The effects of energy accessibility on income inequality in Latin America and Caribbean countries

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I declare that this document is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the *Universidade de Lisboa*.

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Abstract

Transitioning to clean energy offers multiple benefits: curb Carbon Dioxide (CO_2) emissions, foster job creation, and provide affordable electricity. However, such a transition can also intensify inequalities. Indeed, addressing income inequality is vital to avert political and economic instability, which can obstruct poverty alleviation efforts. This thesis explores the intricate relationship between energy access and income inequality, focusing on Sustainable Development Goals (SDGs) 7 (clean energy access) and 10 (reducing income inequality). The focus is on Latin America and the Caribbean (LAC) nations that experience disparities in energy access and income inequality. Lack of access to modern energy services, often prevalent in marginalised communities, hampers well-being, health, and economic prospects. Data from six LAC countries (Bolivia, Brazil, Colombia, Costa Rica, El Salvador, and Honduras) between 2000 and 2019 is analysed using a Fixed Effects multiple linear regression (OLS) model, correlation analysis, and Granger causality tests. The results reveal that the link between GDP per capita and income inequality varies across countries, being responsible for increasing disparities in some of them and reducing them in others. At the same time, Granger causality tests demonstrate that energy-related factors, like electricity and clean cooking fuel access, can mitigate income disparities in the six LAC nations studied, but the impact is country-specific. This thesis emphasises the potential of clean energy access in income inequality reduction and offers recommendations to policymakers and stakeholders. Despite focusing on LAC countries, these findings have broader implications for other middle-income countries. It also underscores that strategies to diminish income inequality through enhanced energy access must be tailored to each country's unique context.

Keywords

Income inequality; Energy accessibility; LAC region; OLS model; Correlation analysis; Granger causality.

Resumo

A transição para as energias limpas oferece múltiplos benefícios: reduzir as emissões de dióxido de carbono (CO_2), promover a criação de emprego e fornecer eletricidade a preços acessíveis. No entanto, essa transição pode também intensificar as desigualdades. De facto, a resolução da desigualdade de rendimentos é vital para evitar a instabilidade política e económica, que pode obstruir os esforços de redução da pobreza. Esta tese explora a intrincada relação entre o acesso à energia e a desigualdade de rendimentos, centrando-se nos Objetivos de Desenvolvimento Sustentável (ODS) 7 (acesso à energia limpa) e 10 (redução da desigualdade de rendimentos). O foco está nas nações da América Latina e das Caraíbas (ALC) que apresentam disparidades no acesso à energia e na desigualdade de rendimentos. A falta de acesso a serviços energéticos modernos, frequentemente prevalecente em comunidades marginalizadas, prejudica o bem-estar, a saúde e as perspetivas económicas. Dados de seis países da ALC (Bolívia, Brasil, Colômbia, Costa Rica, El Salvador e Honduras) entre 2000 e 2019 são analisados usando um modelo de regressão linear múltipla de efeitos fixos (OLS), análise de correlação e testes de causalidade de Granger. Os resultados revelam que a relação entre o PIB per capita e a desigualdade de rendimentos varia consoante os países, sendo responsável pelo aumento das disparidades em alguns deles e pela sua redução noutros. Ao mesmo tempo, os testes de causalidade de Granger demonstram que os fatores relacionados com a energia, como o acesso à eletricidade e a combustíveis limpos para cozinhar, podem atenuar as disparidades de rendimento nos seis países da ALC estudados, mas o impacto é específico de cada país. Esta tese enfatiza o potencial do acesso à energia limpa na redução da desigualdade de rendimentos e oferece recomendações aos decisores políticos e às partes interessadas. Apesar de se centrar nos países da ALC, estas conclusões têm implicações mais amplas para outros países de rendimento médio. Também sublinha que as estratégias para diminuir a desigualdade de rendimentos mediante um melhor acesso à energia devem ser adaptadas ao contexto único de cada país.

Palavras-chave

Desigualdade de rendimentos; Acessibilidade energética; Região da ALC; Modelo OLS; Análise de correlação; Causalidade de Granger.

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List of Abbreviations

BRICS	A grouping of Brazil, Russia, India, China, and South Africa
CO_2	Carbon dioxide
DESA	Department of Economic and Social Affairs
ECB	European Central Bank
EU	European Union
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GE	General Entropy
GEA	Global Energy Assessment
ICT	Information and Communication Technology
IEA	International Energy Agency
ILO	International Labor Organization
IMF	International Monetary Fund
KMO	Kaiser-Meyer-Olkin
kWh	kilowatt-hour
LAC	Latin America and the Caribbean
LPG	Liquefied Petroleum Gas
OECD	Organization for Economic Cooperation and Development
OLS	Ordinary Least Squares (regression)
P90/P50	The ratio of the 90th percentile value over the distribution median
PCA	Principal Component Analysis
R&D	Research and development
SDG	Sustainable Development Goals
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Program
US	United States
USO	Universal Service Obligations
VAR	Vector Autoregressive
VIF	Variance Inflation Factor
WHO	World Health Organization
WIID	World Income Inequality Database

List of Symbols

α	Parameter to calculate General Entropy. Its weight controls the sensitivity to different benefit values. The Generalised Entropy indices can be computed for all variable values when $\alpha \neq 1$ is a positive integer
α_i	Fixed effect for entity i
$\beta 0$	Constant coefficients associated with the independent variables
β	Coefficients associated with the independent variables
ε	Parameter to calculate the Atkinson indicator. In practice, ε values of 0.5, 1, 1.5 or 2 are used; the higher the value, the more sensitive the Atkinson index becomes to inequalities
μg	Micrograms

List of Software

Stata 17	Software package for statistics, data management, and graphics

Chapter 1

Introduction

This chapter overviews the present work and establishes its targets, original contributions, scope, and motivations. The dissertation's structure is also provided.

1.1 Overview

The 2030 Agenda for Sustainable Development prioritises the reduction of income inequality, side-by-side with the need for people to have access to reliable and clean energy – Sustainable Development Goals (SDGs) 10 and 7, respectively. The preferential path to a future clean energy system is through the large-scale deployment of renewable energy sources, reducing emissions while potentially creating employment opportunities and providing accessible electricity at a reasonable cost. However, if income inequality concerns are not fully addressed, political and economic instabilities may arise, constraining poverty alleviation.

Moreover, achieving SDG 7, which focuses on ensuring access to affordable, reliable, sustainable, and modern energy for all, is crucial. However, it is essential to note that addressing SDG 7 is necessary and significantly impacts other SDGs as it is closely interconnected with several different goals, such as eradicating poverty and reducing inequality. Lack of access to modern energy can inhibit a nation's ability to tackle various other challenges it faces, including issues like air pollution, low life expectancy, inadequate healthcare services, providing quality education, climate change adaptation, food production and security, economic growth and employment, sustainable industrialisation, and more (IEA, 2017; UNDP, 2018a). Fulfilling SDG 7 not only addresses the goal of ensuring access to modern energy but also plays a critical role in advancing progress across various other SDGs by providing the foundation for improved living conditions and poverty reduction, especially for low-income populations.

In a world where energy is an indispensable ingredient for progress and well-being, the unequal distribution of this fundamental resource is a matter of global concern. In addition, access to electricity is critical in realising the United Nations' "Leave no one behind" principle because it can improve households' living conditions and capacities, particularly relevant to low-income individuals. There is a close association between low levels of human development and unequal access to energy. When access to power is uneven and energy justice[1] is forgotten, it can generate energy poverty, which refers to inefficient access to affordable and modern energy services. It is a condition in which individuals or communities do not have sufficient access to electricity, clean cooking fuels, and technologies. Energy poverty can manifest in various ways and significantly affect people's well-being, health, and economic opportunities (Sovacool et al., 2017; UNDP, 2018a).

1.2 Motivation and Contents

Literature examining the relationship between energy accessibility and income inequality remains scarce. This dissertation aims to contribute to discussing the effects of energy accessibility and other relevant energy issues, such as energy structure (the access to clean cooking fuels) and international economics variables on inequality, evaluating if the increase in energy access, consequently, a

[1] Energy justice advocates for a more equitable and inclusive energy landscape, one that ensures that the benefits of energy access are shared by all, regardless of economic status, geographic location, or social background (Sovacool et al., 2017)

reduction in energy poverty, could diminish income inequality and prevent other intersecting disparities. Because, access to energy affects income inequality directly by helping people build and own assets (which reduces the income gap) and indirectly by improving health, education, employment, gender equality, and agriculture – concepts that will be discussed in Section 2. For this reason, the relationship between access to energy services and inequality is becoming a critical subject in political discourse, and further research is needed.

To provide a global view of the results, in Section 3, the methodology used to create this analysis is detailed to explain that the econometric models were first applied to 37 OECD and Latin America and Caribbean (LAC) region countries – low, medium, and high-income countries – with income inequality databases available between 2000 and 2019. Accordingly, one multiple regression model (OLS) with fixed effects was employed for the complete group of countries and another for the LAC countries. For this purpose, relevant economic data variables were gathered, such as income inequality measures (e.g., Gini Coefficient), GDP, urban and rural population sizes, labour force statistics indicators, the ratio of female to male labour force participation rate in percentage, and current Health expenditure per capita. As for energy-related variables, indicators include the portion of the population with access to electricity and the ratio of the people with access to clean fuels and technology for cooking. These variables were collected from reliable databases, including OECD Statistics, The World Bank, The World Inequality Database, The Sustainable Development Reports from the U.N., and the U.S. Energy Information Administration. The models were developed using the program Stata 17.

After analysing the 37 countries, this dissertation focused on the LAC region because it has significant disparities in energy access. While some urban areas in the region enjoy reliable and modern energy services, many rural and marginalised communities still lack access to electricity and clean cooking fuels. This disparity in energy access within a single region provides a clear context for studying its impact on income inequality. Furthermore, many countries in the LAC region struggle with income inequality and are characterised by various energy access and income distribution policy approaches (Barnes et al., 2018).

This research believes that exploring the relationship between energy access and income distribution in such an environment can illuminate whether improved energy access can help alleviate income disparities. To that end, in Section 4, the empirical results are presented, which consist of the OLS model results in the complete panel and the LAC region. This research also provides new knowledge on the impact of energy accessibility and access to clean cooking fuels on inequality by performing a correlation analysis and Granger causality tests to evaluate the variables' relationship with income inequality in each of the six LAC countries investigated – Bolivia, Brazil, Colombia, Costa Rica, El Salvador and Honduras, the only countries with consistent inequality data for the desired period.

The findings indicate that energy-related variables can reduce income disparities in the LAC countries. However, how they cause or are caused by income inequality differs depending on the country and its context. Comparing these results can yield insights into which strategies are more effective in reducing income inequality through improved energy access, which will be discussed in Section 5, together with the dissertations' policy implications and recommendations. Section 6 presents the conclusions, limitations, and potential perspectives for future research.

This dissertation aims to contribute to the discussion of the effects of energy accessibility on inequality, analysing the resulting policy implications and providing suggestions on how to take advantage of the incoming energy revolution to tackle inequality matters. The final objective is to provide guidelines and recommendations to several political and economic agents on overcoming the challenges associated with energy accessibility, contributing to the transition to a prosperous clean energy economy.

Chapter 2

Literature Review

This chapter provides the current state-of-the-art concerning the scope of the dissertation.

This literature review explores the existing knowledge about the relationships between energy accessibility and income inequality by analysing academic articles, reports, and empirical studies conducted in various geographical contexts, with a particular emphasis on developing regions characterised by disparities in energy access, such as Latin America and the Caribbean region, in opposition to high-income areas such as the European Union.

As this study delves into the literature review, the complexities of energy poverty and its ramifications on society will be revealed, exploring how varying energy structures and access patterns intersect with economic variables and policy measures and how these factors collectively shape income distribution dynamics. The ultimate objective is to contribute to a deeper understanding of the interactions between energy access and income inequality, offering insights into practical strategies for reducing disparities and leveraging the transformative potential of energy access for sustainable development.

By examining the existing body of research, this work aims to provide a comprehensive synthesis of the knowledge in this field, identify gaps in the literature, and highlight the policy implications that can guide stakeholders and decision-makers in their efforts to address energy poverty and income inequality on a global scale.

2.1 Energy poverty: Concepts, measures, and consequences

Three significant shifts related to energy security, climate change, and energy poverty will need to be made in the energy sector during the next few decades. Still, most studies are related to the first two issues (González-Eguino, 2015). However, according to the United Nations Development Program (UNDP, 2018, p. 2), *"about 1.2 billion people still lack access to electricity and nearly 40 per cent of the people in the world lack access to clean cooking fuels"*, which means that several people around the world are suffering from energy poverty, illustrating the importance of approaching this theme.

Energy poverty can have many distinct meanings and interpretations depending on the situation and the country of reference, so it might be challenging to define it globally. However, all definitions and interpretations relate to energy usage that cannot satisfy some fundamental necessities (Sovacool, 2012). For instance, energy poverty is a lack of access to electricity and clean cooking fuels – when people rely on biomass fuels – and technologies (IEA, 2017; UNDP, 2018). Furthermore, the International Energy Agency argues that *"energy poverty can take different forms, including a lack of access to modern energy services, a lack of reliability when services do exist, and concerns about the affordability of access"* (IEA, 2017, p. 24). It can also be illustrated as a multifaceted notion that includes, among other features, *"caloric intake, life expectancy, housing quality, literacy"* (Njiru & Letema, 2018, p. 2).

There is a concept similar to energy poverty studied by Boardman (1991) and named fuel poverty, which is described as the inability to purchase sufficient heating because of the house's inefficient use of energy, which has low income, energy efficiency, and fuel prices as its main drivers. However, the United Nations (U.N.) clarified that energy poverty includes fuel poverty in the developed world, even though it is most often used in the context of the developing world (UNDP, 2018a). Although strongly related, the main difference between these two concepts might be that energy poverty is more related to a lack of access to electricity networks. In contrast, fuel poverty refers to low household incomes or energy-inefficient dwellings that make it challenging to buy energy for space heating - and other relevant domestic services (Bouzarovski & Petrova, 2015). In this case, if affordability was not a burden, the household could have more warmth while using less energy when there is a capital investment in energy efficiency upgrades. An increase in energy efficiency makes it possible to use more power for the same amount of money (Boardman, 1991).

As presented by the U.N. (UNPD, 2018), energy is appreciated more for the services it makes possible than for its own sake. It is used for lighting, thermal energy, powering machinery, equipment, and appliances. Plus, all forms of technology are necessary to assist night-time activities and enhance food quality, cooking effectiveness, productivity, and work quality (Sambodo & Novandra, 2019). Access to energy services is essential for promoting human development and the social inclusion of the most vulnerable and underprivileged members of society (IEA, 2017). A reason why UNDP (2018) and IEA (2017) believe that SDG 7 is most helpful is because it supports the achievement of other SDGs since, for instance, the community can increase economic efficiency, improve health, and expand study hours and other activities with access to power (Sambodo & Novandra, 2019).

Therefore, achieving SDG 7 is necessary, but more is needed to complete all other SDGs. However, there is a solid connection between SDG 7 and several SDGs, including SDG 1 (No Poverty) and SDG 10 (Reduced Inequality) (UNDP, 2018a). Furthermore, a nation may find it difficult or impossible to address the other issues it faces - air pollution, low life expectancy and lack of access to essential healthcare services (SDG 3), providing quality education (SDG 4), adapting to and mitigating climate change (SDG 11), food production and security (SDG 2), economic growth and employment (SDG 8), sustainable industrialisation (SDG 9), and many others – if it lacks access to modern energy (IEA, 2017). Access to electricity also helps realise the idea of "Leave no one behind" because it can potentially improve households' capacities and living situations, given that low levels of human development and unequal access to energy are closely associated (UNDP, 2018a). Having that said, it is possible to understand that, for instance, increased access to electricity can give low-income people better chances to raise their standard of living and leave the poverty line.

The IEA, as well as other organisations, use measures that evaluate energy poverty as outputs (such as a lack of electrical connections) as opposed to assessing energy poverty as outcomes (such as electricity usage and related welfare improvements). Indeed, energy poverty can be measured in a variety of ways since there is no measurement of energy poverty in industrialised nations that is acknowledged universally, as explained by the agency and several authors (IEA, 2017; Njiru & Letema, 2018; Pachauri & Spreng, 2011; Sovacool, 2012). Consonant to Pachauri and Spreng (2011), there are three different but complementary ways of measurement:

a. First is the technological threshold, a strategy based on the notion that a significant obstacle to addressing energy poverty is accessing “modern” energy services – sources of energy other than biomass for house heating and cooking. According to this viewpoint, the population without access to these services is used to calculate the level of energy poverty;

b. The second is the physical threshold, which calculates the minimal energy required to meet basic necessities. Anyone found to be below that mark is regarded as experiencing energy poverty;

c. Finally, the third method is the economic threshold, which aims to determine the highest percentage of income that can reasonably be allotted for spending on energy. In wealthy nations, this is the method of evaluating energy poverty or, in this case, fuel poverty that is most frequently employed. A family is often deemed energy-poor if it spends more than 10% to 15% of its income on energy per month or year. Due to both reasons, first, households earn low-than-average incomes, and second, however, they usually consume less energy than other strata of homes; they may need access to more efficient fuels, increasing their energy supply expenditures to satisfy their basic needs (Sovacool, 2012; IEA, 2017).

More focused on developing countries, Sovacool (2012) complemented the above measures with additional approaches, such as (1) keeping track of the minimal quantity of material or life-form energy required for necessities like cooking and lighting; (2) analysing the types and quantities of energy used by the poorest individuals and households in a particular nation, such as those in the lowest income quantile; and (3) assessing the income level below which energy consumption or expenditures are equal, which implies that this level is the absolute most minor required to satisfy essential energy requirements.

In addition, according to Oum (2019), since households with lower incomes tend to spend a more significant proportion of their disposable income on energy services or choose not to join grid networks, revenue and prices (cost) can directly contribute to energy poverty through accessibility and affordability. When people have access to energy, those with lower incomes frequently spend disproportionate amounts of their income on energy, partly because energy-efficient equipment has more significant initial costs. Public clean energy incentive programmes may have disproportionately high costs for lower-income taxpayers, and public funding favours large-scale on-grid infrastructure over more modest off-grid development (UNDP, 2018). Homes with poor energy efficiency and outdated home furnishings would need people to pay more for the same energy services (Oum, 2019), which increases inequality and negatively impacts their quality of living.

Moreover, energy poverty is only a symptom of overall poverty: when households must choose between cooking, eating, and the ability to move, it is evident that they do not distinguish between energy, food, and mobility insecurity (Middlemiss, 2020). As a consequence, energy poverty may also affect other types of poverty since the lack of access to energy could entail being denied not only necessities like cooking and house heating but also other components essential for both individual and societal growth, such as access to information, health care, education, and political involvement (González-Eguino, 2015).

Proving that increasing energy access can significantly affect individuals' quality of life, several findings reveal that more people with higher educational levels and longer life expectancies reside in regions with higher electrification rates. Improvements in school completion rates enable residents to obtain well-paying jobs, increasing their purchasing power and raising living standards. Furthermore, access to electricity increases the quality of medical care and lowers maternal and infant mortality, increasing life expectancy (Njiru & Letema, 2018). Therefore, improving access to energy and modern energy services is crucial to raising the quality of living and reducing energy poverty, income, gender, and other inequalities (Acheampong et al., 2021), which will be discussed in the following topics.

2.1.1 The Influence of Prices and Regulation on Energy Access

According to different agencies (GEA, 2012; IEA, 2017; UNDP, 2018a), understanding the influence of energy prices on energy access helps address several issues and is vital for creating sustainable and inclusive energy systems that benefit individuals, communities and the environment. Among the concerns is, for instance, energy poverty, since rising energy prices can exacerbate energy poverty, preventing individuals and communities from meeting their basic energy needs. Also, by understanding the relationship between energy prices and access, policymakers, organisations, and researchers can develop targeted strategies to alleviate energy poverty and ensure affordable energy.

In addition, analysing the role of prices on energy access can help guide energy planning and investment decisions because low energy prices and more stringent environmental regulations can incentivise investment in energy infrastructure and encourage the adoption of cleaner and more sustainable energy sources, ensuring that resources are allocated efficiently and effectively. Conversely, high energy prices can discourage investment, particularly in underserved areas. Furthermore, this comprehension can also encourage energy efficiency because higher energy prices create economic incentives for individuals and businesses to search and adopt alternatives such as energy-efficient technologies and practices, which can promote energy efficiency initiatives, leading to reduced energy demand, lower energy costs, and improved energy access to all.

Finally, energy prices can significantly impact the pace and scale of the transition from fossil fuels to renewable energy sources, fostering an equitable energy transition. By comprehending the impact of energy prices and regulations on energy access, policymakers can design policies and incentives that facilitate fair energy transitions, ensuring that vulnerable communities are not left behind and have access to affordable and clean energy options.

Thus, the price of energy can significantly influence energy access, particularly for individuals and communities with limited financial resources. Below are listed different paths in which energy prices can impact energy access (GEA, 2012; IEA, 2017; UNDP, 2018a):

a. Affordability: High energy prices can make energy services unaffordable for many people, particularly those living in poverty or with low incomes. When energy costs are high, individuals and communities may struggle to pay their bills or afford the necessary infrastructure to access modern energy sources, resulting in energy or fuel poverty.

b. Availability: In some cases, high energy prices can limit the availability of energy sources, which can restrict energy access, particularly in remote or marginalised areas already underserved.
c. Energy transition: Energy prices can also influence the change from traditional and polluting energy sources to cleaner and more sustainable alternatives. Lower energy prices for renewables encourage their adoption, leading to increased energy access as communities can harness these sources for their energy needs.
d. Energy efficiency: Energy prices can drive incentives for energy efficiency measures because, when they are high, individuals and businesses are more motivated to reduce their energy consumption and adopt energy-efficient technologies.
e. Government subsidies and policies: Governments often intervene in energy markets to reduce market power and to promote energy access and affordability, particularly for vulnerable populations. Subsidies and price regulations can be implemented to mitigate the impact of high energy prices, making energy more accessible for those who need it most.

However, the relationship between energy price and accessibility is complex and can vary across different regions and contexts. Other factors, such as infrastructure development, technological advancements, and policy frameworks, are crucial in ensuring equitable and sustainable energy access. Regarding the role of regulation in improving energy access, it can occur through several forms, as listed below (European Parliament, 2023; GEA, 2012; IEA, 2017; OECD, 2004):

a. Pricing and tariff regulation: Ensuring that energy prices are fair and affordable, especially for vulnerable populations. Regulators can implement pricing mechanisms to prevent excessive pricing by energy suppliers to ensure that energy remains accessible to low-income households and marginalised communities.
b. Universal service obligations: Regulators can impose Universal Service Obligations (USOs) on energy providers, requiring them to extend their services to underserved or remote areas. In addition, regulators can establish targets and incentives to encourage energy providers to fulfil their USOs effectively.
c. Quality and reliability standards: Regulations can set minimum quality and reliability standards for energy services, ensuring that consumers can access reliable and safe energy sources. By holding energy providers accountable for meeting these standards, consumers can have confidence in the reliability of their energy supply.
d. Incentives for renewable energy: They can create incentives and supportive frameworks for developing and deploying renewable energy sources. By promoting renewable energy, regulators can facilitate the transition from fossil fuels, improve environmental sustainability, and expand energy access through decentralised energy systems, especially in rural and off-grid areas.
e. Energy efficiency standards: Regulations can establish energy efficiency standards for appliances, buildings, and industrial processes. These standards can mandate energy-efficient technologies and practices, reducing energy demand and promoting affordability. By promoting

energy efficiency, regulators can contribute to energy access by ensuring energy is used more effectively and sustainably.

f. Consumer protection: They can protect consumer rights and ensure fair practices in the energy sector, safeguarding consumers' interests, promoting trust, and ensuring that energy access barriers are minimised.

g. Market design and competition: Regulations can foster competitive energy markets that promote innovation, efficiency, and lower prices, encouraging new entrants and investments in the energy sector. It can increase access to energy services and more affordable consumer options.

However, it is essential to note that the specific regulatory approaches and mechanisms can vary across countries and regions. Effective regulation requires a comprehensive understanding of the local context, stakeholders' engagement, and ongoing monitoring and evaluation to ensure its impact on improving energy access. The following sections will analyse the relationships between energy access and other relevant issues.

2.2 The relationship between energy access and gender equality, health, education, and productivity

The IEA argues that gender equality and energy access overlap in significant ways. While both men and women are affected by a lack of access to contemporary, sustainable types of energy, women frequently bear a disproportionate share of the burden due to differences in social status, economic capacity, and gender-defined responsibilities (IEA, 2017). Mainly because, in many parts of the world, women spend more time than men cooking, gathering water, and gathering fuel. Access to clean energy is essential for women's health, education, and creative activities (UNDP, 2018). Besides, the long hours spent in these unpaid fields of work lower women's earnings, exacerbating gender inequity (Acheampong et al., 2021; Sunikka-Blank, 2020). Likewise, enhancing energy accessibility would make it more feasible for women to access school and career opportunities and improve their standard of living by lessening their unpaid work burden and the consequences of their inadequate access to energy (Bouzarovski & Petrova, 2015; UNDP, 2018). Reinforcing that energy access might also be directly tied to lowering poverty and inequality for women.

This relationship is demonstrated by Nguyen and Su (2021), who concluded that a rise in the proportion of female wage and salaried workers compared to their male counterparts similarly correlates with a reduction in energy poverty. In other words, reducing energy poverty often promotes gender equality in the workforce. The study also demonstrates that, according to health indicators, a decline in energy poverty appears to rebalance gender inequalities. It is also interesting to note that, according to the authors, reducing energy poverty has been linked to increased gender equality in education and socio-economic rights for women, illustrating that measures taken in this direction could improve women's living standards.

In line with the previous authors, Sunikka-Blank (2020) explained that women are especially susceptible to energy poverty due to time poverty (lower hourly rates than men), unpaid domestic labour, and unequal financial distribution. Women are more vulnerable to poverty during certain risky times, such as giving birth to a child or due to ending a relationship with a partner when they become single parents. Indeed, according to the author, in the U.K. and all E.U. nations, women predominately head single-parent households, and they are twice as likely to experience energy poverty. Moreover, women from lower socio-economic classes and members of ethnic minorities are more likely to end their relationship because of the cumulative adverse effects of single-parent families: energy poverty can last for decades and hinder intergenerational mobility. Furthermore, despite having college degrees, women might be unable to maintain "proper" jobs since they must fit their working hours around their studies, trapping them in the informal economy, low-paying part-time jobs, and having little time to advance their talents.

The impact of energy poverty on health can intersect with the impact on women. For instance, most houses without access to modern energy for cooking burn fuels indoors, generating several dangerous chemicals and exposing these households to sixty times more air pollution than permitted outdoors, for instance, in city centres in North America and Europe (Sovacool, 2012). It happens because *"burning solid fuels produces extremely high levels of indoor air pollution with peaks during cooking may be as high as 10 000 µg/m3"* (WHO, 2006, p.10). This is dangerous since women spend 3 to 7 hours a day in the kitchen, and this pollution from the stoves is emitted while people cook or eat. Not to mention that women, children, the elderly, and people with disabilities are more likely to be exposed to indoor pollution as they spend more time at home (Bouzarovski & Petrova, 2015; González-Eguino, 2015). Coupled with that comes the fact that women and children are especially at risk for other health problems than respiratory diseases as they go through the complex and time-consuming process of gathering fuel, suffering, for example, from back and foot injuries, wounds, cuts, sexual assaults, and exposure to severe weather, especially in underdeveloped countries and low-income regions (Sovacool, 2012). Statistics show that the lack of access to clean fuels and cooking technologies harms the health of 3 billion people and is responsible for approximately 2.8 million premature deaths per year worldwide, while household air pollution is responsible for 4 million non-communicable disease deaths each year, including cancer, heart disease, and stroke (IEA, 2017; UNDP, 2018a).

Another health influence happens in the case of people who have access to electricity. However, the burden is its affordability, with the most vulnerable population at risk for health problems and loss of income due to inefficient household energy use (UNDP, 2018a). In this scenario, the problem may not be related to biomass usage for energy but instead to keeping homes adequately warm. In developed countries, the health impact of fuel poverty is perceived concerning low temperatures since, in conjunction with other factors, such as humidity and degree of clothing insulation, cold exacerbates the risk of respiratory diseases and cardiovascular problems. Moreover, physical discomfort resulting from cold and anxiety relating to the cost of keeping the house warm results in stress that can create mental health issues relating to anxiety and depression (Adom et al., 2021; Hills, 2011).

However, the influence of energy poverty goes beyond indoor air pollution and inadequate temperatures. The U.N. (UNDP, 2018a) complements the health consequences of the lack of energy with access to heating, ventilation, cooling systems, blood banking, cold-chain vaccine storage, and ICT services, which can limit the availability of life-saving care in healthcare facilities. Furthermore, many basic life-saving procedures in medical facilities cannot be carried out correctly or at all in the absence of power, including lighting operating and examination rooms, sterilising equipment to prevent infection, medications and blood for transfusions, running medical devices for diagnosis and treatment, and implementing hygiene and infection control measures (UNDP, 2018). Once again, the importance of energy accessibility is evident. SDG 3's core objectives for public health, including increasing child survival and reducing non-communicable diseases, can only be met with increasing access to clean energy. That said, it is reasonable to believe that access to affordable, dependable, and clean energy services for the house can lessen the health effects of climate-sensitive diseases, potentially preventing millions of deaths yearly (UNDP, 2018).

In an intersection between health and education, energy poverty can influence education through increasing disease rates and absenteeism from school. Numerous medical research studies have linked children's acute respiratory illnesses, the main reason for absences from school in many nations, and the effects of indoor air pollution (Sovacool, 2012) previously mentioned. Besides, schools, college dorms, kitchens, and staff facilities are forced to rely on non-sustainable sources of energy such as kerosene, charcoal, and biomass for lighting and cooking due to a lack of access to sustainable energy, which undermines the health and learning skills of students and staff by exposing them to indoor air pollution, increasing health concerns ranging from respiratory illnesses to headaches (UNDP, 2018c). Studies also defend that the lack of energy contributes to behavioural issues in school, including trouble concentrating, lack of academic enthusiasm, depression, somatic complaints, and rule-breaking behaviour (Adom et al., 2021). In addition, Sovacool (2012) explains that several children — primarily girls — stay home from school to finish duties like cooking and collecting firewood. Notably, not having to perform such tasks due to accessing advanced energy technology can promote gender equality and better education because girls will have more time available to devote to their studies (Acheampong et al., 2021; IEA, 2017; Sovacool, 2012).

Additionally, energy services can help schools hire and keep more talented instructors. In contrast, the use of lighting powered by clean energy technologies can increase the amount of time children have to study at night and improve schools' access to computers and the internet, or even raise school attendance due to lighting, particularly in areas where natural light penetration is low (GEA, 2012; Sovacool, 2012; UNDP, 2018c), collaborating with the U.N. goal of delivering quality education (SDG 4). Moreover, since it fosters a mindset that respects environmental laws, uses appropriate energy products to minimise energy poverty and lessens income inequality, education is crucial for halting environmental degradation (Hassan et al., 2022), contributing to the achievement of even more SDGs.

It seems reasonable to assume that access to modern and clean sources of energy is crucial to support good quality education, which can proportionate to people's ability to land good-paying jobs, increasing their purchasing power and significantly improving their well-being (GEA, 2012; Njiru & Letema, 2018). Such as, for instance, a decline in income inequality in Latin America is primarily attributable to the narrowing of wage gaps that secondary education expansion, together with efforts to reduce informal employment, higher minimum wages, a decrease in returns to the labour market, and increases in social spending made possible (DESA, 2020). Similarly, access to information and communication technology through energy use may even promote the creation of microbusinesses, making it possible for individuals to enrol in high-quality online training programs free of charge and encouraging societal empowerment (González-Eguino, 2015), contributing to economic growth and reduction of income inequality.

Furthermore, in which it concerns energy access related to productivity, as previously illustrated, energy insecurity and poverty are closely related, with low-income households' earnings being significantly impacted by energy costs, aggravating their poverty. However, more than ensuring that every home has access to electricity is required to guarantee economic and social progress. Although all production sectors are impacted by energy poverty, which limits development opportunities (González-Eguino, 2015), to assist in reaching the SDG goal on poverty, energy must also be accessible for productive purposes like agriculture and manufacturing (IEA, 2017). Moreover, the availability of electrical power can result in job creation directly by ensuring the manufacturing of new goods and services (Acheampong et al., 2021) and indirectly by impacting aggregate consumption since higher employment levels allow the population to have more purchasing power and improve the standards of living (Hassan et al., 2022; Njiru & Letema, 2018).

Productivity is also related to agriculture, which is essential for all countries. Access to electricity for agricultural production is crucial for most developing nations to support economic progress. For instance, irrigation, especially groundwater irrigation, is vital for raising farm productivity and frequently relies on energy availability to pump and transfer water (IEA, 2017).

One example of the detrimental impact of lack of access to energy for agriculture is the findings of Shi et al. (2022), showing that a 1% increase in energy poverty causes a 0.073% decline in agricultural technical efficiency. This result implies that low energy availability harms agriculture and that achieving agricultural sustainability and guaranteeing food security depends on lowering energy poverty.

Energy is also a crucial input for all manufacturing sectors, which combine energy and machinery with inputs like raw materials and other materials to create finished goods, from the most basic to the most sophisticated and technologically advanced. As clarified by the Global Energy Assessment Council (GEA, 2012), the relationship between energy and the development goals of establishing full and productive employment and decent work for all seems evident. However, the agency explains that while several nations have ongoing initiatives to support job creation through worker training or other skill-building activities, sources of energy for machines or funding plans to access energy-consuming equipment are frequently absent from the agenda. Likewise, service industries use energy as input through electricity devices, such as phones, computers, other information technology, air conditioners, specialised machinery, or security systems. As a result, in the services industry, energy can enable business owners to launch and expand new ventures and offer services to communities to promote economic growth and increase their well-being (IEA, 2017).

Coupled with agricultural development, industrialisation will increase the community's income due to access to modern and affordable forms of energy, and employment will increase, reducing poverty and boosting residents' capacity to pay for energy (GEA, 2012; Zhang et al., 2019), promoting economic growth. Therefore, a more robust economy will give the nation the resources it needs to expand access to electricity. Otherwise, since a lower electrification rate is typically correlated with poor economic development, a country is likely to strengthen its power infrastructure if it does so in other areas of its economy (Zhang et al., 2019). It illustrates how crucial energy access is to increase productivity and support a country's healthy economy.

2.3 Income inequality

Income inequality has its roots in the emergence of neoliberalism, which might be the pivotal moment when the previous era of economic growth, characterised by equality, gave way to the current generation of steadily rising economic disparity (Galvin & Sunikka-Blank, 2018). According to the Department of Economic and Social Affairs (DESA) of the United Nations (2020), making progress towards the SDGs has been hampered by this high and still growing inequality because societies with high-income inequality experience slower economic growth and are less successful in eradicating poverty. The agency clarifies that inequality produces or maintains unequal opportunities without the right institutions and policies by concentrating political power among those already better off.

Although economic disparities are still very high globally and have generally increased in most developed nations since 1990 (Figure 1), they have decreased, albeit from very high levels, in many Latin American nations – income inequality increased in most of the LAC countries throughout the 1990s, a period of severe economic instability, but it has started to reduce since 2000 – and several African and Asian countries. For example, the average income of individuals in the European Union is 11 times more than that of individuals in sub-Saharan Africa. In contrast, that of individuals in Northern America is 16 times greater. The absolute difference between the per capita incomes of high- and low-income countries increased from roughly $27,600 in 1990 to over $42,800 in 2018, even though low-income countries are expanding faster than high-income countries (DESA, 2020).

Currently, according to the World Inequality Database (WIID, 2022), the Gini coefficient – expressed as a number between 0 and 1 or 0 and 100, with 0 referring to perfect equality and 1 or 100 indicating total inequality – varies significantly by global region: North America: 0.35; Europe: 0.30; Asia-Pacific: 0.39; Middle East and North Africa: 0.38; Sub-Saharan Africa: 0.44 and Latin America and the Caribbean: 0.47. However, it is essential to note that these indexes can fluctuate over time and may provide a partial picture of economic inequality in each region. Furthermore, the timing, direction, and intensity of distributional changes vary among nations and even within areas, consequently generating the fact that group-based inequality trends differ by country and rely on the metric employed to measure development.

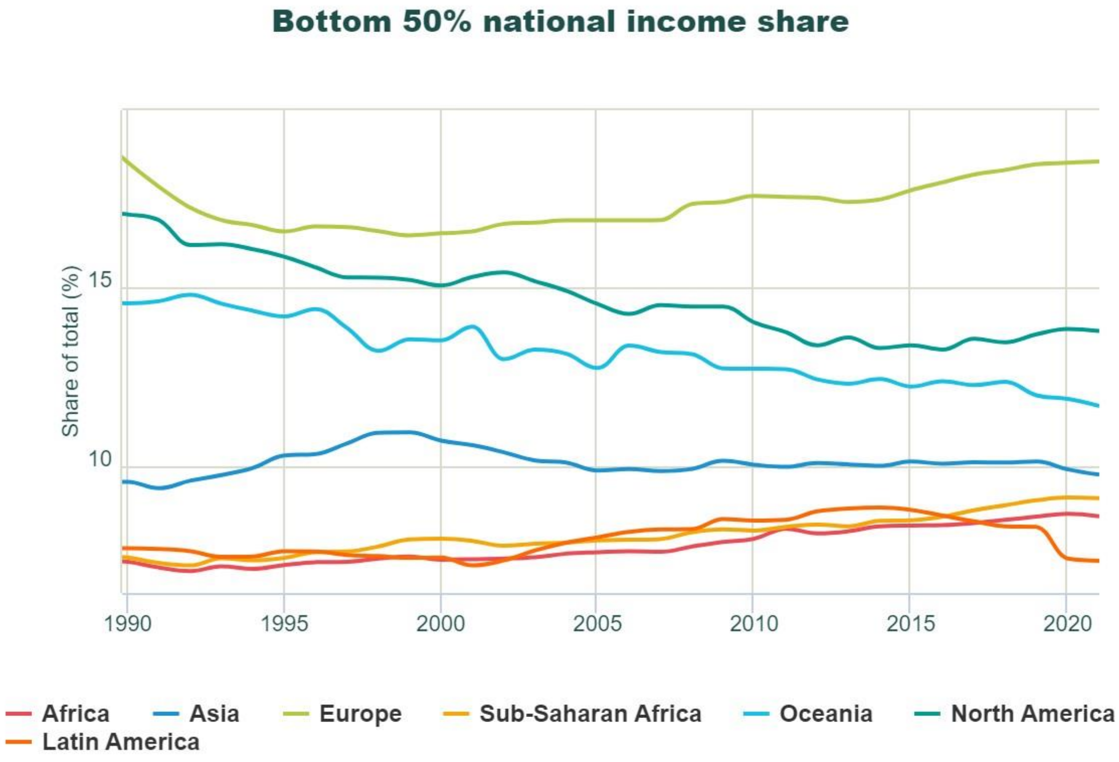

Figure 1. Pre-tax national income share held by the bottom 50% of the national income share group. Source: WIID, 2023[2].

As disclosed by the Organisation for Economic Co-operation and Development (OECD), rising income inequality significantly impacts economic growth, mainly because it reduces the capacity of the lower-income segments to invest in their skills and education. Reducing inequality is necessary to ensure equality of opportunities since people from low-income families face much weaker job prospects. As a result, higher-income inequality of parents tends to imply higher inequality of life chances of their children (OECD, 2023). Since they represent a particularly vulnerable group, the community's lower-income members are the most affected by economic imbalances (Hassan et al., 2022). For that reason, ensuring that the investment in human capital is repaid with access to profitable and fulfilling jobs is another aspect of promoting equality of opportunity and expanding access to high-quality education. (OECD, 2023). The economy suffers due to reduced growth in the future, as well as weaker demand today when those at the bottom of the income distribution are at a greater risk of not reaching their potential (DESA, 2020).

2.3.1 Measures of inequality

Different inequality measures describe income or wealth distribution across a population. Various

[2] Bottom 50% national income share, World Income Inequality Database (WIID).

https://wid.world/share/#0/countriestimeseries/sptinc_p0p50_z/QB;QD;QE;XF;QF;QP;XL/last/eu/k/p/yearly/s/false/6.3445/25/curve/false/country indicators provide insights into income inequality among individuals and households. Each measure has advantages and disadvantages and may use different sources and variables to perform different types of analysis.

The Gini coefficient or Gini Index is the most used measure of inequality. For instance, if the Gini coefficient is below 0.3 or 30, it suggests a relatively equal distribution of income or wealth. If it is between 0.3 or 30 and 0.4 or 40, it implies moderate inequality; if the Gini coefficient is above 0.4 or 40, it indicates significant disparities. Its application means that the Gini coefficient of within-country inequality gauges how much money is distributed across people or households in each nation.

In contrast, the income per capita of each nation is used as one observation or data point to calculate the Gini coefficient of global inequality (DESA, 2020). In other words, it determines the income disparity between the average citizen in each nation worldwide. Moreover, its importance comes from the fact that income and wealth levels are significant variables in and of themselves, but low income and wealth in an environment of great inequality results in additional structural disadvantages, for instance, for users of energy, since they must compete more fiercely for particular commodities and services (Galvin, 2020a).

However, since some surveys use income as the primary indicator of economic well-being while others use consumption expenditure, data sources must be more comparable. In this situation, the Gini coefficient cross-country datasets that must be harmonised frequently combine consumption and income data. This combination is necessary because estimates of inequality based on consumption are typically lower than estimates based on income, tending to understate the level of inequality when compared to calculations based on income data (DESA, 2020). Higher-income households tend to consume a smaller share of their incomes than lower-income households (and save more), thus having a lower marginal propensity to consume.

While the Gini index has many advantages and is widely used, it is essential to note that it is not the only measure of income inequality. Researchers and policymakers often use multiple measures to gain a complete understanding of income inequality. Other measures, such as the Atkinson index and General Entropy (G.E.) index, offer different perspectives and insights into income inequality and are sometimes used alongside the Gini index to provide a more nuanced assessment of income distribution. The measure’s selection depends on the specific research objectives and the characteristics of the data being analysed (ECB, 2019).

The Gini Index derives from the Lorenz Curve, in which the total number of income beneficiaries ranked from the poorest to the wealthiest person or household is shown on the horizontal axis, and the cumulative percentage of total income is represented on the vertical axis. The Lorenz curve shows the amount of income that x% of the population owns, and it is typically depicted about a 45-degree line that indicates absolute equality when every x per cent of the population receives the same x per cent of the income. Therefore, income distribution is more unequal the farther the Lorenz curve is from the 45-degree line (DESA, 2015). In other words, the closer the Lorenz curve is to the diagonal line of perfect equality, the lower the level of inequality. The degree of inequality increases with the distance between the diagonal line and the Lorenz curve.

Also, based on the Lorenz Curve, the Hoover index displays the percentage of total income that would need to be transferred to attain perfect equality, in which more inequality is shown by higher values, indicating that more redistribution is required to achieve income equality. It measures the difference between the actual income distribution and a hypothetical distribution in which all individuals have the same income. In total equality, or when every person has the same (positive) wealth, the Gini and Hoover indices are equal to 0. Both indicators tend to equal 1 when calculated for non-negative values of the variable – when there is total inequality when one person has all the wealth and everyone else has nothing. The Gini and Hoover measures are not above bounded but can be calculated for all variable values. A higher value for the metrics denotes a more significant distributional disparity (ECB, 2019). The maximum vertical distance between the Lorenz curve and the 45-degree line that depicts complete income equality can be used to display it graphically (DESA, 2015), meaning that if the distribution is non-equal, the Lorenz curve coincides with the axes, and the maximum distance between it and the diagonal is 1. If it is totally equal, the Lorenz curve coincides with the diagonal, so the distance is 0. For example, if the Hoover index is 0.4, 40% of the population's total income must be redistributed to achieve perfect equality.

Another method for measuring income inequality is the Kuznets Curve theory, which demonstrates that income inequality rises throughout the early stages of economic development with industrialisation, democratisation, and welfare development until GDP per capita reaches a tipping point and begins to fall. Thus, an inverse U-shaped relationship may exist between income disparity and income level (Nguyen & Nasir, 2021). This theory originates the Energy-Environmental Kuznets Curve hypothesis that will be presented in Subsection 3.1.

There is also a welfare-based indicator of inequality known as Atkinson's index, which displays the proportion of total revenue that a society would have to sacrifice to achieve more equitable income distribution among its members. The index measures how far an income distribution is from an equal distribution. In other words, it measures the difference between the actual income distribution and an ideal, perfectly equal distribution. While the Gini index measures relative inequality, meaning it is sensitive to disparities in different parts of the distribution but does not allow for a high degree of customisation, the Atkinson index is more customizable. It allows for a more nuanced analysis of inequality. By choosing different values for the parameter "ε," it is possible to focus on specific aspects of inequality in the distribution. For example, the parameter can be adjusted to make the index more sensitive to inequality among the poorest or wealthiest segments of the population. A number of 0 denotes complete equality, or that everyone has the same income, while a value of 1 denotes maximum inequality or that all income is concentrated in the hands of one person. The index's final value falls between these two ranges. The Atkinson index's interpretation depends on the parameter ε's chosen value. Different values of ε will lead to other variations, focusing on specific aspects of inequality within the distribution. Typical values of ε include 0 (focuses on the mean income), 1 (equalizes incomes), and 2 (reduces sensitivity to extreme inequalities) (ECB, 2019).

Moreover, the Atkinson index's ability to be divided into within- and between-group inequality is a crucial characteristic. If the Atkinson index is below 0.2, it suggests a relatively equal distribution of income or wealth. If it is between 0.2 and 0.4, it means moderate inequality; if the Atkinson index is above 0.4, it suggests significant inequality. For instance, an Atkinson index of 0.7 indicates that just 30% of the total wealth would be needed to provide the same level of social welfare if wealth were distributed equally (DESA, 2015).

The G.E. measure is another option, where indicators are equal to zero in a situation of total equality or when everyone has the same wealth. A higher index value denotes a greater distributional inequality. When a theoretical distribution is considered, the G.E. is unbounded; nevertheless, it is bounded in the case of a finite independent sample with an identical distribution. Similarly to the Atkinson index, the G.E. index is more customizable because it allows an adjustment in the parameter α to focus on specific aspects of inequality. Depending on the value of α, the index can be more or less sensitive to inequality in different parts of the income distribution (ECB, 2019).

In summary, concerning their applicability, the Gini index provides a straightforward, single-number overview of overall income or wealth inequality that is suitable when there is a need for a widely recognised and accepted measure for cross-country or cross-time comparisons, and that is simple to interpret and communicate to a broad audience, without any specific focus on a particular part of the income or wealth distribution. However, suppose there is a need to customise the sensitivity of the inequality measure to different parts of the income distribution. In that case, the Atkinson index allows to focus on specific aspects of inequality when there is an interest in assessing the impact of income inequality on the well-being of the poor or the rich, adjusting the index to be more or less sensitive to extreme incomes. Alternatively, if the objective is to capture the effects of inequality on different segments of the population, it is possible to conduct a more nuanced analysis of income inequality with the G.E. index.

Coupled with these measures, some methods are based on ratios, such as the percentage of total wealth held by households above the corresponding percentile of the wealth distribution. For instance, the homes to the right of the 90th percentile own 10% of the total wealth, according to the top 10% share. Top shares are constrained below by the share's worth and above by 100% in the case of positive net wealth values. A higher maximum share indicator value denotes greater wealth concentration. Another one is the ratio of the respective percentiles of the distribution used to define quantile ratios. The household at the 90th percentile of the distribution is four times wealthier than the household with median wealth when the P90/P50 value is 4. The bottom percentiles in wealth distribution can be negative or very close to zero. The quantile ratios are constrained below by 1 (i.e., all quantile ratios are equal to 1 in total equality, where all households have the same wealth). Higher values of the quantile ratios show a more considerable discrepancy in net worth (ECB, 2019).

The selection of the best income inequality measure depends on the goal, whether the objective is to have a complete result or create a mix of some of them to benefit the most from each method's advantages.

2.4 Energy-related determinants of inequality

In addition to understanding the measures of inequality, it is crucial to comprehend its causes. To evaluate the relationship between energy access and inequality, and although the recent literature has identified other determinants of income inequality – apart from income levels – such as financial development, human capital investments, economic integration (impact of trade openness and FDI inflows), taxes and transfers, and industrialisation levels (IMF, 1998; Nguyen & Nasir, 2021), this dissertation will focus on energy-related drivers of inequality: how energy access and other energy variables, such as the availability and capacity of renewable energies, energy prices and policies can impact income inequality.

As characterised by Nguyen and Nasir (2012, p. 2), *"income inequality is essentially the difference between high-income earners and low-income earners"*. It demonstrates the disparity in income between these two main groups since, for example, low earners could have trouble accessing electricity and other forms of energy.

For instance, 17 million people in Latin America and the Caribbean currently do not have access to power, and 75 million do not have access to clean fuels and cooking technologies. Deficiencies are linked to issues with affordability and accessibility, such as trouble paying for or a lack of infrastructure. Nevertheless, there are considerable variations between LAC nations. First, those without access to these fundamental services fall into the lowest income group in the country. To cover the cost of these services, the most vulnerable populations must exert a proportionately greater economic effort — up to 2.5 times more than the wealthiest communities. Second, geographic, and social disparities further exacerbate this economic disparity, with rural, indigenous, and Afro-descendant people experiencing the most significant deprivation. Finally, access to these fundamental services is influenced by the standard and design of housing since 15% of the people in the area do not have access to electricity and live in unstable houses (United Nations, 2022).

Consequently, a rise in income disparity could worsen energy poverty. At the same time, households experience inequality in several areas of their lives, which can accumulate and result in intersecting imbalances (Middlemiss, 2020). Therefore, there may be a bidirectional relationship between energy poverty and income inequality, which makes it crucial for policymakers to consider this connection when drafting legislation that must aim at eliminating both problems simultaneously (GEA, 2012; Nguyen & Nasir, 2021; Zhao et al., 2023).

Furthermore, Galvin and Sunikka-Blank (2018) identified areas where rising inequality influences energy use in high-income nations, starting on the fact that homes are becoming thermally less efficient as house ownership rates are down and the private renting market is growing. Then, since household poverty is one of the leading causes of lack of energy access, fuel poverty is exacerbated. At both ends of the poverty-wealth spectrum, higher CO_2 emissions are created by low-income households that cannot invest in essential energy efficiency and by the extremely wealthy due to hyper-consumption. In addition, these economic inequality-related energy effects seem highly gender-specific, with women suffering disproportionately in some nations (Galvin & Sunikka-Blank, 2018), which is also related to energy access, as approached before in Subsection 2.2.

Therefore, increasing energy service accessibility is essential not only for reducing poverty, gender inequality, spatial inequality, and other energy-related issues but also for lowering global and regional income inequality. For instance, increasing access to electricity would improve and expand the functioning of households, especially those in rural and low-income areas; consequently, having access to electricity would allow the underprivileged to construct and acquire property, increasing their income share (Acheampong et al., 2021).

Additionally, for Galvin (2020c), it is essential to comprehend whether the growing disparity in wealth among the wealthiest individuals impacts energy policy in ways that distort climate-friendly energy policies and exclude an increasing number of households from the fundamental advantages of energy services. As a result, there are two ways that inequality and environmental pressure are related: one is based on how households behave economically, and the other is based on how environmental policies are decided (Berthe & Elie, 2015). Furthermore, significant changes in the distribution of income and wealth result in some people having much more influence than others over who gets to use which energy services, how our future energy infrastructure develops, and how this may impact CO_2 emission levels (Galvin, 2020c) since the primary sources of energy consumed by nations throughout the world today are coal and oil, both of which are highly harmful to the environment (Zhao et al., 2023). Thus, it is reasonable to conclude that economic inequality leads to energy poverty and environmental damage, which consequently can increase income disparity.

2.4.1 Access to modern energies, technological innovation, and environmental impact

Several social, economic, and environmental issues caused by the continuous use of fossil fuels for cleaner and modern power generation sources could be resolved by switching to renewable electricity. The fact that fossil fuels continue to be used and contribute to climate change by releasing CO_2 into the atmosphere may be the most urgent problem (McGee & Greiner, 2019). Moreover, using traditional biomass as a power source in cases of energy poverty and its overexploitation can "*increase deforestation, desertification, and land degradation*" (González-Eguino, 2015, p. 383).

According to the GEA (2012), most anthropogenic emissions of greenhouse gases (GHGs), other compounds that function as radiative forcing, and air pollutants into the atmosphere are brought on by energy-related activities. The agency complements clarifying that these radiative forcing characteristics bring consequences and that their deposition in sensitive ecosystems harms them through processes like acidification and eutrophication, which also have detrimental outcomes for human health. Consequently, since the global energy infrastructure is a significant contributor to climate change, providing households with access to clean energy sources can significantly contribute to its mitigation due to its potential to reduce CO_2 and other air pollutants emissions (Acharya & Sadath, 2019; GEA, 2012; Madlener, 2020; McGee & Greiner, 2019).

As a result, energy access and consumption directly link sustainability due to its environmental impact. Moreover, both factors are also related to economic growth, as previously illustrated. To understand this relationship, Filippidis et al. (2021) defined the Energy-Environmental Kuznets Curve hypothesis – which describes an inverted U-shaped relationship between energy consumption and economic development – during the early phases of economic growth, energy consumption increases with per capita income, peaks at a particular income level. Then, it starts to decline during the latter stages of economic growth. At this last stage, the goal is to support environmental sustainability through energy-efficient strategies (Filippidis et al., 2021), which explains why energy poverty is also a result of the failure to adopt cleaner renewable energy sources (Njiru & Letema, 2018).

To illustrate how this failure impacts poverty-stricken households, Galvin (2020) discloses the fact that landlords have no incentive to upgrade their houses with renewable energy sources if tenants have no choice but to accept any available residence because they lack the financial resources to select a more energy efficient one. It also happens because the majority of landlords perceive their properties as both investments and sources of income, which makes them wary of taking out loans to pay for improvements if there is little to no market pressure to do so, believing that an inefficient energy house is usual (Terry, 2020).

Furthermore, poor households often consume more energy and emit more CO_2 than they would otherwise because they cannot afford essential expenditures in energy efficiencies (Madlener, 2020; Reames, 2016), such as new boilers, refrigerators, insulation for the loft or under the floor, or airtight windows (Galvin, 2020b), which contributes to increasing energy poverty and environmental damage, negatively influencing economic growth.

Other authors also evaluated the link between energy poverty and development outcomes while speculating on the viability of switching to green energy (Acharya & Sadath, 2019; Adom et al., 2021; Dong et al., 2021; Han et al., 2020; Zhao et al., 2021). For instance, Adom et al. (2012) discovered that adopting renewable energy could offer some partial resilience to shocks in energy poverty and thereby facilitate improvements in development outcomes by conditioning the effects of energy poverty on the green energy transition.

However, the environmental effects of utilising renewable energy depend heavily on the laws and incentives developed by national governments and the climatic and infrastructure factors (McGee & Greiner, 2019). Switching to renewable energy directly enhances economic development, although it is initially more expensive than conventional energy sources. A shift to green energy could improve development results in the long run by lowering the cost of energy. However, in the short run, it could burden consumers with more charges and worsen development outcomes (Adom et al., 2021). To approach this concern, two critical strategies for increasing access to energy must be implemented: distributing energy subsidies to low-income families and enhancing local capacity to sustainably operate contemporary energy services (Sambodo & Novandra, 2019).

Still, the availability of alternatives, the rate of price change, and the significance of energy in household spending all affect how electricity prices and energy poverty impact welfare because people who are experiencing energy poverty spend a more significant portion of their income on energy consumption and are therefore more sensitive to changes in the cost of energy (Adom et al., 2021; McGee & Greiner, 2019). It means that the availability of renewable energy sources can impact the ability to withstand shocks in energy prices, which can be significantly enhanced by having a sustainable energy plan and an alternative energy source (Adom et al., 2021). Moreover, in the long run, when clean energy supplies are adequate, the energy cost will fall (IEA, 2017), and people who can afford clean energy will use less traditional biomass energy, hastening the reduction of energy poverty (Zhao et al., 2021).

Another relevant factor is that a sustainable energy plan can include two approaches when shifting to a cleaner energy source. One is based on an active thermal energy source that can be found in the implementation of the system to generate energy, for instance, a photovoltaic system. The other is related to passive thermal energy, a technique that utilises design principles and materials to maximise the use of natural heat sources, such as sunlight, minimising heat loss. It can significantly reduce the demand for artificial heating and cooling in buildings, decreasing reliance on fossil fuel-based energy through a cost-effective solution well-suited for off-grid and remote areas where access to centralised energy infrastructure may be limited. By utilising passive thermal energy strategies, buildings can maintain comfortable temperatures with reduced reliance on energy-intensive heating and cooling systems. Which lowers energy consumption, reduces energy costs, and increases energy affordability, particularly in regions with limited access to reliable and affordable energy sources. While some initial costs may be associated with implementing passive thermal energy techniques, their long-term energy savings and benefits often make them a cost-effective choice (Barone et al., 2020; Qu et al., 2021) that could help Governments fight energy poverty. Embracing passive thermal energy strategies in building design and construction can contribute to a more sustainable, affordable, and accessible energy future.

Moreover, to increase the whole reach of a country's energy infrastructure and reduce energy poverty, using new renewable energy generation technologies is the best option for Governments to address income inequality and energy poverty simultaneously (McGee & Greiner, 2019). Although, since 2012, more than 100 million individuals worldwide have gained access to electricity annually, and the proportion of individuals who have access to renewable energy is gradually rising (via both grid connections and decentralised systems), with hydropower accounting for 34% of all energy access (IEA, 2017), policymakers must consider technological advancements through the availability of resources to invest in R&D and innovation projects as well as infrastructure development programmes (Filippidis et al., 2021). In this sense, to achieve their electrification goals, nations must employ diverse technologies and tactics to profit from the favourable effects of economic expansion on using renewable energy sources and generating renewable power.

Regarding developed countries, Madlener (2020) clarified that between 2007 and 2016, the E.U. share of renewable electricity in overall electricity consumption nearly tripled. However, it is not yet achieving the goal of alleviating energy poverty since this rapid expansion of renewable energy has generated regressive pricing structures for electricity, which means that the cost of electricity per kilowatt-hour (kWh) is higher for lower-income households than for wealthier families and even lower for the largest firms (Madlener, 2020), which is partially due to how subsidies are given for the installation of renewable energy sources (Filippidis et al., 2021). Because the price of electricity is discounted according to volume, lower-income households pay more for each unit of energy consumed even though they use less electricity in most E.U. countries (Madlener, 2020). It is an example of how the current electricity markets worsen economic inequality in developed countries.

The three elements that make up the retail price of electricity — the energy charge, the network costs, and taxes and tariffs — determine the difference in what the smallest and largest consumers pay per kWh (Haar, 2020). With this in mind, appropriate social norms and financial incentives are also required to promote economic efficiency, lessen energy/fuel poverty, and achieve and uphold energy justice (Madlener, 2020). Considering all factors, the E.U. countries could ameliorate their renewable energy transitioning plans so that the energy-poor population could profit more from it, increasing economic growth and reducing inequality.

On the other hand, China, the largest developing nation in the world, can serve as a valuable example for other developing nations as the country is establishing its policies and studying the impact of the low-carbon energy transition, having as a primary goal the reduction of energy poverty (Dong et al., 2021). For instance, at the beginning of 2018, 22 Chinese provinces implemented the annual photovoltaic station construction targets to fight energy poverty, aiding 882,883 households in reducing national photovoltaic poverty. In addition, over 1.50 million families living in poverty will be able to benefit from photovoltaic energy over the next 25 years. The household power stations, which involve constructing a 3-5 kWh power generation system using available resources, such as the roofs of low-income families or vacant land, are considered the most popular form for individuals but can also be built on collective village land. The household uses the electricity produced, and the Government repurchases the surplus to boost the income of low-income families or village collectives, which own the power stations' property rights and revenues (Han et al., 2020).

Thus, through investments in solar energy, China is improving its energy system and is increasing energy poverty alleviation while reducing CO_2 emissions. A strategy that could be replicated in other countries with similar solar resources to support energy poverty reduction and the achievement of other sustainable development goals since some authors believe that, to meet carbon reduction goals adequately, energy poverty must be reduced (Dong et al., 2021; Zhao et al., 2021). Another project studied in China is related to encouraging the broader popularisation of natural gas consumption when the construction of solar panels is geographically not feasible. It is argued that local Governments should actively increase the building of gas pipelines, allowing them to achieve the mitigation of CO_2 emissions and alleviate energy poverty (Zhao et al., 2021).

There are also regions such as the LAC countries, where most nations have made significant progress in creating programmes to promote access to electricity over the past forty years. Between 1970 and 2016, coverage increased from 50% to over 90%, mainly due to the Government's dedication to bringing electricity to remote communities that lacked it. Most of LAC's rural electrification initiatives are far along and have more than 90% electricity coverage rates. Nevertheless, for this project to continue, it is crucial to consider customer affordability and the utilities' financial viability while planning projects and programmes for remote rural communities that still lack access to electricity. Private enterprises cannot offer energy services without heavy losses if households are not incentivised to afford these services. Rural areas' relatively low electricity consumption levels may discourage utilities from expanding the power grid since rural consumers are typically dispersed, resulting in lower revenue as a percentage of investment expenses due to the low customer density per km of the power line (Barnes et al., 2018).

By implementing the right transition plans, the shift to sustainable energy will likely significantly impact economic and energy inequality. For Madlener (2020), along the sustainable energy transition pathways adopted in different countries, altering the energy mix and upgrading the energy infrastructure – implying decentralisation, decarbonisation, and digitalisation – can also enable better monitoring, improve transparency, and promote changes in energy justice and fuel/energy poverty. Therefore, through economic and regulatory policies in the renewable energy sector, economic growth in developed and developing countries can ensure the expansion of renewable energy sources. As a result, the economy is anticipated to gain from the rising percentage of renewable energy sources, their long-term cost reduction, and their practical usage in reducing environmental concerns and income disparity because they are more accessible to lower-income populations (Filippidis et al., 2021).

Policymakers should think about establishing mechanisms that could reduce, at the same time, both inequality and emissions related to energy use. Such regulations must safeguard geographically and financially vulnerable groups from the perils of energy poverty while encouraging renewable energy sources (McGee & Greiner, 2019). Furthermore, each nation should establish the best approach for its reality, considering urban and rural characteristics and needs. Access to modern and clean energy may impact income inequality differently, according to the country and region. It must be affordable to have a total economic impact (Acheampong et al., 2021). For instance, energy poverty is more severe in rural areas, which restricts employment opportunities, enterprise growth, and income equality while causing poverty to persist (UNDP, 2018b).

Another critical thing to remember is that a sustainable energy transition cannot be achieved without considering justice (Galvin, 2020a; Madlener, 2020; Sovacool et al., 2017; Walker & Day, 2012). For Sovacool et al. (2017), when justice is considered during the process of energy policy creation, the perspective of the entire energy system will change, with issues like equity and distributional equality taking centre stage. It is necessary to address the fair allocation of energy services (and expenses) among present and future generations, and energy resources should be depleted with consideration for savings, community development, and precaution (Sovacool et al., 2017) in a way to serve the most in need best (Reames, 2016). As a result, sustainable energy can help communities that lack access to electricity become more resilient to the effects of climate change. It can also lessen inequalities within and between countries (UNDP, 2018b).

For instance, in developed countries, according to Walker and Day (2012), this view would correct the distributive injustice caused by fuel poverty in the availability of energy services generated by the interaction of underlying disparities in income, energy costs, and housing. However, the authors defend that addressing fuel poverty is a matter of procedural justice, which refers to ensuring access to information, legal process, and effective influence in decision-making. To that end, all these factors should be considered because it is necessary to recognise vulnerable groups' different rights and needs to develop policies that could improve energy access and promote economic and social equality.

In their research on the BRICS (Brazil, Russia, India, China, and South Africa) countries, Hassan et al. (2022) found that wealth disparity is the primary factor contributing to rising CO_2 emissions. Economic differences in developing nations may make people less aware of low-emission and energy-saving fuel options and raise costs. Low-income individuals are increasingly forced to exploit the environment and natural resources to meet their basic requirements, reinforcing their relationship with sustainable concerns. Moreover, economic inequality also adds to the difficulty of regulating the environment, which could reduce environmental protection, increase emissions, and worsen ecological degradation. It might happen because, especially in countries where elites control the policy-making process, incentives and subsidies to promote investments in renewable energy can be prevented from existing (Uzar, 2020), which can be the case in some developing countries.

Adopting renewable energy might lead to several economic changes in a country, such as labour demand, stable energy costs, and investment subsidies, which could impact economic inequality (Topcu & Tugcu, 2020). Therefore, Governments can influence the market for renewable energy in many ways, such as direct subsidies, tax breaks for projects using renewable energy sources, and levies for a set level of carbon emissions, the most popular methods of encouraging investment (Aquila et al., 2017). At the same time, to handle income inequality, decision-makers should actively regulate the relationship between income distribution among different groups, speed up the reform of the income distribution system, and provide study and employment opportunities for low-income groups (Zhao et al., 2023).

Nevertheless, it is critical to eliminate the persistent income inequality, especially in industrialised nations, to use more sustainable energy sources and address climate challenges (Nguyen & Nasir, 2021). In addition, as energy is crucial to the production process, it is anticipated that lower costs will lead to an increase in production, particularly for small and medium-sized businesses, which will ultimately decrease income disparity. Since the renewable energy sector employs more people than fossil fuel technologies, more jobs can be created for every unit of electricity produced (Topcu & Tugcu, 2020).

To minimise global CO_2 emissions it is essential to alter the energy consumption structure and close the income gap (Zhao et al., 2023). Given the significant decrease in the cost of renewable technologies in the past decade and the anticipated additional declines in the future, one of the most immediate ways that the usage of renewable energy might affect income inequality is by aiding in the stabilisation of energy costs, which can occur coupled with a gradual shift from fossil fuels to renewables. This stabilisation of energy costs is essential for ensuring energy access, particularly for individuals and communities with limited financial resources, also promoting affordability and allowing effective budgeting, long-term investments, and economic development while also facilitating the transition to sustainable energy sources by attracting investments and encouraging their adoption (Topcu & Tugcu, 2020). It provides stability and predictability, allowing individuals, communities, and businesses to access reliable, affordable energy services. Considering the weight of energy products in determining general inflation measures is imperative.

Environmental issues may become more prominent, and the need for a clean environment may rise with a collective consciousness in civilisations where economic worries are lessened, and income distribution is equitable. Maintaining a fair distribution of income will balance how political power is distributed in society, which may cause the reduction of elitist political organisations, preventing the weakening of environmental protection laws (Uzar, 2020), which would also allow policymakers to think about putting in place tools for lowering emissions caused by energy use as well as inequality (McGee & Greiner, 2019; Nguyen & Nasir, 2021).

In conclusion, as detailed in this chapter, it is possible to understand that the consumption of renewable energies, energy poverty and income inequality are related, impacting one another and, consequently, influencing the achievement of several SDGs. It explains why these factors will be the focus of this dissertation when approaching the effects of energy accessibility on income inequality. For a summary of the literature review, see Annex A.

Chapter 3

Methodology

This section presents the methodological framework underpinning this investigation into how energy access, or the lack thereof, influences income distribution in diverse countries. It will provide a detailed description of the data collection, model specifications, and analytical procedures employed to explore the intricacies of this relationship.

3.1 Databases and variables description

This work aims to analyse the effects of energy accessibility and other relevant issues on income inequality. In an attempt to propose a global overview of the results, econometric models were initially applied to thirty-four OECD countries and three countries from the Latin America and Caribbean regions. These countries were from three income ranges defined by the United Nations (WIID, 2022): lower-middle, upper-middle, and higher-income countries. The lack of income inequality and some energy access data prevented this work from having more diverse countries, namely low-income countries. The initial models considered income inequality, energy access and other relevant economic variables for the period 2000 to 2019 (Table 1).

This period was selected since most of the chosen countries started to have more data available on inequality measures and some energy-related data only after 2000. The year 2019 was selected as the end of the evaluation period to avoid interference with the increase in income inequality values related to the COVID-19 pandemic that started in 2020. Because of the pandemic, around 100 million additional people lived on less than $1.90 per day in 2020, marking the first increase in extreme poverty in more than 20 years. The poor and vulnerable have been disproportionately affected by COVID-19 in 2021, from unequal economic recovery to unequal access to vaccines, from growing income losses to divergence in learning. It led to a negative turn regarding development levels and is a setback to initiatives to eradicate extreme poverty and lessen disparities (The World Bank, 2021). As a result, income inequality increased worldwide.

A set of relevant energy and economic data variables was used to estimate the impact of energy access and other control variables on inequality. Regarding the dependent variable, some of the income inequality measures tested include the Gini Index (with 0 to 100 as parameters, instead of 0 to 1, since this was the database source choice), three variations of General Entropy and four Atkinson indexes, the Palma Ratio, the Top 20 Bottom 20, Bottom 40, and quintiles.

For the independent variables, the analysis included the Gross Domestic Product (GDP) per capita growth and other variations of GDP, such as GDP growth in annual percentages and GDP in constant 2015 prices. Estimates of natural resource rents, as a share of GDP, were also considered. In addition, the variables urban and rural population sizes, labour force statistics indicators, the ratio of female to male labour force participation rate, current Health expenditure per capita, the rate of individuals using the internet, and the yearly growth rate of exports of goods and services were also considered.

Table 1. The first set of countries analysed and correspondent data. Own production based on WIID (2022) information.

Country	Income Level	Country	Income Level
Austria (EU)	High	Israel (AS)	High
Belgium (EU)	High	Italy (EU)	High
Bolivia (LAC)	Lower-middle	Latvia (EU)	High
Brazil (LAC)	Upper-middle	Lithuania (EU)	High
Canada (NA)	High	Luxembourg (EU)	High
Colombia (LAC)	Upper-middle	Netherlands (EU)	High
Costa Rica (LAC)	Upper-middle	New Zealand (OC)	High
Czech Republic (EU)	High	Norway (EU)	High
Denmark (EU)	High	Poland (EU)	High
El Salvador (LAC)	Lower-middle	Portugal (EU)	High
Estonia (EU)	High	Slovak Republic (EU)	High
Finland (EU)	High	Slovenia (EU)	High
France (EU)	High	Spain (EU)	High
Germany (EU)	High	Sweden (EU)	High
Greece (EU)	High	Switzerland (EU)	High
Honduras (LAC)	Lower-middle	Türkiye (AS)	Upper-middle
Hungary (EU)	High	United Kingdom (EU)	High
Iceland (EU)	High	United States (NA)	High
Ireland (EU)	High		

**EU - Europe; LAC - Latin America and Caribbean; NA - North America; AS - Asia; OC - Oceania.*

Several energy-related variables were tested, namely, the share of urban, rural, and total population with access to electricity, renewable electricity output, CO_2 emissions from fuel combustion per total electricity output, percentage of renewable energy share in final energy consumption, portion of people with access to clean fuels and technology for cooking, the energy intensity level of primary energy, and crude oil prices. These variables were collected from reliable databases, including OECD Statistics, The World Bank, The World Inequality Database, The Sustainable Development Reports from the U.N., and the U.S. Energy Information Administration (Table 2). The data was analysed using Stata 17. To examine the code used, see Annex B.

The choice of the independent variables came from insightful points in the literature review, their definitions found in their database sources, and how each could be related to income inequality. By including this diverse set of variables, this research intended to comprehensively analyse income inequality from multiple angles, considering economic, social, environmental, and technological factors contributing to income disparities. This holistic approach provides a more comprehensive understanding of the complex factors driving income inequality, especially those linked with energy access.

Table 2. Complete dataset and sources.

Code in Stata	Indicator	Theme	Source
GDPC	Growth in GDP per capita	Economic and social	OECD (2023)
GDP	GDP growth (annual %)		The World Bank (2023)
GDPcons	GDP (constant 2015 US$)		The World Bank (2023)
Nresources	Total natural resources rents (% of GDP)		The World Bank (2023)
Urbanpop	Urban population		The World Bank (2023)
Ruralpop	Rural population		The World Bank (2023)
Labourrate	Labour force statistics indicators		The World Bank (2023)
LabourratioF	The ratio of female to male labour force participation rate (modelled ILO estimate)		The World Bank (2023)
HealthexpC	Current Health expenditure per capita (current US$)		The World Bank (2023)
Exports	Exports of goods and services (annual % growth)		The World Bank (2023)
Gini	Gini index	Income Inequality	WIID (2022)
GE0	General Entropy 0 index		
GE1	General Entropy 1 index		
GE2	General Entropy 2 index		
AT025	Athikson 0.25 index		
AT050	Athikson 0.50 index		
AT075	Athikson 0.75 index		
AT1	Athikson 1 index		
Palma	Palma Ratio index		
Top20bot20	Top 20 bottom 20 index		
Bottom40	Bottom 40		
q1	Quintile 1		
q2	Quintile 2		
q3	Quintile 3		
q4	Quintile 4		
q5	Quintile 5		
Eletric_Urb	Population with access to electricity (%) Urban	Energy access	The World Bank (2023)
Eletric_Ru	Population with access to electricity (%) Rural		The World Bank (2023)
Eletric	Access to electricity (% of the total population)		The World Bank (2023)
Re_elec_op	Renewable electricity output (% of total electricity output)		The World Bank (2023)
sdg7_co2twh	CO_2 emissions from fuel combustion per total electricity output		Sustainable Development Report (2023)
sdg7_recon	Renewable energy share in total final energy consumption (%)		Sustainable Development Report (2023)
Cleanf_cook	Population with access to clean fuels and technology for cooking (%)		The World Bank (2023)
Energy_int	The energy intensity level of primary energy		The World Bank (2023)
Net_users	Individuals using the Internet (% of the population)	Technology	The World Bank (2023)
Oil_prices	Annual imported crude oil prices (dollars per barrel)	Energy (Fuel)	U.S. Energy Information Administration (2023)

3.2 Model construction, econometric models, and techniques

Before specifying the model, the stationarity of the variables was checked through Fisher unit root tests with augmented Dickey-Fuller and the Phillips-Perron test methods. This test was selected due to its better performance in handling missing values when compared to the other unit root tests (Zhao et al., 2021). When necessary, the variables were transformed using first differences to make them stationary to avoid spurious regressions.

After selecting the variables and guaranteeing their stationarity, the econometric model was constructed using a panel data set, as has been done by other researchers (e.g., Topcu & Tugcu, 2020). Panel data refers to datasets containing observations on the same entities (cross-sectional units) at different time points and is a concept used in econometrics to analyse data that involves observations on the same entities (individuals, firms, countries, and others) over multiple periods. Analysing panel data allows researchers to examine individual and time effects and interactions between variables over time. Panel data models include fixed effects, random effects, and other specifications considering entity-specific and time-specific factors (Wooldridge, 2012).

In the case of this dissertation, the panel data evaluates the effects of the period from 2000 to 2019. It allows analysis of individuals and, when necessary, the interactions between variables within a panel structure.

The panel data model was estimated with the fixed effects option. Applying multiple linear regression models with fixed effects in Stata for analysing the influence of energy access on income inequality was relevant to account for unobserved entity-specific factors. It focused on changes within entities (in this dissertation, countries) over time. This approach can provide more robust and credible insights into the relationship between energy access and other independent variables and income inequality while controlling for potential sources of bias.

Indeed, fixed effects are a method within panel data analysis that helps control for unobserved individual-specific or entity-specific characteristics that remain constant over time. By considering fixed effects, it is possible to essentially control for these regular individual-specific effects and focus on the relationships among the time-varying variables of interest (Wooldridge, 2012). The fixed effects regression model can be written as follows (Equation 1):

$$y_{it} = \beta_1 x_{it} + \beta_2 x_{it} + \cdots + \beta_k \, x_{k,it} + \alpha_i + u_{it}, \;\; t = 1, 2, \ldots, T. \qquad (1)$$

Where:

y_{it} is the dependent variable for entity i at time t.
α_i is the fixed effect for entity i.
$x_{1,it}$, $x_{2,it}$, … $x_{k,it}$ are the independent variable for entity i at time t.
$\beta_1, \beta_2, \ldots, \beta_k$ are the coefficients associated with the independent variables.
u_{it} is the error term representing unobserved factors affecting y_{it} that are not accounted for in the model.

This work used the fixed effects (within) model option through the "*xtreg, fe*" command on Stata. The option "*vce (cluster Country)*" was also selected to compute robust standard errors that take into account potential correlation or heteroscedasticity within clusters defined by the variable "Country" (Stata, 2023).

To verify that there was no multicollinearity, an uncentered Variance Inflation Factor (VIF) test was performed, adopting a maximum value of 30 to detect possible collinearity of the regressors with the constant (Stata, 2023).

Finally, aiming to help remove the differences in scale and units among the original variables and avoid future collinearity issues, improving further analysis, a Principal Component Analysis (PCA) technique was implemented to make the independent variables more comparable. PCA is a dimensionality reduction technique that can convert the original variables into a new set of uncorrelated variables called principal components. These main components are linear combinations of the actual variables and are ordered by the amount of variance they capture. Using PCA makes it possible to identify a small number of linear combinations of the covariates that are uncorrelated with one another. By doing so, the multicollinearity issue is avoided, computation time is cut down, interpretability is increased, and overfitting is decreased (Fu et al., 2021; Ul-Saufie et al., 2011).

With this technique, it was possible to decrease the number of variables in the dataset while preserving the regression model's ability to predict the future by keeping only the most crucial elements. Removing eigenvalues below 1, the PCA returned only five components, concentrated into three principal components. After this, a Kaiser-Meyer-Olkin (KMO) test was performed with the PCA results. KMO measure is a statistical test used to assess the sample size's adequacy and the data's suitability for performing factor or principal component analysis. It provides information about the proportion of variance among variables that underlying factors might cause. A KMO value closer to 1 demonstrates that the data is well-suited for factor analysis, while values closer to 0 suggest that the study might not be appropriate (Ul-Saufie et al., 2011).

The KMO value of 0.4948 suggests that the data might not be well-suited for a PCA or factor analysis. Generally, KMO values below 0.5 are considered less suitable for such investigations. For this reason, although it could solve any autocorrelation problem, the PCA will not be further investigated in any other model.

To define the more relevant combinations of variables, a multiple linear regression (Ordinary Least Squares - OLS) was performed, testing different income inequality indexes as the dependent variable, in which the Gini index was selected as the one with the best performance and considering various independent variables used in the literature, but selecting only the variables with statistical significance for the final model. Several variables were tested by adding variables and checking their contribution to the model (Acheampong et al., 2021; Nguyen & Su, 2021; Zhong et al., 2020).

The regression output provided coefficient estimates, standard errors, t-values, and p-values for each independent variable. The coefficients express the change in the dependent variable (in standard deviation units) associated with a one standard deviation change in the independent variable (Wooldridge, 2012). The best combination for the general model was made by analysing the p-values on each option until a more statistically significant and robust variation was discovered, leading to the exclusion of the variables with no statistical significance in the model (Equation 2):

$$\widehat{Gini} = \beta 0 + \beta_9 Healthexp + \beta_{14} sdg7co2 + \beta_{16} Cleanfcook + \beta_{20} Exports + \alpha_i + u_i \qquad (2)$$

Results for the model in Equation 2 will be presented in Section 4, and Table 3 reveals the descriptive statistics of the variables considered in this model formulation, highlighting those that actually stayed in the final model. This model was the first step towards assessing the effects of energy access on inequality. However, this dissertation focuses on the LAC region. Thus, the primary model, presented in the following subsection, will focus on these regions.

Table 3. Descriptive analysis with all variables - 37 countries panel.

Variable	Obs	Mean	Std. dev.	Min	Max
GDPC	740	1.969296	3.101729	-14.45649	23.2233
GDP	740	2.62531	3.101751	-14.83861	24.37045
GDPcons	740	1.01e+12	2.73e+12	1.18e+10	1.99e+13
NResources	740	1.299797	2.241693	0	14.63346
Urbanpop	740	2.48e+07	4.77e+07	259836	2.71e+08
Ruralpop	740	7030145	1.13e+07	20437	5.95e+07
Labourrate	736	61.59963	6.514223	46.23847	81.94889
LabourratioF	740	76.25084	10.82745	33.01251	91.06659
HealthexpC	**740**	**2786.048**	**2334.466**	**42.95851**	**10661.03**
Gini	705	35.15826	8.266912	22.9	61.47
Eletric	740	98.57748	5.140474	63.14114	100
Eletric_Urb	740	99.75651	.9688457	88.57921	100
Eletric_Ru	740	96.60773	10.99074	22.5278	100
sdg7_co2twh	**720**	**77.9737**	**14.48511**	**0**	**98.203**
sdg7_recon	740	21.82395	16.35352	.9	81.1
Cleanf_cook	**740**	**96.11284**	**11.303**	**30.7**	**100**
Energy_int	740	4.242	1.957418	1.32	15.78
Net_users	740	59.75519	26.99648	1.177397	99.50494
Oil_prices	740	82.02758	32.69654	37.72746	138.509
Exports	**740**	**4.909942**	**6.464201**	**-20.30855**	**39.16576**

Note: While this table presents the descriptive statistics of all the variables tested, the ones in bold are the ones considered in the final model (Equation 2). The differences in the number of observations are related to missing values.

3.3 Subdivisions of the general group

After this first test, the 37 countries were divided into two groups to increase heterogeneity and comparability. The selection of the independent variables also had to be modified to the ones that best performed with each subgroup, leading to different sets of variables, since those with no statistical significance had to be removed from each model. In one group, the countries were organised by regions and the other by income levels (World Income Inequality Database classification[3]) to evaluate if this separation could impact the results. This separation was relevant because countries vary significantly in economic development, infrastructure, policy frameworks, and social structures. Since energy access and its impact on income inequality can differ considerably between countries, categorising countries into regions or income levels may produce more meaningful and interpretable results, making it easier to isolate the specific impact of energy access.

Moreover, policymakers often focus on regions or income groups when designing energy access and income inequality interventions. By categorising countries this way, the dissertation can provide more directly applicable insights for policymakers addressing specific issues within certain regions or income brackets. Which can also help identify best practices or understand how particular policies or interventions have worked in specific contexts. Furthermore, grouping countries can help smooth out some noise and provide more stable estimates. It can also help deal with missing data more effectively, especially when certain regions or income groups have more complete data than others.

However, most of the high-income countries studied were European. Because they are countries with well-developed energy structures, their results on the regressions were inconclusive because variables such as access to electricity and clean cooking fuels were close to 100% and statistically irrelevant. Moreover, the energy-related variables did not significantly impact inequality, leaving the final model with only control variables. To verify the results of the European OLS regression with fixed effects, see Annex C.

Nevertheless, due to the objective of focusing on a group with more similarities in both region and income levels to avoid multicollinearity and reach more significant results, a new group was formed by the lower and upper-middle-income LAC countries: Bolivia, Brazil, Colombia, Costa Rica, El Salvador, and Honduras. According to The World Bank (2022), the total population of the LAC region is over 659 million people, and the countries selected represent around 47% of this number, being a sample size that is almost half of the region's total population.

A new model (Equation 3) was created, with a new set of statistically significant variables plus the GDPC (GDP per capita), which although not statistically significant, was kept in the model for further comparison – without applying the PCA again to evaluate this new group – and complementary analysis will be performed. First, the OLS regression model for this group was set by the variables with more statistical significance for it:

[3] UNU-WIDER, World Income Inequality Database (WIID). Version 30 June 2022.

https://doi.org/10.35188/UNU-WIDER/WIID-300622

$$\widehat{Gini} = \beta 0 + \beta_1 GDPC + \beta_5 Urbanpop + \beta_{12} Eletric + \beta_{16} Cleanfcook + \alpha_i + u_i \qquad (3)$$

This variables group is crucial for the analysis because each can collaborate with the model assumptions due to their relationship with income inequality. Growth in GDP per capita is commonly used to assess overall economic development. A higher GDP per capita can indicate a more robust economy, potentially reducing income inequality through increased job opportunities and social welfare programs (The World Bank, 2023c).

Urban population size is relevant because urbanization can impact income inequality differently. Cities frequently offer various economic options, such as higher-paying jobs, access to healthcare and education, and more advanced infrastructure. These may draw people from rural regions looking for better economic opportunities, raising average earnings and lowering poverty. However, marginalised and underprivileged populations frequently exist in cities where they face prejudice, social marginalisation, and restricted access to employment possibilities. Income disparity may continue or worsen if these problems are unresolved (The World Bank, 2023d).

Concerning variables for energy access, the focus of this dissertation, the percentage of the population with access to electricity was considered since access to basic amenities like electricity can affect the quality of life and economic opportunities in different regions, which, in turn, may impact income inequality, as previously explained (The World Bank, 2023b).

In addition, the percentage of people with access to clean fuels and technology for cooking can improve health and reduce the time spent on household chores, especially for women and girls, potentially allowing individuals to participate more in economic activities and improve their access to education since, as discussed previously, they are the ones usually responsible for the cooking. As a result, this variable was also considered in the primary model (The World Bank, 2023a).

The variables were re-checked for unit roots, and the LAC countries were analysed in a panel with fixed effects. The descriptive statistics of the variables considered in the model for the LAC region are presented in Table 4, again, highlighting the variables that stayed in the final model, even though all other variables were tested.

Next, the countries will be evaluated separately as a time series analysis for comparison and to understand better the LAC regression results, similar to the rationale of other researchers (Santosa & Catalão-Lopes, 2014). For this purpose, the model's variables of the individual countries will be tested again for unit roots. Then, correlation analysis will determine the variables' relationship, and a Vector Autoregressive (VAR)-based Granger causality Wald test will be performed in the variables with the same stationary levels, aiming to recognise the causal effects of one variable on another, more specifically the impact of energy access on inequality, and vice-versa.

Table 4. Descriptive analysis with all variables - LAC countries panel.

Variable	Obs	Mean	Std. dev.	Min	Max
GDPC	**120**	**2.068626**	**1.905513**	**-4.500622**	**6.727566**
GDP	120	3.416768	2.073459	-3.545763	8.215132
GDPcons	120	3.21e+11	5.80e+11	1.18e+10	1.87e+12
NResources	120	1.788345	2.261434	.0157284	9.860492
Urbanpop	**120**	**3.62e+07**	**5.88e+07**	**2349793**	**1.84e+08**
Ruralpop	120	8577789	1.03e+07	1013042	3.31e+07
Labourrate	116	64.58406	4.193676	58.38869	72.72
LabourratioF	120	63.90368	8.306178	47.22233	79.44973
HealthexpC	120	356.1903	273.0788	42.95851	1028.085
Gini	**114**	**50.65395**	**4.94361**	**38.01**	**61.47**
Eletric	**120**	**91.23115**	**9.957023**	**63.14114**	**99.8**
Eletric_Urb	120	98.52158	1.995651	88.57921	100
Eletric_Ru	120	79.08101	19.50468	22.5278	99.16959
sdg7_co2twh	120	79.23505	9.049621	51.508	89.288
sdg7_recon	120	31.94767	12.10511	7.27	55.24
Cleanf_cook	**120**	**77.1025**	**18.74239**	**30.7**	**95.8**
Energy_int	120	3.544	.8702327	1.98	5.23
Net_users	120	27.60928	21.02958	1.177397	81.2026
Oil_prices	120	82.02758	32.81144	37.72746	138.509
Exports	120	4.421201	5.666171	-15.89694	16.62055

Note: While this table presents the descriptive statistics of all the variables tested, the ones in bold are the ones considered in the final model for the LAC region (Equation 3). The differences in the number of observations are related to missing values.

3.4 Correlation and Granger causality tests

Correlation analysis and Granger causality are two distinct statistical techniques used to examine relationships between variables, especially in the context of time series data. Correlation analysis assesses the direction and strength of a linear relationship between two continuous variables. It supports understanding how changes in one variable are associated with changes in another and considers that the relationship between the variables is linear and only captures linear associations. However, measuring the degree of association does not imply causation. In turn, the VAR-based Granger causality Wald test is a statistical test used to assess whether the one-time series variable "Granger causes" another time series variable in a VAR model. It estimates whether past values of one variable provide information that helps predict future values of another variable, and it assumes that any causality detected is statistical and does not necessarily imply a genuine causal relationship in the real world. It also assumes that the data is stationary, meaning its statistical properties do not change over time (Wooldridge, 2012).

In summary, correlation analysis focuses on the magnitude and direction of the relationship, while Granger causality focuses on the predictive power of one variable for another. Both tests are performed together to complement each other (Nguyen & Nasir, 2021), and for that reason, the same set of variables used in the OLS regression model will be analysed with the two techniques, creating a more comprehensive comparison.

This perspective is relevant to this dissertation because a correlation analysis can identify the initial, potentially linear relationship between access to energy and income inequality. By calculating the correlation coefficient between these variables, it is possible to quantify the strength and direction of the association while also comparing it with the regression model with the complete LAC panel. For instance, if there is a strong negative correlation between access to electricity and Gini, it suggests that areas with better access to energy tend to have lower income inequality. Moreover, correlation analysis can highlight whether there is a simple statistical association between access to energy and income inequality and offer valuable information since it can inform policymakers and researchers about potential connections.

Granger causality tests take the analysis a step further by testing whether changes in access to energy can predict future changes in income inequality or vice-versa. Establishing Granger causality implies that one variable provides valuable information for predicting changes in the other (Wooldridge, 2012). For instance, if the p-value is less than the chosen significance level of 0.10, there is evidence to reject the null hypothesis of no Granger causality from the potential causal variable to the dependent variable, suggesting that Granger causality exists between the variables. If Granger's access to energy causes income disparity, policymakers may be able to remedy it by developing policies to address it. While correlation analysis provides evidence of an association, Granger causality analysis helps determine if there is a causal relationship between access to energy and income inequality. It is essential because policy interventions should target causal factors if the goal is to address income inequality.

Suppose Granger causality is established from access to energy to income inequality. In that case, improving access to power could positively impact income inequality, such as in Nguyen and Nasir (2021), who discovered significant evidence of Granger causality between income inequality and energy poverty. This information can guide policymakers in making informed decisions about where to allocate resources. Furthermore, Granger causality analysis considers the temporal aspect of the relationship, shedding light on the direction of causality over time, which explains its applicability in many studies (Carrilho-Nunes & Catalão-Lopes, 2022; Nguyen & Nasir, 2021; Santosa & Catalão-Lopes, 2014; Sun et al., 2023). It can reveal whether changes in access to energy precede changes in income inequality or vice-versa, providing insights into the relationship dynamics.

Using correlation and Granger causality analyses makes it possible to cross-validate the results. Finding a solid correlation and Granger causality in the same direction strengthens the evidence for a meaningful relationship. To that end, the variables studied for correlations within each country are the Gini coefficient, GDP per capita, urban population, and total population with access to electricity and clean cooking fuels. For the Granger causality, three hypothesis options will be applied to each country, varying according to the stationarity of its variables. The following hypotheses are tested:

H1. Does access to electricity have an impact on the Gini Coefficient?

H2. Does access to clean cooking fuels have an impact on the Gini Coefficient?

H3. Does access to electricity impact the access to clean cooking fuels?

The objective of this analysis is to comprehend better whether energy access can influence income inequality in a middle-income region such as the LAC region and if this effect occurs in the same ways in all countries, to guide policymakers to develop the best strategies to improve the inhabitant's quality of life through energy access and reduce income disparities in underdeveloped countries.

Chapter 4

Results

This section introduces the results of the econometric models performed in both panels (one with 37 countries and another with the LAC region) and the results of the other two techniques applied by LAC country.

4.1 Panel with the 37 countries

Considering the complete panel with the 37 countries, some variables were found non-stationary through Fisher unit root tests with augmented Dickey-Fuller and the Phillips-Perron test methods. Accordingly, these variables were transformed, using first differences, to make all variables in the dataset comparable and ensure they are in the same level of stationarity for the causality analysis (Table 5).

Table 5. Unit root test results with 37 countries panel.

Code	Indicator	P-value (Inverse normal - z - max 0.1)
GDPC	Growth in GDP per capita	0
GDP	GDP growth (annual)	0
GDPcons	GDP (constant 2015)	1
sGDPcons		0
Nresources	Total natural resources rents (% of GDP)	0
Urbanpop	Urban population	0
Ruralpop	Rural population*	0.9864
sRuralpop		0
Labourrate	Labour force statistics indicators	0.9656
sLabourrate		0
LabourratioF	The ratio of female to male labour force participation rate	0.6194
sLabourratioF		0
HealthexpC	Current health expenditure per capita	0.2604
sHealthexpC		0
Gini	Gini index	0
Eletric_Urb	Population with access to electricity - Urban	0
Eletric_Urb	Population with access to electricity - Rural	0
Eletric	Total population with access to electricity	0
Re_elec_op	Renewable electricity output	1
sRe_elec_op		0
sdg7_co2twh	CO_2 emissions from fuel combustion per total electricity output	0.9362
ssdg7_co2twh		0
sdg7_recon	Renewable energy shares in total final energy consumption	1
ssdg7_recon		0
Cleanf_cook	Population with access to clean fuels and technology for cooking	0
Energy_int	The energy intensity level of primary energy	1
sEnergy_int		0
Net_users	Individuals using the Internet	0
Oil_prices	Annual imported crude oil prices	0.3017
sOil_prices		0
Exports	Exports of goods and services (annual growth)	0

** Needed two differences to become stationary*
Note: All variables starting with s had to be changed into stationary

After guaranteeing that all variables were stationary, the OLS with fixed effects was modelled with the variables that best performed statistically, as presented in Equation 2, and returned the following results (Table 6):

Table 6. Fixed-effect OLS regression with 37 countries panel.

Fixed-effects (within) regression

Group variable: ID	Number of obs	=	657
	Number of groups	=	36
R-sq	Obs per group		
Within = 0.4546	min	=	16
Between = 0.4517	avg	=	18.3
Overall = 0.4510	max	=	19
corr(u_i, Xb) = -0.1063	F(4,35)	=	17.34
	Prob > F	=	0.0000

(Std. err. adjusted for 36 clusters in Country)

Gini	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
Exports	.0289717	.0090212	3.21	0.003	.0106578	.0472856
Cleanf_cook	-.5421819	.0756973	-7.16	0.000	-.6958556	-.3885082
sHealthexpC	-.0005001	.0002225	-2.25	0.031	-.0009518	-.0000484
ssdg7_co2twh	-.0263816	.0097053	-2.72	0.010	-.0460844	-.0066789
_cons	87.07891	7.276683	11.97	0.000	72.30645	101.8514
sigma_u	6.0665475					
sigma_e	1.4407446					
rho	.94660977	(fraction of variance due to u_i)				

Variable	VIF	1/VIF
Cleanf_cook	1.64	0.608146
Exports	1.51	0.663785
sHealthexpC	1.15	0.868338
ssdg7_co2twh	1.01	0.993398
Mean VIF	1.33	

In the complete panel, the final model ended up having four independent variables that showed a statistically significant relationship with the dependent variable Gini: two energy-related variables (population with access to clean cooking fuels and CO_2 emissions from fuel combustion per total electricity output) and two control variables (annual growth in exports and current Health expenditure per capita).

Taking the within R-squared to measure the goodness of fit of the model within each group, due to the use of the fixed effects, it is possible to infer that 45.46% of the variance in Gini can be predicted from the variables. The 17.34 F-statistics confirm that the independent variables reliably predict Gini by being more significant than the critical value of 0.10, which in this case is 0, leading to the rejection of the null hypothesis, concluding that there is a substantial relationship between the predictor variables and the response variable. Moreover, multicollinearity is not a problem since the VIF test is 1.33.

The results of this regression show that in the context of the 37 countries considered, export growth can increase Gini, meaning income inequality rises. By contrast, boosting expenditures in Health per capita and promoting access to clean cooking fuels reduce income disparities – this second result agrees with Acheampong et al. (2021) concerning Europe, Central Asia and LAC regions.

Moreover, surprisingly, an expansion in the measure of the carbon intensity of energy production can also diminish Gini, which was an unexpected result according to the literature. Indeed, reducing CO_2 emissions is expected to improve air quality, which can have significant health benefits. However, while developed countries tend to have higher per capita emissions due to their industrialisation and consumption patterns, in the case of developing countries, economic growth – expected to reduce income inequality – may positively impact CO_2 emissions because it requires massive energy consumption and energy intensity (Zhao et al., 2021), which might have influenced the results of this panel.

4.2 LAC countries

Following the 37 countries panel, a group of middle-income Latin American and Caribbean countries was formed for further research: Bolivia, Brazil, Colombia, Costa Rica, El Salvador, and Honduras.

The groups' panel unit roots test had the same results as the panel with the 37 countries. Thus, the same variables were changed for their first or second differences, as illustrated in Table 3. Next to the variables' preparation, another OLS regression with fixed effects was performed, creating a new combination of variables (as presented previously in Equation 3). Compared with the previous model with the 37 countries, this new model will have as independent variables the population with access to clean cooking fuels, the total population with access to electricity, the GDP per capita, and the urban population size. See Table 7 for the results of the regression.

Table 7. Fixed-effect OLS regression with LAC countries panel.

Fixed-effects (within) regression

Group variable: ID	Number of obs	=	114
	Number of groups	=	6
R-sq	Obs per group		
Within = 0.8425	min	=	18
Between = 0.0115	avg	=	19
Overall = 0.0262	max	=	20
	F(4,5)	=	289.58
corr(u_i, Xb) = -0.8964	Prob > F	=	0.0000

(Std. err. adjusted for 6 clusters in Country)

Gini	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
GDPC	.1122357	.1199178	0.94	0.392	-.196023	.4204943
Urbanpop	-5.64e-08	1.51e-08	-3.74	0.013	-9.51e-08	-1.76e-08
Eletric	-.2476637	.0881254	-2.81	0.038	-.4741973	-.0211301
Cleanf_cook	-.3380262	.0342102	-9.88	0.000	-.4259662	-.2500862
_cons	101.1521	6.236078	16.22	0.000	85.12177	117.1825
sigma_u	11.579245					
sigma_e	1.510764					
rho	.98326206	(fraction of variance due to u_i)				

Variable	VIF	1/VIF
Cleanf_cook	46.95	0.021299
Eletric	43.71	0.022880
GDPC	2.34	0.427534
Urbanpop	1.79	0.557697
Mean VIF	23.70	

The energy access variables in this model are essential to understanding the LAC region because it is on the verge of being the first developing region in the world to attain universal access to electricity, with more than 96 per cent of its population now having access to it. However, certain LAC nations have done better than others, as exemplified in Figure 2, and there are still around 17 million people in the region who do not have access to reliable power supply. Over 75 million people still cook with firewood and charcoal on inefficient primitive stoves, maintaining the region's heavy reliance on biomass fuels.

Due to the unsustainable use of biomass, these conventional cooking methods produce a substantial amount of indoor air pollution, which has been related to respiratory conditions and adverse environmental effects (Barnes et al., 2018; IEA, 2022).

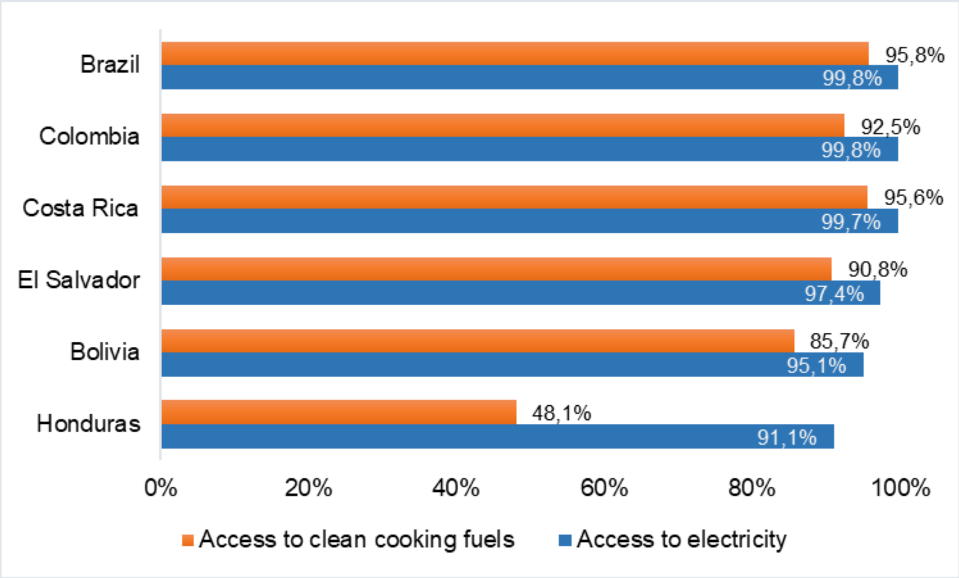

Figure 2. Percentage of the population with access to electricity and clean cooking fuels in 2019. Source: The World Bank, 2023.

In the LAC panel, the within R-squared increased from 45.46% to 84.25%, the variance in Gini that can be predicted from this set of independent variables. The F-statistics also increased from 17.34 to 289.58, rejecting the null hypothesis and concluding a substantial relationship between the predictor and response variables. Again, multicollinearity is not a problem since the VIF test is 23.7, still lower than 30.

An increase in GDP per capita would be expected to reduce income inequality, however, it is not a guaranteed outcome because the relationship between GDP per capita and income inequality is complex and depends on various factors, including how economic growth is distributed among different income groups. It may explain why it performed in a way that, if statistically significant, could illustrate a positive relationship with the dependent variable, the Gini Coefficient, similar to the Acheampong et al. (2021) study, also related to the LAC region. Nevertheless, in the model, their relationship is inconclusive since the GDP per capita variable was not statistically significant. However, the variable was kept in the model due to its relevance for further analysis and to evaluate its performance in each LAC country separately since, in recent years, it is known that inequality in major Latin American countries has stopped declining or has even increased (DESA, 2020).

The results also exhibited a negative relationship between the Gini coefficient and the other three variables of the model. First, an increase in urban population negatively affects the Gini coefficient, which could be explained by the fact that cities often provide diverse economic opportunities, including better-paying jobs, access to education and healthcare, and a more developed infrastructure. People from rural areas looking for better economic opportunities may be drawn to this scenario, which could result in lower poverty rates and greater average wages. Nonetheless, it is imperative to consider the possible drawbacks and difficulties linked to urbanisation, as it may exacerbate regional inequalities.

According to Wang et al. (2023), both cases are likely to happen, changing according to a country's urbanisation level since the presence of urbanisation can mitigate the negative relationship between energy efficiency and income inequality, thus easing the apparent conflict between the two goals. When influenced by urbanisation, a non-linear relationship emerges between income inequality and energy efficiency. When urbanisation is lower, income inequality has a more pronounced impact on energy efficiency, resulting in a weaker restraint on energy efficiency by income equality, especially in developing countries. For that reason, even though the effects of an increase in urban population could be beneficial or harmful for inequality, their relationship is not straightforward; however, according to this model, urban rate and inequality display a negative relationship for the LAC region.

The energy-related variables behaved as expected, having the power to diminish inequality in the LAC countries with an estimated coefficient of access to electricity of 0.248% and access to clean cooking fuels of 0.338%, proving a negative relationship between the energy access and income inequality – similar to Acheampong et al. (2021) for the LAC region and Nguyen and Nasir (2021) according to global evidence. However, to understand how this connection occurs, the rest of the analysis was done on a case-study basis, i.e., by country, to investigate if more access to energy causes a decrease in income inequality or if it happens the other way around.

The following subsections present this country-by-country analysis. All countries had to have their unit roots tests checked again, now as a time-series analysis instead of a panel. First, the graphs of each variable were checked to indicate if the data displayed a trend. These unit root tests again are essential for further analysis because, although the OLS regression will not be repeated in each country, the Granger causality can only be performed in variables with the same level of stationarity.

4.2.1 Bolivia

Starting with the unit root test for Bolivian model variables, by analysing their graphs (Figure 3), it is possible to determine that all variables but the GDP per capita have a trend, which was considered in the tests.

The variable measuring inequality, the Gini Coefficient, is stationary at the first difference, I(1). Access to clean cooking fuels is stationary at the second difference, I(2), and Urban Population was already stationary at a level I(0), making it impossible to study if these two variables could impact Gini, with the Granger causality afterwards. Nevertheless, the remaining variables, GDP per capita and access to energy are stationary at the first difference, I(1). Granger causality analysis will be performed for electricity access and the Gini Coefficient only, as this dissertation focuses on the effects of energy access on inequality (see Table 8 for these unit root test results).

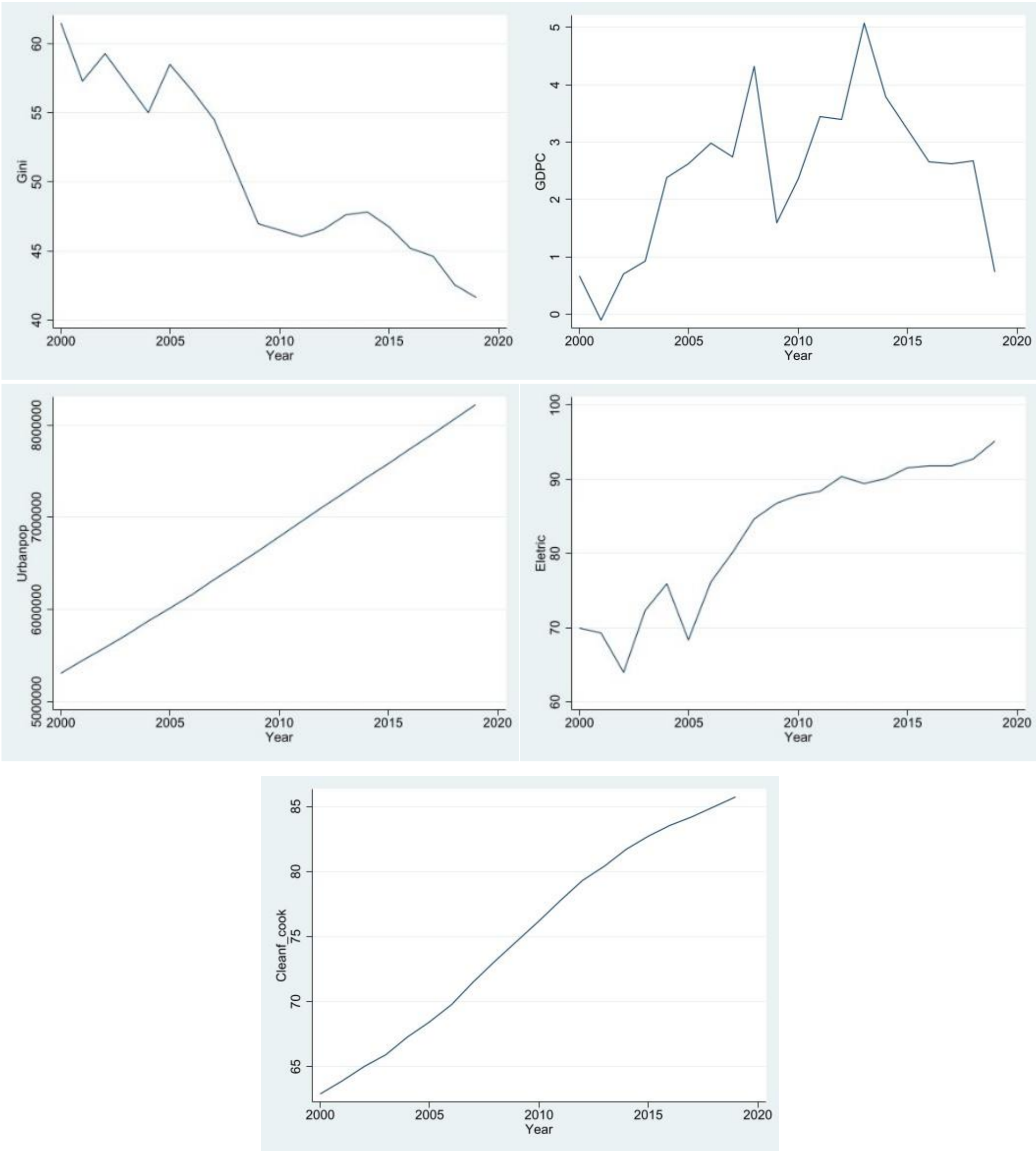

Figure 3. Variables trend identification in the Bolivian analysis.

Table 8. Augmented Dickey-Fuller unit root test results - Bolivia.

Variable	Test Statistics	Mackinnon p-value	Trend	Nº of differences	Variable after difference	Test Statistics	Mackinnon p-value
Gini	-2.276	0.4473	yes	1	sGini	-3.403	0.0510
GDPC	-2.063	0.2597	no	1	sGDPC	-5.309	0.0000
Urbanpop	-5.003	0.0002	yes	0			
Eletric	-2.513	0.3217	yes	1	sEletric	-5.158	0.0001
Clean_cook	0.740	1.0000	yes	2	ssCleanf_cook	-6.569	0.0000

Following this process, a correlation analysis (Table 9) served as a valuable initial step in exploring the relationship between energy accessibility and income inequality. It contributed to a better understanding of the potential connections between the previously considered independent variables in the OLS regression and the Gini coefficient.

Table 9. Correlation analysis - Bolivia.

	GDPC	Urbanpop	Gini	Eletric	Cleanf_cook
GDPC	1.0000				
Urbanpop	0.3989	1.0000			
Gini	-0.3756	-0.9480	1.0000		
Eletric	0.4967	0.9352	-0.9647	1.0000	
Cleanf_cook	0.4540	0.9952	-0.9551	0.9525	1.0000

In opposition to the OLS regression results of the LAC region, in the correlation analysis for Bolivia, it is possible to notice that all variables have a negative relationship with Gini, including the GDP per capita, which in the panel was positive, meaning that all variables could have a role in reducing income inequality. A result that agrees with the UNDP (2018a), which believes that SDG 7 is a condition for economic growth, poverty alleviation (SDG 1) and reducing inequalities (SDG 10).

Next, the Granger causality was performed to evaluate the direction of this impact in the selected variables, which, in the case of Bolivia, were between Gini and access to electricity (Table 10). The null hypothesis is rejected from the variable access to electricity to the variable Gini since it had a p-value lower than the significance level of 0.10. It illustrates that in the Bolivian scenario, access to electricity Granger causes Gini, implying that an increase in energy access could support a reduction in income inequality.

Table 10. VAR-based Granger causality Wald test results - Bolivia.

Null hypothesis	χ2	Prob > χ2	Null hypothesis	χ2	Prob > χ2
Gini does not cause Eletric	3.3508	0.187	Eletric does not cause Gini	7.8615	0.020

4.2.2 Brazil

The exact process was applied to all LAC countries, and now, considering Brazil, starting with the unit root tests based on the presence or not of trend in the variables' graphs (Figure 4).

In the Brazilian case, only the variables of urban population size, population with access to electricity, and access to clean cooking fuels demonstrated a trend. Next, the variables' stationarity was tested according to their corresponding characteristics and was changed to a level of difference that guaranteed the stationarity of the variables.

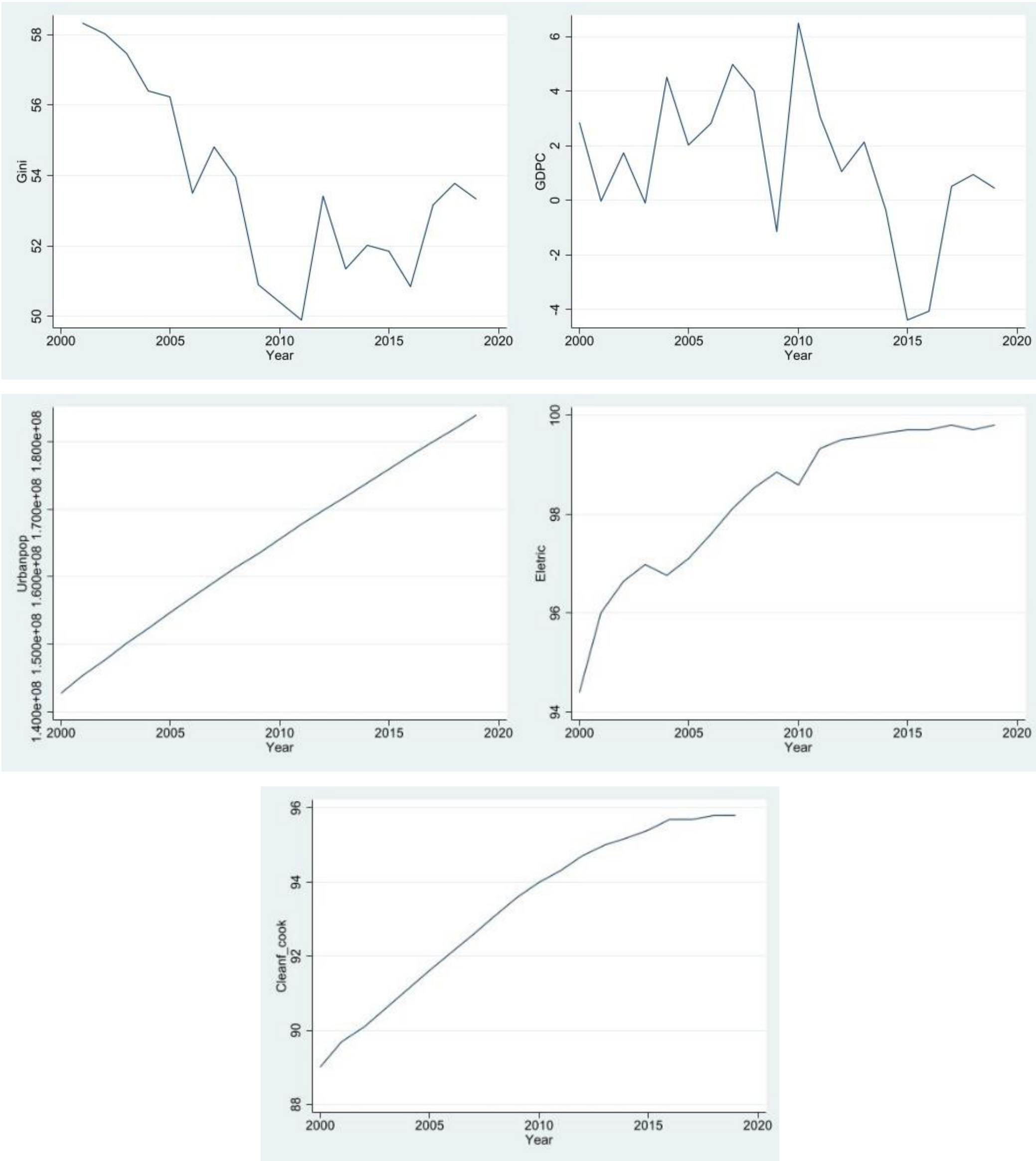

Figure 4. Variables trend identification in the Brazilian analysis.

The results in Table 11 illustrate that Gini and access to clean cooking fuels are stationary at first differences, I(1), while the rest of the variables were already stationary at level, I(0). It will impact the Granger causality test by only allowing an evaluation of the causal relation between the variables with the same level of differences.

Regarding the correlation (Table 12), the results of Brazil are similar to the LAC region by having Gini positively correlating with GDP per capita and negatively with the other variables. As a result, it is possible to have the same conclusion, which may indicate that in the case of Brazil, its economic growth is not fairly distributed with its population, leading to an increase in income inequality – which agrees with the fact that inequality increased in Brazil since 2015 (DESA, 2020).

Table 11. Augmented Dickey-Fuller unit root test results - Brazil.

Variable	Test Statistics	Mackinnon p-value	Trend	Nº of differences	Variable after difference	Test Statistics	Mackinnon p-value
Gini	-2.290	0.1751	no	1	sGini	-5.358	0.0000
GDPC	-3.011	-3.011	no	0			
Urbanpop	-7.099	0.0000	yes	0			
Eletric	-3.479	0.0417	yes	0			
Clean_cook	1.898	1.0000	yes	1	sCleanf_cook	-3.705	0.0220

Table 12. Correlation analysis - Brazil.

	GDPC	Urbanpop	Gini	Eletric	Cleanf_cook
GDPC	1.0000				
Urbanpop	-0.4060	1.0000			
Gini	0.3030	-0.7395	1.0000		
Eletric	-0.3657	0.9561	-0.8554	1.0000	
Cleanf_cook	-0.3876	0.9846	-0.8255	0.9877	1.0000

However, regarding the Granger causality results (Table 13), between the variables Gini and access to clean cooking fuels, the null hypothesis that the first does not Granger cause the second one cannot be rejected. At the same time, the contrary does not happen, which implies that considering their negative correlation, a reduction in income inequality could increase access to clean energy sources to cook, following other studies (eg., Nguyen & Nasir, 2021).

Table 13.VAR-based Granger causality Wald test results - Brazil.

Null hypothesis	χ2	Prob > χ2	Null hypothesis	χ2	Prob > χ2
Gini does not cause Cleanf_cook	6.1953	0.045	Cleanf_cook does not cause Gini	3.2248	0.199

It can occur because when income inequality decreases, more people within lower-income brackets are expected to have increased purchasing power, even if not equally distributed, as seen in the GDP per capita and Gini correlation. It could make clean cooking fuels, such as liquefied petroleum gas (LPG) or electric stoves, more affordable for lower population segments.

4.2.3 Colombia

The variables’ graphs (Figure 5) show that Gini and GDP per capita do not have a trend, while the remaining variables have.

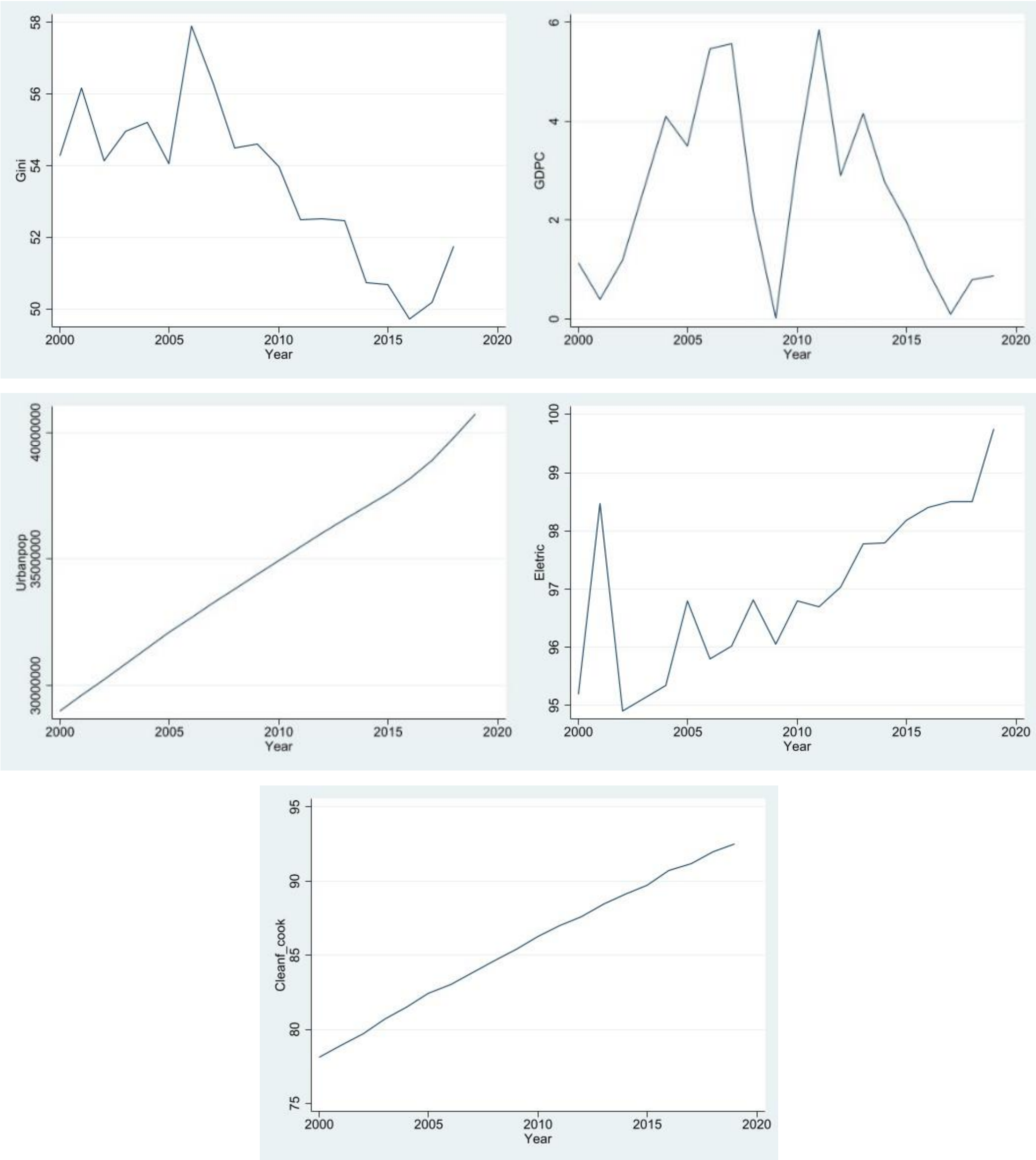

Figure 5. Variables trend identification in the Colombian analysis.

This information allows the model variables to have their unit roots appropriately tested (Table 14), resulting in stationary at a level I(0), only the population with access to electricity. The urban population variable had to be ignored for further analysis because it needed more than two differences to become stationary. The remaining variables were stationary at the first difference, I(1).

Table 14. Augmented Dickey-Fuller unit root test results - Colombia.

Variable	Test Statistics	Mackinnon p-value	Trend	Nº of differences	Variable after difference	Test Statistics	Mackinnon p-value
Gini	-1.319	0.6205	no	1	sGini	-5.806	0.0000
GDPC	-2.240	0.1920	no	1	sGDPC	-4.134	0.0009
Urbanpop	0.989	1.0000	yes	5	sssssUrbanpop	-4.178	0.0048
Eletric	-4.259	0.0036	yes	0			
Clean_cook	-1.185	0.9135	yes	1	sCleanf_cook	-7.037	0.0000

The correlation analysis (Table 15) confirmed that with Brazil, Columbia was another country in the LAC region where the relationship between Gini and GDP per capita was positive, revealing that economic growth may also be unfairly distributed in Colombia. At the same time, all other variables could reduce income inequality.

Table 15. Correlation analysis - Colombia.

	GDPC	Urbanpop	Gini	Eletric	Cleanf_cook
GDPC	1.0000				
Urbanpop	-0.1039	1.0000			
Gini	0.3598	-0.7793	1.0000		
Eletric	-0.3247	0.7333	-0.6505	1.0000	
Cleanf_cook	-0.0897	0.9990	-0.7867	0.7316	1.0000

Next, the Granger causality test was performed to evaluate Gini and its Granger causal effect in the population with access to clean cooking fuel since these two variables were stationary with the same differences (Table 16). However, the results could not reject the null hypothesis in either direction, which means that the results do not provide evidence to support the idea that changes in income inequality (Gini) are Granger caused by changes in access to clean cooking fuels. Likewise, it does not support the notion that changes in access to clean cooking fuels are Granger caused by changes in Gini. These findings do not illustrate a causal relationship between the variables. Due to that, it is possible to infer that if policymakers were considering interventions to address income inequality through improving access to clean cooking fuels, this finding suggests that this may not be a straightforward or immediate solution. It underscores the need to consider broader factors contributing to income inequality.

Table 16. VAR-based Granger causality Wald test results - Colombia.

Null hypothesis	χ2	Prob > χ2	Null hypothesis	χ2	Prob > χ2
Gini does not cause Cleanf_cook	3.1371	0.208	Cleanf_cook does not cause Gini	.17529	0.916

4.2.4 Costa Rica

The variables' graph from Costa Rica illustrated that the Gini and GDP per capita do not have a trend, but the remaining variables have (Figure 6).

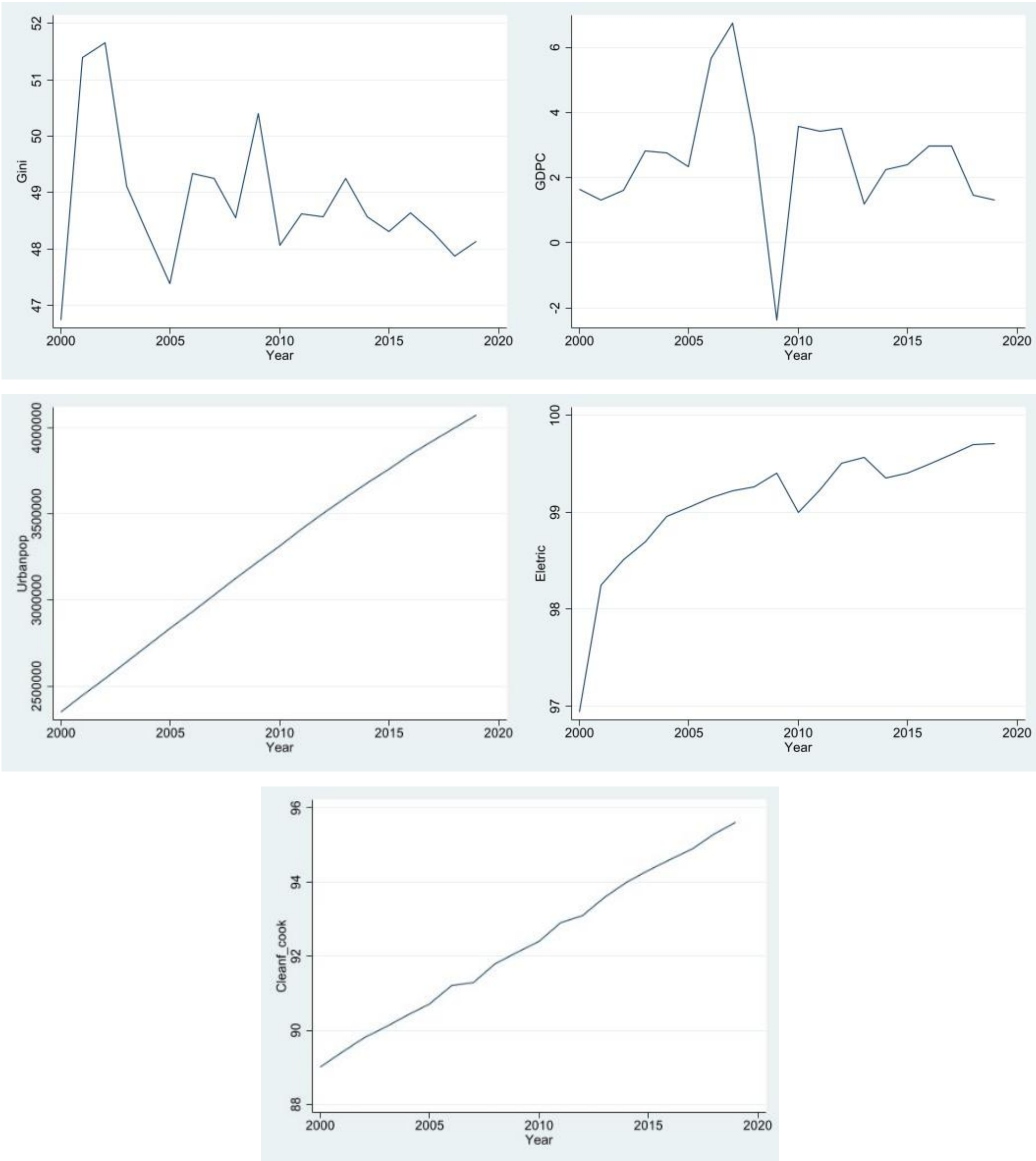

Figure 6. Variables trend identification in the Costa Rican analysis.

With this information, the unit roots test was performed accordingly, resulting in a model with all variables declared stationary at a level I(0), apart from the Urban Population, which required more than two differences to become stationary and excluded it from further analysis (Table 17).

Table 17. Augmented Dickey-Fuller unit root test results - Costa Rica.

Variable	Test Statistics	Mackinnon p-value	Trend	Nº of differences	Variable after difference	Test Statistics	Mackinnon p-value
Gini	-5.291	0.0001	no	0			
GDPC	-3.442	0.0096	no	0			
Urbanpop	9.284	1.0000	yes	4	ssssUrbanpop	-4.783	0.0005
Eletric	-8.515	0.0000	yes	0			
Clean_cook	-4.563	0.0012	yes	0			

In the Costa Rican case, the correlation (Table 18) between the independent variables and Gini was like in Bolivia, where all showed a negative relationship with the dependent variable, meaning that all the variables selected could potentially support a reduction in income inequality.

Table 18. Correlation analysis - Costa Rica.

	GDPC	Urbanpop	Gini	Eletric	Cleanf_cook
GDPC	1.0000				
Urbanpop	-0.0599	1.0000			
Gini	-0.2023	-0.3086	1.0000		
Eletric	0.0569	0.8138	-0.0129	1.0000	
Cleanf_cook	-0.0738	0.9987	-0.3027	0.8024	1.0000

Then, for the first time in the analysis, a country had more than one energy-related variable with the same level of stationarity, allowing them to be studied with the Granger causality (Table 19). In the relationship between Gini and the population with access to electricity, the test indicates that the two variables exhibit mutual causality, which means that there is evidence to suggest that each variable influences the other in a time-dependent manner, consonant with similar research (Nguyen & Nasir, 2021). In other words, both variables affect each other's future values statistically significantly within the Costa Rican context. It may suggest a feedback loop in which a decrease in income inequality can cause more energy access, which will react to reducing income disparities after this increase.

Table 19. VAR-based Granger causality Wald test results - Costa Rica.

Null hypothesis	χ2	Prob > χ2	Null hypothesis	χ2	Prob > χ2
Gini does not cause Eletric	7.0089	0.030	Eletric does not cause Gini	10.429	0.005
Gini does not cause Cleanf_cook	5.1392	0.077	Cleanf_cook does not cause Gini	.3071	0.858
Eletric does not cause Cleanf_cook	5.5864	0.061	Cleanf_cook does not cause Eletric	.13846	0.933

While, in the interconnection between Gini and the population with access to clean cooking fuels, the first Granger causes the second, as occurred in the Brazilian test, possibly implying that with less inequality, more people would have access to more sustainable fuels for cooking.

Since the correlation between GDP per capita and Gini is negative, even if the value is relatively low, it is possible to assume that when income inequality decreases, its population gains purchase power, and the country’s infrastructure to promote access to clean cooking fuels could be enhanced by its Government. In this scenario, people would need reduced income inequality to have the necessary infrastructure and means to access this fuel type. This interpretation can be reinforced by learning the results of the third Granger causality test, where an increase in the population with access to electricity can Granger cause a boost in access to clean cooking fuels.

4.2.5 El Salvador

The reading of the variables' graph from El Salvador revealed that only GDP per capita does not have a trend in the country, in contrast with the other four variables (Figure 7).

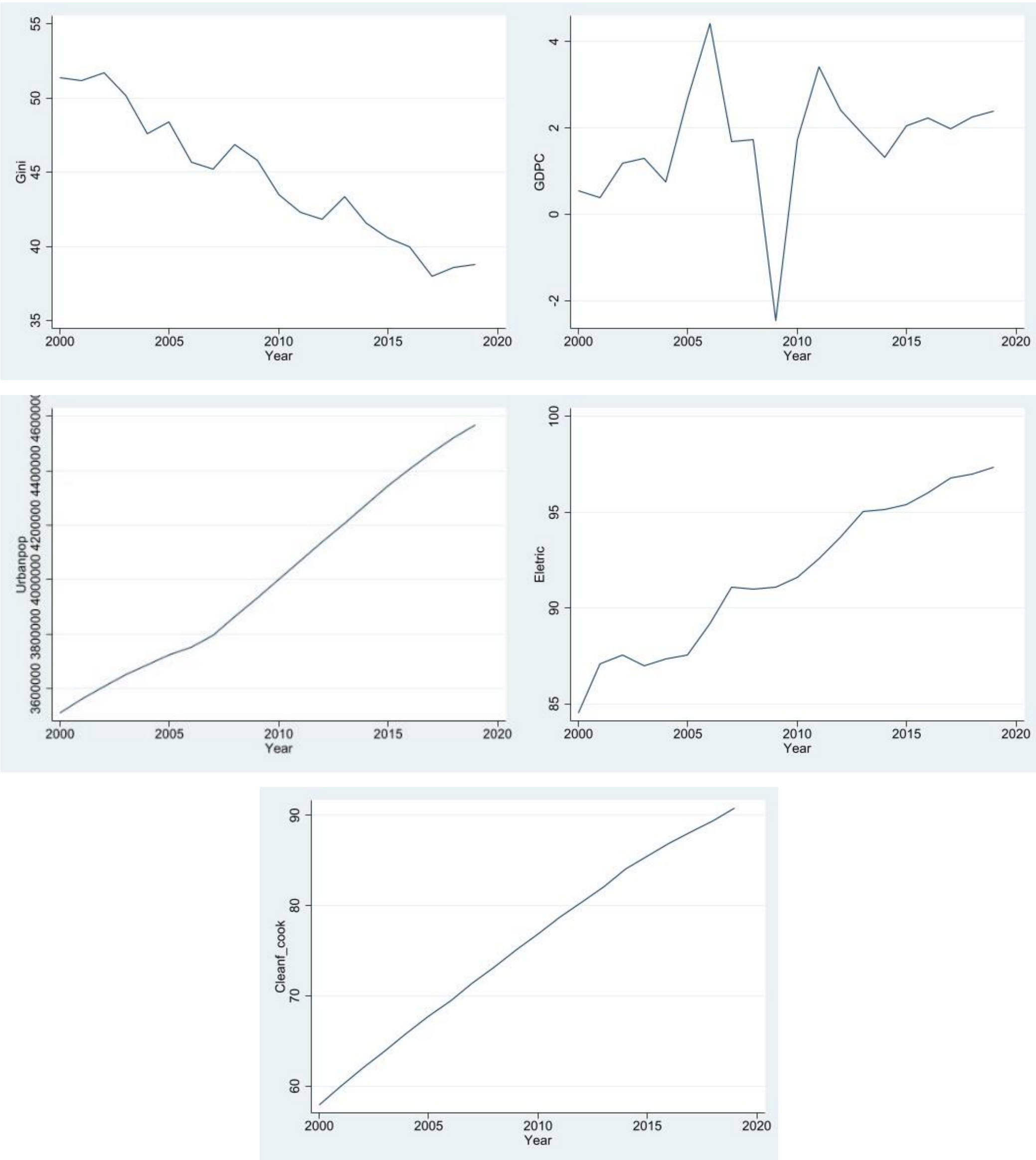

Figure 7. Variables trend identification in the Salvadoran analysis.

By having this perception, their unit roots could be evaluated accordingly (Table 20), resulting in another country where the variable related to urban population is ignored due to the high number of differences required to become stationary. Gini and GDP per capita were already stationary at level I(0), and access to electricity and clean cooking fuels was stationary at first differences, I(1). These results prevented further analysis regarding inequality since the possibility of performing the Granger causality test between Gini and the energy-related variables was excluded.

Table 20. Augmented Dickey-Fuller unit root test results - El Salvador.

Variable	Test Statistics	Mackinnon p-value	Trend	Nº of differences	Variable after difference	Test Statistics	Mackinnon p-value
Gini	-3.494	0.0400	yes	0			
GDPC	-3.463	0.0090	no	0			
Urbanpop	-1.723	0.7406	yes	3	sssUrbanpop	-4.434	0.0019
Eletric	-3.049	0.1188	yes	1	sEletric	-4.225	0.0041
Clean_cook	1.419	1.0000	yes	1	sCleanf_cook	-3.721	0.0210

The Salvadoran correlation analysis disclosed another LAC country in which all variables from the model negatively correlate with Gini, exemplifying another case in which an increment in all variables could be responsible for a decline in income inequality (Table 21).

Table 21. Correlation analysis - El Salvador.

	GDPC	Urbanpop	Gini	Eletric	Cleanf_cook
GDPC	1.0000				
Urbanpop	0.2728	1.0000			
Gini	-0.3643	-0.9647	1.0000		
Eletric	0.2753	0.9811	-0.9590	1.0000	
Cleanf_cook	0.2889	0.9899	-0.9773	0.9877	1.0000

Even though causality analysis could not be performed between the Gini coefficient and energy-related variables, the causal relationship between the population with access to electricity and the people with access to clean cooking fuels could be tested. The Granger causality test (Table 22) shows that the population with access to electricity Granger causes access to clean cooking fuels. It implies that changes or variations in the population with access to electricity precede and have a statistically significant predictive effect on modifications or variations in access to clean cooking fuels, which also occurred in Costa Rica. The result might inform policymakers about where to prioritize efforts. For example, if electrification programs are shown to impact clean cooking fuel access positively, policymakers might allocate resources accordingly.

Table 22. VAR-based Granger causality Wald test results - El Salvador.

Null hypothesis	χ2	Prob > χ2	Null hypothesis	χ2	Prob > χ2
Eletric does not cause cleanf_cook	44.098	0.000	Cleanf_cook does not cause Eletric	.53938	0.764

4.2.6 Honduras

Finally, in the last LAC country studied, apart from the GDP per capita variable, all Honduran model variables have trends (Figure 8), leading to their corresponding unit roots test.

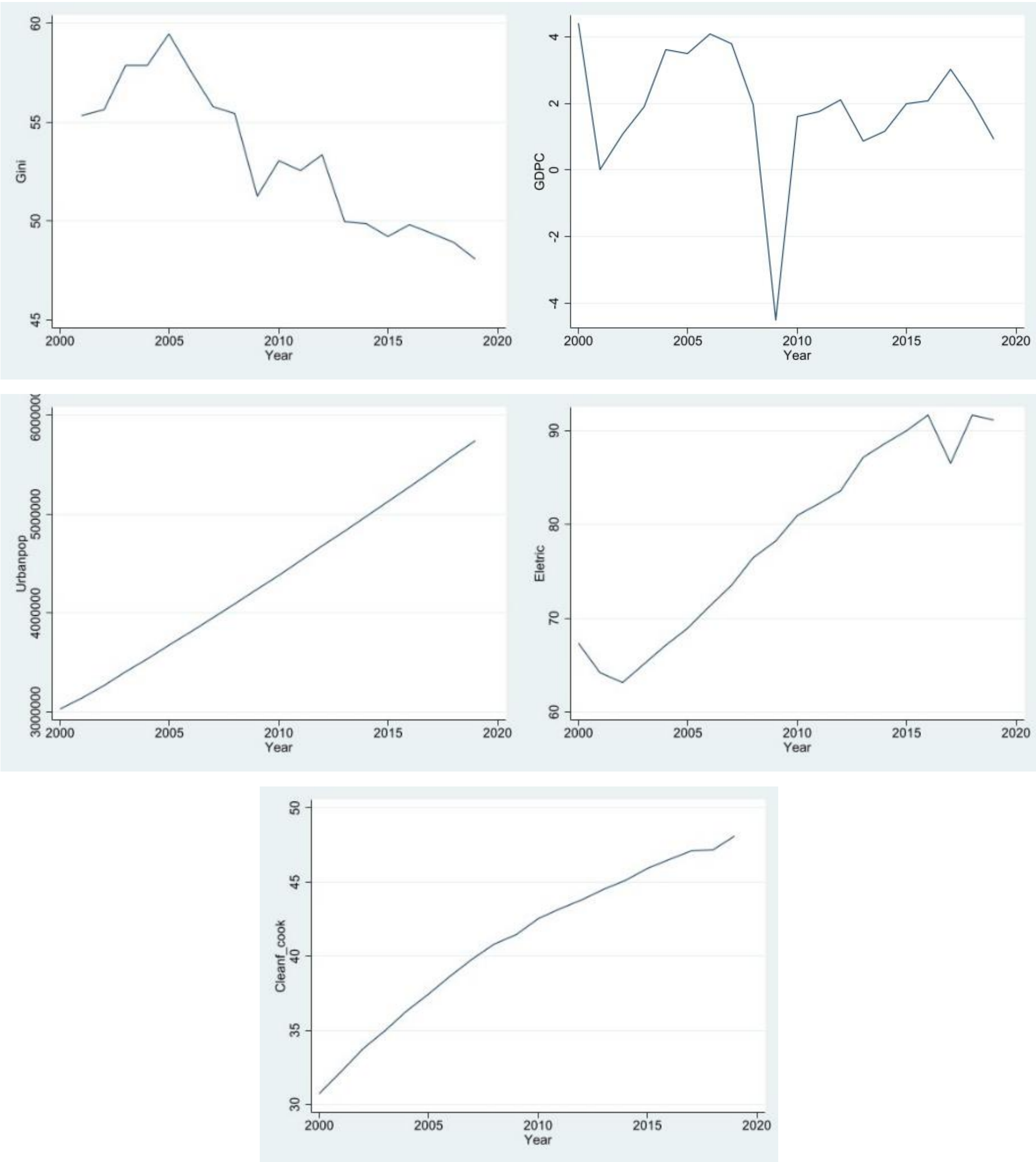

Figure 8. Variables trend identification in the Honduran analysis.

While GDP per capita and the urban population were stationary at level I(0), the rest of the variables were stationary at first differences, I(1) (Table 23).

According to the correlation analysis results (Table 24), together with Brazil and Colombia, in Honduras, the correlation between GDP per capita and Gini is positive. At the same time, it had a strong and negative linear association amid Gini and the other variables (higher than 0.86). It may indicate that Honduras is another LAC country where economic growth might not contribute to an equally distributed income among its population. Moreover, it represents a situation that happened in half of the countries from the sample chosen for this research, but that together symbolises more than 43% of the LAC total population, explaining why the OLS regression performed in this region also displayed a positive relationship between these variables.

Table 23. Augmented Dickey-Fuller unit root test results - Honduras.

Variable	Test Statistics	Mackinnon p-value	Trend	Nº of differences	Variable after difference	Test Statistics	Mackinnon p-value
Gini	-3.058	0.1166	yes	1	sGini	-4.962	0.0002
GDPC	-3.740	0.0036	no	0			
Urbanpop	-4.409	0.0021	yes	0			
Eletric	-2.815	0.1915	yes	1	sEletric	-5.144	0.0001
Clean_cook	-2.182	0.4999	yes	1	sCleanf_cook	-5.199	0.0001

Table 24. Correlation analysis - Honduras.

	GDPC	Urbanpop	Gini	Eletric	Cleanf_cook
GDPC	1.0000				
Urbanpop	-0.0338	1.0000			
Gini	0.3596	-0.8993	1.0000		
Eletric	-0.0923	0.9737	-0.9058	1.0000	
Cleanf_cook	-0.0257	0.9821	-0.8624	0.9808	1.0000

Once again, since Gini and the other energy-related variables were at the same level of stationarity, the Granger causality test could be executed in three different combinations (Table 25). The results express that Gini, i.e., inequality, Granger causes the population to have access to electricity and access to clean cooking fuels. Next, the test shows that the variables people with access to electricity and access to clean cooking fuels mutually cause each other, suggesting a bi-directional or feedback relationship between these two variables.

Table 25. VAR-based Granger causality Wald test results - Honduras.

Null hypothesis	χ2	Prob > χ2	Null hypothesis	χ2	Prob > χ2
Gini does not cause Eletric	19.386	0.000	Eletric does not cause Gini	2.932	0.231
Gini does not cause Cleanf_cook	21.506	0.000	Cleanf_cook does not cause Gini	.21262	0.899
Eletric does not cause Cleanf_cook	16.36	0.000	Cleanf_cook does not cause Eletric	11.689	0.003

The result implies that an increase in the population with access to electricity may lead to increased adoption of clean cooking fuels, which, in turn, can enhance the appeal of electrification by promoting the use of electric stoves and appliances. Conversely, improved access to clean cooking fuels can make electricity more attractive for households when affordable, as they can use it for cooking. In this scenario, policymakers may need to consider coordinated efforts to improve access to electricity and clean cooking fuels, recognising that progress in one area can positively influence progress in the other, leading to more sustainable energy access solutions.

Chapter 5

Discussion

This section discusses the results and their implications on policies and strategies that tackle income inequality challenges and increase clean energy accessibility.

Access to electricity brings several advantages to households and communities. It enables income generation, for instance, through evening small businesses, creates job opportunities, and improves education by allowing nighttime studying and internet access. Moreover, school electricity can improve student performance, attract talented educators to rural areas, enhance local institutions' operational efficiency, and improve street lighting safety. In addition, electricity can reduce a nation's reliance on environmentally harmful and polluting fuels, reducing greenhouse gas emissions.

Income inequality and energy accessibility are associated since enhancing energy access can lead to more equitable income distribution through income generation, improving health and education, and promoting economic development, particularly in underserved communities. This concept leads to the fact that addressing income inequality involves also addressing energy poverty and ensuring that energy policies and investments prioritise the needs of low-income and marginalised populations.

To that end, efforts to expand access to electricity worldwide have yielded positive results, accelerating progress in recent years. As of 2016, the number of people without electricity dropped to 1.1 billion for the first time, and approximately 1.2 billion individuals have gained access since 2000. The most significant advancements have occurred in developing Asia, where the number of people lacking electricity reduced from over one billion in 2000 to fewer than half a billion in 2016. Sub-Saharan Africa has also seen progress, with electrification efforts surpassing population growth since 2014. However, in 2018, many remote areas in LAC countries still lacked access to energy services, especially electricity, hindering growth in many countries (Barnes et al., 2018; IEA, 2017).

Disparities have been increasing since, in 2022, the number of individuals without access to electricity was expected to rise for the first time in many years. After the pandemic-related slowdown in 2020 and 2021, it was anticipated to reach 774 million, an increase of 20 million people from 2021, which would bring the number of people without access to electricity to levels last seen in 2019. The cost of obtaining and sustaining access to power is increasingly prohibitive for consumers due to rising inflation rates, leading to a global expansion of energy poverty. The pandemic and the energy crisis have left 75 million people unable to afford extended power services and 100 million unable to afford clean cooking options (IEA, 2022).

The poorest households in emerging markets and developing countries use nine times less energy than the wealthiest households, yet they spend a much higher percentage of their income on energy. The less fortunate frequently reside in less energy-efficient structures, employ outdated, inefficient appliances, and rely on more inefficient heating and cooking methods. Policy initiatives are needed to reverse this situation and help them deal with the higher initial costs of renewable energy investments – such as efficiency and electrification (IEA, 2022).

In this scenario, evaluating the impact of energy accessibility on income inequality is essential for promoting equitable development, addressing poverty, ensuring social justice, and making informed policy decisions. It helps understand the benefits of energy access in reducing income disparities and guides efforts to create a more inclusive and sustainable future, which is a reason that explains the growing importance of impact evaluation in developing energy access projects and why this dissertation's objective was to analyse if energy accessibility could impact income inequality and to provide crucial insights for energy access policies and investments.

To understand this relationship, this dissertation evaluated social, economic, and energy-related indicators from 2000 to 2019 – to avoid the COVID-19 pandemic's influence on income inequality. A group of 37 countries (formed by OECD and LAC countries) was considered, conducting an analysis using an OLS regression with Fixed Effects to explore the relationship between energy access and income inequality since regression-based methods are commonly used to determine whether the development of modern energy services is a cause or effect of development outcomes (Barnes et al., 2018).

However, due to most of this panel being European high-income countries, the electricity access indicators were not statistically significant when evaluating their influence on income inequality, leaving in the model only the access to clean cooking fuel and the CO_2 emissions per total electricity output representing the power of energy access to reduce disparities. This outcome is consistent with studies that reinforce that developed countries have already been heading towards a low-carbon economy by renewable consumption and that it negatively impacts income inequality (Topcu & Tugcu, 2020). When the European countries were analysed separately, only the CO_2 emissions remained significant in the model, leading this research to focus on middle-income countries.

One possible explanation for this result is that Europe has made significant progress in ensuring universal access to essential energy services, such as electricity and clean cooking methods. Many European countries have extensive energy infrastructure and policies to guarantee access to all residents, regardless of their income level. It means that a smaller portion of the population lacks access to energy services, reducing the potential for energy access to be a significant driver of income inequality. In addition, Europe has been at the forefront of energy efficiency initiatives and renewable energy adoption, which can help lower household energy costs, reducing the financial burden on low-income individuals (GEA, 2012).

The choice to elect middle-income LAC countries – Bolivia, Brazil, Colombia, Costa Rica, El Salvador, and Honduras – to represent the developing group analysis came from two facts. First, in Latin America, electricity access reached 97% of the population in 2017. The majority of those without access, approximately 17 million people, reside in rural regions, frequently within remote and challenging terrain, far removed from the electrical grid. Only three countries in the region have yet to attain a 90% access rate, specifically Haiti, Honduras, and Nicaragua, which falls below that threshold. In urban areas, the access rate stands at 45%, whereas in rural areas, only 7% of the population enjoys access to electricity (IEA, 2017). Second, together with Africa, the LAC remain the region with the highest levels of income inequality, where in many of its countries, the Gini index has either stopped declining or even increased in recent years (DESA, 2020).

Furthermore, as the world increasingly focuses on sustainable energy sources, studying the LAC region allows for exploring potential trade-offs between energy access and environmental sustainability in the context of income inequality. Together with these facts, the LAC region generally has reasonably good data collection systems and databases, making it conducive to research. However, it lacked consistent data on income inequality for the chosen period, which led to the selection of only the six mentioned countries for this investigation.

A regression model was specifically tested for the LAC region to gauge the advantages of energy access and modern energy services. This method typically investigates whether the advancement of modern energy services is a driving force behind or a result of developmental outcomes (Barnes et al., 2018). At the same time, suitable Econometric methods, such as correlation analysis and Granger causality, were applied to each of the six countries to establish causation when assessing the impact of energy accessibility and access to clean cooking fuels on income inequality.

Its results have shown that in the LAC region, GDP per capita could be responsible for increasing income inequality – although it did not achieve the significance level in the OLS model – illustrating that economic growth might not be evenly distributed in some of the LAC countries – such as occurred in the correlation analysis of Brazil, Colombia, and Honduras. However, since solving this challenge is a complex task, it would require implementing various policies and strategies on a country-level basis and by region since "*cooperation among countries remains essential for ensuring equitable and inclusive development – because the consequences of rising inequality and unsustainable growth do not respect national borders*" (DESA, 2020, p. 168).

For instance, countries could enforce labour laws to protect workers' rights to equal wages and safe working conditions. These policies can play a role in ensuring businesses' adherence to labour regulations, which can help reduce income inequality by improving workers' earnings and well-being. Also, Governments could collaborate with social welfare agencies to ensure that vulnerable populations receive the assistance they need, which may involve protecting distribution centres, monitoring food and aid delivery, and ensuring that resources reach those in need. Alternatively, even implementing rigorous anti-corruption measures within the police force ensures that resources are allocated fairly and not drained through corrupt practices that can exacerbate income inequality and hinder economic growth.

It is important to note that reducing income inequality by fairly distributing economic income is a multifaceted task that requires a comprehensive approach involving law enforcement and economic, social, and political policies, where policies could play a role by promoting safety and stability. However, broader systemic changes might be necessary to address the root causes of income distribution in the LAC region.

The second control variable of the model, related to the urban population, returned similar results in the LAC region and each of the six countries where urbanisation can play a role in reducing income inequality. Nevertheless, the correlation coefficient between Gini and the urban population was higher than 0.9 in the countries with less than 70% of their population living in urban areas, according to the United Nations (2018), such as Bolivia, El Salvador and Honduras – all low-middle-income countries – but lower than 0.78 in Brazil, Colombia and Costa Rica where urbanisation is more developed – upper-middle-income countries.

Having that said, it is possible to assume that the increase in urban population can help reduce income inequality. However, it is more relevant in lower-income countries with a high rural population, which could profit from urban areas' structure and economic opportunities. Hence, it is crucial for developing nations' Governments to actively advance rural development, enhance the well-being of rural populations, narrow the income disparity between urban and rural residents, and maintain a reasonable level of urbanisation, to achieve income equality, making sure that rural areas will catch up to urban areas' rate of progress (DESA, 2020; Wang et al., 2023). Governments must also fund off-grid technology to improve rural residents' access to power since off-grid solar solutions are reportedly successful in rural Africa and several developing Asian countries by making electricity easily accessible and reasonably priced. Furthermore, enhancing rural residents' access to energy necessitates solid political commitment and resolve that transcends their political interests (Acheampong et al., 2021; IEA, 2017).

Moreover, reducing income inequality in urban areas requires deliberate policies and investments in affordable housing, education, healthcare, workforce development, and social safety nets to ensure that the benefits of urbanisation are shared more equitably among all residents. Addressing urban challenges such as informal labour markets and spatial inequality could also play a role in achieving more equitable outcomes.

Concerning the energy-related variables – the total population with access to electricity and the percentage of people with access to clean cooking fuels – they all returned results that confirm that energy access can support a reduction in income inequality. Nonetheless, as happened with the urban population indicator, the correlation coefficient of both energy-based variables' relationship with the Gini index had higher values in the lower-income countries, with more than 0.95 in Bolivia and El Salvador and more than 0.86 in Honduras. This number was lower in the upper-middle-income countries Brazil and Colombia (more than 0.65) and a lot lower in Costa Rica (0.01 for access to electricity and 0.3 for access to clean cooking fuels). It indicates that apart from Costa Rica, in the remaining countries, there is a substantial negative relationship between energy access and income inequality, which is even stronger in the poorest countries. It illustrates that it is impossible to have a one-size-fits-all strategy in the LAC region for increasing access to electricity, making it difficult to comprehend how it could impact income disparities.

Moreover, the Granger causality test reinforced that the impact of energy access can be different from one country to another. While in Colombia, no causation could be defined, Bolivia was the only country in which access to electricity Granger caused income inequality, i.e., the Gini index, to reduce, meaning that improvements in access to electricity are associated with changes in income inequality. In this case, one strategy could be that, even though most Governments have limited resources, they can work with private investors to raise money for power production initiatives. To that end, Governments must create and carry out national energy policies with specific objectives and incentives to promote investment in the energy industry to collaborate with private investors (Acheampong et al., 2021; Barnes et al., 2018). In Costa Rica and Honduras, there is a reciprocal influence between these two variables, showing the presence of a mutual Granger causality, suggesting a feedback loop between energy accessibility and income inequality. These findings have important policy implications since policymakers and organisations may need to consider a two-way relationship and develop comprehensive strategies to improve access to electricity and address income disparities to create a more equitable and sustainable impact. Improvements in access to electricity can help reduce income inequality, but concurrently, addressing income inequality may also improve access to electricity by boosting economic capacity. For example, access to electricity might affect income inequality through improved education and job opportunities, while income inequality could influence access to electricity through affordability issues.

Despite this difference, the relationship between income inequality and access to clean cooking fuels was homogeneous in the countries where it could be analysed by having the first responsible for Granger cause the second in Brazil, Costa Rica, and Honduras. In other words, variations in income inequality are associated with changes in the availability and use of clean cooking fuels over time, possibly due to income levels influencing affordability and access to modern energy sources.

The comparatively expensive cost of clean and contemporary energy may be one of the reasons for its limited usage. If renewable energy is not affordable, its economic impact will be minimal. In this scenario, policymakers and organisations may need to consider addressing income inequality as part of their strategy since policies aimed at reducing income disparities might indirectly lead to improved access to clean cooking fuels. However, economic development, Government policies, and cultural factors must be considered because they may influence how income inequality affects access to clean cooking fuels and evaluate the impediments to clean energy usage. Increasing the use of clean energy after access is affordable requires launching educational initiatives highlighting the advantages of doing so and educating people — especially women — on how to use these modern, clean energy technologies (Acheampong et al., 2021).

Furthermore, when the relationship between access to electricity and access to clean cooking fuels was tested in Costa Rica and El Salvador, electricity access Granger caused the access to clean cooking fuels, while in Honduras, they mutually Granger caused each other. In the first case, the result indicates that improvements in access to electricity are associated with improvements in access to clean cooking fuels. Policies should aim at expanding the availability of electricity infrastructure, which may indirectly enhance access to clean cooking fuels. In the second situation, policymakers and organisations need to recognise the interdependence of these variables since policies and initiatives may need to address both access to electricity and clean cooking fuels simultaneously to maximise their effectiveness, suggesting that an integrated approach to energy and infrastructure policies may be more successful. This type of project is relevant because, for example, improved access to electricity may lead to using electric stoves for cooking, reducing reliance on traditional cooking fuels, which results in improved air quality and health benefits.

Even though a project for ensuring universal access to affordable and reliable modern energy services poses significant challenges, for it to be successful, it requires the development of energy policies, strategies, and action plans to support its implementation. The empirical evidence provided by this dissertation suggests that the impact of energy accessibility on income inequality is not only region-specific but also country-related, implying that to profit from the benefits of energy accessibility to reduce income disparities, the context of each country should be considered. While the findings reveal a strong relationship between expanded access to clean and affordable energy and reduced income inequality in the LAC countries, they shed light on how their correlation can be even more substantial in lower-income countries, disclosing the need to address both challenges simultaneously.

Chapter 6

Conclusion

This chapter finalises this dissertation, summarising conclusions and highlighting aspects to be developed in future work.

The availability of modern energy plays a crucial role in facilitating the achievement of various SDGs. For instance, addressing poverty (SDG 1) by enabling economic opportunities and reducing inequalities is essential (SDG 10). Energy is also a prerequisite for enhancing food security, nutrition, and sustainable agriculture (SDG 2). Moreover, it contributes to economic growth and employment (SDG 8), mainly through job creation in general industry, food processing and preservation, and the operation of agricultural systems and conservation of perishable products. Furthermore, modern energy supports water pumping systems, which, in turn, improves water and sanitation (SDG 6). In the context of health services and promoting well-being (SDG 3), energy is indispensable for preserving medicines through refrigeration, sterilizing medical equipment, and providing lighting for nighttime surgeries and deliveries. In education (SDG 4), electricity is essential for quality learning, including modern communication services and school computers, which enhance educational outcomes. Energy services also contribute to better working conditions for women and their participation in community activities, aligning with the goal of gender equality and empowering women and girls (SDG 5) (Barnes et al., 2018; IEA, 2017; UNDP, 2018a).

Since unequal access to energy and low human development are highly correlated, for instance, through energy poverty – when there is a lack of access in the developing world to electricity and clean cooking fuels or technologies (UNDP, 2018a) – this dissertation decided to focus on the relationship between energy accessibility and income inequality by trying to understand the impact of the first on the second.

To comprehend how access to energy could impact income inequality, this dissertation applied a fixed effects linear regression (OLS) model to a panel of six middle-income countries from the LAC region – Bolivia, Brazil, Colombia, Costa Rica, El Salvador, and Honduras. The LAC region was chosen for this study because, before the COVID-19 pandemic, indicators already demonstrated that households spent a significant amount of money on fuel — up to 10% of overall expenditures. Up to 5% of household expenses may be attributed to electricity; in most countries, that amount may be four times greater. Indigenous and Afro-descendant people in the area are among the most at risk. The inability to get clean sources for cooking and the procurement and management of household energy (biomass, firewood) are manifestations of gender disparities. For the most marginalised and isolated populations, it is critical to guarantee sustainable sources of energy dependability and enhance access to combat energy poverty (IEA, 2022). Correlation analysis and Granger causality tests for each country were also performed, aiming to respond to the following hypothesis:

H1. Does access to electricity have an impact on the Gini Coefficient?
H2. Does access to clean cooking fuels have an impact on the Gini Coefficient?
H3. Does access to electricity impact the access to clean cooking fuels?

The analysis of energy-related variables, including the population with access to electricity and access to clean cooking fuels, consistently demonstrated that energy access can contribute to reducing income inequality. This relationship was particularly pronounced in lower-income countries. Furthermore, Granger causality tests revealed that the impact of energy access on income inequality varied by country, with Bolivia experiencing a causal relationship where increased access to electricity led to reduced income inequality. At the same time, Costa Rica and Honduras exhibited a mutual causation, suggesting a feedback loop between energy accessibility and income inequality. Income inequality is responsible for Granger cause access to clean cooking fuels in Brazil, Costa Rica, and Honduras. In Costa Rica and El Salvador, electricity access Granger caused the access to clean cooking fuels, while in Honduras, they mutually Granger caused each other. These findings confirm the three hypotheses related to the relationship between the variables — however, the impact direction changes from one country to another. It underscores the need for tailored strategies and policies to improve access to electricity and address income disparities in the LAC region, as energy access can both impact and be influenced by income inequality, ultimately contributing to a more equitable and sustainable impact.

In summary, the impact of energy accessibility on income inequality varies by country and income level. Policies should be tailored to the particular context of each nation to maximise their effectiveness. An integrated approach to addressing energy access and income inequality can yield significant benefits. Reducing income inequality through the fair distribution of economic growth requires a multifaceted approach involving legal reforms, economic, social, and political policies, and international cooperation.

6.1 Further research and limitations

The lack of access to consistent income inequality data from 2000 to 2019 prevented this dissertation from having a larger group of countries representing the LAC region. The same occurred related to other developing countries that this dissertation wanted to include in the global panel analysis, restricting the diversity aimed at the beginning of the research.

Concerning perspectives for future work, inequalities in income, gender, and other dimensions, such as rural/urban income discrepancies, can all be reduced by reducing global energy inequality. Further research could extend this study by investigating the impact of energy accessibility on other types of inequality, such as gender, health, education, social, and environmental disparities, especially in the LAC region, where this type of research is scarce.

These future research avenues are essential to fill the gap in the literature related to comprehending the connection between energy accessibility and inequalities. It is essential to comprehend more deeply why the lack of adequate, dependable, and affordable modern energy sources disproportionately affects women and children. Alternatively, why does the lack of energy access in rural areas limit employment opportunities, the expansion of businesses, and the potential for productivity, exacerbating income inequality and perpetuating poverty?

Understanding these relationships can support effective policies and strategy creation to increase energy accessibility and reduce disparities in other types of vulnerable populations. For instance, it can also empower marginalised groups, such as indigenous populations, by enhancing access to modern energy services. This comprehension is essential since inequality within and across countries could be decreased, and vulnerable groups' resistance to the impact of climate change could be strengthened through sustainable energy (UNDP, 2018a).

Annex A

Literature Review Summary

A summary table with the scientific papers and reports used to develop this dissertation, organised by correspondent research focus related to region/income group.

Table 26. Literature review summary.

Author	Year	Title	Region/ Income Group	Research focus
Njiru, C. W., & Letema, S. C.	2018	Energy poverty and its implication on standard of living in Kirinyaga, Kenya.	Africa	Energy Poverty
Acharya, R. H., & Sadath, A. C.	2019	Energy poverty and economic development: Household-level evidence from India.	Asia	Energy Poverty
Dong, K., Ren, X., & Zhao, J.	2021	How does low-carbon energy transition alleviate energy poverty in China? A nonparametric panel causality analysis.		Energy Poverty
Han, M., Xiong, J., Wang, S., & Yang, Y.	2020	Chinese photovoltaic poverty alleviation: Geographic distribution, economic benefits and emission mitigation.		Renewable Energy
Oum, S.	2019	Energy poverty in the Lao PDR and its impacts on education and health.		Energy Poverty
Sambodo, M. T., & Novandra, R.	2019	The state of energy poverty in Indonesia and its impact on welfare.		Energy Poverty
Zhao, J., Jiang, Q., Dong, X., & Dong, K.	2021	Assessing energy poverty and its effect on CO2 emissions: The case of China.		Energy Poverty
Haar, L.	2020	Inequality and renewable electricity support in the European Union.	Europe	Energy Access and Income Inequality
Santosa, J. F., & Catalão-Lopes, M.	2014	Does R&D matter for economic growth or vice-versa? An application to Portugal and other European Countries.		R&D
Carrilho-Nunes, I., & Catalão-Lopes, M.	2022	The effects of environmental policy and technology transfer on GHG emissions: The case of Portugal.		Renewable Energy
European Parliament	2023	Energy Policy: General Principles. Fact Sheets on the European Union		Energy Policy
Galvin, R.	2020	Economic inequality, energy justice and the meaning of life.		Energy Access and Income Inequality
Galvin, R.	2020	Energy poverty research: A perspective from the poverty side.		Energy Poverty
Galvin, R.	2020	Recent increases in inequality in developed countries.		Income Inequality
Sunikka-Blank, M.	2020	Why are women always cold? Gendered realities of energy injustice.		Energy Justice
Terry, N.	2020	Housing tenure and thermal quality of homes — How home ownership affects access to energy services.		Energy Poverty
Walker, G., & Day, R.	2012	Fuel poverty as injustice: Integrating distribution, recognition and procedure in the struggle for affordable warmth.		Energy Poverty
Acheampong, A. O., Dzator, J., & Shahbaz, M.	2021	Empowering the powerless: Does access to energy improve income inequality?	Global	Energy Access and Income Inequality
Adom, P. K., Amuakwa-Mensah, F., Agradi, M. P., & Nsabimana, A.	2021	Energy poverty, development outcomes, and transition to green energy.		Energy Poverty

Berthe, A., & Elie, L.	2015	Mechanisms explaining the impact of economic inequality on environmental deterioration.		Income Inequality
Boardman, B.	1991	Fuel poverty is different.		Fuel Poverty
Bouzarovski, S., & Petrova, S.	2015	A global perspective on domestic energy deprivation: Overcoming the energy poverty-fuel poverty binary.		Energy Poverty
DESA	2015	Inequality Measurement		Income Inequality
DESA	2020	The World Social Report 2020: Inequality in a rapidly changing world.		Income Inequality
ECB	2019	Not all inequality measures were created equal.		Income Inequality
Filippidis, M., Tzouvanas, P., & Chatziantoniou, I.	2021	Energy poverty through the lens of the energy-environmental Kuznets curve hypothesis.		Energy Poverty
Fu, F. Y., Alharthi, M., Bhatti, Z., Sun, L., Rasul, F., Hanif, I., & Iqbal, W.	2021	The dynamic role of energy security, energy equity and environmental sustainability in the dilemma of emission reduction and economic growth.		Energy Access and Economic Growth
GEA	2012	Global Energy Assessment: toward a sustainable future.		Energy Access
González-Eguino, M.	2015	Energy poverty: An overview.		Energy Poverty
Hills, J.	2011	Fuel poverty: the problem and its measurement.		Energy Poverty
IEA	2017	Energy Access Outlook 2017: From Poverty to Prosperity.		Energy Poverty
IEA	2022	World Energy Outlook		Energy Access
IMF	1998	Fundamental determinants of inequality and the role of Government.		Income Inequality
McGee, J. A., & Greiner, P. T.	2019	Renewable energy injustice: The socio-environmental implications of renewable energy consumption.		Renewable Energy
Middlemiss, L.	2020	Energy poverty: Understanding and addressing systemic inequalities.		Energy Poverty
Nguyen, C. P., & Nasir, M. A.	2021	An inquiry into the nexus between energy poverty and income inequality in the light of global evidence.		Energy Access and Income Inequality
Nguyen, C. P., & Su, T. D.	2021	Does energy poverty matter for gender inequality? Global evidence.		Energy Poverty
Pachauri, S., & Spreng, D.	2011	Measuring and monitoring energy poverty.		Energy Poverty
Sovacool, B. K.	2012	The political economy of energy poverty: A review of key challenges.		Energy Poverty
Sovacool, B. K., Burke, M., Baker, L., Kotikalapudi, C. K., & Wlokas, H.	2017	New frontiers and conceptual frameworks for energy justice.		Energy Justice
Sun, C., Khan, A., & Ren, Y.	2023	Empowering Progress: Education, innovations and financial development in the battle against energy poverty.		Energy Poverty
UNDP	2018	Interlinkages among energy, poverty and inequalities.		Energy Access and Income Inequality
UNDP	2018	Policy brief for health and energy linkages-maximizing health benefits from the sustainable energy transition.		Energy Transition

UNDP	2018	Policy Brief on the interlinkages between Energy and Education.		Energy Access and Education
Uzar, U.	2020	Is income inequality a driver for renewable energy consumption?		Energy Access and Income Inequality
Wang, Q., Hu, S., Li, L., & Li, R.	2023	Accelerating urbanization serves to reduce income inequality without sacrificing energy efficiency – Evidence from the 78 countries.		Energy Access and Income Inequality
WHO	2006	Fuel for life: household energy and health.		Energy Poverty
Zhao, J., Dong, K., & Taghizadeh-Hesary, F.	2023	Is income inequality a stumbling block to the global natural gas market?		Energy Access and Income Inequality
OECD	2004	Universal service obligations.		Energy Policy
Aquila, G., Pamplona, E. de O., Queiroz, A. R. de, Rotela Junior, P., & Fonseca, M. N.	2017	An overview of incentive policies for the expansion of renewable energy generation in electricity power systems and the Brazilian experience.	LAC	Renewable Energy
Barnes, D. F., Samad, H., & Rivas, S.	2018	Meeting challenges, measuring progress.		Energy Access
United Nations	2022	A transformative recovery in Latin America and the Caribbean with basic drinking water and electricity services as key sectors.		Electricity Access
Zhong, H., Feng, K., Sun, L., Cheng, L., & Hubacek, K.	2020	Household carbon and energy inequality in Latin American and Caribbean countries.		Energy Access and Income Inequality
Reames, T. G.	2016	Targeting energy justice: Exploring spatial, racial/ethnic and socioeconomic disparities in urban residential heating energy efficiency.	North America	Energy Justice
Hassan, S. T., Batool, B., Zhu, B., & Khan, I.	2022	Environmental complexity of globalization, education, and income inequalities: New insights of energy poverty.	Middle-Income	Energy Access and Income Inequality
Zhang, T., Shi, X., Zhang, D., & Xiao, J.	2019	Socio-economic development and electricity access in developing economies: A long-run model averaging approach.		Electricity Access
Galvin, R., & Sunikka-Blank, M.	2018	Economic Inequality and Household Energy Consumption in High-income Countries: A Challenge for Social Science Based Energy Research.	High-Income	Energy Access and Income Inequality
Madlener, R.	2020	Sustainable energy transition and increasing complexity: Trade-offs, the economics perspective and policy implications.		Energy Transition
Topcu, M., & Tugcu, C. T.	2020	The impact of renewable energy consumption on income inequality: Evidence from developed countries.		Energy Access and Income Inequality

Annex B

Code

The Stata 17 code used for the calculations: OLS regression with Fixed Effects, Correlation analysis and Granger Causality.

 # Complete Panel (37 countries)

```
xtset ID Year, yearly

xtunitroot fisher GDPC, dfuller lags(0)
xtunitroot fisher Urbanpop, dfuller lags(0)
xtunitroot fisher Ruralpop, dfuller lags(0)
xtunitroot fisher ssRuralpop, dfuller lags(0)
xtunitroot fisher Labourrate, dfuller lags(0)
xtunitroot fisher sLabourrate, dfuller lags(0)
xtunitroot fisher LabourratioF, dfuller lags(0)
xtunitroot fisher sLabourratioF, dfuller lags(0)
xtunitroot fisher HealthexpC, dfuller lags(0)
xtunitroot fisher sHealthexpC, dfuller lags(0)
xtunitroot fisher Gini, dfuller lags(0)
xtunitroot fisher Eletric_Urb, dfuller lags(0)
xtunitroot fisher Eletric_Ru, dfuller lags(0)
xtunitroot fisher Re_elec_op, dfuller lags(0)
xtunitroot fisher sRe_elec_op, dfuller lags(0)
xtunitroot fisher sdg7_co2twh, dfuller lags(0)
xtunitroot fisher ssdg7_co2twh, dfuller lags(0)
xtunitroot fisher sdg7_recon, dfuller lags(0)
xtunitroot fisher ssdg7_recon, dfuller lags(0)
xtunitroot fisher Cleanf_cook, dfuller lags(0)
xtunitroot fisher Energy_int, dfuller lags(0)
xtunitroot fisher sEnergy_int, dfuller lags(0)
xtunitroot fisher Net_users, dfuller lags(0)
xtunitroot fisher Oil_prices, dfuller lags(0)
xtunitroot fisher sOil_prices, dfuller lags(0)
xtunitroot fisher Exports, dfuller lags(0)
xtunitroot fisher GDP, dfuller lags(0)
xtunitroot fisher GDPcons, dfuller lags(0)
xtunitroot fisher NResources, dfuller lags(0)
xtunitroot fisher sNResources, dfuller lags(0)
xtunitroot fisher Eletric, dfuller lags(0)
xtunitroot fisher sEletric, dfuller lags(0)

xtreg Gini Exports Cleanf_cook sHealthexpC ssdg7_co2twh, fe vce(cluster Country)
vif, uncentered
```

 # EU Panel

```
xtset ID Year, yearly

xtunitroot fisher GDPC, dfuller lags(0)
xtunitroot fisher Urbanpop, dfuller lags(0)
xtunitroot fisher Ruralpop, dfuller lags(0)
xtunitroot fisher ssRuralpop, dfuller lags(0)
xtunitroot fisher Labourrate, dfuller lags(0)
xtunitroot fisher sLabourrate, dfuller lags(0)
xtunitroot fisher LabourratioF, dfuller lags(0)
xtunitroot fisher sLabourratioF, dfuller lags(0)
xtunitroot fisher HealthexpC, dfuller lags(0)
xtunitroot fisher sHealthexpC, dfuller lags(0)
xtunitroot fisher Gini, dfuller lags(0)
xtunitroot fisher Eletric_Urb, dfuller lags(0)
xtunitroot fisher Eletric_Ru, dfuller lags(0)
xtunitroot fisher Re_elec_op, dfuller lags(0)
xtunitroot fisher sRe_elec_op, dfuller lags(0)
xtunitroot fisher sdg7_co2twh, dfuller lags(0)
xtunitroot fisher ssdg7_co2twh, dfuller lags(0)
xtunitroot fisher sdg7_recon, dfuller lags(0)
xtunitroot fisher ssdg7_recon, dfuller lags(0)
xtunitroot fisher Cleanf_cook, dfuller lags(0)
xtunitroot fisher Energy_int, dfuller lags(0)
xtunitroot fisher sEnergy_int, dfuller lags(0)
xtunitroot fisher Net_users, dfuller lags(0)
xtunitroot fisher Oil_prices, dfuller lags(0)
xtunitroot fisher sOil_prices, dfuller lags(0)
```

```
xtunitroot fisher Exports, dfuller lags(0)
xtunitroot fisher GDP, dfuller lags(0)
xtunitroot fisher GDPcons, dfuller lags(0)
xtunitroot fisher NResources, dfuller lags(0)
xtunitroot fisher sNResources, dfuller lags(0)
xtunitroot fisher Eletric, dfuller lags(0)
xtunitroot fisher sEletric, dfuller lags(0)

xtreg Gini sGDPcons sLabourratioF sHealthexpC ssdg7_co2twh, fe vce(cluster Country)
vif, uncentered
```

 # LAC Panel

```
xtset ID Year, yearly

xtunitroot fisher GDPC, dfuller lags(0)
xtunitroot fisher Urbanpop, dfuller lags(0)
xtunitroot fisher Ruralpop, dfuller lags(0)
xtunitroot fisher ssRuralpop, dfuller lags(0)
xtunitroot fisher Labourrate, dfuller lags(0)
xtunitroot fisher sLabourrate, dfuller lags(0)
xtunitroot fisher LabourratioF, dfuller lags(0)
xtunitroot fisher sLabourratioF, dfuller lags(0)
xtunitroot fisher HealthexpC, dfuller lags(0)
xtunitroot fisher sHealthexpC, dfuller lags(0)
xtunitroot fisher Gini, dfuller lags(0)
xtunitroot fisher Eletric_Urb, dfuller lags(0)
xtunitroot fisher Eletric_Ru, dfuller lags(0)
xtunitroot fisher Re_elec_op, dfuller lags(0)
xtunitroot fisher sRe_elec_op, dfuller lags(0)
xtunitroot fisher sdg7_co2twh, dfuller lags(0)
xtunitroot fisher ssdg7_co2twh, dfuller lags(0)
xtunitroot fisher sdg7_recon, dfuller lags(0)
xtunitroot fisher ssdg7_recon, dfuller lags(0)
xtunitroot fisher Cleanf_cook, dfuller lags(0)
xtunitroot fisher Energy_int, dfuller lags(0)
xtunitroot fisher sEnergy_int, dfuller lags(0)
xtunitroot fisher Net_users, dfuller lags(0)
xtunitroot fisher Oil_prices, dfuller lags(0)
xtunitroot fisher sOil_prices, dfuller lags(0)
xtunitroot fisher Exports, dfuller lags(0)
xtunitroot fisher GDP, dfuller lags(0)
xtunitroot fisher GDPcons, dfuller lags(0)
xtunitroot fisher NResources, dfuller lags(0)
xtunitroot fisher sNResources, dfuller lags(0)
xtunitroot fisher Eletric, dfuller lags(0)
xtunitroot fisher sEletric, dfuller lags(0)

xtreg Gini GDPC Urbanpop Eletric Cleanf_cook, fe vce(cluster Country)
vif, uncentered
```

 # LAC Countries

```
# Bolivia
twoway (line Gini Year)
dfuller Gini, trend regress lags(0)
gen sGini = d.Gini
dfuller sGini, trend regress lags(0)
twoway (line GDPC Year)
dfuller GDPC , regress lags(0)
dfuller sGDPC , regress lags(0)
twoway (line Eletric Year)
dfuller Eletric , trend regress lags(0)
dfuller sEletric , trend regress lags(0)
twoway (line Urbanpop Year)
dfuller Urbanpop , trend regress lags(0)
twoway (line Cleanf_cook Year)
dfuller Cleanf_cook , trend regress lags(0)
```

```
dfuller sCleanf_cook , trend regress lags(0)
dfuller ssCleanf_cook , trend regress lags(0)

# Correlation and causality
correlate GDPC Urbanpop Gini Eletric Cleanf_cook
var Gini Eletric
varsoc Eletric Gini
vargranger

# Brazil
twoway (line Gini Year)
dfuller Gini, regress lags(0)
dfuller sGini, regress lags(0)
twoway (line GDPC Year)
dfuller GDPC , regress lags(0)
twoway (line Eletric Year)
dfuller Eletric , trend regress lags(0)
twoway (line Urbanpop Year)
dfuller Urbanpop , trend regress lags(0)
twoway (line Cleanf_cook Year)
dfuller Cleanf_cook , trend regress lags(0)
dfuller sCleanf_cook , trend regress lags(0)

# Correlation and causality
correlate GDPC Urbanpop Gini Eletric Cleanf_cook
var Gini Cleanf_cook
varsoc Cleanf_cook Gini
vargranger

# Colombia
twoway (line Gini Year)
dfuller Gini, regress lags(0)
dfuller sGini, regress lags(0)
twoway (line GDPC Year)
dfuller GDPC , regress lags(0)
dfuller sGDPC , regress lags(0)
twoway (line Urbanpop Year)
dfuller Urbanpop , trend regress lags(0) # ignored after 2 differences
twoway (line Eletric Year)
dfuller Eletric , trend regress lags(0)
twoway (line Cleanf_cook Year)
dfuller sCleanf_cook , trend regress lags(0)

# Correlation and causality
correlate GDPC Urbanpop Gini Eletric Cleanf_cook
var Gini Cleanf_cook
varsoc Cleanf_cook Gini
vargranger

# Costa Rica
twoway (line Gini Year)
dfuller Gini, regress lags(0)
twoway (line GDPC Year)
dfuller GDPC, regress lags(0)
twoway (line Eletric Year)
dfuller Eletric , trend regress lags(0)
twoway (line Urbanpop Year)
dfuller Urbanpop , trend regress lags(0)
twoway (line Cleanf_cook Year)
dfuller Cleanf_cook , trend regress lags(0)

# Correlation and causality
correlate GDPC Urbanpop Gini Eletric Cleanf_cook
var Gini Eletric
varsoc Eletric Gini
vargranger
var Gini Cleanf_cook
```

```
varsoc Cleanf_cook Gini
vargranger
var Eletric Cleanf_cook
varsoc Cleanf_cook Eletric
vargranger

# El Salvador
twoway (line Gini Year)
dfuller Gini, trend regress lags(0)
twoway (line GDPC Year)
dfuller GDPC , regress lags(0)
twoway (line Eletric Year)
dfuller Eletric , trend regress lags(0)
dfuller sEletric , trend regress lags(0)
twoway (line Urbanpop Year)
dfuller Urbanpop , trend regress lags(0)
twoway (line Cleanf_cook Year)
dfuller Cleanf_cook , trend regress lags(0)
dfuller sCleanf_cook , trend regress lags(0)

# Correlation and causality
correlate GDPC Urbanpop Gini Eletric Cleanf_cook
var Eletric Cleanf_cook
varsoc Cleanf_cook Eletric
vargranger

# Honduras
twoway (line Gini Year)
dfuller Gini, trend regress lags(0)
dfuller sGini, trend regress lags(0)
twoway (line GDPC Year)
dfuller GDPC ,  regress lags(0)
twoway (line Eletric Year)
dfuller Eletric ,  trend regress lags(0)
dfuller sEletric ,  trend regress lags(0)
twoway (line Urbanpop Year)
dfuller Urbanpop ,  trend regress lags(0)
twoway (line Cleanf_cook Year)
dfuller Cleanf_cook ,  trend regress lags(0)
dfuller sCleanf_cook ,  trend regress lags(0)

# Correlation and causality
correlate GDPC Urbanpop Gini Eletric Cleanf_cook
var Gini Eletric
varsoc Eletric Gini
vargranger
var Gini Cleanf_cook
varsoc Cleanf_cook Gini
vargranger
var Eletric Cleanf_cook
varsoc Cleanf_cook Eletric
vargranger
```

Annex C

E.U. Fixed-Effects regression

Table with the results of the OLS regression with Fixed Effects.

Table 27. Fixed-effect OLS regression with EU countries.

Fixed-effects (within) regression			
Group variable: ID	Number of obs	=	476
	Number of groups	=	26
R-sq: Within = 0.0362	Obs per group		
Between = 0.0736	min	=	16
Overall = 0.0069	avg	=	18.3
	max	=	19
	F(3,25)	=	.
corr(u_i, Xb) = -0.1811	Prob > F	=	.

(Std. err. adjusted for 26 clusters in Country)

Gini	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
sGDPcons	-2.52e-12	5.54e-13	-4.56	0.000	-3.67e-12	-1.38e-12
sLabourratioF	-.1974268	.1171223	-1.69	0.104	-.4386447	.0437911
sHealthexpC	-.0004259	.0002439	-1.75	0.093	-.0009282	.0000764
ssdg7_co2twh	-.0298265	.0095232	-3.13	0.004	-.0494399	-.0102132
_cons	31.22878	.0553922	563.78	0.000	31.1147	31.34287
sigma_u	3.5864007					
sigma_e	1.4219642					
rho	.86415292	(fraction of variance due to u_i)				

Variable	VIF	1/VIF
sHealthexpC	1.05	0.954798
sLabourrat~F	1.04	0.964108
sGDPcons	1.03	0.972994
ssdg7_co2twh	1.00	0.996644
Mean VIF	1.03	

References

Acharya, R. H., & Sadath, A. C. (2019). Energy poverty and economic development: Household-level evidence from India. *Energy and Buildings*, *183*, 785–791. https://doi.org/10.1016/j.enbuild.2018.11.047

Acheampong, A. O., Dzator, J., & Shahbaz, M. (2021). Empowering the powerless: Does access to energy improve income inequality? *Energy Economics*, *99*, 105288. https://doi.org/10.1016/j.eneco.2021.105288

Adom, P. K., Amuakwa-Mensah, F., Agradi, M. P., & Nsabimana, A. (2021). Energy poverty, development outcomes, and transition to green energy. *Renewable Energy*, *178*, 1337–1352. https://doi.org/10.1016/j.renene.2021.06.120

Aquila, G., Pamplona, E. de O., Queiroz, A. R. de, Rotela Junior, P., & Fonseca, M. N. (2017). An overview of incentive policies for the expansion of renewable energy generation in electricity power systems and the Brazilian experience. *Renewable and Sustainable Energy Reviews*, *70*, 1090–1098. https://doi.org/10.1016/J.RSER.2016.12.013

Barnes, D. F., Samad, H., & Rivas, S. (2018). *Meeting challenges, measuring progress - The benefits of sustainable energy access in Latin America and the Caribbean*. https://doi.org/http://dx.doi.org/10.18235/0001407

Berthe, A., & Elie, L. (2015). Mechanisms explaining the impact of economic inequality on environmental deterioration. *Ecological Economics*, *116*, 191–200. https://doi.org/10.1016/J.ECOLECON.2015.04.026

Boardman, B. (1991). Fuel poverty is different. In *Policy Studies* (4th ed., Vol. 12, pp. 30–41). Routledge. https://doi.org/10.1080/01442879108423600

Bouzarovski, S., & Petrova, S. (2015). A global perspective on domestic energy deprivation: Overcoming the energy poverty-fuel poverty binary. *Energy Research and Social Science*, *10*, 31–40. https://doi.org/10.1016/J.ERSS.2015.06.007

Carrilho-Nunes, I., & Catalão-Lopes, M. (2022). The effects of environmental policy and technology transfer on GHG emissions: The case of Portugal. *Structural Change and Economic Dynamics*, *61*, 255–264. https://doi.org/10.1016/J.STRUECO.2022.03.001

DESA. (2015). *Inequality measurement* (Issue 2). https://www.un.org/en/development/desa/policy/wess/wess_dev_issues/dsp_policy_02.pdf

DESA. (2020). The World Social Report 2020: Inequality in a rapidly changing world. In *World Social*

Report 2020. United Nations. https://doi.org/10.18356/7f5d0efc-en

Dong, K., Ren, X., & Zhao, J. (2021). How does low-carbon energy transition alleviate energy poverty in China? A nonparametric panel causality analysis. *Energy Economics*, *103*(September), 105620. https://doi.org/10.1016/j.eneco.2021.105620

ECB. (2019). Not all inequality measures were created equal. *Statistics Paper Series*, *31*. https://www.ecb.europa.eu/pub/pdf/scpsps/ecb.sps31~269c917f9f.en.pdf

European Parliament. (2023). Energy policy: general principles. *Fact Sheets on the European Union*, 1–10. https://www.europarl.europa.eu/ftu/pdf/en/FTU_2.4.7.pdf

Filippidis, M., Tzouvanas, P., & Chatziantoniou, I. (2021). Energy poverty through the lens of the energy-environmental Kuznets curve hypothesis. *Energy Economics*, *100*(December 2020), 105328. https://doi.org/10.1016/j.eneco.2021.105328

Fu, F. Y., Alharthi, M., Bhatti, Z., Sun, L., Rasul, F., Hanif, I., & Iqbal, W. (2021). The dynamic role of energy security, energy equity and environmental sustainability in the dilemma of emission reduction and economic growth. *Journal of Environmental Management*, *280*(May 2020), 111828. https://doi.org/10.1016/j.jenvman.2020.111828

Galvin, R. (2020a). Economic inequality, energy justice and the meaning of life. In *Inequality and Energy: How Extremes of Wealth and Poverty in High Income Countries Affect CO2 Emissions and Access to Energy*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-817674-0.00004-7

Galvin, R. (2020b). Energy poverty research: A perspective from the poverty side. In *Inequality and Energy: How Extremes of Wealth and Poverty in High Income Countries Affect CO2 Emissions and Access to Energy*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-817674-0.00010-2

Galvin, R. (2020c). Recent increases in inequality in developed countries. In *Inequality and Energy: How Extremes of Wealth and Poverty in High Income Countries Affect CO2 Emissions and Access to Energy*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-817674-0.00001-1

Galvin, R., & Sunikka-Blank, M. (2018). Economic inequality and household energy consumption in high-income countries: a challenge for social science based energy research. *Ecological Economics*, *153*(January), 78–88. https://doi.org/10.1016/j.ecolecon.2018.07.003

GEA. (2012). Global Energy Assessment: toward a sustainable future. In *Global Energy Assessment*. Cambridge University Press. https://iiasa.ac.at/projects/gea

González-Eguino, M. (2015). Energy poverty: An overview. *Renewable and Sustainable Energy Reviews*, *47*, 377–385. https://doi.org/10.1016/J.RSER.2015.03.013

Haar, L. (2020). Inequality and renewable electricity support in the European Union. In *Inequality and Energy: How Extremes of Wealth and Poverty in High Income Countries Affect CO2 Emissions* *and Access to Energy*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-817674-0.00009-6

Han, M., Xiong, J., Wang, S., & Yang, Y. (2020). Chinese photovoltaic poverty alleviation: Geographic distribution, economic benefits and emission mitigation. *Energy Policy*, *144*. https://doi.org/10.1016/J.ENPOL.2020.111685

Hassan, S. T., Batool, B., Zhu, B., & Khan, I. (2022). Environmental complexity of globalization, education, and income inequalities: New insights of energy poverty. *Journal of Cleaner Production*, *340*(January), 130735. https://doi.org/10.1016/j.jclepro.2022.130735

Hills, J. (2011). Fuel poverty: the problem and its measurement. *Annals of Physics*, 184. http://sticerd.lse.ac.uk/dps/case/cr/CASEreport69.pdf

IEA. (2017). Energy access outlook 2017: From poverty to prosperity. *Https://Www.Iea.Org/Energyaccess/*, 1–143. https://www.oecd.org/publications/energy-access-outlook-2017-9789264285569-en.htm

IEA. (2022). World energy outlook. *International Energy Agency*, 524. https://www.iea.org/reports/world-energy-outlook-2022

IMF. (1998). Fundamental determinants of inequality and the role of Government. *IMF Working Papers*, *178*. https://www.imf.org/en/Publications/WP/Issues/2016/12/30/Fundamental-Determinants-of-Inequality-and-the-Role-of-Government-2848

Madlener, R. (2020). Sustainable energy transition and increasing complexity: Trade-offs, the economics perspective and policy implications. In *Inequality and Energy: How Extremes of Wealth and Poverty in High Income Countries Affect CO2 Emissions and Access to Energy*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-817674-0.00011-4

Manavalan, E., & Jayakrishna, K. (2019). An analysis on sustainable supply chain for circular economy. *Procedia Manufacturing*, *33*, 477–484. https://doi.org/10.1016/j.promfg.2019.04.059

McGee, J. A., & Greiner, P. T. (2019). Renewable energy injustice: The socio-environmental implications of renewable energy consumption. *Energy Research and Social Science*, *56*. https://doi.org/10.1016/J.ERSS.2019.05.024

Middlemiss, L. (2020). Energy poverty: Understanding and addressing systemic inequalities. In *Inequality and Energy: How Extremes of Wealth and Poverty in High Income Countries Affect CO2 Emissions and Access to Energy*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-817674-0.00005-9

Nguyen, C. P., & Nasir, M. A. (2021). An inquiry into the nexus between energy poverty and income inequality in the light of global evidence. *Energy Economics*, *99*, 105289. https://doi.org/10.1016/j.eneco.2021.105289

Nguyen, C. P., & Su, T. D. (2021). Does energy poverty matter for gender inequality? Global evidence. *Energy for Sustainable Development*, *64*, 35–45. https://doi.org/10.1016/j.esd.2021.07.003

Njiru, C. W., & Letema, S. C. (2018). Energy poverty and its implication on standard of living in Kirinyaga, Kenya. *Journal of Energy*, *2018*, 1–12. https://doi.org/10.1155/2018/3196567

OECD. (2004). Universal service obligations. In *Policy Roundtables* (Vol. 19). https://www.oecd.org/daf/competition/45036202.pdf

OECD. (2023). *Inequality - Income inequality - OECD Data*. https://doi.org/10.1787/459aa7f1-en

Oum, S. (2019). Energy poverty in the Lao PDR and its impacts on education and health. *Energy Policy*, *132*(May 2019), 247–253. https://doi.org/10.1016/j.enpol.2019.05.030

Pachauri, S., & Spreng, D. (2011). Measuring and monitoring energy poverty. *Energy Policy*, *39*(12), 7497–7504. https://doi.org/10.1016/J.ENPOL.2011.07.008

Reames, T. G. (2016). Targeting energy justice: Exploring spatial, racial/ethnic and socioeconomic disparities in urban residential heating energy efficiency. *Energy Policy*, *97*, 549–558. https://doi.org/10.1016/J.ENPOL.2016.07.048

Sambodo, M. T., & Novandra, R. (2019). The state of energy poverty in Indonesia and its impact on welfare. *Energy Policy*, *132*(May), 113–121. https://doi.org/10.1016/j.enpol.2019.05.029

Santosa, J. F., & Catalão-Lopes, M. (2014). Does R&D matter for economic growth or vice-versa? An application to Portugal and other European Countries. *Archives of Business Research*, *2*(3), 1–17. https://doi.org/https://doi.org/10.14738/abr.23.194

Sovacool, B. K. (2012). The political economy of energy poverty: A review of key challenges. *Energy for Sustainable Development*, *16*(3), 272–282. https://doi.org/10.1016/J.ESD.2012.05.006

Sovacool, B. K., Burke, M., Baker, L., Kotikalapudi, C. K., & Wlokas, H. (2017). New frontiers and conceptual frameworks for energy justice. *Energy Policy*, *105*, 677–691. https://doi.org/10.1016/J.ENPOL.2017.03.005

Stata. (2023). *Stata 18 documentation*. https://www.stata.com/features/documentation/

Sun, C., Khan, A., & Ren, Y. (2023). Empowering Progress: Education, innovations and financial development in the battle against energy poverty. *Journal of Cleaner Production*, *425*(September), 138941. https://doi.org/10.1016/j.jclepro.2023.138941

Sunikka-Blank, M. (2020). Why are women always cold? Gendered realities of energy injustice. In *Inequality and Energy: How Extremes of Wealth and Poverty in High Income Countries Affect CO2 Emissions and Access to Energy*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-817674-0.00008-4

Terry, N. (2020). Housing tenure and thermal quality of homes—How home ownership affects access to energy services. In *Inequality and Energy: How Extremes of Wealth and Poverty in High Income Countries Affect CO2 Emissions and Access to Energy*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-817674-0.00006-0

The World Bank. (2021). *2021 Year in Review in 11 Charts: The Inequality Pandemic*. https://www.worldbank.org/en/news/feature/2021/12/20/year-2021-in-review-the-inequality-pandemic#:~:text=From uneven economic recovery to,extreme poverty and reduce inequality.

The World Bank. (2022). *Population, total - Latin America & Caribbean*. https://data.worldbank.org/indicator/SP.POP.TOTL?locations=ZJ

The World Bank. (2023a). *World Development Indicators - Access to clean fuels and technologies for cooking (% of population)*. https://databank.worldbank.org/reports.aspx?source=2&series=EG.ELC.ACCS.ZS,EG.ELC.ACCS.UR.ZS,EG.ELC.ACCS.RU.ZS,EG.CFT.ACCS.ZS,EG.FEC.RNEW.ZS,EG.ELC.RNEW.ZS#

The World Bank. (2023b). *World Development Indicators - Access to electricity (% of population)*. https://databank.worldbank.org/reports.aspx?source=2&series=EG.ELC.ACCS.ZS,EG.ELC.ACCS.UR.ZS,EG.ELC.ACCS.RU.ZS,EG.CFT.ACCS.ZS,EG.FEC.RNEW.ZS,EG.ELC.RNEW.ZS#

The World Bank. (2023c). *World Development Indicators - GDP per capita growth (annual %)*. https://data.worldbank.org/indicator/NY.GDP.PCAP.KD.ZG

The World Bank. (2023d). *World Development Indicators - Urban population*. https://databank.worldbank.org/reports.aspx?source=2&series=SP.URB.TOTL&country=

Topcu, M., & Tugcu, C. T. (2020). The impact of renewable energy consumption on income inequality: Evidence from developed countries. *Renewable Energy*, *151*, 1134–1140. https://doi.org/10.1016/j.renene.2019.11.103

Ul-Saufie, A. Z., Yahya, A. S., & Ramli, N. A. (2011). Improving multiple linear regression model using principal component analysis for predicting PM 10 concentration in Seberang Prai, Pulau Pinang. *INTERNATIONAL JOURNAL OF ENVIRONMENTAL SCIENCES*, *2*(2).

UNDP. (2018a). Interlinkages among energy, poverty and inequalities. In *Accelerating SDG 7 Achievement: Policy Brief* (Issue 8). https://sustainabledevelopment.un.org/content/documents/17480PB8.pdf

UNDP. (2018b). *Policy brief for health and energy linkages-maximizing health benefits from the sustainable energy transition*. https://sustainabledevelopment.un.org/EnergyConference/documentation

UNDP. (2018c). *Policy Brief on the Interlinkages between Energy and Education*. https://sustainabledevelopment.un.org/content/documents/17553PB11.pdf

United Nations. (2018). *Country Profiles*. World Urbanization Prospects. https://population.un.org/wup/

United Nations. (2022). *A transformative recovery in Latin America and the Caribbean with basic drinking water and electricity services as key sectors.* | *CEPAL*. Natural Resources. https://www.cepal.org/en/notes/transformative-recovery-latin-america-and-caribbean-basic-drinking-water-and-electricity

Uzar, U. (2020). Is income inequality a driver for renewable energy consumption? *Journal of Cleaner Production*, *255*. https://doi.org/10.1016/J.JCLEPRO.2020.120287

Walker, G., & Day, R. (2012). Fuel poverty as injustice: Integrating distribution, recognition and procedure in the struggle for affordable warmth. *Energy Policy*, *49*, 69–75. https://doi.org/10.1016/J.ENPOL.2012.01.044

Wang, Q., Hu, S., Li, L., & Li, R. (2023). Accelerating urbanization serves to reduce income inequality without sacrificing energy efficiency – Evidence from the 78 countries. *Sustainable Cities and Society*, *92*, 104477. https://doi.org/10.1016/J.SCS.2023.104477

WHO. (2006). Fuel for life: household energy and health. In *Household Energy and Health*. https://www.who.int/publications/i/item/9789241563161

WIID. (2022). *World Income Inequality Database*. https://doi.org/https://doi.org/10.35188/UNU-WIDER/WIID-300622

Wooldridge, J. M. (2012). *Introductory Econometrics - A modern approach* (5th ed.). South-Western, Cengage Learning.

Zhang, T., Shi, X., Zhang, D., & Xiao, J. (2019). Socio-economic development and electricity access in developing economies: A long-run model averaging approach. *Energy Policy*, *132*, 223–231. https://doi.org/10.1016/J.ENPOL.2019.05.031

Zhao, J., Dong, K., & Taghizadeh-Hesary, F. (2023). Is income inequality a stumbling block to the global natural gas market? *Energy Economics*, *118*(January), 106520. https://doi.org/10.1016/j.eneco.2023.106520

Zhao, J., Jiang, Q., Dong, X., & Dong, K. (2021). Assessing energy poverty and its effect on CO2 emissions: The case of China. *Energy Economics*, *97*, 105191. https://doi.org/10.1016/j.eneco.2021.105191

Zhong, H., Feng, K., Sun, L., Cheng, L., & Hubacek, K. (2020). Household carbon and energy inequality in Latin American and Caribbean countries. *Journal of Environmental Management*, *273*, 110979. https://doi.org/10.1016/J.JENVMAN.2020.110979