Comparative Analysis of Energy Efficiency and Poverty Reduction

A Research Paper presented by:

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in partial fulfilment of the requirements for obtaining the degree of
MASTER OF ARTS IN DEVELOPMENT STUDIES

Major:

GDP

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The Hague, The Netherlands
November 2024

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Contents

List of Tables

List of Figures

List of Acronyms

BADEHOG	Household Survey Data Bank (Base de Datos de Encuestas de Hogares)
BEP	Barrel of Oil Equivalent (Barril Equivalente de Petróleo)
BID	Inter-American Development Bank (Banco Interamericano de Desarrollo)
CEPAL	Comision Economica para America Latina y el Caribe
CEPALSTAT	Statistical Database of ECLAC
ECLAC	Economic Commission for Latin American and the Caribbean
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
OLADE	Latin American Energy Organization
SDG	Sustainable Development Goals
sieLAC	Energy Information System of Latin America and the Caribbean (Sistema de Información Energética de Latinoamérica y el Caribe)
UNDESA	United Nations Department of Economic and Social Affairs

Abstract

This research makes a relevant panel data analysis to explore the relationship between energy efficiency, renewable energy adoption and poverty reduction across Latin America, especially focus on Latin America, and contrast by Brazil, Chile and Mexico, from 2000 to 2022. This is principally for the regional socio-economic inequalities and vulnerabilities due to environmental challenges, for that reason understanding how energy policies can influence poverty is relevant for developing successful strategies to support sustainable development and social equity. Moreover, using a fixed effects model, this study explores and observe how macroeconomic factors such as GDP, energy consumption, CO2 emissions, and public investment in renewable energy can impact poverty levels in the region and in the three countries analyzed. Furthermore, the model integrates regional dummies to capture the single effects within each country. The outcomes show significant differences in how energy efficiency and economic variables can influences poverty rates across the region, highlighting the meaning of suited energy and poverty policies. In conclusion, this research underscores the relevant role of energy policies in sustainable development and poverty mitigation in Latin America.

Relevance to Development Studies

This research is important to development studies, because addresses relevant connections between energy policy, poverty mitigation and governance structures. Additionally, more often governance debates in development studies have been focused on institutional frameworks, socio economic policies, and regulation. However, the relationship about energy efficiency and poverty reduction has been less explore. Furthermore, this research makes an improvement in understanding development studies by analyzing how energy efficiency interventions facilitated by an efficient governance, can results in a better poverty outcome. For instance, governance framework which support renewable energy investment and equitable access to clean energy can decrease energy cost for those household with low income, this permits them to assign saving to relevant services, such as health or education (Rogers, 2014).

Furthermore, although most of the time the focus in governance literature has been on the role of institutions influencing economic outcomes, it is clear that governance frameworks that promote energy efficiency can generate relevant social and economic benefits (Bacon & Kojima, 2016). Moreover, this research tries to fulfil a critical gap by exploring how governance can enable energy efficiency involvements, which not just improve sustainability but also decrease energy cost for most vulnerable groups, therefore helping to reduce poverty. For that reason, policies focused to promoting equitable access to renewable energy sources and efficiency measures are indispensable to complement main poverty mitigation strategies. Therefore, this is notably important in Latin America, where the differences in energy access and consumption remain to exacerbate poverty, especially in marginalized groups (Ravallion & Chen, 2013)

Keywords

Energy efficiency, poverty reduction, environmental sustainability, Latin America, economic growth.

Chapter 1
Introduction

1.1 Background

Latin America is known by its inequalities, which is highlighted by socio economic differences in income, wealth and access to basic services, such as energy. Moreover, these inequalities obstruct the capacity of the region to reach sustainable and economic development. Therefore, to understand these problems is relevant a broad understanding in how several factors influence poverty and inequality, and in this research will be energy efficiency. Thus, the relationship between energy efficiency and poverty reduction is complex, in which are related multiple pathways and consequences. For this reason, the purpose of this research is to analyze the causal relationship between energy efficiency and poverty reduction in Latin America.

Additionally, for the purpose of this research, I will refers as Latin America to the group of countries which are in Central America; including Costa Rica, Cuba, El Salvador, Guatemala, Haiti, Honduras, México, Nicaragua, Panama and Dominican Republic; and South America including Argentina, Bolivia (Plurinational State of), Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay and Venezuela (Bolivarian Republic of). For this study Caribbean countries will be not included for analytical purpose. Moreover, energy efficiency will be defined in this research as the ratio of GDP to total energy consumption (Ravillard, et al., 2019), while poverty reduction is measured by changes in poverty rates. These variables let for a comprehensive analysis of how improvements in energy efficiency can lead for a reduction in energy costs. Consequently, increasing household disposable income, and improving economic stability, which are relevant for poverty alleviation. According, to the Economic Commission for Latin American and the Caribbean (ECLAC), the region includes a wide diverse socio-economic context and different level of development (CEPAL,2024).

Therefore, improving energy efficiency will have the potential to significantly reduce energy consumption, and thus decrease greenhouse emissions and lower energy cost for both businesses and households (Ravillard, et al., 2019). These benefits are relevant for improving economic stability and promote social welfare, especially for low-income households that spend a greater proportion of their income on energy (Abbas, et al., 2021).

1.2 Research problem

Latin America is characterized by significant economic inequalities and with several populations facing different grades of poverty and limited access to basic services, and this include energy (ECLAC, 2023b; World Bank, 2022). Moreover, the role of energy efficiency in attending these inequalities and helping to mitigate and reduce poverty is significant, however, it remains underexplored (Ürge-Vorsatz, et al., 2014; IRENA, 2023). Energy efficiency, described as the ability to provide the same or improved energy services, while using less energy consumption, can decrease household energy cost, enhanced economic resilience, and support broader socio-economic development (IRENA, 2023). Hypothetically, improving energy efficiency can support economic stability, because this can reduce household energy expenditures, and therefore support in the alleviation of poverty. (Sovacool, 2015; Ürge-Vorsatz, et al., 2014). Nevertheless, a preliminary literature review indicates that there remains a lack of research which investigates different mechanism

through which energy efficiency policies have affected low-income households, especially in Latin American context (González-Eguino, 2015).

This issue is made more complex by the concept of energy poverty, which refers to the incapacity of households to afford basic energy services, such as clean cooking system, heating or lighting (González-Eguino, 2015; Bouzarovski & Petrova, 2015). Despite the fact that energy poverty is an important problem and challenge, especially in rural areas and marginalized communities, it is important to explore if improvements in energy efficiency might help to reduce poverty, by decreasing energy costs, and distributing resources for essential needs. This particularly in Latin America, where low-income households, frequently spend a significant amount of their income on energy expenditure (ECLAC, 2023a). Therefore, energy efficiency policies might improve households' financial resources, and readdresses these resources to other critical areas, improving their overall standard of living.

Most of the research tends to focus and observe the environmental and macroeconomic benefits of energy efficiency, such as reducing carbon emissions or increasing national productivity (Sun, et al., 2019; IRENA, 2019; IEA, 2023a). For instance, the International Renewable Energy Agency (IRENA, 2023), highlights the role of energy efficiency in how this contributes to global economic growth and greenhouse gas emission reduction. Likewise, Sun, et al. (2020) examines the macroeconomic advantages of energy efficiency in developing countries, however this does not investigate its household level effects or its especific impacts on poverty reduction. Althought these studies demonstrate how energy efficiency can support sustainable development, they do not discuss how it directly impacts reducing household poverty.

Research on how energy efficiency might help to reduce poverty among low-income groups is necessarily needed in region like Latin America, where socio economic inequalities is principally noticeable (ECLAC, 2023b). Moreover, in many countries in Latin America poorest households spend an excessive amount of their incomes on energy, consequently, limits their ability to spend in other essential services (INEGI, 2020; INE, 2023). Furthermore, this is particularly observed in countries such as Brazil, Chile and Mexico, where energy policies and economic conditions differ significantly, offering a diverse range of context in which to evaluate the impact of energy efficiency policies on poverty (ECLAC, 2023a). The main question to explore is whether improvements in energy efficiency help to reduce household energy cost satisfactorily to mitigate poverty in these low-income groups.

Although it has provided useful insights, the literature about energy poverty does not totally address the broader issue. While several research are focused on energy poverty, specifically on access to energy, this research examines how energy efficiency policies, such as investment in renewable energy, subsidies for energy efficient technologies, and technological innovation, can reduce overall energy consumption and consequently household energy cost. Furthermore, as mentioned by Rasoulinezhad & Taghizadeh-Hesary (2021), they observe that energy efficiency has the potential to reduce consumption in both homes and businesses. However, the specific impacts of energy efficiency policies on poverty are still not well understood.

Furthermore, the distributional impacts of energy efficiency policies require a comprehensive analysis. Although theoretically energy efficiency can benefit all socioeconomic groups, there is certain concern because wealthier households are more likely to take advantages of energy efficiency advances and subsidies, due to their higher financial capacity (IRENA, 2023). Thus, this raises relevant questions about the equity of energy efficiency policies and if these might unintentionally worsen socio economic disparities (Camioto et al., 2018; Middlemiss & Gillard, 2015). Consequently, the relationship between

energy efficiency and poverty reduction is complex and a comprehensive study is needed to determine if such policies might improve the lives of the most marginalized population.

Moreover, there is an important gap in the existing literature about the relationship between energy efficiency and poverty reduction in Latin America. Even though, there are studies focused on the environment and macroeconomic implications of energy efficiency, such as increasing productivity and decreasing carbon emissions, these studies do not sufficiently cover the household effects, particularly in terms of poverty alleviation (Sun et al., 2020; IRENA, 2023). Similarly, investigation on energy poverty tends to give more emphasis on energy access, leaving unexplored the importance of energy efficiency policies in their capacity to reduce poverty, by decreasing household energy expenditures and improving access to energy innovations (Rasoulinezhad & Taghizadeh-Hesary, 2021). This research aims to help to reduce this gap by analyzing how energy efficiency can benefit to poverty reduction in Brazil, Chile and Mexico, three countries with diverse economic and energy profiles. In conclusion this research will evaluate how policies related to energy efficiency, can help to decrease household energy expenses and improve the stability of low-income households (ECLAC, 2023a).

1.3 Research questions

This research will explore the impact of energy efficiency (independent variable) on poverty reduction (dependent variable) in Latin America, with especial focus on key countries, Brazil, Chile and Mexico, three countries with different socio-economic conditions and energy policy frameworks. Thus, focusing on these elements, the research aims to provide a comprehensive analysis of this relationship, while at the same time analyzing socio economic factors, which can improve or constrain the efficacy of these policies.

To carry out this research, we will seek to analyze the following main research question and related sub questions:

1.3.1 Main Research Question:

- How do energy efficiency policies and socio-economic factors influence poverty reduction in selected Latin American countries, with a focus on Brazil, Chile, and Mexico, between 2000 and 2022?

Energy efficiency most of the time is recognize as an important tool for reducing energy consumption and face environmental challenges, nonetheless its role in alleviate poverty is less understood, specifically at home levels in developing countries. This research seeks to analyze and understand how the application of energy efficiency policy, can impacts in different socio-economic factors, especially decreasing poverty levels. These countries have experienced different level of economic growth, energy policy reforms, and investment in renewable energy (ECLAC, 2023a; Ravillard et al., 2019).

1.3.2 Sub-Questions:

1. How do energy efficiency policies affect poverty rates across Brazil, Chile, and Mexico?

By analyzing impacts on household level, this sub-question will be addressing into microeconomic effects of energy efficiency. It will provide a framework for measuring if energy efficiency policies can mean into noticeable benefits for the most vulnerable populations.

2. What role do GDP growth and income inequality play in moderating the impact of energy efficiency measures on poverty reduction?

This sub-question helps to analyze the impacts of energy efficiency policies into the broader socio-economic dynamics. This will be by analyzing the controlling effects of GDP growth and income inequality.

3. How does public investment in renewable energy influence the effectiveness of energy efficiency measures in reducing poverty?

This sub-question links the policy and financial aspects of energy efficiency, highlighting how government expenditures might improve the efficacy of energy programs. Therefore, it will evaluate if public investment might lead to a long-term economic benefit.

In conclusion the main research question and sub-questions aims to analyze the relationship between energy efficiency initiatives and poverty reduction in Latin America, with especial focus in Brazil, Chile and Mexico. Moreover, this research aims to investigate a comprehensive understanding of how energy efficiency might help to reduce poverty in those countries by observing the impacts at home level, the works of socio-economic variables and the influence of government investment. Therefore, this research might be valuable for policy maker, who seeks to implement energy policies that are inclusive for the population.

1.4 Importance of the Study

This research is relevant for expanding the knowledge of the relationship between energy efficiency policy, poverty alleviation and sustainable development in the Latin American context. Furthermore, this investigation provides important insights to academic debates, policy and socio-economic development, due to the examination about how energy efficiency policies can impact poverty reduction in Brazil, Chile, and Mexico. The outcomes could help to shape energy efficiency strategies, which not just achieve environmental goals bur also support equitable economic growth.

One of the main contributions of this research is to address the knowledge gap about the relationship between energy efficiency and poverty reduction. While, the economic and environmental benefits of energy efficiency have been studied in the past, few research have analyzed its impact on poverty reduction at household level, especially in Latin America. Camioto et al. (2018), provides important insights about sustainable efficiency and renewable energy in Latin America, nevertheless the socio-economic benefits, still remain underexplored

Moreover, by measuring the effects of energy efficiency policies on household energy expenditures, this research contributes to academic understanding about how these policies might mitigate poverty. Ravallion and Chen (2013) underscores the relevance of accurately measure poverty to improve policy inform; therefore, this study uses poverty metric to estimate the impact of energy efficiency on low-income populations.

Additionally, this research aligns with some of the Sustainable Development Goals (SDGs), especially SDG 7 (affordable and clean energy), and SDG 1 (no poverty), furthermore promote SDG 3 (good health and well-being), SDG 8 (decent work and economic growth), and SDG 9(industry, innovation and infrastructure) (UNDESA, 2023; Breunig & Majeed, 2020). Moreover, United Nations highlights that to achieve these

interconnected goals is necessary energy policies that promote equitable economic development and improve access to affordable and reliable energy (UNDESA, 2023).

Moreover, the results of this research can help Latin American governments to create energy policies that balance economic, environment and social goals. This research directly targets SDG 7, which seeks to make energy more affordable for everyone, in especial those marginalized groups, by analyzing how energy efficiency might decrease household energy expenditures. Furthermore, investment in renewable energy and energy efficient technologies contributes to SDG 9, supporting innovation and building infrastructure that promote industrial growth (Sun et al., 2020).

This research contributes to the academic discussion about energy policy by highlighting its socio-economic implications, a topic which is often ignored in favor of macroeconomic outcomes. Moreover, the study can be an academic contributor, because can improve the debate about the socio-economic effects of energy policy, by measuring how energy efficiency impacts the improvement of poverty rates. This research help as an understanding of the connection between energy policy and socio-economic outcomes, in this way we can wider the range of the energy studies to incorporate the substantial attention on poverty alleviation (Ravallion & Chen, 2013; Breunig & Majeed, 2020).

This study provides relevant policy recommendations for Latin American countries, which seeks to create energy policies that promote poverty reduction and sustainable economic development. Moreover, the outcomes of this research can help policy makers to identify energy efficiency measures, which support to reduce household energy costs, therefore allowing low-income households reallocate more resources to vital needs. Camioto et al. (2018), highlights that Latin America renewable energy potential remains underused, and this research highlights public how investment in renewable energy can provide insights about how Latin America can optimize these resources to improve energy access.

Chapter 2
Contextual background and theoretical framework

This section explains how inequality is a significant problem in the region, then shows how this connects to energy efficiency and why their relationship presents an important research gap that needs to be addressed.

2.1 General context on regional inequality

Latin America is currently facing a wide range of socio-economic challenges aggravated by climate change and inequalities. The region is mainly exposed to the consequences of climate change, and we can include changes in the intensity and frequency of extreme weather conditions, for instance, floods, droughts and rising the sea levels (ECLAC, 2023a). These environmental issues are closely related to some economic activities, especially those which depends on agriculture and natural resources, two industries that are essential to the local economies. These problems not only threat the environmental sustainability but also put at risk the regional economic stability and social welfare (ECLAC, 2023a).

While ECLAC (2023a) highlights the direct impact of environmental issues on economic activities, other scholars discuss that this relationship is more complex. According to Breunig & Majeed (2020) institutional factor and governance play a relevant role in facilitating the impacts of climate change on socio economic outcomes. Moreover, Breunig & Majeed (2020) argue that without strong institutions, the capacity to mitigate climate change effects might not translate into better economic stability. Likewise Sachs (2005) suggests that access to infrastructure, for example in energy is important for economic development and poverty reduction. Nevertheless, Todaro & Smith (2020) mention that infrastructure itself is insufficient, moreover equitable socio economic policies are necesesary to guaratee that the benefits spread to the pooerest population.

Latin America is highlighted by is noticeable socio-economic inequalities, there exist large disparities in income, wealth and access to basic services, including energy (ECLAC, 2023a). These inequalities continue, despite on the efforts to decrease inequality, establishing challenges for reaching equitable and sustainable development (Breunig & Majeed, 2020; UNDESA, 2023). Regardless of the recognition of these inequalities, some scholars argue about the efficacy of policies employed to address them. For instance, Breunig & Majeed (2020) argue that without focusing in the main institutional weakness, policies targeted to reduce inequality might have limited impact. In contrast UNDESA (2023) highlights that targeted interventions, such as social programs and inclusive energy policies, can make relevant progress in reducing inequalities.

According to Todaro and Smith (2020), economic inequalities in regions with limited access to important resources, such as energy, frequently limits opportunities for progress and development. Moreover, these differences create structural obstacles which preserve poverty. This is because the poorest groups are unable to secure the necessary services, that helps to participate in the economic and social life. While Sachs (2005) highlights the relevance of infrastructure for economic development, Todaro and Smith (2020) mention that this infrastructure should be implemented with policies that guarantee equitable access. Additionally, infrastructure investments alone cannot alleviate structural poverty without focusing on problems like income inequality and educational access.

Furthermore, access to energy play a relevant role influencing both economic and social outcomes in the region. Energy poverty, described as the lack of access to modern energy services, affects the poorest groups, therefore limiting their capacity to participate in economic activities and improve their basic conditions. Consequently, without reliable and affordable energy access these poorest groups face difficulties in the access to education, healthcare, and job opportunities, aggravating socio-economic inequalities (Middlemiss & Gillard, 2015). Additionally, there is a debate about the main drivers of energy poverty, Bouzarovski & Petrova (2015) highlights that energy poverty is a complex problem influenced by economic, social and infrastructural factors. Moreover, Bouzarovski & Petrova (2015) argue that income boundaries, quality of the home and energy prices all of these contribute to energy vulnerability. Furthermore, Middlemiss & Gillard (2015) underscore that social and cultural issues, such as energy literacy and societal norms about energy consumption, significantly influence outcomes.

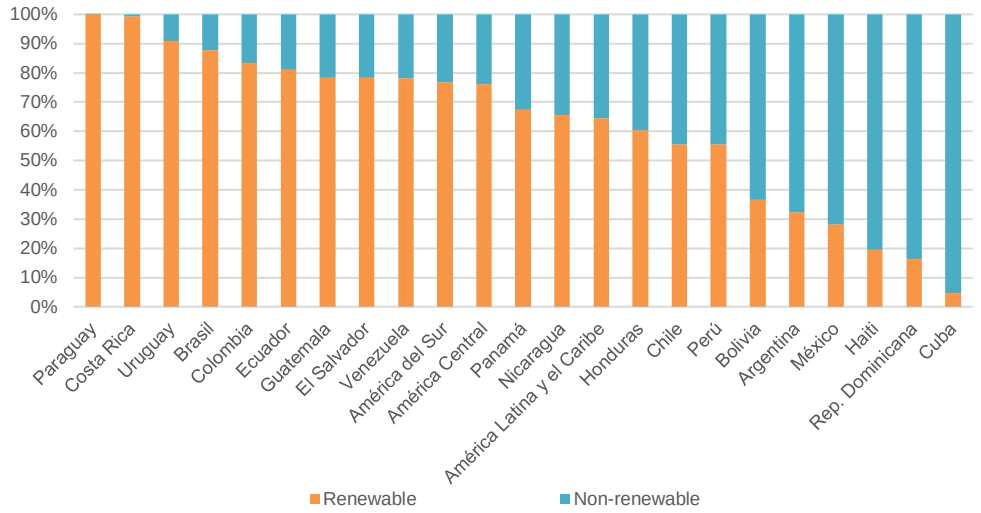
The economic consequences of energy poverty are evident in Latin America, where higher energy costs hinder economic growth and might contribute to marginalization of disadvantages communities. That is why energy efficiency improvements can significantly decrease energy costs and improve economic output per unit of energy consumed (Ravillard, et al., 2019). Consequently, by improving energy efficiency, countries can reduce their energy expenditures, and re allocate resources more efficiently, and manage socio economic disparities. Additionally, Sovacool, et al.(2012) argue that tailored energy efficiency policies, can mitigate energy poverty by decreasing energy costs, therefore increasing disposable income for low-income households.

For instance, Latin America and the Caribbean generates 64.5% of its electricity from renewable sources (figure 1), although, according to the International Energy Agency (IEA) (2023b) many regions struggle with energy access and affordability, despite having one the highest shares of renewable energy in their power generation mix globally, especially in rural and underprivileged areas. Additionally, according to data from Sielac-OLADE[1] in 2022 about 9 million people in Central and South America lacked access to electricity, this situation increases to 16 million when adding the Caribbean. Moreover, inequalities persist in electricity access by quintiles (figure 2), although there has been a reduction in the proportion of people without access across all quintiles from 2004 to 2021, significant inequalities persist, particularly in rural and underprivileged places.

Figures 1 and 2 shows these disparities, showing that the electricity generation renewability index and the population without access disparities to electricity by quintile, respectively. These two figures, highlights the importance of progress in equitable energy access, which can help to reduce poverty and support sustainable development. Additionally, is important to aim investments and policy reforms to force the renewable energy potential in the region, which could be fundamental in mitigating the socio-economic inequalities that exist (IEA, 2023b). González-Eguino (2015) argues that renewable energy policies should be wisely designed to guarantee that these do not aggravate current inequalities. Moreover, Sachs (2005) discusses that access to infrastructure is an important factor for poverty mitigation. Additionally, Todaro & Smith (2020) mention that infrastructure investment need to be related with policies that guarantee equitable access and affordability.

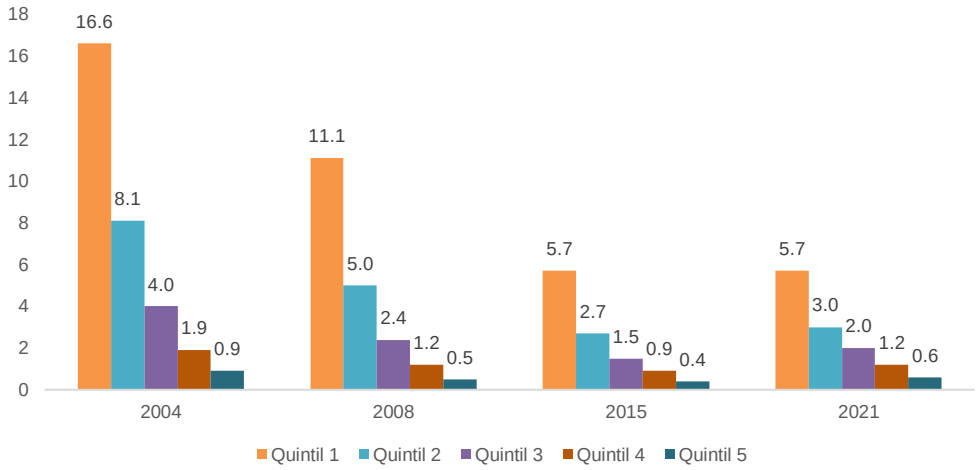
[1] Latin American Energy Organization (OLADE), Latin American and the Caribbean Energy Information System (sieLAC) [online database] https://sielac.olade.org

Figure 1 Latin America, electricity generation renewability index, 2022
(percentages)



Source: Own elaboration, based on the Latin American Energy Organization (OLADE), Latin American and the Caribbean Energy Information System (sieLAC) [online database] https://sielac.olade.org

Figure 2 Latin America, population without access to electricity, by quintile



Source: Own elaboration, based on CEPALSTAT, based on country household surveys, Household Survey Data Bank (BADEHOG).

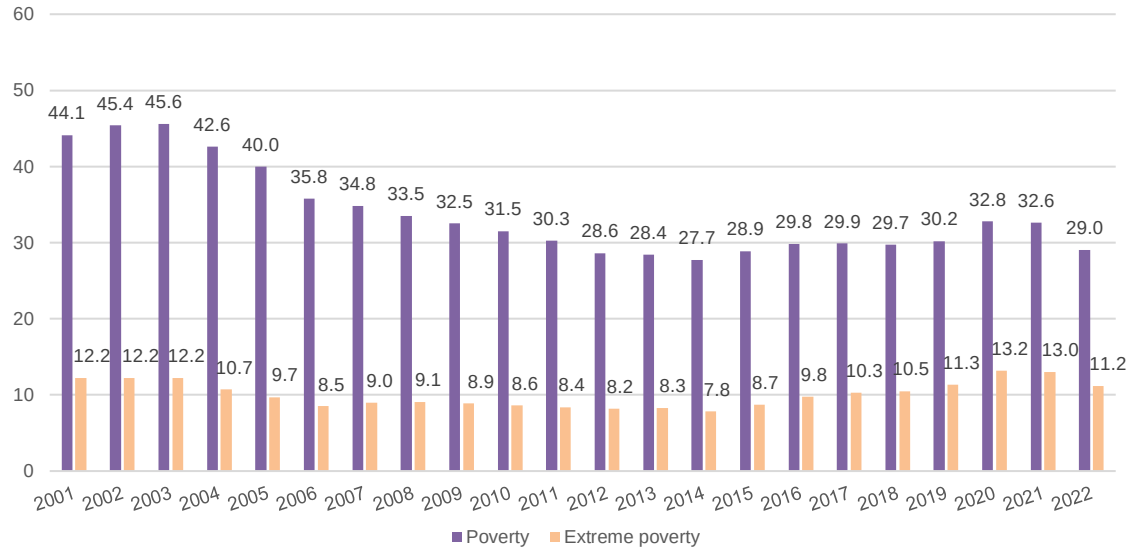
Furthermore, although several efforts have been made to reduce inequality, disparities remain, especially in energy access, this element plays a crucial role in socio economic development. Therefore, without reliable and affordable energy access, underprivileged groups can face significant obstacles to education, healthcare and job opportunities, intensifying socio-economic inequalities (Middlemiss & Gillard, 2015). There is a debate about the effectiveness of policies tailored to improve energy access. While some scholars support market-based solution to improve energy access, other suggest that are governments who need to make an intervention to guarantee equitable distribution (Breunig & Majeed, 2020).

Poverty and extreme poverty are significant problem in Latin America, figure 3 shows that in 2001, poverty affected 44.1% of the population, with 12.2% living in extreme poverty. By contrast, in 2020 and 2021 there were a slightly increase due to Covid-19 pandemic,

however, these proportions were reduced in 2022 to 29% and 11.2% respectively, showing some progress. Nevertheless, if we observe absolute numbers (figure 4) still remained alarming, with around 187 million people living in poverty and 72 million in extreme poverty in 2022. The data highlights the significant issue of poverty in the region, which is intensified by the impacts of energy inequality. Ravallion & Chen (2013) mention that just focusing on poverty rates might underestimate the depth and gravity of poverty, underscoring the need for multidimensional approaches, which can incorporate elements such as energy access.

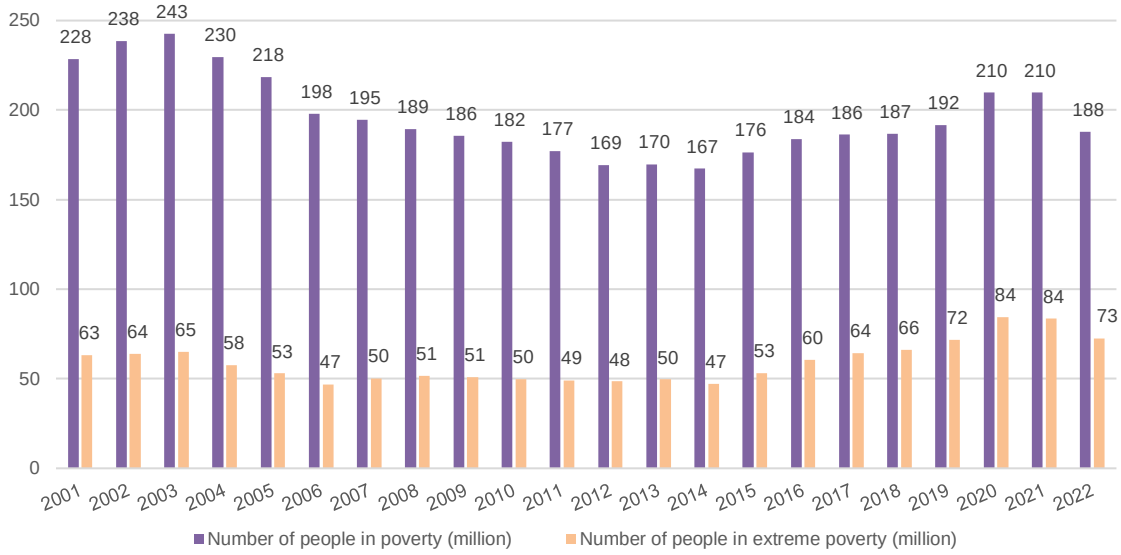
In conclusion Todaro and Smith (2020) mention that poverty creates a deep effect on the population, where lack of access to resources stimulates marginalization and limits social mobility. Eventually, if Latin America wants to achieve equitable and sustainable development, it needs to seek investment in energy infrastructure, which should put in first place the access to underprivilege groups. Therefore, improving energy facility and efficiency might help to decrease energy poverty and support economic growth, reducing poverty goals (Sachs, 2005).

Figure 3 Latin America, poverty and extreme poverty, 2000-2022
(percentages)



Source: Own elaboration, based on CEPALSTAT, based on country household surveys, Household Survey Data Bank (BADEHOG).

Figure 4 Latin America, Poverty and extreme poverty in Latin America, 2000-2022
(million)



Source: Own elaboration, based on CEPALSTAT, based on country household surveys, Household Survey Data Bank (BADEHOG).

2.2 Theoretical framework

2.2.1 Energy economics

Energy economics highlights the importance of energy as relevant trigger for economic activity, this theory is focused on how efficiency might improve growth and well-being (Todaro & Smith, 2020), especially in developing countries. Scholars such as Bacon & Kojima (2016) mention that the efficacy of policy depend on government support, and particularly with targeted subsidies. Additionally, Zhou, et al. (2023) mention the concept of green premium, arguing that initial green investment, despite their inmmediate costs, generate long term economic benefits, by decreasing emissions and improving productivity.

2.2.2 Development economics

Development economics observes the structural factors that impact in the economic growth and poverty reduction (Todaro & Smith, 2020). Moreover, Solow (1999), argues that growth is promoted by capital, labor and technology. Additionally Solow (1999), highlights the relevance of invest in human capital and technology, as a crucial factor in long term growth, and for continuous increase in energy efficiency. Moreover, Zhou, et al. (2023) in concondance with Solow, incorporating socio economic and behavioral factors, arguing that effective energy policy should address structural and behavioral obstacles.

2.2.3 Endogenous growth theory

Endogenous growth theory argues that economic growth is promoted by internal factor, such as technology and innovation (Todaro & Smith, 2020; Romer , 1990). Moreover, Solow (1999) promote models that include technology as an endogenous growth, through domestic innovation. Additionally, Zhou, et al. (2023) provide the green Schupeterian model, which integrate green innovation with endogenous growth. Moreover, Zhou, et al. (2023) suggests

that sustainable growth is achievable when policy frameworks promote green behaviour and technologies.

2.2.4 Behavioral economics

Behavioral economics observe how individual behavior, societal norms and economic stimulus influence choices (Bacon & Kojima, 2016), additionally Datta & Mullainathan (2014) mention that this is motivate by psycological factors. This is important in the design of energy policies that promote sustainable practices.

2.3 Energy Poverty and Its Role in Inequality

Energy poverty, as it was described before as the lack of access to modern energy services, still aggravate socio economic inequalities in Latin America. Moreover, poorest energy households spend large amount of their income on energy services, leaving small amounts for other essential need, such as education, healthcare and groceries (Abbas, et al., 2021). This interaction creates a vicious circle of which disadvantaged groups remain economically stuck due to their unequal energy costs. Abbas, et al. (2021) mention that improving energy efficiency can decrease these energy costs, and therefore rising disposable income and supporting to overall social welfare, especially for those low inncome households. However, Breunig & Majeed (2020) argue that in regions with high levels of poverty and inequality, structural problems might constrain the efficacy of those measures. Therefore, Breunig & Majeed (2020) argue that without improve socio economic disparities, energy efficiency advances might benefit wealthier households, who can afford the initial investment in energy efficient technologies.

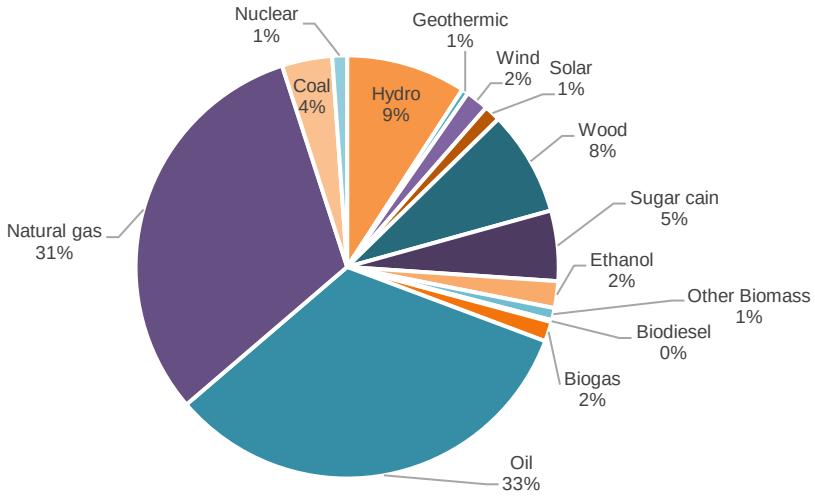
Nevertheless, the advantages of energy efficiency are not globally recognized. Breunig & Majeed (2020) argue that in regions with high levels of poverty and inequality, the basic issues which are embeded in the socio economic core can limit the effectiveness of energy efficiency measures. Moreover, in Latin America where economic inequality is generalized, there have been significant improvements in energy access, however substantial inequalities still remains, especially in rural areas among the poorest households (CEPAL, 2023). Additionally, as energy access is limited, and expensive for vulnerable populations, this hinders their ability to benefit from economic and social opportunities, increasing permanent inequalities (Middlemiss & Gillard, 2015).

Renewable Energy and the Pathway to Reducing Energy Poverty

There are some key worries about access to energy and its affordability. According to sieLAC-OLADE (2023), fossil fuels (69.1%) continuing dominating the primary energy supply in Latin America in 2022, while renewable energy sources contributing with 30.9%. Therefore, increasing the share of renewable energy is relevant for reducing regional greenhouse gas emissions, which is currently about 10% of global emissions, improving energy security and decreasing energy costs. (CEPAL, 2023). Figure 5 shows the dependence on fossil fuels, highlighting the necessity for renewable transition to create a more equitable energy panorama. Therefore, while CEPAL (2024) and IRENA (2023) promote renewable energy as a relevant factor to reduce energy costs and improve access, some scholars are caution about the high initial cost associated with new technologies, and this may produce obstacles to low-income households. Sovacool , et al. (2015) argue that without support policies, for example, subsidies or other financial helps, the advantages of renewable energy might not be extended to the poorest households. Additionally, Camioto, et al. (2016)

underscore that renewable energy investments might lead to macroeconomic benefits, however may not reach the most vulnerable populations without targeted interventions.

Figure 5 Latin America, primary energy supply, 2022
(percentages)



Source: Own elaboration, based on the Latin American Energy Organization (OLADE), Latin American and the Caribbean Energy Information System (sieLAC) [online database] https://sielac.olade.org

Moreover, transition to renewable energy is relevant to reduce energy poverty. According to IRENA (2023), the global energy transition is required to reach the international climate target of keeping global warming to 1.5ºC above preindustrial levels, these means that there will be necessary an increase in renewable energy capacity. Latin America should be using its great potential of renewable energy to increase its energy efficiency, consequently, this reduces the dependence on fossil fuels, decrease costs, and improve energy security, all of these will support poverty reduction efforts. Additionally, IRENA (2023), highlights that if countries increase the share of renewables sources in the energy mix, this not only will be helpful for environmental sustainability but also for reaching energy equity, principally by decreasing energy prices for low-income households, thus directly supporting poverty reduction efforts.

Benefits of Energy Efficiency for Low-Income Households

improvements in energy efficiency in Latin America can be a significant opportunity to reduce energy bills, and that will be a benefit for low-income households, supporting poverty alleviation. Thus, in this context IEA (2023a) mention that: "Efforts to enhance energy efficiency in Latin America and the Caribbean deliver numerous benefits, including reduced in energy consumption and related emissions, bolstering energy security, and generating new job opportunities" (p.81). Therefore, for low-income groups, energy efficiency can influence cost saving and releasing resources for other important needs. Furthermore, IEA (2023b) reveals that the region possesses significant renewable resources. If countries of the region utilized effectively these resources, will have the potential to provide energy self-sufficiency and endorse sustainable economic growth.

Nevertheless, Latin America has been facing challenges in its energy transition. Rasoulinezhad & Taghizadeh-Hesary (2021) mention that energy efficiency and renewable energy should be aligned with tailored policy interventions related to each country socio-economic context. Moreover, in some Latin American countries, improvements in energy

efficiency at first sight has benefited wealthier groups, while the poorest groups continue facing difficulties to accessing to these efficiency. Therefore, without specific policies, such as subsidies or economic incentives for low incomes households, energy transition may suffer the risk to increase the current inequalities. For example, transportation, storage, and communications sectors, which account 36% of regional energy consumption, shows a reduction in efficiency (CEPAL, 2023). Therefore, addressing inefficiencies in these sectors might lead to significant economic improvements, especially for those low-income households, who rely for instance on affordable transport services.

In conclusion, as we can observe energy poverty in Latin America is relatively tied to wider socio-economic inequalities. Moreover, improvements in energy efficiency and increasing renewable energy utilization, have the potential to alleviate energy poverty, reduce cost and promote economic equality. Additionally, as the region advances in its sustainable energy transition, tailored policies and investments are relevant to ensure that these benefits are accessible to all socio-economic groups, especially for those most vulnerable.

2.4 Challenges associated with sustainable energy development

Energy transition is an important element for Latin American countries, however the shift to more sustainable energy sources is not just relevant for mitigating climate change effects, but also for supporting socio economic growth, and decreasing poverty (CEPAL, 2024). Furthermore, Latin America has a significant potential for developing renewable energy, especially in hydro, solar and wind power, nonetheless using this potential require a several number of institutional, financial and environmental barriers to be removed (IEA, 2023a).

These challenges are multifaced, and are included sociopolitical, economic and technological limitations, which collectively affects the region ability to achieve an inclusive energy transition (Ravillard et al., 2019). The integration of renewable energy sources into national grids is further complicated by institutional weaknesses and regulatory disparities across the countries, which reduce the capacity of the efficiency of the policies aimed to increase energy efficiency (Moreno Castillo, 2017). Moreover, while some scholars highlight the relevance of external investment and technology transfer in overcoming these obstacles (IEA, 2023d), other argue for a more grounded approach. Middlemiss & Gillard (2015) mention that community based initiatives and local empowerment are important for effective energy transition,

In Latin America, one of the main obstacles to achieve sustainable energy development, is the high dependency on fossil fuels, which according to Latin American Energy Organization (OLADE), accounts about 70% of the region primary energy supply (OLADE, 2023). Despite, several efforts to increase the proportion of renewable energy, this dependence remains a challenge, because of the high costs related to developing and supporting renewable infrastructure. According to Camioto, et al. (2016) a high dependence on fossil fuel is a result of embedded interest and subsidies that benefit fossil fuel industries. Additionally, Camioto, et al. (2016) suggests that is necessary policy reforms, which might facilitate the shift to renewable energy. On the other hand, Taghizadeh-Hesary & Yoshino (2019) underscore the relevance of financial instruments and green financing in alleviating the high initial cost associated with renewable projects.

Furthermore, several Latin American countries, are incapable to invest in renewable projects at the minimum essential scale required for significant impacts, due to financial limitations and limited access to green finance (IRENA, 2023). However, scholars like Bacon

& Kojima (2016) argue that the reliance on external finance can lead to dependence and might not be sustainable in the long term. Bacon & Kojima (2016) mention that is necessary develop domestic financial markets and mechanisms to promote renewable energy investments.

Communities with lower income, recognize challenging to take advantage of energy efficiency advances and renewable initiatives, due to the socio-economic inequalities that exist in the region, which relate to energy transition obstacles. Moreover, poorest household face higher energy costs, which hinder their capacity to invest in new technology and therefore increase their vulnerability to energy price fluctuation (Breunig & Majeed, 2020). Furthermore, this is highlighted by Ravillard et al. (2019) who mention that achieving energy equity is not just about economic affordability, but also about policy inclusivity, which guarantees that energy policies are made to reach, and support marginalized communities.

In order to address these challenges, this section will analyze the effects of sustainable energy policies on economic development, the dynamics between poverty mitigation and energy efficiency, and the contribution of environmental efficiency to sustainable development. Furthermore, this analysis will be guided by theorical approaches, including energy economics, development economics and behavioral economics, to provide a comprehensive understanding of the barriers and opportunities in Latin America.

2.4.1 Energy policies and economic growth

Energy policies play an important role in Latin America, because these might shape the economic landscape, especially through their effects on productivity and the reduction of energy poverty. Moreover, efficient energy policies might promote economic expansion by increasing productivity and supporting poverty mitigation, and thus contribute to economic growth by guaranteeing affordable and reliable energy access. The relationship between energy policy and economic growth is supported by energy economic theory, which highlight the improvements of energy use to maximize economic productivity (Todaro & Smith, 2020). However, IEA (2023d), highlights the role of market-based mechanisms and deregulation to promote efficiency and investment. Moreover, in countries such as Brazil, Chile and Mexico, where exist significant disparities in both socio economic and energy access, well implemented energy policies might have transformative economic effects (Breunig & Majeed, 2020).

The IEA (2023d) highlights the relevance of energy efficiency in promoting economic resilience. Moreover, according to the IEA (2023d) World Energy Outlook 2023 energy efficiency improvements reduce operational cost, and this allow businesses, and households to reallocate budget to other productive investments. Furthermore, reducing the cost of the energy, policies can support different economic activities in many sectors, such as manufacturing and agriculture, which are important for Latin America development. Consequently, if energy prices are steady due to the improvements of efficiency, the economic environment become more certain and resilient, fostering investment and economic growth (IEA, 2023d)

According to Ravillard et al. (2019), Latin America energy policy face structural challenges, such as inadequate infrastructure and undeveloped regulatory frameworks. Thus, these challenges hinder the full potential of energy efficiency programs. Camioto, et al. (2016) highlights that variations in institutional quality among countries impact the efficacy of energy policies. Moreover, Camioto, et al. (2016) they mention that countris with strong institutions and governance are more likely to implement successful energy policies, which can contribute to economic growth. Additionally, this analysis is supported by Taghizadeh-

Hesary & Yoshino (2019), who highlights the significance of financial development and insitutional capacity in promoting energy transition.

Moreover, regulatory frameworks are relevant for developing standards and address investments, which support both sides, efficiency and growth. For instance, Moreno Castillo (2017), highlights how regulatory promote and helps to facilitate private investment in renewable energy. Consequently, countries like Brazil, who have implemented regulatory initiatives for renewable energy, show how strong policies may attract private capital, therefore, decreasing financial problem on governments and promoting energy sector improvements (Moreno Castillo, 2017).

Furthermore, the report made by Inter-American Development Bank (IDB) and other relevant international institutions (BID et. all, 2017) highlights that an inclusive energy policy can promote to reduce energy poverty by decreasing the cost of electricity for low-income households, and therefore fostering economic equity. Likewise, many Latin America households are affected by energy poverty, which limits their ability to fully participate in the economy. Moreover, governments might increase the economic participation of marginalized groups, by implementing tailored policies, which can alleviate energy poverty. For instance, Brazil the "Luz para Todos" (Light for All) Program (LPT)[2], aimed to improve electrification in rural areas, has shown how government initiatives in energy access can promote socio economic development (IDB, 2017).

Moreover, the advantages of the energy policy in the economy are evident in the in the decrease of production cost across industries. For instance, improving energy efficiency in the industrial sector permit companies to decrease energy costs, therefore improving their competitiveness in domestic and international markets. Additionally, CEPAL (2024) highlights that improvements in energy efficiency can decrease the cost in important industrial sectors, such as manufacturing and agriculture, which are essential for Latin America export economy. Consequently, decreasing energy cost might transform in reducing production costs, improving exports, making then more competitive, and therefore promoting economic growth at national level.

In conclusion, the connection between energy policy and economic growth in Latin America highlights the necessity for comprehensive and equitable regulatory frameworks. Thus, robust policies which can promote energy efficiency and the inclusion of renewable, might improve economic resilience, decreasing energy poverty, and improving productivity across all sectors. Nevertheless, achieving these outcomes needs overcoming regulator and infrastructural difficulties, which hinders the full realization of energy efficiency in the region. Moreover, the implementation of these issues through well designed policies might allow Latin America countries to use energy efficiency as a mechanism for sustainable and inclusive economic growth., and therefore advancing in the long-term development goals.

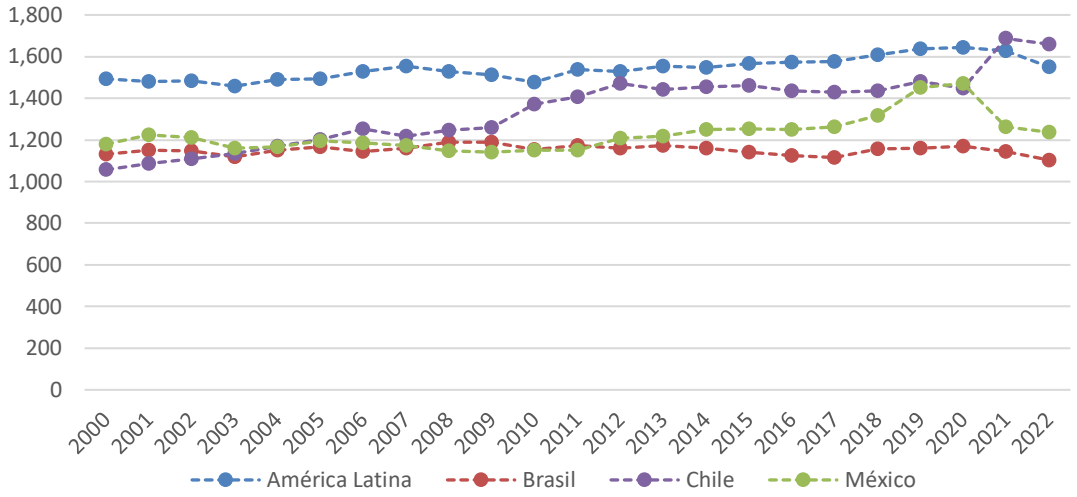
2.4.2 Energy efficiency and poverty dynamics

Energy efficiency is an important component that is essential for mitigating poverty, by focusing in one of the main economic issues, faced by low-income households, "high energy costs". This is due to that households assign a substantial portion of their income to energy expenses, even slight improvements in energy efficiency can transform into significant economic relief, moreover this can allow for the reallocation of resources for essential needs,

[2] "Light for Everyone" program has already served 39 thousand people this year. https://www.gov.br/planalto/en/latest-news/2024/03/201clight-for-everyone201d-program-has-already-served-39-thousand-people-this-year

such as healthcare, education and food security. Consequently, this section analyzes the theoretical and empirical relationship between energy efficiency and poverty alleviation, using development economics. Additionally, figure 6 illustrate trends in energy efficiency in Latin America and selected countries, this highlights the improvements and disparities in energy efficiency in the region and the selected countries. Moreover, analyzing this trend this research can explore how improvements in energy efficiency might decrease energy costs and might reduce poverty in these countries.

Figure 6 Energy efficiency 2000-2022, selected countries
(GDP 10^6 Constant prices dollars/Final consumption BEP 10^6)



Source: Own elaboration, based on CEPALSTAT and the Latin American Energy Organization (OLADE), Latin American and the Caribbean Energy Information System (sieLAC) [online database] https://sielac.olade.org

The theory of development economics, postulates that structural adjustments and tailored policies can significantly affect poverty levels, by creating an advantageous environment for economic growth (Todaro & Smith, 2020). Moreover, energy efficiency improves this framework by decreasing the overall cost of energy, which is significantly beneficial for low-income households, by improving their financial vulnerability and promoting economic stability. Nevertheless, there is a debate regarding the efficacy of energy efficiency programs in reducing poverty. Breunig & Majeed (2020) sugguest that without targeting vital socio economic inequalities, improvements in energy efficiency may not reach to the poorest households. Consequently, Breunig & Majeed (2020) undercores that wealthier groups capabilities are better to adopt energy efficient technologies due to the higher initial cost.

Some studies indicate that improving energy efficiency might help to reduce household expenses, which can permit families to redistribute income to other essential needs (CEPAL, 2024; Abbas et al., 2021). The IEA (2023d) highlights the role of energy efficiency in improving the purchasing power of disadvantaged groups, by reducing their energy bills. Additionally, investment in energy efficiency technologies and infrastructure, can help to Latin America governments to directly benefit low-income households, thus supporting equitable socio-economic development and mitigating income inequalities.

Latin America has challenge related with energy poverty, because is a persistent issue, in which are several low-income families spending excessively on energy due to ineffective consumption habits and limited access to affordable and clean energy. Consequently, this energy poverty nexus highlights the interdependent relationship between energy efficiency

and economic opportunity. Additionally, Sovacool, et al. (2012) argue that energy poverty is a multidimensional problem, which require inclusive solutions. Moreover Sovacool, et al. (2012), mention that intervations need not just be focused on improving energy, but also enhancing energy access, affordability and reliance. Thus, limited access to affordable energy constrains opportunities for economic mobility, preserving socio economic inequalities (Middlemiss & Gillard, 2015).

Studies from CEPAL (2024) indicate that improvements in energy efficiency in residential sectors, might alleviate these inequalities by reducing household energy costs. For instance, analysis of energy consumption in Latin America, indicate that energy cost for low-income households is significantly larger than wealthier households, as a proportion of the total income (CEPAL, 2024). This is more critical in rural areas and poor urban areas, where energy cost is more difficult due to inadequate modern and efficient infrastructure (IEA, 2023d).

Energy efficiency programs focused to reduce household costs might have a noticeable impact on poverty reduction (Ravallion & Chen, 2013). Moreover, improving household energy efficiency, may allow low-income families to save a significant proportion of their income, thus contributing to poverty reduction. Abbas et al. (2021), analyze how energy efficiency can help to alleviate energy poverty and promote social welfare, decreasing household energy cost, and improving living conditions, especially for those who are economically disadvantaged. Ravallion & Chen (2013) underscore the necessity for policies that can be extended beyond traditional income-based poverty to include energy affordability. Therefore, integrating energy efficiency with poverty reduction plans, might improve broader development goals.

Furthermore, development economics suggests that poverty reduction is more effective when structural inequalities are alongside addressed, as these inequalities often constrain the impact of growth-oriented policies (Todaro & Smith, 2020). In Latin America, where socio economic inequalities are deeply embedded, improvements in energy efficiency might help to alleviate these disparities, making energy more affordable for underprivileged groups. Nevertheless, countries with higher levels of income inequality, face significant challenges in expanding the benefits of energy efficiency policies, because wealthier groups are frequently better situated to implement energy efficiency technologies (Breunig & Majeed, 2020).

In conclusion, energy efficiency arises as significant instrument for economic development and poverty reduction in the context of Latin America. Moreover, the development economic framework theory supports this approach, highlighting the socio-economic advantages of reducing energy inequalities and facilitating equitable growth (Todaro & Smith, 2020). Therefore, countries of Latin America must prioritize energy efficiency as an important element to improve poverty reduction strategies across governments. Ravallion and Chen (2013) suggest that implementing multidimensional poverty measures that consider energy cost, might be relevant for monitoring progress.

2.4.3 Energy transition and economic impacts

The transition to renewable energy and the implementation of energy efficient technology, have significant economic implications for Latin America. Moreover, energy transition is not just about reducing greenhouse gas emissions, but also the promotion of inclusive economic growth and the alleviation of poverty by guaranteeing access to sustainable energy. Sachs (2005) argue that energy access is relevant for economic development and indicate that limited access to affordable and reliable energy maintain poverty, because this restricts opportunities. Thus, this is aligned with endogenous growth theory, which suggest that

economic growth is focused by internal factors, such as technology and innovation, which are affected by energy accessibility (Sachs, 2005; Todaro & Smith, 2020). Nevertheless, the literature provides different perspectives on the methods for achieving energy transition. While some organization highlights the role of technology innovation and investment in infrastructure (IEA, 2023a, 2023b, 2023c,2023f), others highlight the importance of policy frameworks and institutional capabilities (Taghizadeh-Hesary & Yoshino, 2019).

Behavioral economics offers insights about how human behavior as individual, societal norms, and economic incentives, can influence the adoption of sustainable energy solutions. For example, energy consumption patterns and the implementation of measures about efficiency are perceived as benefits, costs and accessibility, which can change significantly across socio economic groups. Furthermore, are necessary financial incentives, such as subsidies and tax reductions, these can motivate low-income households to use energy efficient equipment, consequently decreasing energy costs, and families might have the option of reallocation of saving to other needs (Moreno Castillo, 2017). Middlemiss & Gillard (2015), mention that social factors, involving institutional trust and cultural behavior towards energy use, play a relevant roles. Additionally, Sachs (2005) highlights this idea, mention that socio economic measures, like education and subsidies, are important for guaranteeing that energy efficiency improvements are accessible for the most vulnerable groups.

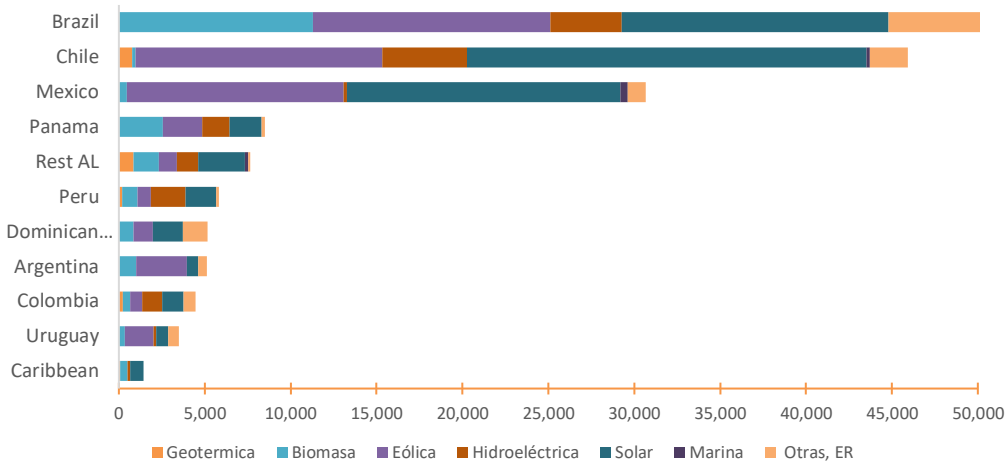
Regarding to the economic impact of energy efficiency at household level, Bacon and Kojima (2016) highlights how reducing the cost of energy, can lead to an increase in the disposable income, specifically in low-income households. For instance, small improvements in energy efficiency in households, like the implementation of new devices that can save energy, can reduce household expenses and the improve the well-being. This is an important concept in behavioral economics, because is related to financial decision-making Bacon and Kojima (2016). Furthermore, is relevant the significance of maintaining a macroeconomic stability and generate tailored policies which can promote energy transition, while considering economic considerations (Taghizadeh-Hesary, et al., 2021).

On the other hand, endogenous growth theory, which is contrasted with neoclassical theories, gives a framework for understanding how is addressed the economic growth, through internal factors in the economy, for example through technology and innovation (Todaro & Smith, 2020). This theory supports the idea that an improvement in energy efficiency can improve economic productivities. Sachs (2005) suggests that investment in renewable energy can stimulate local employment and improve economic resilience.

Furthermore, countries like Brazil, Chile and Mexico, have invested in renewable resource (figure 7), such as hydroelectric and solar energy, improving energy security and economic stability. Therefore, significant foreign direct investment (FDI) in renewable resources, support the narrative that the transition to renewable energy can invite to invest to international capital. While FDI can promote energy transition, some scholars are care about the risk for external dependence and weakened control over vital industries (Aykut & Goldstein, 2006). Additionally, Aykut & Goldstein (2006) argue that policies should equilibrate the attraction of investment with the protection of national interests and guaranting that the benefits are inside the country.

Additionally, Bacon and Kojima (2016) underscore that energy efficiency improve the productivity in the country's economy; by reducing energy consumption per unit of output, this is an incentive in the energy especially in sectors such as manufacturing and transport. Moreover, Bacon and Kojima (2016) suggest that improving energy efficiency, might improve the competitiveness of industries, by decreasing operational costs, while supporting sustainability.

Figure 7 Latin America and the Caribbean: Foreign investment announcements in renewable energy by source and main countries, accumulated 2005–2022,
(in millions of dollars)



Source: Own elaboration, based on Financial Times, fDi Markets.

Likewise, policies about energy transition provide important possibilities to face poverty, because these programs facilitate access to reliable and affordable energy, which is an important element for improving living standards. According to Sachs (2005) the expansion of energy is a key strategy to break the cycle of poverty, because access to modern energy can facilitates economic activity, such as education and healthcare services. Moreover, Bacon and Kojima (2016) highlight the positive impact of energy efficiency on social equity, because this help households to reduce the cost in energy, and programs about energy efficiency help to liberate financial resources and reallocate this for other needs.

In conclusion, research such as Sachs' (2005) and with Bacon and Kojima's (2016), show that energy transition can influence economic growth, and the reduction of poverty. This can be analyzed from the behavioral economics and endogenous growth theory. Therefore, through these theories it is clear that energy policies supporting the adoption of renewable resources and energy efficiency are both environmental beneficial and economically transformative.

2.5 Conclusion

The research analytically assesses the intertwined relation between energy efficiency, their socio-economic effects and environmental impacts in a broader perspective in Latin America, and how the region is facing, and pursuit the sustainable development through energy transition, this relationship involve significant socio-economic inequalities. Furthermore, by analyzing the complex relationship between energy efficiency and poverty, this research highlights how inefficiencies in energy use can intensify economic disparities, and hinder socio-economic progress, especially in those most in disadvantaged groups (Breunig & Majeed, 2020; Ravallion & Chen, 2013).

Additionally, the chapter provides a conceptual framework to understand the relationship between energy efficiency, socio economic development and environment sustainability in Latin America. Furthermore, this analysis is grounded in the following theories, energy economics, development economics, endogenous growth and behavioral economics. Thus, these theories help to clarify how energy efficiency policies might mitigate poverty, reduce inequality and promote sustainable development in the region.

This analysis has underscored the significant potential of diverse measures about energy efficiency and the improvements in the reduction of poverty, moreover, promoting environmental sustainability. Furthermore, Latin America can decrease greenhouse emissions, energy cost for consumers and reduce the gap in the poorest groups of society, by reducing the energy consumption and improving the efficiency energy use. By analyzing energy efficiency on poverty alleviation, this research offers robust evidence to promote policy recommendations (IEA, 2023; Moreno Castillo, 2017).

Additionally, policies and procedures that promote energy efficiency are relevant to achieving sustainable development. Thus, is important considering in this process technological advancements, policy reforms and socio-economic involvement. Therefore, the relevance of this measures and their next effects on reducing poverty and supporting environmental sustainability would be more successfully communicated by simplifying the unnecessary details.

This research provides strong evidence that multi theoretical frameworks is relevant for understanding the socio economic and environmental impacts of energy efficiency in Latin America. Moreover, integrating the theories mentioned before, provides a robust and comprehensive approach to drive energy policy. Additionally, the theories help to highlights that energy efficiency is not just a mechanism for environmental issues, but also as a channel for social equity and economic empowerment, especially for vulnerable communities. There exists a necessity for a more inclusive policy making that can take into account the challenges that are faced by the more vulnerable communities (IDB, 2017).

In conclusion, this research highlights the potential of energy efficiency policy in Latin America, through the applied theoretical frameworks. This is due to the relationship between policies with broader socio-economic goals. Therefore, Latin America countries might promote sustainable, and equitable development, which can address poverty reduction and environmentally sustainable development.

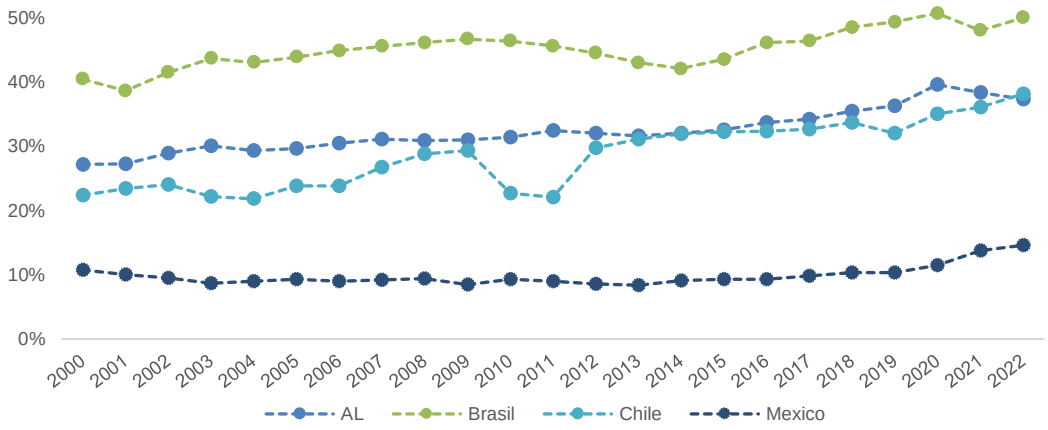
2.6 Justification for Focusing on Brazil, Chile, and Mexico

The selection of Brazil, Chile and Mexico as the main countries of analysis is made because its relevant energy scenarios, their socio-economic contexts and their important role in making and producing energy policies in Latin America. Moreover, these countries show differences but complementary examples of how energy efficiency measures, adoption in renewable energy in their matrix and energy policies may influence poverty reduction and sustainable development. Consequently, Brazil, Chile and Mexico have been pursuing different but complementary patterns in energy transformation, providing significant insights into the efficacy of different energy policy in Latin America.

- Brazil

Brazil is highlighted as one of the global leaders in renewable energy, with approximately 50% of its primary energy supply coming from renewable sources (Figure 8). This country has built an extensive hydropower infrastructure, additionally has increased the investment in wind and solar energy, expanding its energy matrix. Moreover, hydropower itself provides about 80% of Brazil power generation, highlighting the capacity of the country to reliance on renewable sources for energy security and growth (IRENA, 2023). Additionally, public policies, such as National Plan for Energy Efficiency (PNEF) support these efforts aimed to reducing industrial energy consumption and improving productivity (World Bank, 2022).

Figure 8 total primary renewable supply 2000-2022, selected countries,
(percentages)



Source: Own elaboration, based on the Latin American Energy Organization (OLADE), Latin American and the Caribbean Energy Information System (sieLAC) [online database] https://sielac.olade.org

Therefore, by focusing on energy efficiency Brazil, not just is decreasing its own demands, but also improving its economic resilience, especially for those sectors with high demand and energy consumption (World Bank, 2022). Furthermore, bioenergy resource in Brazil, through the production of bioethanol, help to reduce their carbon emissions while, support rural and economic development in region that depends in agriculture (CEPAL, 2024)

- Chile

Chile is frequently mentioned as one of the regional leaders in the generation of energy transition policies, especially in its efforts to include renewable energy into its power generation. according to IEA (2023b), Chile generates about 40% of its power from renewable energy sources, and this include solar, wind, and hydropower, therefore making it one of the leaders in the transition in Latin America. Additionally, the government has implemented the policy to become carbon neutral by 2050. Additionally, Atacama Desert in Chile, allow to the country expand its energy capacity and decrease the reliance on fossil fuels (IEA, 2023c). This is due to the promotion of solar energy, thus achieving notable progress in energy independence and reducing import costs (IEA, 2023b).

Furthermore, Chile's energy efficiency Law has significantly contributed to the reduction of energy demand in urban areas, where most of the time the consumption of energy is high, due to heating and cooling needs (BID, 2017). Moreover, the legislation mandates minimum standards for energy efficiency in buildings, and promote public awareness initiatives, which have resulted in the reduction of energy costs and consumption in several sectors (Rodríguez

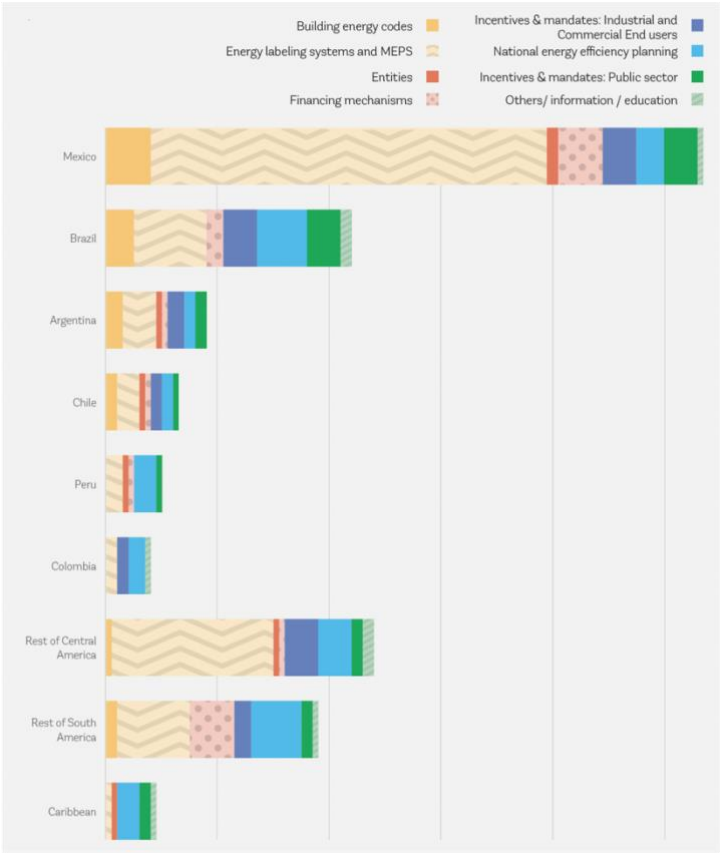
Padilla, 2018). Thus, the emphasis of Chile to show the relevance of suitable energy efficacy measures in urban areas, where the potential for energy and environmental impacts is significant. Therefore, there exist and important objective in chiles which is to mitigate climate change effects, while addressing energy poverty in underprivileged areas, especially in rural areas, where renewable energy plans are still in development (ECLAC, 2023a).

- Mexico

This country shows an important case inside Latin America, this is due to its size, is economically influence in the region and for its energy profile. Mexico is a relevant producer of fossil fuels and nonrenewable energy (85%) (sieLAC-OLADE, 2023). Additionally, the country has adopted different polices to support energy efficiency, for public and private sectors. The energy transition in Mexico has been characterized by a considerable regulatory reform aimed to expand access to affordable and reliable resources. The Energy Reform of 2013 (Gobierno de la Republica Mexico, 2013) is focused on foreign investment in renewable energy and the opening of the market to the participation of the private sector. Consequently, Mexico has attracted significant investment in wind and solar projects (IRENA, 2023)

Nevertheless, Mexico has faced several challenges in the implementation of reliable renewable energy policies, due to the uncertainty in the regulation. Moreover, different reforms aimed at prioritizing the state-owned utility, has affected the stability of renewable energy investments (UNDESA, 2023). Despite these issues, Mexico has made important progress in increasing the access to renewable energy for low-income households, through suitable subsidies, which has helped to reduce energy cost in underprivileged areas (OLADE, 2023).

Figure 9 Energy efficiency policies and regulations of various types across the LAC region



Source: IEA, BIEE, and RISE databases, from World Bank, 2022. *Realizing the Potential of Energy Efficiency in Latin America and the Caribbean*

Note: [a]MEPS = minimum energy performance standard.

In conclusion, the described figure 9 shows the different policy types presented in the countries selected, and this highlights the strategies differentiation. These policy programs not just make progress on energy efficiency, but also address energy poverty and promote economic resilience. Therefore, by analyzing the effectiveness of these regulation frameworks, this research illustrates how targeted energy strategies can promote sustainable development across multiple socio-economic contexts in Latin America. Thus, the focus in Brazil on hydropower, Chile in solar energy investment and urban efficiency, and Mexico in regulatory efforts to improve energy access; highlights the mixed and interconnected routes that Latin American countries are taking.

Chapter 3
Methodology

3.1 Research Design

This research applies mixed methods approach, to carefully analyze the relationship between energy efficiency policies and poverty reduction in Latin America, specifically observing the situation of Brazil, Chile, and Mexico. Consequently, the mixed method design incorporates quantitative econometric analysis and qualitative policy review to develop a comprehensive understanding of the subject. Therefore, this dual approach provides quantitative insights into measurable effects while adding contextual understanding from qualitative analysis of policy frameworks.

Consequently, the choice for this design is aligned with the theoretical framework discussed in Chapter 2, especially development economics and energy economic theory, this highlights quantitative measures of economic outcomes and qualitative method for policy and institutional contexts (Todaro & Smith, 2020)

Quantitative approach: Panel data analysis

The quantitative research part uses panel data model to analyze the effect of energy efficiency on poverty rates across the time and countries. Panel data provides the advantages for controlling for each cross sectional unites (country specific) and temporal (year specific) fluctuations, improving the robustness of the outcomes (Baltagi, 2021). Consequently, this is an important element in a regional study where unobserved heterogeneity might bias the estimates if not well addressed.

Model specification

The econometric model is specified as follows:

$$\text{Poverty rate}_{it} = \alpha + \beta_1 \text{GDP}_{it} + \beta_2 \text{energy efficiency}_{it} + \beta_3 \text{electricity consumption per capita}_{it} + \beta_4 \text{CO2 emissions per capita}_{it} + \beta_5 \text{public investment in renewable energy}_{it} + \beta_6 \text{proportion of renewable primary energy}_{it} + \beta_7 \text{indice gini}_{it} + regional\ dummies + time\ dummies + \epsilon_{it}$$

Where:

- i: indexes the country,
- t: indexes time (years),
- ϵ_{it}: is the error term,
- Time dummies: account for year-specific effects that are common to all countries, for example global economic shocks or Covid-19 pandemic.

Regional dummies: these dummies account for country-specific characteristics that are not captured by the other variables

Variables Definition

- Gross Domestic Product (GDP): This is the Constant US prices in dollar (millions).
- Energy efficiency: Measured as the ratio of GDP to total energy consumption. Indicating how efficiently a country uses energy to generate economic output.
- Electricity consumption per capita: The total amount of energy consumed in the country. This variable is characterized by total energy use in MWh or equivalent units CO_2 Emissions: Per capita CO_2 emissions, included to account for environmental impacts associated with energy use. This is the total emissions of carbon dioxide from fossil fuel combustion. It is measuring as metric tons per capita.
- Public Investment in Energy: Government expenditure on energy infrastructure and efficiency programs, is measure as 2021 million USD.
- Proportion of renewable primary energy in the total primary energy: This is measuring as renewable primary supply/total BEP primary supply.
- Gini Index (Gini Index): Gini coefficient: Values between 0 and 1. Where the value zero corresponds to absolute equity and one to absolute inequity.

Justification for the Econometric Approach

For this study, is employed Fixed Effects (FE) panel data model to analyze the impact of energy efficiency on poverty reduction in Latin America, focusing on three relevant countries such as Brazil, Chile and Mexico. This model is suitable because it controls for time invariant unobservable characteristics within each country, such as cultural factors or institutional characteristic, which could then bias the outcomes (Wooldridge, 2002). Moreover, the addition of country fixed effects helps account for heterogeneity across nations that could affect poverty levels, for instance, cultural, institutional or geographical differences (Croissant & Millo, 2019). Moreover, the choice for fixed effects model over random effects model is validated by the Hausman test, which guarantees that the model aligns with the data characteristics (Wooldridge, 2002).

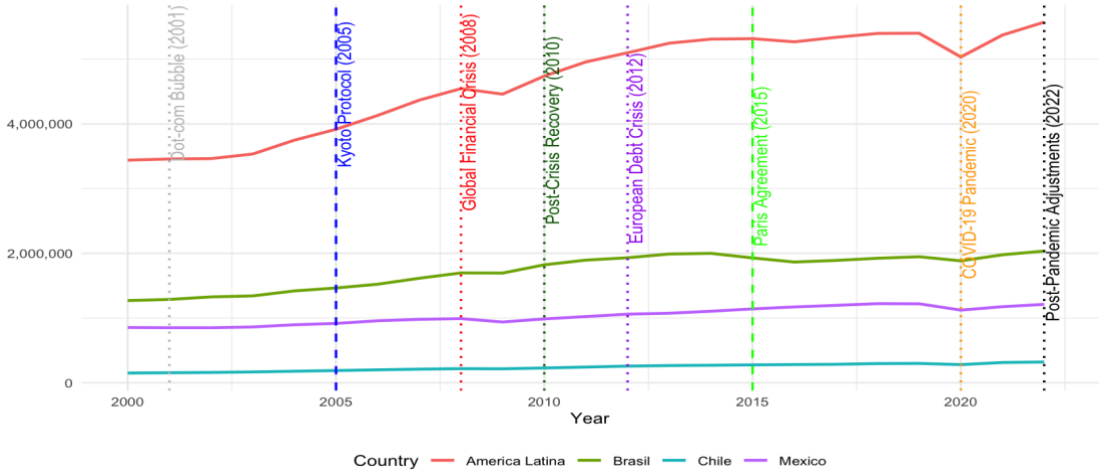
Additionally, by controlling for unobserved heterogeneity, the model is aligned with the theoretical emphasis on institutional and structural factors which influence poverty and energy efficiency (Breunig & Majeed, 2020)

Furthermore, the inclusion of times dummies accounts for broader regional macroeconomic shocks or global changes affecting all countries, such as global economic crisis or pandemics. Additionally, observe the impacts of poverty levels across the research period from 2000 to 2022.

Time period

The study covers the period from 2000 to 2022, including data from various Latin American countries, ensuring a representative sample of the region. Moreover, energy efficiency policy require many year to be fully implemented in countries, and in that way can show significant impact, that is why is relevant start to analyze from 2000, additionally this period is important because permit observe effort made in different periods of economic crisis and how this influence increase of poverty in the region (figure 10), as we can see in global financial crisis in 2008 and the recently events of Covid-19 pandemic. furthermore, in this period entered in force the Kyoto Protocol (2005), the Paris agreement (2015), the National Determined Contribution as part of the Paris Agreement.

Figure 10 GDP constant price 2018, trends with key economic and policy events 2000–2022
(Millions of USD)



Source: Own elaboration, based on CEPALSTAT, [online database] http://www.cepal.org

Qualitative approach: Policy analysis

The mixed method design is complemented with a deep policy analysis of Brazil, Chile and Mexico. This comparative case study permit for an analysis of how different policy frameworks might influence the efficacy of energy efficiency initiatives. Thus, the countries selected, were chosen due to their diverse energy policy framework and different roles in the region. Therefore, Brazil presents an extensive use of hydroelectric power and has made investments in solar energy, this is an example of renewable energy integration (OECD, 2021; IRENA, 2023). On the other hand, Chile with their investment in solar energy projects and significant carbon neutral target aspiration by 2050 (Ministerio de Energia, 2020), provides insights into the effectiveness of its policy framework. In contrast, the reforms made by Mexico in energy, that face challenges, shows the interaction between traditional energy reliance and renewable energy development

In conclusion, this research integrates quantitative econometric analysis with comparative case study, additionally, this design provides a comprehensive examination of how energy efficiency policies affect poverty reduction in Latin America. This approach allows for robust statistical evaluation while putting findings within the specific policy in the countries analyzed.

3.2 Data collection

The selection of the variables for this research is grounded in the theoretical framework and aligns with the research objectives. Moreover, each variable is carefully chosen to apply key concepts and control for likely confusing factors. Additionally, the research uses secondary data from reliable international and regional sources to guarantee comprehensive and accurate datasets. Furthermore, the period of the data is from 2000 to 2022, providing perspectives from a long period of time, this help to capture significant policy changes and socio-economic trends over time in the selected countries.

Data sources and variables

Dependent variable

Percentage of population on poverty: This data on percentage of the population living in poverty are obtained from CEPALSTAT, based on country household surveys gathered in the Household Survey Data Bank (BADEHOG). This variable is the depended outcome, which observe the main focus of the research, poverty reduction. Moreover, analyzing changes in poverty levels provide a measurable method to evaluate the effects of energy policies on socio economic conditions (Ravallion & Chen, 2013).

Independent variable

Energy efficiency: this is the ratio of GDP to total energy consumption, moreover the GDP data (in constant US dollar values) is from CEPALSTAT, and energy consumption data is sourced from sieLAC-OLADE. Furthermore, the energy efficiency as is measure by GDP to energy consumption ratio, is significant for understanding how efficiently a country can use energy to produce economic outcomes. Additionally, this variable helps to evaluate whether improvements in energy efficiency correlate with reduction of poverty, cost saving and economic growth (Abbas, et al., 2021).

Control variables

Electricity consumption per capita: this variable is from sieLAC-OLADE and is measured as MWh/10^3 hab. Furthermore, the variable work as an indicator of energy accessibility and the influence of energy distribution on household's expenses and economic participation (Middlemiss & Gillard, 2015).

CO_2 Emissions per capita: this is measuring as metric tons per capita and is from World Resources Institute/Climate Watch. Furthermore, CO_2 emissions underscore the environmental consequences of energy use, and include this variable helps to understand energy efficiency within development goals (Sachs, 2005).

Public investment in renewable energy (2021 million USD): This data is obtained from IRENASTAT. Moreover, public investment in renewable energy suggests government commitment to sustainable energy programs. Additionally, this investment might stimulate economic activity, create employment and reduce energy costs, supporting poverty mitigation (IRENA, 2020).

Proportion of renewable primary energy in total primary energy supply: This variable is calculated using data from sieLAC-OLADE. Moreover, the variable measures the share of renewable energy in the primary energy supply, and therefore its potential influence on energy costs and poverty levels.

Gini Index: Gini coefficient: this variable has values between 0 and 1, where the value zero corresponds to absolute equity and one to absolute inequity; the variable is from CEPALSTAT. consequently, high inequality can constrain the poverty reduction, impacting the economic growth (Todaro & Smith 2020).

Gross Domestic Product (GDP): This is measured as GDP in Constant US prices in dollar (millions), and values are from CEPALSTAT. This variable controls for the overall level of the economy, thus higher income might improve and allocate more resources for poverty reduction programs.

In conclusion these variables were chosen to answer the main research question comprehensively. Moreover, energy efficiency as the independent variable and poverty rate as the dependent variable are the center of the analysis. Additionally, the control variables are included to address for external factors and guarantee that the analysis is not biased by omitted variables bias (Croissant & Millo, 2019). Therefore, this research seeks to reproduce reliable and complete comprehensive outcomes by incorporating strong data sources and variables. Consequently, improving the understanding of the influence of energy efficiency and poverty reduction in the countries selected.

Data processing

Cross referencing data between sources was relevant for verifying data consistency. For instance, GDP sourced from CEPALSTAT was validated against data from Work Bank, to verify consistency. Additionally, outlier identification was conducted using statistical methods, such as standard deviation analysis. Moreover, detected outliers were examined to determine if they represented errors or true anomalies, significant to the research. Furthermore, missing values were conducted using robust imputation techniques. Multiple imputation was used, maintaining the statistical distribution and properties of the data (Little & Rubin, 2020). Moreover, to maintain constancy across the dataset, units were standardized as it was needed, to facilitate direct comparisons between countries. Therefore, to manipulate skewed data distributions and align with the criteria of linear regression analysis, several variables were transformed using natural logarithmic. Thus, this transformation mitigate heteroscedasticity and improve the interpretation of the coefficients (Wooldridge, 2002; Croissant & Millo, 2019).

Upon the completion of the mentioned, a balanced panel dataset was created, this contains the observation for each country across the research selection years (2000-2022). Moreover, this approach supports the econometric analysis by making consistent comparisons over time and through different countries, improving the stability of the model and the robustness. Additionally, the observations were categorized by country and year, and dummy variables were created for categorical data, such as the country specific fixed effects.

3.3 Limitations and scope

This section explores the potential limitations in the research and describe the scope of the study. Therefore, understanding these limitations and the description of the scope, might help to contextualize the outcomes and understand their implication with suitable precautions.

Limitations

Data availability and consistency: one the main challenge of this research is the availability of and the accuracy of the sources. Although the data were collected from reliable international sources, some discrepancies in specific variables for certain years were noted. To address this issue, the study used multiple imputation techniques, such as regression base imputation, this can manage missing data and maintain data integrity (Little & Rubin, 2020).

Regional heterogeneity: this research is focused on Brazil, Chile and Mexico, these countries show different socio economic and energy profile. This heterogeneity might influence the scope of the findings across the Latin America region, because these countries are different, in terms of economic size, policy frameworks, and renewable energy adoption.

Therefore, while this comparative model provide significant insights into the research, might not comprehensively reflect the experiences of other countries in the region.

Model and methodology: this research use panel data model, and is included fixed effects and random effects models, in which the selection of the model is drive by the Hausman test. Although these models account for time invariant unobserved characteristics within countries, there might still be unobserved variables that affects energy efficiency and poverty, and therefore, likely results in omitted variables bias. Consequently, the inclusion of control variables, help to mitigate this risk by incorporating significant external influences (Croissant & Millo, 2019)

Scope of the study

Geographic focus: this research is focused on Brazil, Chile, and Mexico, due to their significant influence, and diverse energy policies within Latin America. These countries offer a comprehensive analysis of how energy programs and socio-economic dynamics interact in different contexts. Therefore, the analysis from this study might be relevant to countries with similar characteristics.

Timeframe: the period of the research is from 2000 to 2022, which capture important shift in the economy and in the energy policy. Consequently, the years allows for significant trends over two decades, and thus provide robust dataset to observe the effects of energy efficiency and poverty reduction.

In conclusion, this research is aimed to provide significant insights into the relationship between energy efficiency and poverty reduction in Latin America. Nevertheless, the limitation mentioned should be measured when the outcomes are interpreted. Additionally, the scope guarantees for an accurate and relevant analysis.

Chapter 4
Ethics and Positionality

4.1 Ethics

One of the main ethic problems that this research can face is related with data integrity and transparency. All data collected and used in the analysis will be collected from reliable and recognized sources. These sources are Economic Commission for Latin America and the Caribbean (ECLAC), International Renewable Energy Agency (IRENA) and Latin American Energy Organization, Latin American and the Caribbean Energy Information System (sieLAC -OLADE). All the finding will be informed honestly, moreover, if is used interviews to relevant actors, they will be informed about the study and the purpose of the research, obtained the consent of participants.

Additionally, exist the risk of potential biases that might influence the research, exist the chance that there might be lack of availability and reliable data, this likely will require to reduce and limit the range of the analysis, or the size of the sample used. By recognizing these biases, will be necessary to change or take action to mitigate the potential impacts.

4.2 Positionality

As a professional my career has been developed in the Economic Commission for Latin America and the Caribbean for about eight years, and in the last five years I have been working for the Natural Resources Division inside ECLAC, been part on nonrenewable resources unit and energy unit in the same division. This short and extensive professional experience provide me with a unique perception and a comprehensive understanding of the region energy issues However the knowledge and the position that I have within ECLAC, an international organization that produce some of the data which can be used in this research, give advantages and potential biases. The knowledge and the access to different resources are helpful for conducting a comprehensive and informed research. Nonetheless, it also important to require a critical responsiveness of how this positionality may influence the interpretation of the data and it results.

Chapter 5
Results and Analysis

This chapter shows the outcomes of the panel data analysis performed to explore the relationship between energy efficiency and poverty reduction in Brazil, Chile, and Mexico. The analysis employs fixed effects model, robustness checks and sector specific measurements to estimate the most significant variables that might influence poverty to evaluate the variation in diverse energy strategies across the countries.

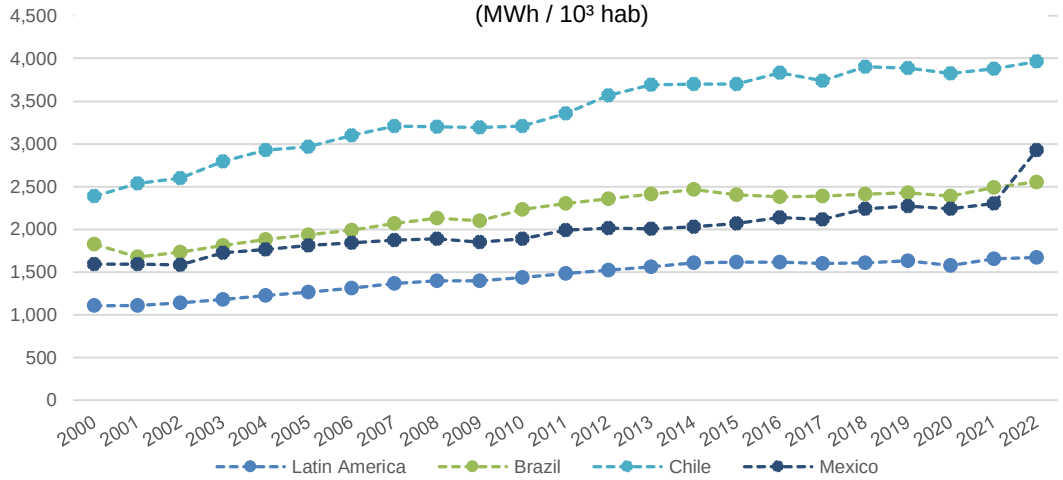
5.1 Overview of energy efficiency trends

This section shows a comprehensive overview of different trends in energy consumption, renewable energy investments and poverty rates, highlighting their evolution from 2000 to 2022. Additionally, these trends provide a context for the economic analysis.

5.1.1 Trends in energy consumption and renewable public energy investment

The figure 11 illustrate the changes in per capita electricity consumption from 2000 to 2022, for selected countries. Moreover, significant trends were observed across the countries, and each of them exhibit different patterns, which are shaped by their socio-economic policies and energy initiatives. Brazil, present a steady rise in energy consumption, this might be due to the growing in their economic and social programs, such as the National Energy Plan (IEA, 2023b). By contrast, Chile has experienced significant periods of increase in energy consumption, which coincide with the implementation of important renewable energy policies. Additionally, these policies highlight the commitment of Chile's government to expand its energy matrix, with solar and wind power (IRENA, 2023). In the other hand, Mexico shows a gradual increase, related with their modernization of urban energy infrastructure and policy reforms, like the 2013 energy reform.

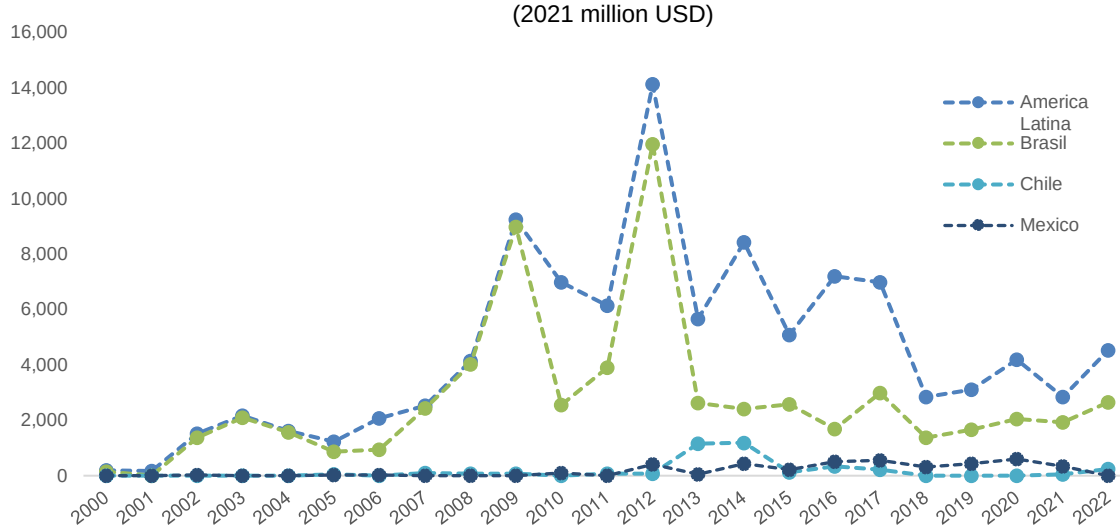
Figure 11 Electricity consumption per capita, selected countries, 2000-2022
(MWh / 10^3 hab)



Source: Own elaboration, based on the Latin American Energy Organization (OLADE), Latin American and the Caribbean Energy Information System (sieLAC) [online database] https://sielac.olade.org

Regarding to public investment in renewable energy, this variable varied significantly across the selected countries. The figure 12 shows how public investment move across the years, and Brazil, show a steady investment in renewable energy, employing its widely hydropower capacity, in combination with investment in wind and solar energy (IRENA, 2023). By contrast, Chile presented significant variability in renewable energy investments, with important flows in year where solar and wind projects were developed. This is due to the work of the government in their legislative and financial incentives, which help the increase in renewable energy (IRENA, 2023). In the other hand, Mexico shows a moderate and steady public investment in renewable energy. However, the 2013 reform promoted the access of private's companies to support renewable energy and efficiency (IEA, 2023b).

Figure 12 Public investment in renewable energies, 2000-2022
(2021 million USD)

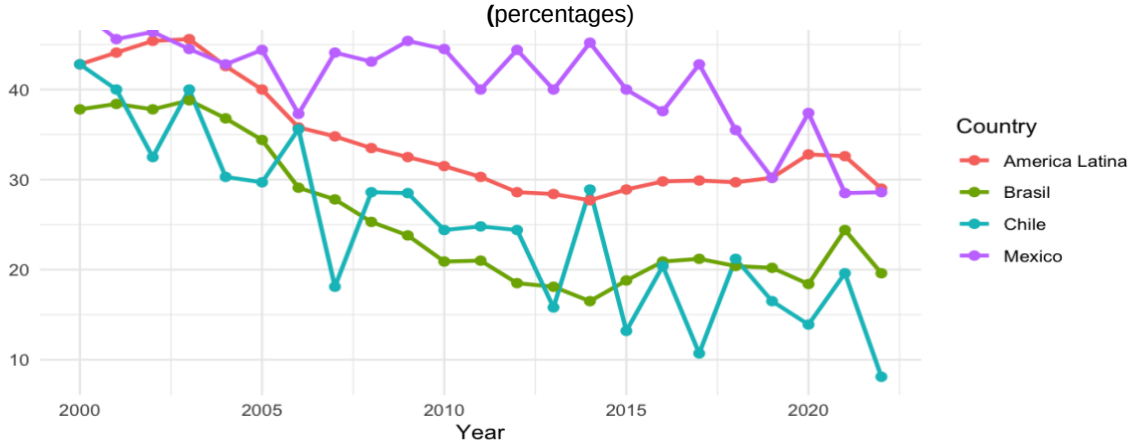


Source: Own elaboration, IRENASTAT [online database] https://www.irena.org/Data/Downloads/IRENASTAT

5.1.2 Trends in poverty rates

Poverty rate for each country were analyzed to understand the reduction across the time and the relationship with energy efficiency and economic policies. Figure 13 shows the notable reduction in Chile, which is supported by their economic growth, which in the last year has been supported by energy efficiency initiatives. This is highlighted by their investment in renewable energy which has contributed to better energy access (IEA, 2023b). in the other hand, Brazil present significant improvements in their poverty reduction. Additionally, Mexico shows gradual poverty reduction, this is due to obstacles related with significant economic disparities, however important portion of the population continue affected by high energy costs, and limited access to renewable alternatives (IEA, 2023b).

Figure 13 population in poverty 2000-2022, selected countries (percentages)



Source: Own elaboration, based on CEPALSTAT, based on country household surveys, Household Survey Data Bank (BADEHOG). [online database] http://www.cepal.org

5.2 Econometric analysis of energy efficiency and poverty reduction

The analysis of energy efficiency effects on poverty is relevant for understanding the socio-economic implications of energy policies in Brazil, Chile and Mexico. This section analyzes de data from the fixed effects panel data model, applying country specific insights and sectoral efficiency analysis to measures how improvements in energy efficiency might influence poverty levels. Moreover, this section includes empirical outcomes and is supported by documents that contextualize the outcomes within broader policy and economic frameworks. Furthermore, it is highlighted that the roles of public investment in renewable energy and the sectors strategies, are relevant to guide through positive outcomes.

5.2.1 Key findings from the Fixed Effects Models

Table 1 shows a comparison of the outcomes from fixed effects models employing robust standard errors and Driscoll-Kraay standard errors. The dependent variable in this analysis is the logarithmic transformed percentage of the population living in poverty. Therefore, the main purpose is to verify that the results are consistent while fixing potential concerns, such as heteroscedasticity and cross-sectional dependence, usual elements in panel data.

The coefficient for GDP is negative and statistically significant in both models, with an estimate of -2.505. This negative relationship suggest that economic growth is an important driver of poverty reduction in the countries analyzed. This is related with the literature that highlights that growth-oriented policies can significantly reduce poverty rates (IEA, 2023c). therefore, improving household income and expanding economic opportunities (CEPAL, 2024).

In contrast the coefficient of energy efficiency is positive (0.684) however is significant in the robust standard model. The positive coefficient in energy efficiency might suggest that improvements in energy efficiency, while contribute to economic growth and environmental benefits, may not translate into poverty reduction without support interventions. Therefore,

this outcome suggest that energy efficiency policies should be complement with targeted policies, such as subsidies or financial incentives (CEPAL, 2024; IRENA, 2023).

In the other hand, the steady and significant coefficients for public investment in renewable energy in both models (-0.034), support the importance of these investments in mitigate poverty. Moreover, investment in renewable energy might stimulate hob creation, improve energy security and provide long term cost benefits, thereby improving economic development (CEPAL, 2024; IRENA, 2020).

Table 1 Comparison of Fixed Effects Models with Robust and Driscoll-Kraay Standard Errors

	Dependent variable:	
	Population Poverty Percent	
	FE Robust	Driscoll-Kraay
	(1)	(2)
GDP	-2.505***	-2.505***
	(0.294)	(0.676)
Energy Efficiency	0.684***	0.684
	(0.185)	(0.518)
Electricity Consumption per Capita	-1.025	-1.025**
	(0.652)	(0.489)
CO2 per Capita	-0.536*	-0.536
	(0.268)	(0.390)
Public Investment in Renewable Energy	-0.034***	-0.034*
	(0.011)	(0.018)
Prop. of Renewable Energy	0.662**	0.662
	(0.011)	(0.018)
Gini Index	-5.069***	-5.069***
	(0.304)	(1.110)
Chile	-0.019	-0.019
	(0.064)	(0.018)
Brazil	0.044	0.044*
	(0.074)	(0.024)
Mexico	0.178***	0.178***
	(0.046)	(0.057)

Note: *p<0.1; **p<0.05; ***p<0.01.
Robust standard errors in parentheses.
Driscoll-Kraay standard errors in parentheses.

5.2.2 Interpretation of Country-Specific Effects

The country specific fixed effects models, for Brazil, Chile and Mexico provide unique insights into the influence of energy efficiency, economic growth and other relevant variables on poverty reduction. These outcomes are summarized in table 2 and show the socio-economic dynamics which are present in each country, highlighting the importance of tailored policy strategies.

Table 2 Country-Specific Fixed Effects Models with Driscoll-Kraay Standard Errors

	Dependent variable:		
	Population Poverty Percent		
	Chile (1)	Brazil (2)	Mexico (3)
GDP	-1.337	-1.187*	0.024
	(3.352)	(0.649)	(0.518)
Energy Efficiency	0.232	-0.362	-0.780*
	(2.016)	(0.607)	(0.425)
Electricity Consumption per Capita	0.828	1.397	-0.997**
	(2.537)	(1.240)	(0.392)
CO2 per Capita	-1.056	-1.098*	0.094
	(1.603)	(0.563)	(0.282)
Public Investment in Renewable Energy	-0.011	0.024**	0.013
	(0.028)	(0.010)	(0.015)
Prop. of Renewable Energy	-2.804	-2.892	-1.797
	(2.266)	(2.003)	(1.664)
Gini Index	-4.541	7.643**	-2.727
	(4.746)	(3.462)	(1.831)

Note: *p<0.1; **p<0.05; ***p<0.01.
Driscoll-Kraay standard errors in parentheses.

For Chile, the coefficient for GDP in negative (-1.337), however is not statistically significant, this indicate that while economic growth this might influence poverty reduction, nevertheless this is not a relevant factor. Therefore, inclusive social policies and targeted public investments might be important to translate into economic growth and poverty mitigation (CEPAL, 2024; IEA, 2023c). furthermore, energy efficiency shows positive coefficient (0.232), however this is not significant, this suggest that energy efficiency improvements might not directly influence poverty reduction in Chile. Although Chile has made important advances in efficiency its benefits, this need to be complemented with supportive policies (CEPAL, 2024). Regarding public investment in renewable energy, the coefficient is negative and not significant. This might suggest that the potential for long term benefits may need time and more supportive policies, such as employment development and community participation (IRENA, 2020)

In the other hand, Brazil GDP is negative and significant (-1.187), highlighting the idea that economic growth is important variable in poverty reduction in the country. Thus, economic expansion in Brazil has facilitated better access to services and job opportunities (Ministerio de Minas e Energia, 2023). By contrast, public investment in renewable energy, show a positive and significant coefficient (0.024), consequently highlights the importance of investment in renewable energy in poverty alleviation. Furthermore, this might contribute to the creation of employments, energy security and economic growth, therefore highlighting the relevance of targeted policies into broader development frameworks (IRENA, 2020; Ministerio de Minas e Energia, 2021).

In the case of Mexico, this presents a negative and significant coefficient for energy efficiency (-0.780). This might indicate that energy efficiency improvements are important

elements in poverty reduction. Therefore, this suggest that lower costs and improvements in disposable incomes are made by new technologies and better practices (Gobierno de la Republica Mexico, 2013; IEA, 2023c). By contrast, the coefficient for electricity consumption per capita is negative and significant (-0.997) highlighting the relevance of electricity access. Therefore, increased electricity access in related with better education, healthcare and employment results (IRENA, 2020; ECLAC, 2024).

5.2.3 Sectoral energy efficiency impacts

This section shows the estimation of energy efficiency improvements across key important economic sectors and their contribution to poverty reduction in Latin America. This analysis uses fixed effects model with Driscoll-Kraay standard errors, and it is focused on agriculture/mining, manufacturing, commerce/hotels, and transport sectors as is illustrate in table 3.

Regarding energy efficiency in agriculture and mining, the coefficient is significantly negative (-0.814). This outcome shows that improving energy efficiency in these sectors, significantly relate with poverty reduction. Moreover, this relationship likely emerges from the important roles of these sector that play in rural employment. According to IRENA (2023), an increase in energy efficiency in relevant sectors help to improve productivity and support well-being in region where principally reliant on agriculture and mining. Moreover, CEPAL (2024) support this highlighting the potential of energy policies that improve productivity in these sectors.

Table 3 Sectoral Efficiency Analysis Results (Driscoll-Kraay Standard Errors)

	Dependent variable:
	Population Poverty Percent
Energy Efficiency in Agriculture/Mining	-0.814***
	(0.191)
Energy Efficiency in Manufacturing	-0.950***
	(0.236)
Energy Efficiency in Commerce/Hotels	0.011
	(0.291)
Energy Efficiency in Transport	-0.398**
	(0.161)

Note: *p<0.1; **p<0.05; ***p<0.01
Driscoll-Kraay standard errors in parentheses.

Likewise, the coefficient for the manufacturing sector is negative and significant (-0.950), this suggest that investment in energy efficiency in this sector contribute to poverty reduction. Additionally, the modernization of the production processes and reducing energy waste can improve jobs opportunities and support economic growth (Ministerio de Minas e Energia, 2023). This is highlighted by Rasoulinezhad & Taghizadeh-Hesary (2021) who suggest that manufacturing efficiency can improve employment creation and increase salary.

Concerning about efficiency in commerce, the coefficient is positive, however is not significantly, this outcome indicates that improvements in energy use within this sector do not have impacts on poverty reduction. Thus, the minimal influence of this sector in poverty

levels might be result from its characteristics, where energy efficiency mainly reduces operational costs (Gobierno de la Republica Mexico, 2013)

The transport sector shows a negative and significant coefficient (-0.398), this outcome indicates that improvements in transport energy efficiency impact in poverty reduction, this might be due to the reduction in costs. Moreover, efficient transport system reduces commuting costs and increase job access and job services (IRENA, 2023; CEPAL, 2024).

5.3 Cross-Country Comparison

This section highlights how government policies, public investment and macroeconomic growth have influenced the efficacy of energy efficiency in reducing poverty in selected countries. To analyze the results, table 4 provide a summary of the policy differences, between Brazil, Chile and Mexico, about energy efficiency, regulatory frameworks, investment and strategies.

Brazil has benefited from robust public investment in renewable energy and from focused policy which include, economic growth with energy efficiency. Moreover, the importance of energy efficiency in reducing poverty, especially in sectors such as agriculture and manufacturing, align with the macroeconomic policies that support growth in Brazil (World Bank, 2022). Additionally, public investment has stimulated job creation and energy security (CEPAL, 2024).

In the other hand, although Chile present positive trends in energy transition, the models show that GDP growth and energy efficiency has less impacted poverty levels, compared to Brazil. Furthermore, the investment in renewable energy has supported energy, however this needs complementary social policies to improve directly poverty reduction (CEPAL, 2024). By contrast, Mexico show significant energy efficiency improvements, thus highlights the focus in the regulatory reform and subsidies aimed at improving energy access. Additionally, the negative and significant coefficient for energy efficient show that those measures might contribute to poverty reduction (Gobierno de la Republica Mexico, 2013)

5.3.1 Government policy and regulatory frameworks

Table 4 highlights broad policies initiatives, which are important for improving energy efficiency, that support economic and social development. Additionally, the integration of growth theory into the analysis of the section highlights that the efficacy of policies relies on the structural conditions and mechanisms that are presented in each country. Banerjee & Duflo (2005) highlitghs that investments in capital might generate significant returns in contexts with efficient market and insitutional support.

Brazil shows relevant regulatory frameworks, this includes measures such as energy label, minimum energy performance standards and incentives for private sector (World Bank, 2022). For Chilean scenario, policies have been proactive, which have been focused on renewable energy and national energy strategies, supporting energy transition. Although these initiatives have facilitated energy access and sustainability, the World Bank (2022) suggests that additional socio-economic policies are essential to improve poverty reduction impacts. On the other hand, Mexico, show relevant regulatory reforms, including subsidies, which improve energy access, and therefore influencing poverty reduction. Mexico's reforms have been effectively expanded energy access and affordability, therefore supporting social well-being, especially in marginalized communities (Gobierno de la Republica Mexico, 2013; World Bank, 2022). Consequently, policies show how regulatory frameworks strategies might align with energy efficiency with socio economic benefits.

Table 4 Key energy policies by Country

Country	Government policies	Regulatory frameworks	Investment strategies
Brazil	National Energy Efficiency Plan (PNEf): Established in 2011. reduce electricity consumption by 10% by 2030 through efficiency measures. Programa Nacional de Conservação de Energia Elétrica (PROCEL): Launched in 1985 to promote energy efficiency in electricity use, including labeling programs and public awareness campaigns Incentives for Renewable Energy Projects: PROINFA support wind, biomass, and small hydroelectric projects to diversify the energy mix	Minimum Energy Performance Standards (MEPS): Mandatory energy efficiency standards for appliances and equipment, enforced by INMETRO Energy Labeling Programs: The Brazilian Labeling Program (PBE). Information on the energy efficiency of appliances. Net Metering Regulation (REN 482/2012): Facilitates distributed generation by allowing consumers to generate their own electricity and receive credits.	Investments in Renewable Energy Infrastructure: Funding for wind and solar power projects through BNDES. Funding for Energy Efficiency Projects: Financial incentives and subsidies for energy efficiency improvements in industries and public buildings. Job Creation Initiatives: Programs to develop human capital in renewable energy sector to boost employment and economic development.
Chile	- National Energy Policy 2050 (Política Energética 2050): 70% of electricity generation from renewable sources by 2050 and emphasizes energy efficiency Energy Efficiency Law 21.305 (Ley de Eficiencia Energética): Enacted in 2021, energy efficiency management for large consumers and promoting efficiency in transportation and buildings. Long-Term Energy Planning (Planificación Energética de Largo Plazo): Sustainable investment and development in the energy sector.	Renewable Energy Law 20.257: A percentage of electricity sold must come from renewable sources, increasing over time. Net Billing Regulation: Allows small-scale renewable generators to sell excess electricity back to the grid, encouraging distributed generation Energy Efficiency Standards and Labeling: Implementation of MEPS and energy labeling for appliances and vehicles to inform consumers.	Investment in Renewable Infrastructure: Government support for large-scale solar and wind projects, particularly in the Atacama Desert region. Energy Access Initiatives: Programs to extend electricity access to remote and rural areas using renewable solutions. Energy Poverty Programs: The "Programa Hogar Mejor" to improve energy efficiency in low-income households.
Mexico	Energy Reform (Reforma Energética, 2013): Constitutional reforms to open the energy sector to private investment, promoting competition and efficiency. National Energy Strategy 2014–2028: Sets goals for energy efficiency improvements and increased use of clean energy sources. Energy Transition Law (Ley de Transición Energética. Nueva Ley DOF24-12-15): established targets for clean energy generation and energy efficiency.	Energy Efficiency Standards (NOMs): Mandatory standards for energy consumption of appliances and equipment, enforced by National Commission for the Efficient Use of Energy (CONUEE) Renewable Energy Certificates (CELs): Market-based mechanism requiring suppliers to acquire certificates proportional to their energy sales, promoting clean energy generation. Support for Decentralized Energy Solutions: Regulations facilitating the installation of distributed generation systems, including net metering.	Investment in Renewable Energy Projects: Investment in wind, solar, and geothermal projects to diversify the energy mix. Energy Access Programs: Initiatives like the "Programa Nacional de Infraestructura" to expand electricity access to marginalized communities

Own elaboration based on data from World Bank (2022), Energía 2050, PEN (2020), Atlas da Eficiência Energética Brasil (2023), and Reforma Energetica Mexico 2013.

In conclusion, the comparative analysis indicates that government policy, public investment and GDP growth influence the efficacy of energy efficiency programs on poverty reduction. Furthermore, Brazil comprehensive strategy, which include significant public investments and macroeconomic policies, align with energy efficiency improvements alongside with poverty reduction. Moreover, Chile has demonstrated that while energy policy progress is necessary, this necessitate be integrated with socio economic policies, for more significant poverty impacts. By contrast, the regulation frameworks in Mexico are supported by public investment, highlighting the importance of policies tailored to improve accessibility and affordability in promoting social equity and poverty reduction.

Chapter 6
Discussion

This chapter analyses the outcomes, characterized them within the broader theoretical frameworks and literature on energy efficiency and poverty reduction. This research discusses the relationship from energy policies, socio economic growth and poverty reduction in Latin America, with a focus on the comparative cases of Brazil, Chile, and Mexico.

6.1 Theoretical Implications

The results of this research are aligned with several challenges that exist about theories that are related with energy efficiency and its impacts on poverty reduction. This analysis support development economics, endogenous growth theory and energy economics to structure the discussion.

6.1.1 Endogenous Growth Theory

The results corroborate the endogenous growth theory, which argue that investments in innovation, human capital and knowledge promote economic growth (Romer , 1990). Furthermore, tailored investment in renewable energy and especially in efficiency in Brazil has demonstrated significant poverty reduction effects, this is supported by the notion that economic factor might promote steady growth (World Bank, 2022; CEPAL, 2024). Moreover, the public investment can create job opportunities and improve energy access, improving poverty mitigation (Ministerio de Minas e Energia, 2023).

Although in Chile the investment in renewable energy is observed, their direct effect on poverty was less significant. Thus, this outcome corroborates the theoretical framework that investment is important, this need be integrated with equitable policy frameworks (Banerjee & Duflo, 2005).

6.1.2 Development economics

The development economics theory highlights the significance of institutional transformation and tailored policies in poverty reduction (Todaro & Smith, 2020). Moreover, this research shows that energy efficiency especially in sectors such as agriculture, manufacturing and transport, significantly influenced poverty reduction in Brazil and Mexico. These findings are aligned with theories that highlights the tailored economic interventions, and investment in infrastructure are relevant to reduce poverty as is show in Brazil (Ministerio de Minas e Energia, 2021)

In the case of Mexico, improvements in energy efficiency are significantly associated with poverty reduction, supported by regulatory reforms and targeted subsidies (Gobierno de la Republica Mexico, 2013; World Bank, 2022). However, the situation of Chile might challenge certain aspects of this framework. Despite their advance in energy policies, inadequate integration with social measures limited their efficacy.

6.1.3 Energy economics

The finding of the model support energy economic theory, this highlights the relationship among energy access, economic resilience and poverty reduction (IEA, 2023c.). Moreover, the outcomes of Brazil show how the role of public investment and regulatory policies, might facilitate energy access, which results in job opportunities and economic stability (World Bank, 2022). Therefore, this corroborates theoretical approach that promote energy efficiency to improve economic productivity and social well-being (Bacon & Kojima, 2016).

In contrast, Chile results suggest that energy policies need to be more inclusive to significantly impacts poverty level. Despite the findings of energy efficiency and GDP growth, their capacity to translate into significant poverty reduction was limited. Consequently, this highlights the needs for integrate policy frameworks that can incorporate energy and social equity (World Bank, 2022)

6.2 Policy implications

The outcomes from this research offer practical information for policymaker, who seeks to use energy efficiency as a tool for poverty alleviation.

6.2.1 Targeted energy efficiency policies

First, policymakers should focus on tailored energy efficiency improvements in key sectors, such as manufacturing, agriculture and transportation. Moreover, the important influence in these sectors indicate their contribution to job creation and cost reduction for low-income households (CEPAL, 2024; Ministerio de Minas e Energia, 2021). Thus, the estrategies support recommendations that tailored investments might promote sustainable growth and social development (World Bank, 2022).

6.2.2 Supporting low-Income households

Subsidies and tax incentives for energy efficiency habits in low-income households are essential strategies. Moreover, the positive outcomes in Mexico show how regulatory measures which improve energy access, can enhance living standards (Gobierno de la Republica Mexico, 2013). Consequently, this approach support literature which highlights policies that focus on affordability and accessibility to achieve inclusive growth (Ministerio de Minas e Energia, 2023)

6.2.3 Regional cooperation

Regarding regional cooperation, this is an essential strategy for sharing solutions about energy challenges. Furthermore, collective initiatives might concentrate on joint financing mechanisms and networking opportunities to improve energy efficiency practices (IRENA, 2023). Moreover, the approach of Brazil using public investment to promote development can be replicated in regional frameworks to stimulate sustainable energy and economic development (World Bank, 2022, CEPAL, 2024).

6.2.4 Integrating social and energy policies

The findings of Chile suggest that energy programs must be aligned with social policies in order to improve their poverty levels. Additionally, these policies should be integrated into

job and educational programs, with energy investments. Therefore, this approach guarantees that energy efficiency improvements can benefits the most vulnerable groups.

In conclusion this research highlights that energy efficiency policies are essential for poverty reduction when they are integrated with inclusive economic and social strategies. The approach from Brazil, the regulatory strategy of Mexico, and the need for tailored social programs in Chile, offer insights for developing energy policies that promote equitable economic development.

Chapter 7
Conclusion

This chapter integrate the main research finding, highlighting their significance for development economic and energy policy in Latin America. Additionally, provide directions for future research to expand the gathered insights. Moreover, the study focused on the impact of energy efficiency policies in Brazil, Chile, and Mexico, analyzing their influence on poverty reduction through econometric model and policy analysis.

7.1 Summary of the model

the econometric analysis showed that there are a significant but negative relationship between GDP and poverty rates across the three countries analyzed. The fixed effects model showed that a 1% increase in GDP is related with a 2.50% decrease in the poverty rates. Consequently, this result is related with development economics theories that suggest economic growth as a main factor in poverty reduction (Todaro & Smith, 2020). In contrast to theoretical probabilities, the overall model showed a positive coefficient for energy efficiency (0.684), this might indicate that an increase in energy efficiency can be related with higher poverty rates, nevertheless this outcome is not significant when using robust model. Therefore, this underscore the necessity for additional policies to guarantee that the benefits of energy efficiency can be reached by the poorest households.

Furthermore, electricity consumption per capita showed a negative and significant relationship with poverty rates, especially in Mexico. In the model, a 1% increase in per capita electricity consumption correlate with a 1.02% decrease in poverty rates. Consequently, this indicates that improvements in access and consumption of electricity might help to reduce poverty improving productivity and living standards. (Apergis & Payne, 2010). Furthermore, public investment in renewable energy showed a negative and significant relationship with poverty rates. Additionally, the model revealed that a one unit increase in public investment results in 0.034% reduction in poverty rates. Therefore, this outcome highlights the importance of government investment in renewable energy projects, thus can stimulate the economy and reduce poverty (IRENA, 2020)

The findings of the model show that impacts of energy efficiency policies on poverty reduction vary across countries. For example, in Brazil public investment in renewable energy significantly reduced poverty rates. Moreover, a 1% increase in energy efficiency in the manufacturing sector permit a 0.95% decrease in poverty rates. Furthermore, the analysis of sectoral efficiency indicates that improvements in energy efficiency in important sectors substantially contribute to poverty reduction. For instance, a 1% increase in energy efficiency in agriculture and mining is related with a 0.81% decrease in poverty levels. Therefore, these findings validate development theories that support tailored measures in essential economic sectors to help vulnerable groups (Todaro & Smith, 2020).

7.2 Contribution to development studies and future research

This research significantly contributes to the field of economic and policy development, improving the knowledge of the energy poverty nexus by offering empirical evidence, analytical insights and practical benefits for policy integration.

Firstly, this research empirically corroborates theoretical models based on endogenous growth theory. This is showed by investment in energy efficiency and renewable energy can provide economic growth and reduce poverty, moreover, support the idea that technological improvement with effective use of the resources is relevant for sustainable development in developing countries. Secondly, the mixed outcomes about the direct effect of energy efficiency on poverty underscore the complexity of this relationship. Therefore, the results highlight the necessity for comprehensive policies that guarantee equitable distribution of benefits. Thus, this is an important factor for policymakers, suggesting that is important targeted measures that address inequality, and consequently translate into energy efficiency improvements with poverty reduction. Thirdly, the analysis of specific sectors improves the discussion, because this demonstrates how tailored innervations may increase social returns. This is due to the examination of sectors like agriculture, transportation and manufacturing.

Furthermore, futures studies might explore deeper into micro levels effects of energy efficiency policies, to understand their influence on living standards and economic opportunities in the population. Moreover, longitudinal studies are recommended to explore the sustainability and the impact of these policies on poverty reduction. Additionally, expanding the research to incorporate additional Latin American countries or regions with similar socio-economic conditions, might improve the applicability of the findings and provide a more comprehensive perspective on the efficacy of several policy initiatives. Furthermore, is important explore the role that play education, technology transfer and institutional frameworks in promoting the implementation of and effectiveness of energy efficiency measures. Therefore, by analyzing these areas, futures studies might improve the insights gathered from this research, facilitating the formulation of strategies that use energy efficiency for economic growth and equitable social progress.

Chapter 8
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