy poverty composite indicator and institutional quality proxy, as well as the used sources are brought forward.

4.1 Model Specification

The aim of this analysis is to shed light on the influences of different RES on energy poverty. Furthermore, a differentiation of these effects regarding a country's IQ is conducted by splitting the observations into four, relatively equally sized groups from low to high IQ. To deal with this kind of data, a panel data model is the most appropriate approach. In this analysis, an unbalanced panel is used. Among panel regression models one can differentiate between static and dynamic models. Within this research field, the literature applies most often dynamic models, due to the lagged effects of RES and poverty alleviation (Adom et al. 2021; Atems & Hotaling, 2018; Garba & Bellingham, 2021; Nguyen & Su, 2022; Topcu & Tugcu, 2020; Zhao et al. 2022). The model most predominantly used is the Generalized Method of Moments (GMM). Assumptions for dynamic models are a large number of individuals over a shorter time period, where the lagged dependent variable is also used as an independent variable (Ahn & Schmidt, 1995). Among static models, fixed (FE) or random-effects (RE), as well as Generalized Least Squares (GLS) models, are used. The characterisitc of FE models' is that they assume that the differences among, in this case, countries are fixed and long-term instead of random (Halkos & Gkampoura, 2021). For RE models, differences are regarded as random and independently distributed over the individuals. The GLS model is a combination of within and between estimators and can therefore be regarded as more efficient (Verbeek, 2004). Furthermore, for the aim of a holistic analysis, the inference does not target specific countries but overall visible trends in the global analysis, which justifies the use of a RE specialization of the GLS model (Verbeek, 2004).

The methodological approach in this analysis is a parallel application of static and dynamic models (GLS and GMM) to establish a benchmark model in a static case first and then test it in a dynamic approach. This type of approach has been previously applied in the field of energy and development, which gives confidence to its choice. However, at the time of conducting this study, an application of this approach to the concrete topic of energy poverty and its relation to RES was not known, therefore leaving a gap for more studies of this kind. Halkos and

Gkampoura (2021) conducted a comparison of GLS and GMM models to illustrate the relationship between economic crises and energy poverty. Furthermore, Kahouli (2019) and Khan, Hou, Irfan, Zakari and Le (2021) conducted comparisons between static (GLS) and dynamic (GMM) models to investigate the effects of economic growth and energy consumption. Static models, like GLS, can lead to issues of endogeneity (Kahouli, 2019). To address this, model estimations using a GMM approach can be applied (Kahouli, 2019). For this analysis, the Arellano-Bond dynamic panel-data estimation, which is a GMM approach, is applied to accommodate the dynamic effects of the topic in question. For the comparison, a Generalized Least Squares (GLS) model with an AR(1) disturbance is used.

There are several static models that can be chosen from, like the within or FE model, the RE model or a GLS model. To decide on a model, first, an F-test was conducted. A retrieved significant p-value led to the rejection of the null hypothesis, which indicated that fixed-effects or random-effects models are preferable to pooled OLS. However, as the diagnostic checks revealed heteroskedasticity as well as autocorrelation, both models are no longer suited and instead, the use of a GLS model is the most fitting, as it can control for these issues (Khan et al. 2021; Alvarado, Ponce, Alvarado, Ponce, Huachizaca & Toledo, 2019). The GLS model in its basic form is the following:

$$(1) \qquad EPI_{i,t} = \alpha_0 + \alpha_1 lnsolar_{i,t} + \alpha_2 lnwind_{i,t} + \alpha_3 lnhydro_{i,t} + \alpha_4 lngdppc_{i,t} + \alpha_5 lneit_{i,t} + \alpha_6 lngexpfc_{i,t} + \alpha_7 lnurban_{i,t} + \gamma_i + \mu_{i,t}$$

i = 1,2,…N stands for the cross-sectional unit, in this case countries, and *t = 1,2,…N* for the time unit, years. In this model, $\mu_{i,t}$ is the error term and γ_i are random factors which are independently distributed across the entities (countries), both are mutually independent from the independent variables (Verbeek, 2004). For all independent variable the logged form was chosen to be able to interpret the estimates as elasticities, and indicated with an ”*ln*” infront of the variable (Pan, Biru & Lettu, 2021). As the log of 0 is undefined, to all findings of 0 an additional 0.01 was added. This procedure followed the approach of McGee and Greiner (2019). *EPI* stands for the composite indicator of energy poverty, *lnsolar* captures the electricity generated by solar energy. Likewise, *lnwind* and *lnhydro* capture electricity generation in kWh. *lngdppc* is the GDP per capita, *lneit* the energy intensity, *lngexpfc* stand for the general government expenditure, and *lnurban* captures the urbanization level. The α_0 resembles the constant of the equation and α_1 to α_7 are the coefficients that are to be estimated.

For the dynamic model, the Arellano-Bond dynamic panel-data estimation was applied to address possible endogeneity issues of the data. This approach uses a lagged variable of the dependent variable to accommodate for the lagged effects of renewable energy development and poverty alleviation. β_0 represents the constant, β_1 to β_7 are the coefficients. ε captures the error and δ are unobserved time-invariant individual effects. The model can be described as the following formular:

$$(2) \qquad EPI_{i,t} = \beta_0 + \beta_1 EP_{i(t-1)} + \beta_2 lnsolar_{i,t} + \beta_3 lnwind_{i,t} + \beta_4 lnhydro_{i,t} + \beta_5 lngdppc_{i,t} + \beta_6 lneit_{i,t} + \beta_7 lngexpfc_{i,t} + \beta_8 lnurban_{i,t} + \delta_i + \varepsilon_{i,t}$$

As a preparation for the analysis, and to perform model specifications, model assumption tests were conducted to check for normality of residuals, heteroskedasticity, auto-correlation and multicollinearity of the panel data. The histogram and Q-Q plot of the residuals indicate normality and can be found in Appendix B. The skewness and kurtosis test for normality was applied using an OLS baseline model and no issues with skewness or kurtosis at a problematic level were detected. To test for heteroskedasticity the modified Wald test for groupwise heteroskedasticity in cross-sectional time-series regression models as well as the Breusch-Pagan test for heteroskedasticity were applied. The null hypothesis of heteroskedasticity was rejected in both cases, indicating that heteroskedasticity is present. To accommodate for this, robust standard errors were included in the GMM model. For the GLS model a version with AR(1) disturbance was specified, meaning that the disturbance term is first-order autoregressive, therefore using past values of the dependent variable to calculate the regression (Hyndman & Athanasopoulos, 2018). Autocorrelation of variables can lead to biased results. To test for this, the Woolridge test for autocorrelation in panel data was conducted for the static model and showed a first-order autocorrelation (Wooldridge, 2002). In the case of dynamic models with lagged variables, like the GMM approach, an assumption is that no serial correlation is present (Arellano & Bond, 1991; Wooldridge, 2002). To control for this, the Arellano-Bond test for zero autocorrelation in first-differenced errors was applied to the dynamic model (Arellano & Bond, 1991). The null hypothesis for no autocorrelation of first-order could be rejected and for the second-order it could not be rejected. This means that there is sufficient evidence to satisfy the assumptions of the Arellano-Bond model (Arellano & Bond, 1991). Additionally, the data was tested for multicollinearity by calculating the Variance Inflation Factor (VIF) for all variables (Craney & Surles, 2002). With multiple predictor variables, collinearity might impact the results. The VIF is a measure to test for collinearity and the generally accepted threshold is 5 or 10, meaning a VIF over 5 shows some collinearity and a VIF over 10 indicates a problematic level of collinearity and the variable choice should be reconsidered (Craney & Surles, 2002). The mean VIF obtained from the test is 1.82, and no variable is higher than 3.33. Therefore, no problem with multicollinearity is present. All test results are presented in Appendix B. While the adjusted models address the shortcomings found during the diagnostic tests, it must be acknowledged that estimates might still suffer from biases and results must be interpreted carefully. Furthermore, this dual analysis, comparing estimates of static and dynamic models, has been conducted before on energy and development topics, but it still is a fairly recent procedure and therefore yet unidentified shortcomings can be assumed.

4.2 Variable Selection and Data Sources

To conduct a holistic analysis, 167 countries are included in the dataset, covering the timespan from 2000 to 2019. However, since not all variables for all countries have observations, this dataset is an unbalanced panel. In the data cleaning process observations with missing values in the dependent variable, as well as in the independent variables solar, wind, and hydro, were removed as these are the concrete effects this analysis aims to measure. This process can be reviewed in Figure 4.1. The static GLS model is run with 2,370 observations, while the dynamic AB model is based on 2,027 observations. This difference in the number of observations is due to missing values that were created for the lagged variables of the first available year, which are omitted in the estimation sample of the model. Descriptive statistics, as well as the sources underlying the variables used in the models, can be found in Table 4.2. An overview of all variables used in the study can be found in Appendix C.

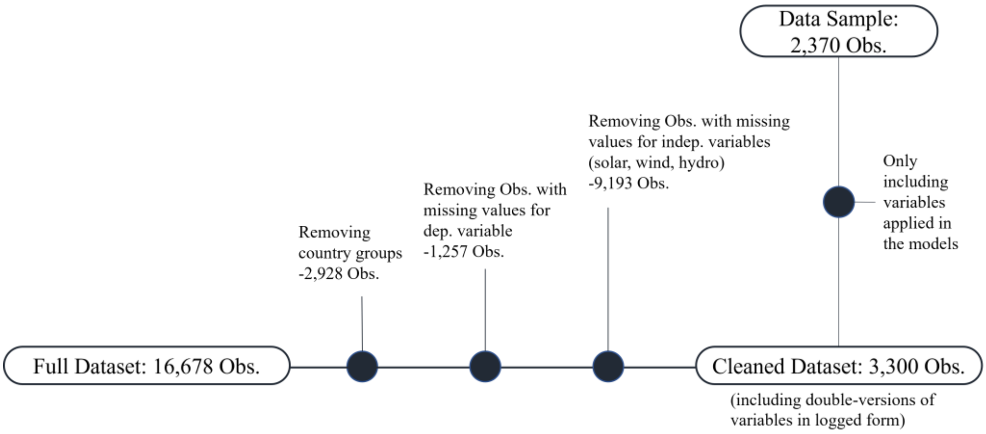

Figure 4.1 Data Cleaning Process (author's elaboration)

4.2.1 Dependent Variable

To accommodate the multidimensional complexity of the concept of energy poverty, a composite indicator is generated which fits the needs of this analysis. Existing composite indicators, like the MEPI by Nussbaumer, Bazilian and Modi (2012) were considered but not deemed suitable due to limitations in their continuity and availability. Following the definition of energy poverty taken here, namely: *an insufficient level of access to clean and safe energy sources as well as end-use appliance to access existing energy for the fulfilment of basic living conditions (e.g., heating, cooking, lighting) and development activities (e.g., internet),* three indicators have been chosen to generate the composite indicator. All three indicators are measured annually in the unit "percentage of total population", to have a homogenous measuring unit. The first variable is access to electricity. The second variable measured clean fuels and technologies for cooking, excluding kerosene based fuels, as suggested by the WHO. At last, the percentage of individuals using the internet was included as a variable. This measured the share of individuals, which accessed the internet during the timeframe of the last three months from any possible location, therefore, including private and public end-use appliances. All variables were retrieved from the World Bank Database (The World Bank, 2022). The underlying sources can be found in Table 4.1 and in Appendix C. The development of energy poverty, as captured from the composite indicator can be seen in Figure 4.2 below. For the construction of the indicator the checklist provided by the OECD was consolidated (OECD, 2008). Using the additive mean approach, the three variables were summed up and the mean of them was generated for every country-year observation. The following, simple, model was applied for this. With *i* standing for the country and *t* for the year observations.

$$EPI_{i,t} = \frac{(electr_{i,t} + cleanfuels_{i,t} + internet_{i,t})}{3} \qquad (3)$$

To inspect the correlation between the variables, a correlation matrix was obtained, and the Cronbach's alpha was tested. The largest correlation was found between "access to clean and safe cooking fuels and technologies" and "access to electricity" with an estimate of 0.87. The lowest correlation is found between "access to the internet" and "access to electricity". A Cronbach's alpha of 0,8671 was estimated, which is an adequate estimation according to a scale proposed by Zeller (2005). While this composite indicator is a proxy for energy poverty, it must be emphasised that this procedure naturally limits the reliability of the data, as only rough estimates were used.

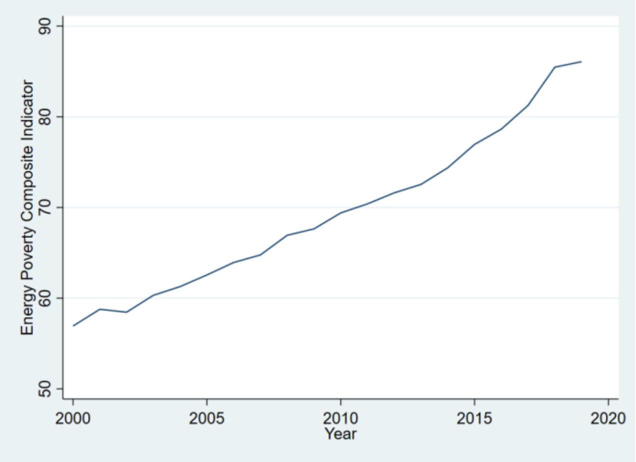

Figure 4.2 Development of Composite Indicator for Energy Poverty (2000-2019) (author's elaboration based on (The World Bank, 2022))

4.2.2 Independent Variables

Predominantly, the literature uses energy consumption to capture the effects of renewable energies on energy poverty (McGee & Greiner, 2019; Topcu & Tugcu, 2020; Zhao et al. 2022). While the consumption gives more exact estimates of how much energy reaches the end-user, this already implies that the energy is accessible and affordable. A focus on consumption also makes it more difficult to trace the energy back to its source, as the data for imported renewable energy capacities is not easily traceable (European Union, 2022). Therefore, for this analysis, electricity generation in kWh is used. Only looking at the generated capacity still leaves the question open of how the electricity will be distributed, how the costs will be covered and who will be able to consume it in the end. As the aim of this analysis is to understand the influences of concrete RES on energy poverty, in particular within the light of different levels of institutional quality, the generation of electricity is more fitting than consumption.

Solar, Wind and Hydro

The variables for solar, wind and hydro power were all measured as the per capita generated electricity from the respective source type, in kWh on an annual basis. The data has been retrieved from the "Our World in Data" website which had collected it from two reports published in 2021 and 2022 (Moore, 2022; bp, 2021).

4.2.3 Control Variables

To be able to better, or more effectively capture the effect of RES on energy poverty, a set of control variables have been implemented in the model. Following Zhao et al. (2022), GDP per capita, energy intensity and the level of urbanization were added. Additionally, Nguyen and Su (2022) found a significant effect of general government expenditures on energy poverty in a global analysis, which gives enough reason to include a control variable for government spending.

GDP per capita

To include the performance of the economy and the economic growth of a country, the variable of GDP per capita[1] is included. It is measured in constant 2015 US$ and retrieved from the World Development Indicator databank (WDI), which itself retrieved the data from the World Bank's National Accounts data and the OECD National Accounts data files (The World Bank, 2022).

Energy Intensity

As it previously has been identified in the literature, energy intensity, or sometimes also called energy efficiency, has an important function when addressing energy poverty (Li et al. 2021). Therefore, the energy intensity level of primary energy will be included as a control variable, measured in megajoules per produced economic output unit, here in 2011 US$ at purchasing power parity. This data is retrieved from the WDI databank, which is based on the Sustainable Energy for All (SE4ALL) databank (The World Bank, 2022).

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[1] Meaning divided by mid-year population size

General Government Final Consumption Expenditure (% of GDP)

Based on the findings of Nguyen and Su (2022), government spending per country is included. More precisely the general government final consumption expenditure is used here, as a percentage of the GDP with annual country-level data. The data was retrieved from the WDI databank, based on the World Bank National Accounts data and the OECD National Accounts data files (The World Bank, 2022). There it is summarized that general government final expenditures "includes all government current expenditures for purchased goods and services", including national defence and security, but excluding military expenditures (The World Bank, 2022, n.p.).

Urbanization

Due to the above-mentioned influence urbanization has on energy poverty it is included in this analysis as the percentage of the total population living in an urban area (Mahumane & Mulder, 2022). An urban area is defined by the national statistical offices, and the data was collected and processed by the United Nations Population Division but made accessible via the WDI databank (The World Bank, 2022). A possible limitation of this variable is that the definitions of the term 'urban area' may differ between national statistical offices.

Institutional Quality

For the sub-analysis based on different levels of institutional quality, a proxy is used. Following the practice of Nguyen and Su (2022), six indices from the Worldwide Governance Indicator databank (WGI) are used to generate a composite indicator (Kaufmann, Aart & Massimo, 2010b). All indicators are measured in estimates derived by Kaufmann & Massimo (2010b) from 30 individual data sources and range from a scale of -2.5 to 2.5. To generate the proxy, averages were calculated. The six indicators used are control of corruption (*ccor*), government effectiveness (gef), political stability and absence of violence/terrorism (ps), regulatory quality (reg), rule of law (rol), and voice and accountability (voc) covering aspects of how much citizens can participate in their government selection, as well as aspects like freedom of expression and free media (Kaufmann, Aart & Massimo, 2010b).

Table 4.1 Descriptive Statistics of Selected Variables

Variable	**Definition**	**Source**	**Obs**	**Mean**	**S.D.**	**Min**	**Max**
addindex_ep	Composite Indicator Energy Poverty	Self-generated	3300	58.16	29.96	0.74	99.90
solar	Electricity generated by solar energy	bp, EER[2]	3300	14.55	55.20	0	543.51
wind	Electricity generated by wind energy	bp, EER	3300	66.47	228.35	0	2798.08
hydro	Electricity generated by hydro energy	bp, EER	3300	1010.78	3638.43	0	42046.08
gdppc	GDP per capita	WB, OECD	3247	12672.96	17776.60	258.63	112372.68
gexpfc	Total government final consumption expenditure	WB, OECD	2926	15.99	6.38	0.95	79.17
eint	Energy intensity	SE4ALL	2707	6.52	5.02	1.09	43.16
urban	Urbanization	UNPD[3]	3294	56.04	22.68	8.25	100
instq	Institutional quality	Self-generated	3134	-0.03	0.90	-2.45	1.97

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[2] European Electricity Review 2022, Ember

[3] United Nation Population Division

5 Empirical Analysis

In this chapter, the results of this analysis will be presented, followed by a discussion of the measured effects of RES on energy poverty and the role of IQ, in relation to the literature review. To test the robustness of the results, two additional robustness checks will be reviewed and at last, the limitations of this analysis will be summoned up.

5.1 Results

Overall, statistically significant estimates for the independent variables were obtained indicating that RES influence energy poverty. However, the economic significance is questionable as the magnitude of the coefficients is rather small. In the dynamic model, the lagged dependent variable is significant and positive throughout the model and sub-analysis groups, which fulfils the assumption of dynamic models (Ahn & Schmidt, 1995). The results of both models can be found in Tables 5.1 and 5.2. The chosen level of significance is a p-value below 0.1. Because the independent variables are log-transformed, and the dependent variables remain linear, the coefficients are generated by dividing the obtained results by 100, times the number of the percentage increase which should be assessed. The formula can be seen below in equation (4).

$$\Delta y = \left(\frac{b}{100}\right) * \%\Delta x \tag{4}$$

The result is then interpreted as a one percent increase in x (independent variable) leads to a unit increase in y (dependent variable). The underlying variables used in the indicator for energy poverty are all measured in percentages of the population with access to the variable (electricity, cooking fuels, internet), which is why a unit of this indicator can be interpreted in percentages of populations. It must be remembered that the composite indicator of energy poverty measures the access to three crucial dimensions which, if there is a lack of access, contribute to energy poverty. This means that an increase in the EPI variable must be interpreted as a reduction in energy poverty.

For electricity generated by solar energy, in the GLS model, positive and statistically significant estimates, with a p-value smaller than 0.1, were calculated in the full model, indicating that a percentage increase in electricity generated by solar energy leads to a reduction of energy poverty by 0.18 percent. For the sub-analysis groups lower-middle, upper-middle and high institutional quality (IQ), the estimates are also statistically significant at the chosen p-value. Furthermore, the estimates are increasing in magnitude with rising IQ, from a 0.11 increase in the lower-middle group to a 0.23 increase in the high IQ group. Similar results were obtained by the dynamic model. The coefficients of solar are also positive and significant for the full model, indicating a 0.13 percent increase in the energy poverty indicator. The estimates for the sub-analysis for the lower-middle, upper-middle and high IQ groups are also significant at the chosen level. Likewise, a slight increase can be observed with rising IQ, from a 0.10 to a 0.11 which corroborates the results of the static model. In both models, static and dynamic the lowest level of IQ was insignificant.

In the case of wind energy, the estimated coefficients of the GLS model are also positive and significant with a p-value smaller than 0.1 and, like solar, show an increase in magnitude with increasing IQ. For the full model, a one percent increase in electricity generated by wind energy leads to a 0.15 percent increase in the dependent variable. In the sub-analysis, an effect of a 0.01 percent increase in the low IQ group up to a 0.40 percent increase in the high IQ group is observable. These findings show similarities to the findings of the dynamic model, which also returned positive and statistically significant coefficients with an increasing magnitude trend with increasing IQ. For the full model a percentage increase of electricity generated by wind power leads to a 0.10 percent increase in the energy poverty indicator. Again, the magnitude increases for the two statistically significant groups, lower-middle with a 0.08 percent increase, and high IQ with a 0.14 increase, both significant at a p-value below 0.1.

For the variable of hydro energy, the static model returned positive and statistically significant coefficients for the full model (0.15 percentage increase) as well as for the groups of lower-middle (0.27), upper-middle (0.45), and high (0.28) IQ. In terms of trends according to the IQ no linear increase or decrease is visible. Furthermore, for the dynamic model, no statistically significant coefficients could be obtained and all show a negative direction.

The results of the control variables also show partially significant estimates that are mostly consistent with the expected directions. The estimates of GDP per capita are positive and statistically significant for all groups and the full model in both cases, dynamic and static model. A comparison of the estimates from the low to high IQ also shows an increase of magnitude. Furthermore, the variable of GDP per capita shows the largest obtained magnitudes. In the GLS model, these range from 11.22 percent to 13.26 percent increases in the energy poverty indicator, with a one percent increase in GDP per capita. In the dynamic model they range from 2.75 to 10.33 percent.

Energy intensity shows contrary directions of the coefficients in the dynamic and static model. While in the GLS model only for the low IQ group a statistically significant and positive coefficient was estimated with an increase in EPI of 1.50 percent, the rest of the coefficients were positive. In the dynamic AB model energy intensity was statistically significant at a 0.1 level and negative for the full model, with an effect of 1.18 which is in line with the expected effects. For the sub-analysis, the coefficients were, while also negative, not significant.

Government spending, likewise, shows some contrary coefficients and is less consistent across the two models. In the GLS model, government spending is positive and significant for the full model, indicating an increase of 1.01 percent in the EPI with an increase in government spending of one percent. Additionally, for the groups of lower-middle and high IQ, estimates that are statistically significant at the 0.1 level, were obtained, with influences of 3.04 and 8.04 percent increases in EPI. There is a clear increase in magnitude visible from the lower-middle to the high IQ group. On the opposite, for the dynamic AB model, government spending is not significant for the full model, but within the sub-analysis, with a p-value below 0.1. Coefficients of positive direction were estimated for the group of high IQ with an effect of an 8.63 percent increase of EPI, similar in magnitude to the GLS models estimates. For the group of upper-middle IQ, a significant but negative coefficient was found.

Table 5.1 Regression Output GLS AR(1) Model – Static

Variables (Log-transformed versions)	(Model 1) **Low IQ**	(Model 2) **Lower-middle IQ**	(Model 3) **Upper-middle IQ**	(Model 4) **High IQ**	(Model 5) **Full Model**
Solar Energy (*lnsolar*)	0.0009	0.0011**	0.0022***	0.0023***	0.0018***
	(0.0616)	(0.0510)	(0.0578)	(0.0487)	(0.0254)
Wind Energy (*lnwind*)	0.0019**	0.0012**	0.0015***	0.0040***	0.0015***
	(0.0782)	(0.0480)	(0.0511)	(0.0705)	(0.0267)
Hydro Energy (*lnhydro*)	0.0018	0.0027*	0.0045***	0.0028**	0.0015**
	(0.119)	(0.149)	(0.160)	(0.130)	(0.0719)
GDP per capita (*lngdppc*)	0.1122***	0.1856***	0.1326***	0.1259***	0.1192***
	(1.140)	(1.315)	(1.301)	(0.922)	(0.646)
Energy Intensity (*lneint*)	0.0150*	-0.0004	-0.0125	-0.0098	-0.0017
	(0.806)	(1.184)	(1.097)	(1.179)	(0.505)
Governm. Expenditures (*lngexpfc*)	0.0052	0.0304***	0.0007	0.0804***	0.0101***
	(0.370)	(0.906)	(0.971)	(1.473)	(0.322)
Urbanization (*lnurban*)	0.2614***	0.1869***	0.2351***	0.1266***	0.2767***
	(2.970)	(2.933)	(3.614)	(2.679)	(2.023)
Constant	-146.4***	-176.5***	-144.9***	-121.5***	-155.0***
	(11.08)	(10.65)	(12.48)	(8.031)	(6.715)
R-sq: within	0.6024	0.6736	0.5367	0.6925	0.5878
R-sq: between	0.6125	0.8160	0.7709	0.8455	0.8010
R-sq: overall	0.5658	0.7715	0.6902	0.8006	0.7912
Observations	567	588	566	649	2,370
Number of countries	62	69	63	142	167

Notes: All coefficients have been rounded to the fourth decimal point, as the effects are small and otherwise differences could not have been included. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

At last, for the urban variable, positive and significant coefficients, with a p-value smaller than 0.01, were found for the full model in both the dynamic and the static model. In the GLS model, all groups of the sub-analysis show significance and a positive direction with estimates ranging from 12.66 to 27.67 percent increases in the EPI with a one percent increase in urbanization, with the magnitude decreasing as IQ increases. In the AB model, next to the significant full model coefficient indicating a 9.06 percent increase in the EPI, only the groups of low and upper-middle IQ show significant positive coefficients with an increase from the low to the upper-middle IQ group.

Table 5.2 Regression output Arellano-Bond Model - Dynamic

Variables (Log-transformed versions)	(Model 1) **Low IQ**	(Model 2) **Lower-middle IQ**	(Model 3) **Upper-middle IQ**	(Model 4) **High IQ**	(Model 5) **Full Model**
Lag of Energy Poverty	0.0078***	0.0076***	0.0077***	0.0063***	0.0077***
	(0.0545)	(0.0486)	(0.0466)	(0.0509)	(0.0268)
Solar Energy (*lnsolar*)	.0004	.0010***	.0012**	.0011***	.0013***
	(0.0665)	(0.0393)	(0.0610)	(0.0394)	(0.0279)
Wind Energy (*lnwind*)	.0013	.0008*	.0006	.0014*	.0010***
	(0.0827)	(0.0483)	(0.0624)	(0.0722)	(0.0393)
Hydro Energy (*lnhydro*)	-.0014	-.0021	-.0007	.0010	-.0004
	(0.0903)	(0.185)	(0.0784)	(0.326)	(0.0586)
GDP per capita (*lngdppc*)	0.0275**	0.0843***	0.0342**	0.1033***	0.0478***
	(1.389)	(2.329)	(1.580)	(2.930)	(1.087)
Energy Intensity (*lneint*)	-0.0088	-0.0018	-0.0035	-0.0064	-0.0118*
	(1.039)	(1.059)	(1.520)	(1.058)	(0.688)
Governm. Expenditures (*lngexpfc*)	-0.0019	0.0082	-0.0274**	0.0863***	-0.0013
	(0.421)	(0.843)	(1.152)	(2.278)	(0.430)
Urbanization (*lnurban*)	0.1199***	0.0342	0.1802***	-0.0007	0.0906***
	(3.882)	(4.180)	(4.582)	(15.42)	(2.589)
Constant	-51.71***	-66.61***	-78.52***	-95.32	-58.88***
	(19.46)	(21.51)	(21.72)	(87.42)	(12.13)
Wald chi2	1194.32	2174.10	2488.63	1201.90	4828.04
Prob > chi2	0.000	0.000	0.000	0.000	0.000
Observations	504	540	511	472	2,027
Number of countries	61	63	58	43	165

Notes: All coefficients have been rounded to the fourth decimal point, as the effects are small and otherwise differences could not have been included. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

In terms of the goodness-of-fit of the models, the between, within, and overall R-squared of each GLS model can be seen in Table 5.1. The between R-squared indicates how much variation between the different countries is explained by the model. The within R-squared on the other hand indicates how much variation within a country is explained. The overall R-squared is a weighted average of both (Verbeek, 2004). From Table 5.1 it can be seen that all R-squared estimates are above 0.5 with a span among the models from 0.5 up to 0.85 indicating an appropriate goodness-of-fit. However, as two different models are used for this analysis, the R-squared cannot be applied to compare the goodness-of-fit of both models. They have to be reviewed separately. For the dynamic model, the R-squared could not be obtained. Instead, the Wald-chi-squared was calculated, which indicates if the selection of independent variables is significant for the model, or otherwise put, different from 0, and therefore adds value to the model (Verbeek, 2004). All estimates of the Wald-chi-squared have significant p-values and large estimates indicating that they indeed add value.

5.2 Discussion

Coming back to the questions posed at the beginning of this analysis: what influences do RES have on energy poverty? And do these effects vary with different RES and varying levels of IQ of the assessed country?

Overall, both in the GLS and AB case, and concluding from the full models, RES are shown to have a reducing effect on energy poverty, as indicated by the positive coefficients. This suggests that an increased implementation of RES is a good approach to address this issue, which successfully answers on the proposed main research question. This similarity in RES results of both models can be seen in Figure 5.1. It has to be stressed at this point that multidimensional poverty issues, like energy poverty, can never be solved by one approach and must be addressed from a multitude of angles, like education, and political stabilization, among others. In terms of the impact of IQ on RES's effectiveness to reduce energy poverty, an increasing trend with higher IQ is observable, suggesting that when IQ is high, RES have a greater energy-poverty-reducing impact. Additionally, the effects seem to vary for different RES. Nevertheless, while statistically significant coefficients for RES in both the dynamic and static models were found, their economic significance is questionable. Effects ranging from 0.01 to 0.04 percent in the static, and 0.008 and 0.14 percent in the dynamic model as results of a one percent increase in electricity generated by RES must be questioned for their economic effects. What difference does a reduction of energy poverty of around 0.1 percent make? In the context of the energy transition towards RES, the expected increases of RES also have to be taken into account. All presented results are based on a one percent increase in electricity generation by RES. While the amounts expected

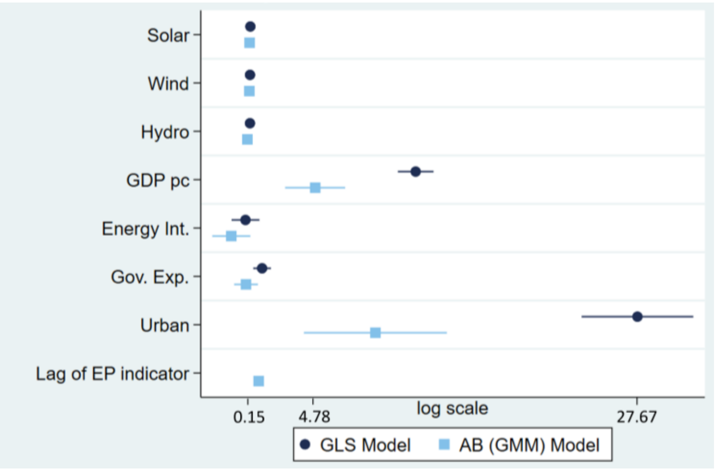

Figure 5.1 Regression Coefficients (Static vs. Dynamic) on a logged scale (author's elaboration)

and needed for the sustainable transition of the energy sector lay much higher and are expected to increase by 60% until 2026, compared to 2020 levels (IEA, 2021a). Based on these projections, the potential effects of RES on energy poverty are between 0,6 and 2,4 per cent for the static and 0,48 and 8,4 per cent decreases in energy poverty for the dynamic model. This confirms the effectiveness of RES as a tool for energy poverty reduction, but also reflects the variability of its effects.

The positive effects found for solar energy are in line with previous literature (Baurzhan & Jenkins, 2016; Liu et al. 2021). For example, Liu et al. (2021) showed that solar PV implementation in rural China had positive effects on energy poverty alleviation. One explanation for this is that solar energy has recently been titled the "least costly option for adding new electricity capacity" for most countries (IEA, 2022a). This cost competitiveness increases the affordability of RES, which is a crucial factor in energy poverty. Additional influencing factors could be the modularity and flexibility of solar, as previously mentioned. It can be employed in small to large-scale plants, independent of existing or missing grid infrastructure, hereby enabling electricity generation in areas where other energy sources could not have been exploited, due to geographic or economic reasons (Hamed & Peric, 2020; Letcher, 2018b). One of the largest concerns with solar energy implementation was the attribution and transfer of initial investment costs to the consumers, for example via Feed-in-Tariffs (FiT), which would render RES unaffordable for households. Hypothetically, this might be observable in the obtained results, by reducing the potential effect solar energy could have on energy poverty. However, this is only a hypothesis and further research addressing the effects of FiT's would be necessary.

Similar to the effects of solar energy, wind energy also shows energy-poverty-reducing effects. Wind power consists of particularly mature technologies which led to high efficiencies and competition on the market (IEA, 2022b). In comparison to the results for solar power, wind power shows to have a smaller effect. A possible contributing factor to this is that wind plants are more limited in terms of resource allocation and availability for efficient generation than solar plants (Bhide & Monroy, 2011; Akpinar & Akpinar, 2005). Similarly, to solar power, wind power is characterised by high initial investment costs and lower maintenance and operation costs. (International Renewable Energy Agency, 2012). This cost competitiveness might enable wind power to increase access rates across households and therefore decrease energy poverty.

The results for hydro power were the least conclusive and robust across the two models. The positive effects attained from the GLS model are in line with the argumentation and findings of research on RES's effect on energy poverty (Bhide & Monroy, 2011; Hussain et al. 2019; Szabó et al. 2013). However, the dynamic model did not show any significant coefficients, which raises doubts about the influence of hydro power on the EPI. Hydro plants are bounded to the availability of water as a resource, which might explain a limited impact on reaching those that are suffering from energy poverty. Furthermore, hydro plants, like dams, impactfully affect their surrounding environment by influencing which lands get flooded or dry out (Hussain et al. 2019). The construction of dams also often leads to the resettlement of populations. These intervening effects of hydro power on the livelihoods of citizens could possibly have separate effects on energy poverty and poverty in general, which is possibly why the results of this analysis are unclear and inconclusive. To assess the impacts of hydro power further, a closer look at social circumstances of communities surrounding hydro plants should be taken in future research.

In the following, the results for all four control variables will be discussed. As predicted and shown in previous studies, the economic performance of a country has a considerable influence on its energy poverty (Yu & Choi, 1985). A higher GDP per capita has a direct influence on the household's ability to make a choice regarding its energy use and it has been proven before to increase the energy consumption level (Komal & Abbas, 2015). Better performing economies can invest larger sums in infrastructure projects and attract business opportunities and innovation, as larger consumption can be expected. These mechanisms give some theoretical reasoning to the sizable positive and statistically significant results that were obtained for the effects of GDP per capita on energy poverty.

The effect of energy intensity on energy poverty cannot accurately be concluded from the results. Based on previous literature and theory, the positive coefficient of the low IQ group in the static GLS model is difficult to explain. A possible explanation for this could be that to few control variables were specified to fully explain energy poverty, and therefore a larger positive effect is wrongly associated with energy intensity. However, the result of the dynamic model is in line with the expected effect. The full model of the dynamic approach showed a negative coefficient, which can be interpreted as an increase in energy intensity would lead to an increase in energy poverty. The inclusion of the dynamic aspect of energy poverty could be a contributing factor to these results. However, the estimates of energy intensity need to be interpreted cautiously due to their different results in the two models, and the fact that in general less significant estimates were obtained for energy intensity, compared to the other variables.

Government spending is shown to have a reducing effect on energy poverty, a finding supported by the work of Nguyen and Su (2022). Furthermore, the catalyst effect of IQ on the effect of government spending, pointed out also by Nguyen and Su (2022) is proven again, as the highest effects of government spending occur in the group of high IQ.

The positive effects of urbanization on the EPI confirm previous findings (Mahumane & Mulder, 2022; Besley, 1995). Generally, urbanization is connected to a variety of development topics and enables investments, which benefit economic performance (Besley, 1995). Therefore, possible reasons for the observed positive effect of higher urbanization on energy poverty could stem from the connectedness to more advanced energy grids, making energy more accessible, as well as offering a larger choice of sources.

The sub-analysis of groups according to four different levels of IQ yielded interesting results. By splitting the observations, the distribution of the effect of the full model could be traced depending on the IQ level. Clearly, a trend became visible that for countries with higher IQ the effects of RES on energy poverty rose in magnitude. High IQ in a country generates a level of security and stability, which are both crucial for economic performance (Chong & Calderón, 2000; Cuervo-Cazurra, Silva-Rêgo & Figueira, 2022). This stability and security might enable RES projects to run more efficiently, as well as attract investments and projects. This in turn further increases access to electricity, safe cooking fuels and technologies as well as end-use appliances and through this decreases energy poverty. Through the incentivizing characteristics of IQ, a country becomes more economically attractive, which increases labour market opportunities and possibly strengthens the financial situations of households. Financially more stable and secure households are then enabled to make healthier choices regarding fuels and are more likely to be able to afford electricity. But again, the causality is not addressed here and it can be expected that higher IQ also brings a range of factors with it, that enable reduced energy poverty, related to RES.

While questions remain about the effects of hydro power on energy poverty, due to inconsistent results obtained from the dynamic model, and the magnitude of the measured effects of solar and wind power are surprisingly small, it can still be concluded that RES have positive and varying energy-poverty-alleviating effects, depending on the source and the IQ. This means that continued efforts to increase the share of renewables in the overall energy mix and tackle energy poverty are not contradictory, as some previous literature indicated (Henry et al. 2021; Bhide & Monroy, 2011; Mastropietro, 2019; Stram, 2016). With steadily decreasing costs of RES and improving technologies, it can be assumed that these effects will gain more impact with time which gives an optimistic outlook. The question is, will this development happen soon enough to reach SDG 7 by 2030?

5.3 Robustness

The dual analysis of a static and a dynamic model itself tests for robustness. As both models by the majority returned comparable estimates, a satisfying level of robustness is assumed. To further test the robustness of the models, the data set was transformed into a balanced panel. Both models were then run using the balanced panel and the results can be seen in Tables D.1 and D.2 in Appendix D. For the GLS model, similar results in terms of direction, and significance were obtained. The magnitude was larger for all variables, estimating effects of 2 to 9 percent increases in the EPI for one percent increases in RES. The similarities between the balanced and unbalanced panel outcomes indicate a sufficient level of robustness, yet it also suggests that the unbalanced panel possibly underestimates the outcomes due to missing observations. The AB model instead showed great differences in the results. Estimates of RES are only marginally statistically significant and show no clear trend regarding their effect on energy poverty, indicating that results must be interpreted with caution. The smaller sample size of the balanced panel might decrease the power of the dynamic model to predict the effects of RES on energy poverty. It might also suggest a methodological shortcoming, and for future research other approaches should be explored.

To further test the robustness, a stepwise integration of the variables was conducted where it has been analysed how the coefficients change from step to step. The results can be obtained from Tables D.3 and D.4 in Appendix D. In the GLS model, this process has shown how the effects are distributed over the variables after they are included one after another. The directions, significance, and magnitude of the results are comparable to the original model. Applying the same procedure to the AB model likewise calculated robust estimates.

5.4 Limitations

While significant and, to a certain degree, robust results were obtained, this analysis is restricted by four main limitations. First, accurately measuring energy poverty remains a challenge. Sometimes, parallel to energy poverty the issue of fuel poverty is discussed (Boardman, 2012). This variation of energy poverty is generally more present in developed countries and was therefore not included in this global analysis. In conclusion, the used measure of energy poverty might be insufficient in picking up this type of energy poverty. While a composite indicator tries to include some aspects of multidimensionality, it has strong limitations and cannot pick up nuances of energy poverty to the extent to which they are probably present. Furthermore, the aspect of energy costs is only indirectly included in this analysis, although it can be expected to be a crucial element in terms of RES's impact on energy poverty. Further research focusing on the financial aspects is therefore advised. Second, in conjunction with these nuances, the scale of the analysis is also a possible limitation. Here a macro-level perspective was chosen to enable a more holistic understanding. However, being able to "zoom in" and look at the effects of RES on energy poverty on a household level might be able to show a greater variation. Third, a general limitation when dealing with global country-level data is the steering by the "count-ability" of data. It can be assumed that aspects such as energy poverty are particularly pronounced in the regions where data collection is most difficult and coverage thus thinnest. However, it is only possible to carry out an empirical analysis with existing data, which is why it must be assumed that there is a certain bias with regard to data collection. Fourth, previous studies pointed out that the situations of grid-connected and off-grid regions differ significantly, as grid connection in off-grid locations requires time and large investments, making these areas more vulnerable to energy poverty. Due to these differences between the areas, different impacts of RES on energy poverty can be assumed. However, the scope of this analysis and the availability of accurate data on on-grid and off-grid regions, hindered the consideration of this here, but it could be an intriguing topic for further research.

6 Conclusion

The aim of this study was to investigate the influences that RES might have on energy poverty in various contexts of IQ. Throughout this analysis it became clear that the topic of energy poverty brings some challenges with it. As a highly intangible, multidimensional issue, with large variations of characteristics and regional differences, it is highly complicated to measure in a comprehensive way. This study sheds light on three gaps in the existing literature on the topic. First, by including a global sample of countries a more holistic perspective was applied. Second, it differentiates between RES, which to the best knowledge, has not been done on this level previously. Third, the whole analysis was conducted with a special focus on the role of IQ on the effects of RES.

This study reveiled the energy-poverty-reducing capabilities of RES, with solar energy being the most effective one. Through the analyses of a static and a dynamic model, the robustness of the estimates was ensured, indicating that the results for solar and wind energy are more conclusive than for hydro power. However, while positive results were found the economic significance of RES as energy-poverty-alleviating tools is questionable, as only small magnitudes were estimated, varying from 0.1 to 0.4 percent increases. Furthermore, the sub-analysis of the role of IQ in this dynamic showed that IQ has a catalyst function on RESs effects on energy poverty, as well as on other control variables (GDP per capita, government spending). The increasing magnitudes of the results among the sub-analysis groups suggest that IQ can possibly increase the energy-poverty-alleviating effects of RES, stressing the importance of increasing IQ in countries. While the research questions were answered to a certain extent, more foci have been identified to fully understand the relationship of RES and energy poverty. Therefore, further quantitative research should be done exploring the financial dimensions of RES and energy poverty, focussing on FiTs, as well as diving deeper into the effects of concrete RES technologies, and differentiating between on- and off-grid locations. From a qualitative perspective, the consideration of social contexts and communities, especially for the implementation of hydro power, is an interesting area for further research. Energy poverty remains a pressing issue of today, due to its devastating effects on development and livelihoods. RES might be an adequate tool to address this issue in a sustainable manner. Therefore, gaining a more detailed and context-specific understanding of their influences remains an important objective.

7 References

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Appendix A

Table A.1 Comparison of Similar Studies

Research Topic	**Year**	**Author**	**Method**	**Country**	**Time**
Energy Poverty, Development Outcomes, and Transition to Green Energy	2021	Adom et al.	Dynamic OLS, ARDL	Ghana	1960/75 - 2017
Energy poverty: A special focus on energy poverty in India and renewable energy technologies	2011	Bhide and Monroy	Qualitative Review	India	
The role of renewable energy resources in alleviating energy poverty in Palestine	2020	Hamed & Peric	Qualitative Review	Palestine	
How will renewable energy development goals affect energy poverty in Guatemala?	2021	Henry et al.	Multi-stage levelized cost of electricity (LCOE) model	Guatemala	2014
What is the anti-poverty effect of solar PV poverty alleviation projects? Evidence from rural China	2021	Liu et al.	DiD regression	China	2018
The influences of government spending on energy poverty: Evidence from developing countries	2022	Nguyen et al.	System Generalized Method of Moments (SYS-GMM)	Global sample (56 developing c)	2002-2005
The impact of renewable energy consumption on income inequality: Evidence from developed countries	2020	Topcu et al.	GMM	Developed economies	1990-2014
Off-grid solar PV: Is it an affordable or appropriate solution for rural electrification in Sub-Saharan African countries?	2016	Baurzhan et al.	Cost Comparison	Sub-Saharan Africa	
How renewable energy alleviate energy poverty? A global analysis	2022	Zhao et al.	SYS-GMM	64 countries	2000-2014

Appendix B

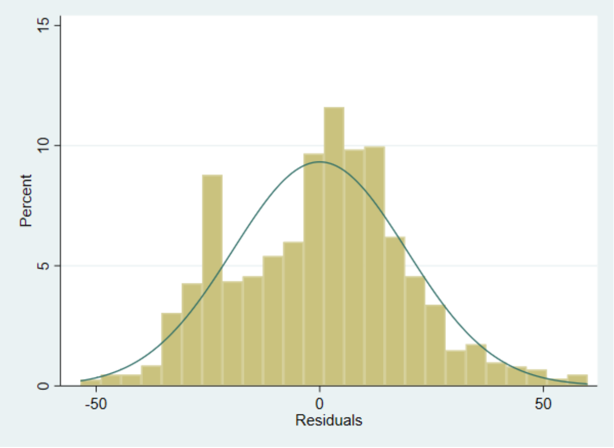

Figure B.1 Histogram of Residual Distribution (author's elaboration)

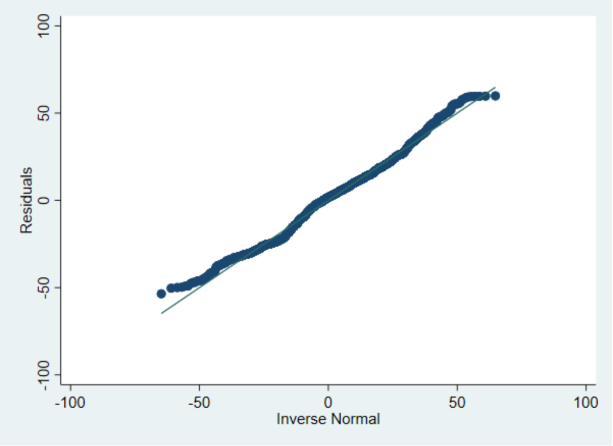

Figure B.2 Qnorm Plot of Residual Distribution (author's elaboration)

Table B.1 Normality of Residuals Test: Joint Test

Variable	**Observation**	**Pr (Skewness)**	**Pr (Kurtosis)**	**Chi2(2)**	**Prob>chi2**
Residuals	2370	0.0000	0.5743	43.31	0.0000

Table B.2 Modified Wald Test for Groupwise Heteroskedasticity

H0: sigma(i)^2 = sigma^2 for all i

chi2 (167)	**Prob>chi2**
4.5e+05	0.0000

Table B.3 Breusch and Pagan Lagrangian Multiplier Test for Random Effects

addindex_ep[countrycode_n,t] = Xb + u[countrycode_n] + e[countrycode_n,t]

Estimated results:	**Var**	**sd = sqrt(Var)**
addinde~p	853.6331	29.217

e	16.74302	4.091824
u	151.9563	12.32706
Test: Var(u) = 0	**chibar2(01)**	**Prob > chibar2**
	11800.22	0.0000

Table B.4 Wooldridge Test for Autocorrelation in Panel Data

H0: no first-order autocorrelation

F(1, 161)	**Prob > F**
413.470	0.0000

Table B.5 Arellano-Bond Test for Zero Autocorrelation in First-Differenced Errors

H0: no autocorrelation

Order	**z**	**Prob > z**
1	-5.7075	0.0000
2	.34975	0.7265

Table B.6 Variance Inflation Factor

Variable	**VIF**	**1/VIF**
lngdppc	3.33	0.299959
lnurban	2.47	0.405366
lnwind	1.96	0.509750
lnsolar	1.45	0.690423
lngexpfc	1.21	0.828725
lneint	1.18	0.850031
lnhydro	1.17	0.854582
Mean VIF	1.82	

Appendix C

Table C.1 Descriptive Statistics

Variable	**Definition**	**Source**	**Obs**	**Mean**	**S.D.**	**Min**	**Max**
addindex_ep	Composite Indicator Energy Poverty	Self-generated	3300	58.16	29.96	0.74	99.90
cleanfuels	Access to clean and safe cooking fuels and technologies	SE4ALL	3300	64.34	39.02	0.00	100
electr	Access to electricity	WB	3300	78.12	30.77	1.27	100
internet	Access to internet	ITU[4]	3300	32.01	29.58	0	99.70
solar	Electricity generated by solar energy	bp, EER[5]	3300	14.55	55.20	0	543.51
wind	Electricity generated by wind energy	bp, EER	3300	66.47	228.35	0	2798.08
hydro	Electricity generated by hydro energy	bp, EER	3300	1010.78	3638.43	0	42046.08
gdppc	GDP per capita	WB, OECD	3247	12672.96	17776.60	258.63	112372.68
gexpfc	Total government final consumption expenditure	WB, OECD	2926	15.99	6.38	0.95	79.17
eint	Energy intensity	SE4ALL	2707	6.52	5.02	1.09	43.16
urban	Urbanization	UNPD[6]	3294	56.04	22.68	8.25	100
instq	Institutional quality	Self-generated	3134	-0.03	0.90	-2.45	1.97
ccor	Control of corruption	WGI	3139	-0.02	1	-1.87	2.47
gef	Government effectiveness	WGI	3139	-0.01	0.97	-2.48	2.44
ps	Political stability and absence of violence	WGI	3134	-0.06	0.96	-3.31	1.76
regq	Regulatory quality	WGI	3139	-0.00	0.96	-2.65	2.26
rol	Rule of law	WGI	3139	-0.05	0.99	-2.61	2.13
vaa	Voice and accountability	WGI	3139	-0.04	0.98	-2.27	1.80

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[4] International Telecommunication Union

[5] European Electricity Review 2022, Ember

[6] United Nation Population Division

Appendix D

Table D.1 Robustness Check Balanced Panel Regression GLS AR(1) Model (estimates are transformed with α/100)

Variables (Log-transformed versions)	(Model 1) **Low IQ**	(Model 2) **Lower-middle IQ**	(Model 3) **Upper-middle IQ**	(Model 4) **High IQ**	(Model 5) **Full Model**
Solar Energy (*lnsolar*)	0.0014	0.0011	0.0024***	0.0025***	0.0020***
	(0.0883)	(0.0688)	(0.0617)	(0.0521)	(0.0304)
Wind Energy (*lnwind*)	0.0019	0.0016**	0.0027***	0.0045***	0.0022***
	(0.130)	(0.0817)	(0.0644)	(0.0722)	(0.0364)
Hydro Energy (*lnhydro*)	0.0074**	0.0092***	0.0053***	0.0036***	0.0026***
	(0.305)	(0.290)	(0.181)	(0.137)	(0.0958)
GDP per capita (*lngdppc*)	0.1584***	0.1738***	0.0890***	0.1127***	0.1053***
	(1.817)	(1.714)	(1.607)	(1.036)	(0.792)
Energy Intensity (*lneint*)	0.0355***	0.0030	-0.0196	-0.0403***	-0.0052
	(1.277)	(1.370)	(1.512)	(1.276)	(0.678)
Governm. Expenditures (*lngexpfc*)	-0.0006	0.0333***	-0.0057	0.1005***	0.0053
	(0.494)	(1.257)	(1.021)	(1.709)	(0.410)
Urbanization (*lnurban*)	0.2048***	0.2193***	0.3869***	0.1374***	0.3152***
	(3.796)	(4.484)	(5.798)	(3.508)	(2.668)
Constant	-165.0***	-183.8***	-167.5***	-115.0***	-158.7***
	(14.41)	(13.93)	(19.15)	(9.663)	(8.414)
Observations	259	389	376	524	1,548
Number of countrycode_n	25	38	37	96	99

Notes: All coefficients have been rounded to the fourth decimal point, as the effects are small and otherwise differences could not have been included. Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table D.2 Robustness Check Balanced Panel Arellano-Bond Model (estimates are transformed with β/100)

Variables (Log-transformed versions)	(Model 1) **Low IQ**	(Model 2) **Lower-middle IQ**	(Model 3) **Upper-middle IQ**	(Model 4) **High IQ**	(Model 5) **Full Model**
Lag of Energy Poverty	0.0077***	0.0079***	0.0085***	0.0057***	0.0079
	(0.0910)	(0.0601)	(0.0354)	(0.0371)	(0.711)
Solar Energy (*lnsolar*)	0.0000	0.0007	0.0006	0.0006	0.0012
	(0.107)	(0.0460)	(0.0522)	(0.0372)	(0.771)
Wind Energy (*lnwind*)	-0.0011	0.0005	0.0004	0.0011*	0.0012
	(0.187)	(0.0421)	(0.0595)	(0.0538)	(0.906)
Hydro Energy (*lnhydro*)	0.0054**	0.0009	0.0002	0.0002	0.0006
	(0.259)	(0.573)	(0.0963)	(0.336)	(3.555)
GDP per capita (*lngdppc*)	0.0464**	0.0752**	-0.0015	0.1066***	0.0320
	(1.925)	(3.022)	(1.929)	(2.131)	(27.72)
Energy Intensity (*lneint*)	0.0025	-0.0025	-0.0029	-0.0119	-0.0023
	(1.488)	(1.233)	(1.350)	(1.117)	(12.45)
Governm. Expenditures (*lngexpfc*)	-0.0047	0.0012	-0.0386***	0.0713***	-0.0125
	(0.424)	(0.866)	(1.094)	(1.997)	(4.605)
Urbanization (*lnurban*)	0.1015***	0.0117	0.2149***	0.2938***	0.0960
	(3.522)	(4.414)	(5.717)	(10.99)	(28.19)
Constant	-64.26***	-51.43**	-65.05**	-215.7***	-48.39
	(22.39)	(21.09)	(26.63)	(56.99)	(187.0)
Observations	238	365	347	401	1,351
Number of countrycode_n	25	36	35	36	98

Notes: All coefficients have been rounded to the fourth decimal point, as the effects are small and otherwise differences could not have been included. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table D.3 Robustness Check Stepwise Variable Inclusion, GLS AR(1) Model (estimates are transformed with α/100)

Variables (Log-transformed versions)	(1) Step 1	(2) Step 2	(3) Step 3	(4) Step 4	(5) Step 5	(6) Step 6	(7) Full Model
Solar Energy (*lnsolar*)	0.0030***	0.0028***	0.0028***	0.0024***	0.0021***	0.0020***	0.0018***
	(0.0238)	(0.0239)	(0.0239)	(0.0225)	(0.0263)	(0.0263)	(0.0254)
Wind Energy (*lnwind*)		0.0018***	0.0018***	0.0013***	0.0015***	0.0016***	0.0015***
		(0.0245)	(0.0245)	(0.0230)	(0.0257)	(0.0277)	(0.0267)
Hydro Energy (*lnhydro*)			0.0008	0.0009*	0.0009	0.0018**	0.0015**
			(0.0500)	(0.0490)	(0.0535)	(0.0748)	(0.0719)
GDP per capita (*lngdppc*)				0.1709***	0.1694***	0.1719***	0.1192***
				(0.482)	(0.513)	(0.549)	(0.646)

Energy Intensity (*lneint*)					0.0060	0.0050	-0.0017
					(0.477)	(0.522)	(0.505)
Governm. Expenditures (*lngexpfc*)						0.0145***	0.0101***
						(0.332)	(0.322)
Urbanization (*lnurban*)							0.2767***
							(2.023)
Constant	58.26***	58.79***	58.58***	-85.72***	-87.23***	-93.22***	-155.0***
	(2.039)	(1.985)	(1.980)	(4.193)	(4.737)	(5.234)	(6.715)
Observations	3,300	3,300	3,300	3,247	2,664	2,370	2,370
Number of countrycode_n	182	182	182	180	179	167	167

Notes: All coefficients have been rounded to the fourth decimal point, as the effects are small and otherwise differences could not have been included. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table D.4 Robustness Check Stepwise Variable Inclusion AB Model (estimates are transformed with β/100)

Variables (Log-transformed versions)	(1) Step 1	(2) Step 2	(3) Step 3	(4) Step 4	(5) Step 5	(6) Step 6	(7) Step 7	(8) Full
Lag of Energy Poverty	0.0096***	0.0090***	0.0088***	0.0088***	0.0078***	0.0079***	0.0079***	0.0077***
	(0.00698)	(0.0134)	(0.0152)	(0.0152)	(0.0236)	(0.0259)	(0.0263)	(0.0268)
Solar Energy (*lnsolar*)		0.0016***	0.0014***	0.0014***	0.0016***	0.0014***	0.0014***	0.0013***
		(0.0275)	(0.0262)	(0.0263)	(0.0272)	(0.0305)	(0.0285)	(0.0279)
Wind Energy (*lnwind*)			0.0016***	0.0015***	0.0013***	0.0013***	0.0010**	0.0010***
			(0.0341)	(0.0341)	(0.0324)	(0.0415)	(0.0397)	(0.0393)
Hydro Energy (*lnhydro*)				-0.0001	-0.0004	-0.0005*	-0.0001	-0.0004
				(0.0313)	(0.0293)	(0.0240)	(0.0646)	(0.0586)
GDP per capita (*lngdppc*)					0.0662***	0.0628***	0.0564***	0.0478***
					(0.956)	(1.070)	(1.118)	(1.087)
Energy Intensity (*lneint*)						-0.0063	-0.0104	-0.0118*
						(0.639)	(0.680)	(0.688)
Governm. Expenditures (*lngexpfc*)							-0.0002	-0.0013
							(0.434)	(0.430)
Urbanization (*lnurban*)								0.0906***
								(2.589)
Constant	3.831***	7.475***	9.201***	9.186***	-41.49***	-37.59***	-32.16***	-58.88***

	(0.428)	(0.842)	(1.000)	(0.971)	(7.151)	(8.606)	(9.243)	(12.13)
Observations	2,898	2,898	2,898	2,898	2,855	2,284	2,027	2,027
Number of countrycode_n	181	181	181	181	179	179	165	165

Notes: All coefficients have been rounded to the fourth decimal point, as the effects are small and otherwise differences could not have been included. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1