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Tackling Energy Inequality in the EU Member States for a Just Transition

Ph.D. Dissertation

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

ABV	State	ABV	Term
BE	Belgium	**CDD**	Cooling Degree Days
BG	Bulgaria	**CEC**	Climate-corrected energy consumption
CZ	Czechia	**EC**	European Commission
DK	Denmark	**EGD**	European Green Deal
DE	Germany	**EI**	Education Index
EE	Estonia	**EP**	Electricity Price
IE	Ireland	**ETS**	Emission Trading Scheme
EL	Greece	**EU**	European Union
ES	Spain	**GDP**	Gross Domestic Product
FR	France	**GNI**	Gross National Income
HR	Croatia	**HDD**	Heating Degree Days
IT	Italy	**HDI**	Human Development Index
CY	Cyprus	**IEA**	International Energy Agency
LV	Latvia	**LE**	Life Expectancy
LT	Lithuania	**LNG**	Liquefied Natural Gas
LU	Luxembourg	**LSDV**	Least Squares Dummy Variables
HU	Hungary	**POP**	Population
NL	Netherlands		
AT	Austria		
PL	Poland		
PT	Portugal		
RO	Romania		
SI	Slovenia		
SK	Slovakia		
FI	Finland		
SE	Sweden		

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1 Introduction

Recently, energy has emerged as a pivotal concern, carrying substantial implications across environmental, societal, and economic dimensions. These implications encompass climate change, poverty alleviation, industrial and agricultural productivity, and the well-being of ecosystems and human populations. The environment is impacted by the level of energy consumption, as a causal relationship exists between energy use and climate change, primarily driven by greenhouse gas emissions (Wu et al., 2012). Energy consumption is the primary contributor to these emissions, with empirical data underscoring a clear link between escalating energy use and the rapid rise in global greenhouse gas levels. Consequently, one of the most critical global challenges of the twenty-first century is developing strategies for a sustainable energy transition. Our energy decisions in the coming years will shape the world for our descendants (Reiter, 2014).

Sustainable energy entails generating and utilizing energy in a manner that meets current needs without endangering the ability of future generations to fulfill their requirements. It is critical to slow the rise of energy demand while improving the energy efficiency of services and systems and increasing the use of renewable energies. Increasing energy availability in developing countries and altering end-user behavior to spend less energy while retaining a good quality of life are also significant energy issues. This will necessitate the active participation of all sectors of society and energy actors, including governments, scientists, local communities, and individual consumers (Reiter, 2014).

In the European context, the European Union (EU) has set ambitious energy goals focused on reducing greenhouse gas emissions, enhancing energy efficiency in buildings, and expanding the use of renewable energy sources. Globally, the energy landscape remains heavily reliant on fossil fuels such as coal, oil, and natural gas (Tian et al., 2022), and this trend is also reflected in the energy composition of the 27 EU Member States, as shown in Figure 1. Since 1965, coal, gas, and oil have dominated the energy mix in these states. As a result, the need to accelerate the transition to alternative energy sources has become increasingly urgent. The EU has positioned itself as a leader in promoting an equitable transition from fossil fuel dependence (McCauley et al., 2023). An energy and climate framework has been established between the European Commission (EC) and Member States to achieve these objectives. This framework limits greenhouse gas emissions and establishes specific renewable energy targets for each Member State. Member States could set national targets to reduce overall energy consumption while adhering to the broader EU goals (Amundsen and Sørensen, 2009).

Over the past decade, the EU has devoted substantial efforts to mitigate the impacts of climate change and enhance energy efficiency. Various plans and strategies have been developed, the most notable being 'Energy 2020.' This initiative aims to reduce energy consumption and greenhouse gas emissions to levels outlined by the EC in 2010 (Langsdorf, 2011) and increase renewable energy use and energy efficiency. The EU achieved its three primary climate and energy targets by 2020, with the assistance of COVID-19 (European Environment Agency, 2023).

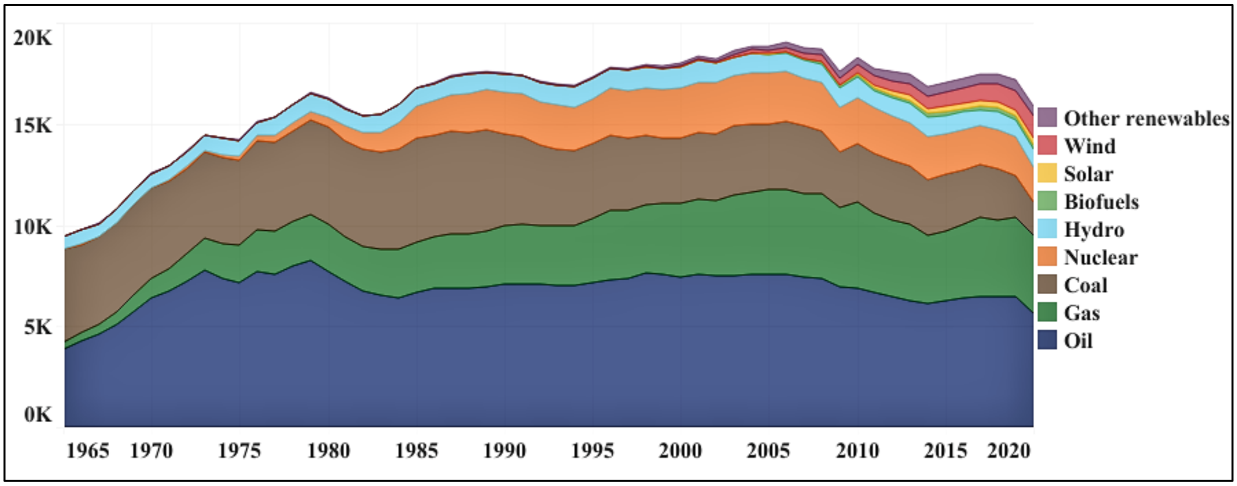

Figure 1 Primary energy consumption (1000 TWh) for the EU-27 from 1965 to 2020
Source: Author's compilation based on Our World in Data (2023)

To sustain these initiatives, the EC introduced the European Green Deal (EGD) in December 2019 as a conclusive strategy to tackle climate change and its associated challenges. The primary objective of the EGD is to transform the EU into a carbon-neutral economic region by 2050 while concurrently fostering a more equitable and prosperous society (Tsetsos, 2021). This vision entails establishing a modern, resource-efficient, competitive economy where its growth is decoupled from the use of resources.

Acknowledging that achieving a zero-emission economy depends on ensuring an environmentally responsible and socially equitable shift, the EC emphasizes the critical importance of mitigating the burden on the most vulnerable segments of society (Sabato and Fronteddu, 2020). In response, the EC introduced the Just Transition Mechanism in 2020, designed to support vulnerable communities in coping with the socio-economic consequences of this transition. The mechanism is intended to protect susceptible EU populations that rely heavily on fossil fuels and carbon-intensive industries. However, more than the allocated funding may be needed to eliminate energy poverty and safeguard all low-income communities.

One of the key proposals within the EGD involves elevating the EU's climate targets for 2030 and 2050. In line with this objective, the EU introduced the 'Fit for 55' initiative in 2021, designed to overhaul and broaden the EU's Emission Trading Scheme (ETS) scope. This initiative's pivotal facet extends the EU's ETS to encompass households and the transportation sector. It holds significant promise, as it incentivizes further reductions in carbon dioxide emissions to achieve a 55% reduction below 1990 levels by 2030. However, expanding the ETS is anticipated to substantially increase energy costs and utility bills, potentially placing economically disadvantaged individuals at risk.

Generally, decarbonizing the energy system requires significant transformation in both supply and demand aspects (Grubler et al., 2018; Riahi et al., 2017), but faces various limitations. These include constraints on renewable energy generation and CO2 removal infrastructure (Jaccard et al., 2021), as well as minimum energy consumption requirements for a decent standard of living (Grubler et al., 2018; Millward-Hopkins et al., 2020). Balancing climate objectives with societal well-being presents challenges, impacting future societal inequality (Leach et al., 2018). Simultaneously, it constrains the allocation of available energy services across the population (Jaccard et al., 2021). If this dual objective is seriously considered in European climate policy, practical constraints emerge on the extent of societal inequality in the future, extending beyond purely political considerations (Leach et al., 2018).

In Europe, due to the Cold War, two groups of countries emerged with different economic and political systems (LaBelle et al., 2022): the 'old' Member States, those that joined the EU before 2004, and the post-communist 'new' Member States, which joined the EU after 2004. The urgency and imperative of transitioning to sustainable energy sources are particularly evident in the old Member States, which have historically been the primary contributors to carbon emissions (Goddard and Farrelly, 2018). These states also possess more significant financial resources to support this transition than their counterparts, where energy poverty remains pervasive (Newell and Mulvaney, 2013). In 2022, over 41 million Europeans (9.3%) encountered difficulties in adequately heating their homes, with the highest proportions observed in Bulgaria (22.5%), Cyprus (19.2%), and Greece (18.7%) (Eurostat, 2023).

Consequently, the transition to green energy and the expansion of the EU ETS to include the household sector is expected to put more households in energy poverty and widen energy inequality among them. The current European energy transition framework overlooks the disparities in energy use among households and Member States. In striving for an energy transition, it is imperative to prioritize energy equality, which is a fundamental element of energy justice, as will be proved later in this research. The fundamental justice issue has, at best, received insufficient attention in the European energy transition framework and, in some cases, has been overlooked entirely (McCauley and Pettigrew, 2022).

Researchers and policymakers need to incorporate the disparities in energy use among the EU Member States into the European regulatory framework of energy transition. Identifying the socioeconomic drivers behind these disparities to mitigate them is also overlooked. Therefore, the objective of this research involves a comprehensive evaluation of disparities in household energy consumption across the 27 EU Member States, coupled with identifying the underlying factors contributing to these disparities. This investigation places a particular emphasis on economic and social dimensions. The research seeks to quantify the influence of these determinants on overall energy consumption inequality and strives to offer valuable insights for its mitigation.

This research also examines the impact of energy price increases between 2021 and 2022 on energy inequality and the advancement of a just transition. Several factors contributed to Europe's energy crisis during this period, beginning with the surge in energy demand due to economic recovery after COVID-19, which was significantly worsened by the ongoing conflict between Russia and Ukraine. As a result, coal and natural gas prices in Europe rose sharply, leading to higher electricity prices, as these fuels are crucial to electricity generation (Szép et al., 2022a). In response, European national energy policies have been significantly reshaped, with EU Member States implementing short—and long-term strategies. Short-term strategies focus on diversifying gas supplies, increasing LNG imports, developing new LNG infrastructure, switching from gas to coal for electricity generation, delaying gas consumption reductions, and extending the operation of nuclear power plants (REPowerEU Plan, 2022). Long-term strategies emphasize advancing the energy transition through renewable energy, energy conservation, and improving energy efficiency (REPowerEU Plan, 2022).

Given that the energy transition is one of the long-term strategies, and the REPowerEU plan in 2022 set higher targets for energy efficiency and the share of renewable energy, evaluating the progress of a just energy transition in the context of rising energy prices is imperative.

The research also explores the interplay between household energy consumption, energy efficiency, and human development. It aims to clarify the connection between increased energy use and higher levels of human development and vice versa. The study advocates for an inclusive energy transition in the EU, aiming to protect low-income households and promote human development, especially in regions with relatively low human development levels.

The research explores several interconnected theories and employs diverse statistical methods to test the hypotheses. The research summary, depicted in Figure 2, outlines the theories, hypotheses, and primary methodologies used.

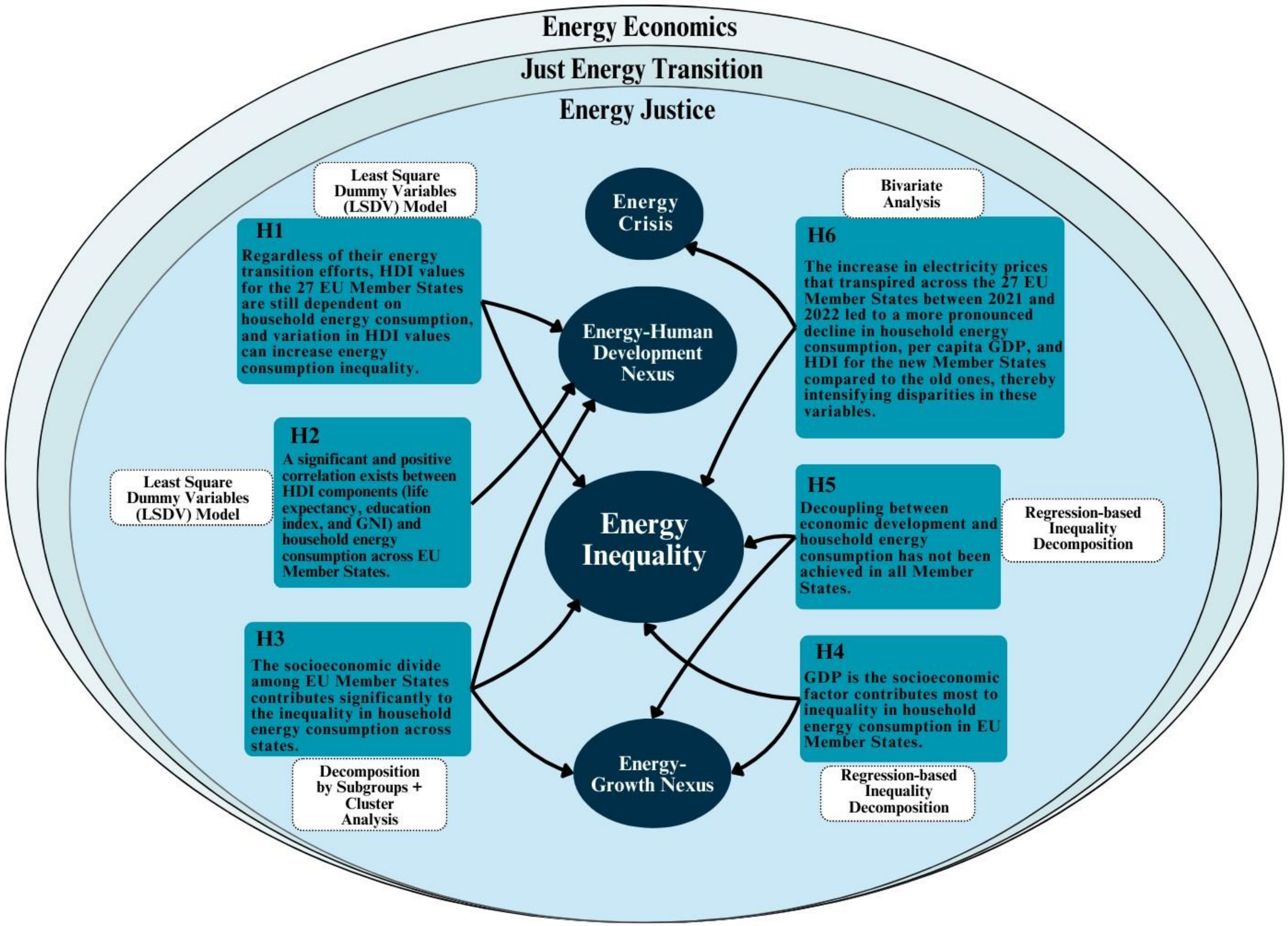

Figure 2 Research Summary
Source: Author's compilation

2 Energy inequality: Concept, theoretical foundations, and research hypotheses

This chapter provides information about energy inequality and defines the most important terms used in this research to be easily identified by readers. Subsequently, it introduces and discusses the economic theories related to energy inequality to place it within a precisely articulated field. This lays the groundwork for the analysis and assists the reader in comprehending the justification for the assumptions made throughout the study. Following this, a review of the literature is provided before the chapter concludes by outlining the hypotheses that will be tested in the study.

2.1 The concept of energy inequality

The term "energy" has Greek roots and indicates "action" or "activity." It was first used in physics in the 19th century, with the development of the mathematical basis of classical physics, thermodynamics, and electromagnetism (Narbel et al., 2014). Energy is fundamentally characterized as the capacity to perform work or induce change and is a foundational concept in numerous scientific disciplines. It can be transformed from one form to another because it exists in various forms, such as thermal, mechanical, electrical, and chemical (Koevering, 1986). Different scientific domains employ the concept of energy in diverse ways. In engineering, it is the ability to do work. Engineers usually study the various forms of energy and their transformation. In economics, it is a factor of production. This indicates that energy is a vital component of the production process used to create products and services (Ulucak et al., 2019). Economists typically study energy generation, consumption patterns, and the impact of energy prices on economic dynamics.

This research investigates energy from an economic perspective, specifically focusing on its use. Energy consumption encompasses all the energy necessary for carrying out actions, manufacturing goods, or simply inhabiting spaces. It can be categorized into primary and final consumption, depending on who uses it and how it is used. Primary energy consumption quantifies the overall domestic energy demand, while final energy consumption pertains to what end users actually use. The key distinction lies in what the energy sector requires for its use, as well as losses incurred during the processes of transformation and distribution (Eurostat, 2020).

Energy consumption, especially in residential settings, can be further classified into direct and indirect categories based on the consumer lifestyle approach (Ding et al., 2017). Direct energy consumption refers to the energy consumed directly by a device or process, such as the energy needed for lighting or heating spaces. In contrast, indirect energy consumption relates to the energy consumed indirectly by a device or process and is essentially the energy embedded in household goods and services (GuangwuChen, 2019). In this research, when energy consumption is mentioned, it solely refers to the final and direct consumption.

The unequal energy usage by end users (consumers, households, or nations) is referred to as energy consumption inequality. This inequality can be assessed through diverse parameters and classifications, from a global perspective to sectoral analyses, extending to household distinctions. Additionally, it can be examined both intra-nationally and internationally. Energy consumption inequality occurs within countries when different income deciles consume different amounts of energy. Consumers consume various amounts of energy based on their ability to afford utility bills, the appliances they use, and the availability of or access to energy sources. Alternatively, energy consumption inequality occurs between countries when there are variations in the amount of energy consumed by countries' inhabitants. It relies on various variables, including weather conditions, the state of the economy, industrialization level, etc. The ultimate aspiration is to attain equality in energy consumption, where everyone globally enjoys access to an equitable allocation of energy resources, ideally sufficient to comprehensively meet their energy requirements. Energy inequality refers to the disparities in energy access and use (Pachauri and Rao, 2012). Since individuals with low energy consumption may also have limited access to energy resources and services, inequality in energy consumption is considered an indicator of energy inequality. As a result, both terms will be used interchangeably in this research.

Energy inequality has emerged as a prominent focal point in scholarly investigation due to its far-reaching societal, economic, and environmental implications. Many academic disciplines, from the social sciences, economics, public policy, and even engineering, have explored different dimensions of energy inequality. These inquiries encompass the determinants of energy inequality, its socioeconomic and health impacts, its effects on vulnerable societal segments, its consequences on environmental sustainability, and the formulation of policy measures and strategic approaches to foster equitable energy access (Volodzkiene and Streimikiene, 2023).

In their systematic literature review, Volodzkiene and Streimikiene (2023) aimed to investigate recent scholarly works addressing energy inequality between the years 2019 and 2023. Their study's primary objective was to clarify the concept of energy inequality and distinguish it from closely related terms. Their examination revealed the prevalence of various terminologies addressing similar facets of energy inequality, such as energy poverty, fuel poverty, energy insecurity, environmental inequality, carbon inequality, and environmental degradation. Among these terms, "energy poverty" and "fuel poverty" emerged as the most frequently used in research.

It is essential to distinguish between these terms and the concept of energy inequality. Energy inequality is characterized by unequal access to energy resources and the persistent challenge of affordability in meeting utility expenses (Chen et al., 2022a). Conversely, "energy poverty" is a multifaceted issue that lacks a uniform and universally accepted definition, both on an international and regional scale (Kashour and Jaber, 2024). Discrepancies in its conceptualization become apparent when comparing developing and developed economies. In developed economies, the emphasis shifts towards ensuring economically viable access to energy services (fuel poverty). In contrast, in developing economies, the focus centers on the absence of access to contemporary energy services (Li et al., 2014).

Energy or fuel poverty is closely linked to the absence of access to energy services or the inability to afford them. In contrast, energy inequality refers to unequal access to energy services. Consequently, energy inequality constitutes one of the contributing factors to energy poverty within a nation.

2.2 Theoretical framework

This section discusses the historical background of energy inequality's most related economic theories. It provides broader sources of knowledge for discussion and demonstrates a comprehensive grasp of ideas and principles associated with energy inequality. According to the previous studies that will be discussed later, the notion of energy inequality developed in the 1970s, during the global energy crisis, as scientists realized the uneven distribution of energy supplies and access to energy worldwide. Consequently, a series of theoretical constructs and conceptual frameworks emerged to explain energy inequality's root causes and consequences. The examination of energy inequality found its place within the domain of energy economics, which centers on the study of energy resources and their dissemination. The underlying factors driving energy inequality must be comprehended to grasp the issue. In the following subsection, energy economics will be discussed, followed by exploring other interconnected theories.

2.2.1 Energy economics

The study of energy resources and commodities is known as energy economics (Sickles and Huntington, 2008). Energy economics is a broad field of science covering issues concerning energy production and consumption in modern societies. Rather than presenting itself as an independent academic discipline, it is better characterized as an applied subdiscipline of economics. This classification is attributed to the diverse array of concerns and research methods it encompasses, which are mutually shared with various academic fields, including econometrics, environmental economics, finance, microeconomics, macroeconomics, and resource economics (Worthy, 2011). Energy economics operates as a subset of applied economics, wherein inquiries are framed using economic principles and methodologies and systematically examined to understand the associated issues comprehensively (Bhattacharyya, 2011).

Energy economics has a history spanning over a century. Still, it only gained recognition as a distinct discipline after the initial oil crisis in the 1970s, as noted by Edwards (2003). A pivotal moment in its emergence occurred in 1972 when Meadows et al. (1972) conducted significant research using system dynamics methods to project a global economic collapse due to diminishing oil reserves and increasing environmental pollution. Shortly after this research was published, the world was profoundly affected by the 1973 oil price shock, seemingly confirming this pessimistic outlook (Zweifel et al., 2017). During this crisis, the Organization of Petroleum Exporting Countries (OPEC) seized control of oil reserves, prohibited U.S. oil companies from production, and restricted oil supply, causing a rapid 300% increase in oil price. This sudden turn of events led to the swift establishment of energy economics as a recognized field of study (Schwarz, 2018).

2.2.1.1 Mainstream economics and opponents' views of economic growth

Countries universally strive for economic objectives such as stable consumer prices, full employment, and higher per capita wealth. Historically, achieving overall economic growth has been the leading way to reach these objectives (Cleveland, 2003). However, scientific investigations highlight a challenge to the sustainability of global economic growth or non-declining production output, as it often depletes essential resources supporting production (Heywood, 1995; Houghton et al., 1996; Postel et al., 1996). Notably, mainstream growth models overlook the role of resources like energy in influencing economic growth (Stern, 2011) despite the significant attention paid to the short-term impact of oil prices on economic activity in macroeconomics (Hamilton, 2009).

The laws of thermodynamics and conservation of matter set boundaries within which the economic system must operate (Ayres and Kneese, 1969; Boulding, 1966). The mass-balance principle dictates that a proportional or greater amount of matter must be utilized as inputs to achieve a specific material output, with the remainder becoming a pollutant or waste product (Ayres and Kneese, 1969). Thus, every production process necessitates minimal material input. The second law of thermodynamics underscores the minimum energy requirement for any transformation, movement of matter, or physical work, given that all economic activities involve some form of work (Stern, 1997).

The primary growth model by Solow (1956) overlooks the inclusion of resources or energy. It asserts that economic growth relies solely on technological advancements, and without them, the economy can persist in a steady state indefinitely. Later extensions incorporate non-renewable resources. For example, Solow (1974) and Stiglitz (1974) argued that the assurance of non-declining production output or sustainability is contingent on technical conditions and institutional arrangements. Technical conditions involve the blend of renewable and non-renewable resources, initial capital and natural resource endowments, and the ease of substituting inputs. The institutional arrangements include market structure, property rights, and values concerning the well-being of future generations.

The elasticity of substitution (σ) between capital and resources is a crucial technical parameter indicating the required increase in one input to maintain the same production level when using the other input decreases (Stern, 2004). A substantial σ suggests easy substitution. When σ is greater than one, inputs become nonessential for production. A unitary elasticity ($\sigma=1$), termed 'perfect substitutability,' implies maintaining production by infinitely increasing capital use as resource use approaches zero (Stern, 2004).

Mainstream economists generally assume the technical feasibility of sustainability ($\sigma=1$) and dismiss cases where the elasticity of substitution between non-renewable resources and capital deviates from unity. When substitution possibilities are substantial ($\sigma>1$), the concern about non-sustainability is deemed negligible. Conversely, if the elasticity of substitution is less than unity, sustainability becomes impractical, mainly when relying solely on non-renewable resources. In addition to substituting capital for resources, the potential for growth or sustained consumption of finite resources is also attributed to technological advancements. Stiglitz (1974) demonstrated that when the elasticity of substitution between capital and resources equals unity, external technical progress enables consumption to expand over time if the rate of technological change divided by the discount rate surpasses the output elasticity of resources. Mainstream economists generally believe sustainability is technically attainable unless proven otherwise (Solow, 1978; 1993).

Contrarily, opponent economists contend that energy plays a vital role in economic growth, asserting that substitution between capital and resources and technological progress have limited efficacy in mitigating resource scarcity (Stern, 1997). Some opponent economists downplay the role of technological change, suggesting that increased energy use explains most apparent productivity growth or that technological innovations primarily enhance productivity by enabling more energy use (Cleveland et al., 1984; Hall, 1986).

The central focus of the debate on the limits to growth and sustainability, as highlighted by Turner (1997), revolves around resource-augmenting technical change and substituting capital and resources. This enduring debate has been characterized by prominent exchanges involving Herman Daly, Robert Solow, and Joseph Stiglitz. Daly (1997; 1997a) critiqued Solow (1974) and Stiglitz (1974) for assuming perfect substitutability between manufactured capital (factories, buildings, tools, etc.) and natural capital (education, skills, culture, and knowledge) in their growth models, emphasizing that human capital is intricately linked to and sustained by energy, materials, and ecological services. Similar viewpoints are shared by other opponent economists (Ayres and Nair, 1984; Costanza and Daly, 1992; Cleveland and Ruth, 1997; Victor et al., 1995).

Substitution can occur within a category of similar production inputs (e.g., different fuels) and between various categories (e.g., energy and machines). Solow (1997) contends that within-category substitution, especially the substitution of renewable for non-renewable resources, is crucial and assumes that new substitutes will consistently emerge. There's a possibility that the elasticity of substitution for within-category types exceeds unity. The historical energy usage pattern in industrial economies reflects substitutions from wood and waterpower to coal, oil, natural gas, and primary electricity (Smil, 1991). However, due to thermodynamic limitations, opponent economists emphasize the restrictions on substituting one type of resource for another, especially replacing natural resources with manufactured capital (Costanza and Daly, 1992). Empirical studies suggest a less-than-unity elasticity of substitution between energy and capital (Koetse et al., 2008).

While technological change is often seen as a potential solution, opponent economists consider it a form of substitution. From a neoclassical perspective, it is assumed that there is an infinite coexistence of efficient techniques at any given time, and substitution takes place among these techniques. Technological advancements entail the development of new, more efficient techniques. However, in essence, these new techniques signify the substitution of knowledge for other factors of production. This knowledge is embodied in enhanced capital goods and more skilled workers and managers, necessitating energy, materials, and ecosystem services for production and maintenance. Consequently, regardless of the sophistication attained by workers and machinery, there are still inherent thermodynamic limitations on minimizing energy and material flows (Stern, 2011).

Mainstream growth models generally ignore energy or only consider the possibility that limited resources might restrict growth. In contrast, opponent economists emphasize energy's central role in driving growth and suggest that there are limits to substitutability and technology, which could ultimately constrain growth. Nonetheless, Stern (2011) proposed a more comprehensive model by modifying the Solow growth model by adding an energy input with low substitutability with capital and labor while allowing the elasticity of substitution between capital and labor to remain at unity. In this model, depending on the availability of energy and the nature of technological change, energy can be either a constraint on growth or an enabler. The model suggests that in the long run, even with labor-augmenting technical change, energy supply or energy efficiency must also be increasing, or eventually, energy will again begin to constrain economic growth. This indicates that the proposed modified Solow growth model recognizes the critical role of energy in driving economic growth and development.

2.2.1.2 Factors influencing the energy-growth nexus

The attention to the connection between energy and economic growth increased following the first oil crisis in 1973. During this time, it was observed that the energy consumption required to generate a dollar's worth of the nation's goods and services exhibited a downward trend. This decrease was a result of enhancements in efficiency and structural transformations within the economy (Stern, 2011). By 2009, the energy consumption level in the US had dropped by 54 percent compared to 1970, as reported by the US EIA (2010). There is a commonly held belief that economic output and resources have separated, suggesting a lasting alteration in the energy-growth relationship (Bohi, 1989; De Bruyn and Opschoor, 1997).

Stern (2011) identifies four key factors influencing the energy-growth relationship: 1) Substitutability of energy and capital, 2) Innovation and energy efficiency, 3) Energy quality and shifts in the composition of energy input, and 4) Shifts in the output.

1. **Substitutability of energy and capital**

Much empirical research examined whether capital and energy function as substitutes or complements and the degree of substitutability (Berndt and Wood, 1979; Koetse et al., 2008; Thompson, 1997). However, most of this empirical literature predominantly focused on cross-price elasticity. Two inputs are considered price substitutes (price complements) if the quantity of one increases (decreases) in response to the rise in the price of the other (Stern, 2011).

Fluctuations in energy prices impact the demand for energy and influence the rates of capital formation and labor utilization (Apostolakis, 1990). The extent of these effects relies on the functional connection between energy and the primary factor inputs. According to Apostolakis (1990), econometric studies have a range of conclusions regarding whether capital and energy act as price complements or substitutes. Time-series analyses, which capture short-term relationships, categorize the two inputs as complements (Berndt and Wood, 1979; Jorgenson and Hudson, 1974; Fuss, 1977). In these studies, the elasticity is negative ($\sigma < 0$), signifying that an increase in the quantity of one input results in a decrease in the price of the other. Conversely, pooled cross-section studies, reflecting long-term relationships, categorize the two inputs as substitutes (Apostolakis, 1987; Griffin and Gregory, 1976; Turnovsk et al., 1982). In such studies, the elasticity is positive (σ > 0), indicating that an increase in the quantity of one input leads to a rise in the price of the other.

Similar conclusions have been reached by Koetse et al. (2008), who conducted a meta-analysis involving 34 prior studies examining cross-price and Morishima elasticities between capital and energy. The Morishima elasticity, which reflects the difficulty of substitution (Blackorby and Russell, 1989), was found to be 0.216 for time series data, indicating that energy and capital are complementary. In panel and cross-sectional data, the Morishima elasticity was higher at 0.592 and 0.848, respectively.

In summary, the studies suggest a less than unity elasticity of substitution between capital and energy, particularly in the short run. Capital and energy appear to be complementary in the short run and substitutes in the long run.

2. Innovation and energy efficiency

Substitution between different production techniques using various ratios of inputs occurs due to changes in the relative prices of the inputs. Changes in the energy-to-GDP ratio not caused by shifts in energy prices are called changes in the autonomous energy efficiency index (Kaufmann, 2004). These could be due to shifts in the composition of input and output, which will be discussed later, not just technological change.

Estimates about the trend in autonomous energy efficiency are inconclusive (Jorgenson and Wilcoxen, 1993). In endogenous technological change, price alterations may prompt technological advancements. Consequently, a rise in energy prices tends to hasten the development of energy-saving technologies, whereas periods of decreasing energy prices may lead to technological changes that increase energy usage (Stern, 2011). However, a rebound effect is observed when energy-saving innovations increase energy consumption, which counteracts the savings achieved through technology (Berkhout et al., 2000).

Technological advancements enhance the energy efficiency of equipment, requiring less energy to produce the same output with the same equipment — *ceteris paribus*. However, as the equipment becomes more energy-efficient, the cost per unit of services provided by the equipment decreases. Typically, a decrease in price results in increased consumption, and some of the *ceteris paribus* gains are offset because there is a tendency to consume more productive services. The additional demand for productive services from the equipment leads to higher energy consumption. This portion of lost energy conservation is called the rebound effect (Berkhout et al., 2000).

The rebound effect can take different forms. It involves a substitution effect where there's an inclination toward increased consumption of the now more affordable energy service, leading to higher energy usage (Khazzoom, 1980). There's also an income effect, which can be positive or negative depending on whether the energy service behaves as a normal good (individuals buy more when their income rises) or an inferior good (individuals buy less when their income rises) (Lovins, 1988). Lovins (1988) discovered that energy services acted as inferior goods in developed economies, resulting in the negative income effect outweighing the positive substitution effect. Additionally, income effects extend to the consumer's consumption of other energy services. Paradoxically, innovations that save energy might contribute to increased energy consumption when the money saved is redirected to other goods and services that require energy in their production (Berkhout et al., 2000).

3. Energy quality and shifts in the composition of energy input

The economic productivity of various energy sources and fuels is not uniform. These variations in productivity are referred to as energy quality (Stern, 2010a). Certain fuels are more versatile and suitable for various activities or valuable tasks. For instance, electricity can significantly transform workplaces and processes, increasing productivity (Enflo et al., 2009), while coal cannot directly power a computer. The quality of a fuel is influenced by a range of characteristics unique to each, such as physical scarcity, capacity for useful work, energy density, cleanliness, storage suitability, safety, flexibility, conversion cost, and more (Berndt, 1978; Cleveland et al., 2000; Schurr, 1982).

Fuel and energy quality can change over time due to technological advancements in production techniques and new products and activities. However, a common belief is that electricity ranks as the highest-quality energy source, followed by natural gas, oil, coal, and wood or other biomass in descending order. This hierarchy aligns with the typical prices of these fuels per unit of energy, serving as one measure of relative energy quality (Stern, 2010a).

There are biophysical and economic methods for evaluating energy quality. The primary biophysical approach involves assessing the exergy-to-total energy ratio, where exergy represents the energy available for performing work and is based on the chemical energy within the material or energy source (Cleveland et al., 2000). A higher exergy-to-energy ratio signifies high energy quality. However, while essential, exergy is just one factor influencing the economic utility of energy sources. The exergy-to-energy ratio remains constant for all chemical fuels, limiting its effectiveness in distinguishing between the qualities of different energy carriers (Cleveland et al., 2000).

Stern (2010a) explored alternative ways to measure energy quality. The most pertinent approach for understanding the impact of minor changes in the energy input's composition on economic output is the marginal product of the fuel. This represents the additional quantity of a good or service produced using one extra heat unit of fuel. It depends on the unique attributes of each fuel, including the activities it is used in, the amount and form of capital, labor, and materials it is used with, and the amount of energy used in each application. More readily available fuels are likely to be used widely and have less productive applications on the margin (Kaufmann, 1994). Consequently, energy qualities measured in this manner are not fixed over time.

Observing the significant changes in the energy consumption mix, Schurr and Netschert (1960) were among the pioneers in asserting that the overall transition to high-quality fuels played a crucial role in diminishing the energy needed to generate a dollar's GDP. Berndt (1990) also highlighted the importance of the evolving energy composition favoring higher-quality inputs. Analyses by Cleveland et al. (1984) and Kaufmann (1992) offered insights, attributing a substantial portion of the US energy/GDP ratio decline to economic structural shifts and the transition from lower to higher quality fuels. They emphasized the necessity for growth models to acknowledge the factors shaping the broad energy and material intensity trends relative to GDP. The substantial decrease in energy use per dollar of GDP in industrialized nations is primarily linked to substituting high-quality fuels for low ones.

Conversely, some studies focused more on the influence of technological advancements on the decreased energy intensity rather than changes in energy quality. For instance, Ma and Stern (2008) discovered that substituting different fuels had minimal impact on China's energy intensity decline from 1994 to 2003. They found that technological progress accounted for a greater reduction in energy intensity compared to the actual decline attributed to fuel substitution. Additionally, shifts in economic activity towards regions with lower-quality energy compositions, like China and India, further contributed to the global increase in energy intensity (Stern, 2010b).

4. Shifts in the output

The composition of economic development output changes over time, transitioning from agriculture to heavy industry and eventually to services and manufacturing. This shift might initially result in increased energy consumption per output unit, followed by a later-stage reduction (Panayotou, 1993). Nevertheless, the consideration of indirect energy usage embedded in manufactured goods and services is often overlooked. When this indirect energy use is considered, sectors like services and households in the US were found to be more energy-intensive than initially perceived (Costanza, 1980). Service industries continue to require substantial energy and resource inputs.

Moreover, the Internet's influence on the energy intensity of commerce has gained scholars' attention (Yi and Thomas, 2007). Compared to newspapers, technologies such as news websites can significantly decrease emissions (Toffel and Horvath, 2004). However, the benefits might be offset by the effects on other activities. Matthews et al. (2002) presented evidence that online book retailing consumes more energy than traditional retail. Also, Herring and Roy (2002) demonstrated that electronic distance learning results in more energy use than conventional distance learning using printed material.

The four factors mentioned above are the primary influencers of the energy-growth relationship. Figure 3 illustrates these factors.

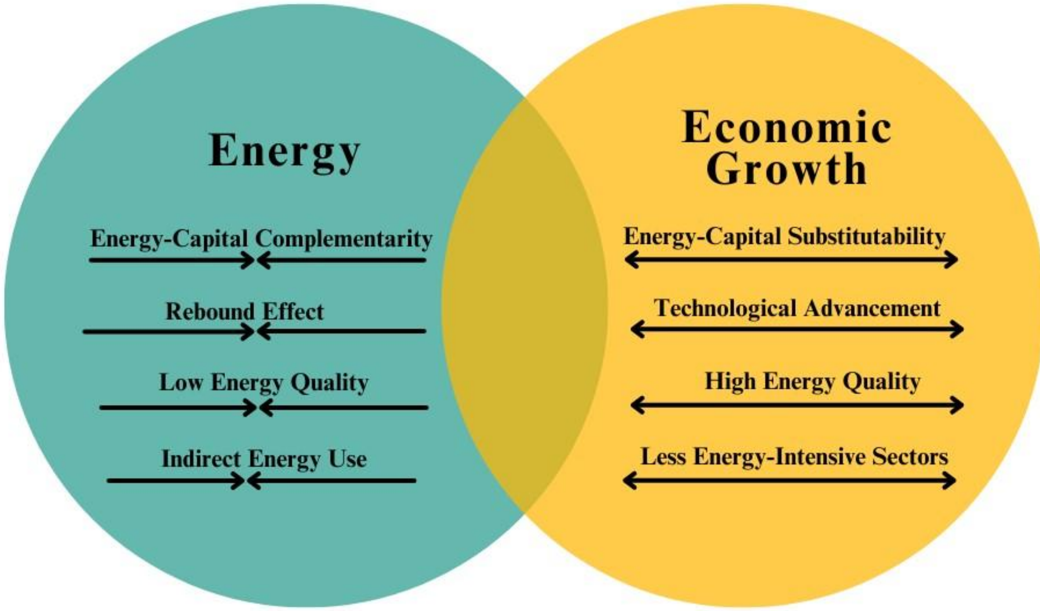

Figure 3 Factors influencing the energy-growth relationship
Source: Author's compilation based on Stern (2011)

2.2.1.3 Energy-growth empirical investigations

The extensive empirical literature examining the relationship between energy consumption and economic growth has grown significantly, particularly following the influential study by Kraft and Kraft (1978) on the US economy. Subsequent research has expanded to include various countries worldwide, spanning different data periods and employing diverse methodological approaches. However, the results obtained exhibit considerable diversity, leading to a lack of consensus among researchers regarding not only the existence of the relationship but also the direction of causality between these two variables (Ozturk et al., 2010; Rahman and Mamun, 2016; Shahbaz et al., 2017).

Researchers have approached the energy-growth nexus through four hypotheses (Ozturk et al., 2010; Rahman and Mamun, 2016). First, the growth hypothesis suggests that increased energy consumption causes economic growth, establishing energy as a crucial input for output. This hypothesis supports studies across different countries and periods (Apergis and Payne, 2010; Ben Mbarek et al., 2018; Bowden and Payne, 2009; Narayan and Smyth, 2008; Tang et al., 2016). Second, the conservative hypothesis suggests a unidirectional causality from economic growth to energy consumption, implying that policies aimed at reducing energy use may not adversely affect economic growth (Huang et al., 2008; Lise and Montfort, 2007). Third, the feedback hypothesis suggests that energy consumption and economic growth are interdependent, featuring bidirectional causality (Belke et al., 2011; Fuinhas and Marques, 2012; Kaplan et al., 2011; Saidi et al., 2017). Lastly, the neutrality hypothesis assumes no causality between energy use and economic growth, positing that policies affecting one variable will not impact the other (Altinay and Karagol, 2004; Hondroyiannis et al., 2002; Menegaki, 2011; Yildirim and Aslan, 2012).

Some studies have validated multiple hypotheses; for instance, Ozturk et al. (2010) validated the feedback and conservation hypotheses, Apergis and Payne (2009) validated the growth and feedback hypotheses, Szép (2014) validated the growth and neutrality hypotheses, and Soytas and Sari (2003) validated the growth, feedback, and conservative hypotheses. It is essential to note that results may vary based on sample selection, investigated countries, and timeframes. However, the methodology employed to test the relationship, the variables considered, and the incorporation of energy quality considerations significantly influence the determination of this relationship (Stern, 2011). Table 1 displays the four energy-growth hypotheses along with their respective assumptions.

Table 1 Energy-growth hypotheses in the literature

Energy-growth Hypothesis	Assumption
Growth	Energy → Growth
Conservative	Growth → Energy
Feedback	Bidirectional Causality
Neutrality	No Causality

Source: Author's compilation

According to Stern (2011), earlier research predominantly employed Granger causality tests on unrestricted vector autoregressions (VARs) in the levels of the variables, while recent studies have shifted toward utilizing cointegration methods. Another distinguishing factor among these studies is the choice between a bivariate model of energy and output or a multivariate model. A third point of divergence lies in whether energy is measured in standard heat units or if an indexing method is employed to address variations in fuel quality.

The contemporary understanding underscores that a Granger causality test on a VAR in levels is inappropriate without cointegration between variables. Toda and Phillips (1993) demonstrated that the test statistic distribution for Granger causality in a VAR with nonstationary variables deviates from the standard chi-square distribution. Consequently, the reported significance levels in early studies on the Granger-causality relationship between energy and GDP might be inaccurate, given that both variables are generally integrated series. If there is no cointegration between the variables, the causality test should be conducted on a VAR with differenced data. Conversely, if cointegration exists, standard chi-square distributions apply when cointegrating restrictions are imposed (Toda and Yamamoto, 1995).

Moreover, early studies that assessed Granger causality using a bivariate model typically yielded inconclusive results (Stern, 1993). Despite the consensus among economists that capital, labor, and technical change significantly influence output, early studies only considered energy as an independent variable. This oversight leads to a lack of cointegration, resulting in a spurious regression. In the presence of omitted variables and no cointegration, results tend to be sample-dependent (Stern and Common, 2001).

The pioneering cointegration study on the energy-GDP relationship was conducted by Yu and Jin (1992). Nevertheless, results from this and subsequent studies diverge based on regions, timeframes, and input and output measures (Stern, 2011). If a multivariate approach aids in uncovering Granger causality relations between energy and GDP, then such an approach should be adopted to explore cointegration relations among the variables. Stern (2000) estimated a dynamic cointegration model for GDP, quality-weighted energy, labor, and capital using the Johansen methodology. The analysis indicated a cointegrating relation among the four variables. Energy was found to Granger cause GDP either unidirectionally or possibly through a mutually causative relationship, depending on the model version used. Warr and Ayres (2010) replicated this model for the United States, substituting Stern's Divisia energy use index with their exergy and useful work measures. They discovered short- and long-run causality from either exergy or useful work to GDP, but not vice versa. Additional studies, such as Oh and Lee (2004) and Ghali and El-Sakka (2004), reached identical conclusions when applied to diverse countries, extending the applicability of Stern's findings beyond the United States.

The empirical investigation of the relationship between energy and growth has produced varied and inconclusive findings. Acknowledging the crucial role of methodology, variable selection, and energy quality considerations, recent research using multivariate approaches has unveiled more nuanced insights into the energy-GDP relationship. This evolving understanding underscores the need for ongoing research to refine our comprehension of the intricate interplay between energy and growth.

2.2.2 Just transition

The close relationship between economic growth and energy use underscores the importance of energy inequality as a critical marker of uneven economic development. Recent research on the energy-growth relationship has expanded to consider its impact on environmental quality, recognizing potential positive or negative externalities (Cicea et al., 2021). Urgent efforts for climate change mitigation now necessitate absolute reductions in the global average per capita energy consumption (Rogelj et al., 2018; Semieniuk et al., 2019). Successfully addressing this challenge requires a comprehensive understanding of global energy consumption inequality. However, traditional measures like carbon taxes may disproportionately affect low-income people due to their higher energy consumption share in expenditure (Boyce, 2018; Fremstad and Paul, 2019). Therefore, adopting a more precise and equitable tool is essential. The concept of a "just transition" emerges as a solution – a process transitioning from a fossil fuel economy to a green, environmentally sustainable one, where growth is detached from resource use. Importantly, this process emphasizes fairness, avoiding harm to specific communities or regions and ensuring no one is left behind (EU, 2022).

The term "just transition" has gained prominence in academic and policymaking literature (Heffron and McCauley, 2022). However, a notable divergence exists in understanding what the concept entails (Heffron and McCauley, 2022), and there is no conclusive definition or established framework for it (Henry et al., 2020). As Wang and Lo (2021) have pointed out, there are five key themes around which discussions of the just transition revolve: (1) a labor-focused concept, (2) an integrated framework for justice, (3) a theory of socio-technical transition, (4) a governance strategy, and (5) public opinion and awareness (see Figure 4).

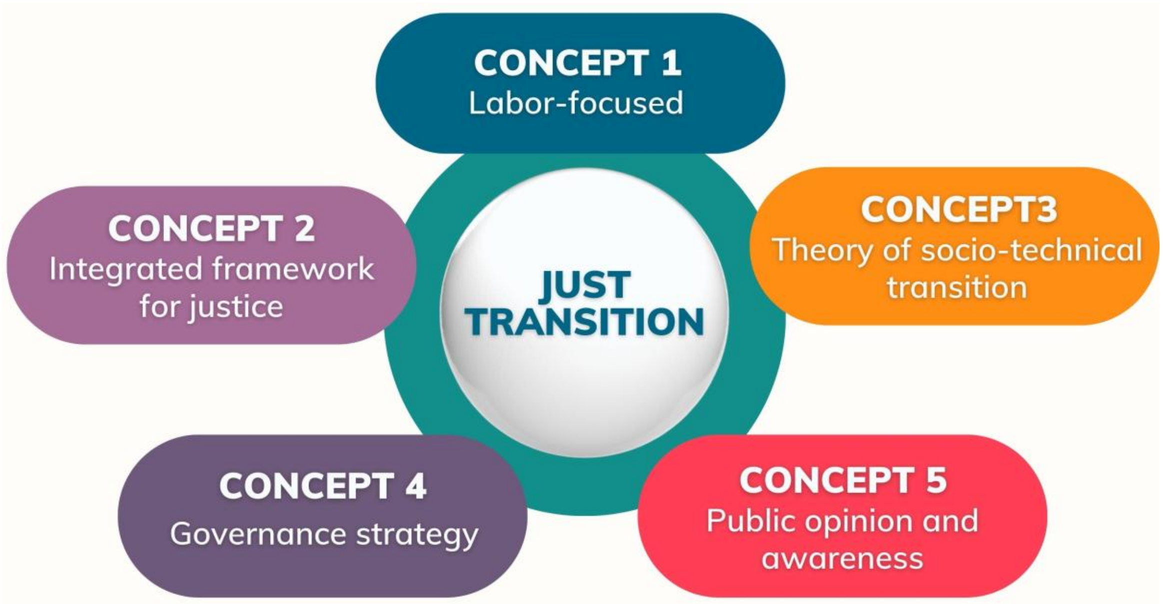

Figure 4 Just transition concepts in literature
Source: Author's compilation based on Wang and Lo (2021)

Global trade unions initially introduced the term "just transition" in the 1980s (McCauley and Heffron, 2018). This concept has since gained recognition within the International Labor Organization (ILO) and the United Nations Environmental Program (UNEP), where its principles have been incorporated into policy documents that emphasize the need to address affected regions (UN Environment Programme, 2008). Additionally, the concept has penetrated various national unions through global union networks and has become a central element of labor-related environmental initiatives worldwide (Goddard and Farrelly, 2018). It has evolved into a rallying term for advocating the inclusion of green jobs as an essential component of the shift away from fossil fuels (Abraham, 2017).

In the initial academic exploration of the concept, researchers employed a historical perspective to trace its origins and explore its contemporary applicability (Wang and Lo, 2021). Numerous scholars have emphasized the concept's roots in labor movements, leading them to perceive a fundamental interconnection between energy transition and economic transition (Carley and Konisky, 2020; Newell and Mulvaney, 2013; Snell, 2018; Stevis and Felli, 2020). From this perspective, transitioning away from fossil fuels implies the widespread closure of numerous associated industries, with the development of new energy sectors offering the potential for green employment opportunities (McCauley and Heffron, 2018). Consequently, critiques have arisen regarding this term's potential to frame the issue as a choice between jobs and environmental or climate concerns, which can be used detrimentally against communities and the transition itself (McCauley and Heffron, 2018).

Nevertheless, the concept of a just transition can extend beyond its initial strategic purpose (Healy and Barry, 2017). It can lead to increased government intervention to create green jobs or provide a labor-based incentive to accelerate decarbonization policies (Altintzis and Busser, 2014). The second phase of academic discourse on this concept saw it becoming intertwined with other justice-related fields, such as environmental, energy, and climate justice (Wang and Lo, 2021). It also promises to unite climate, energy, and environmental justice, offering a more comprehensive framework for analyzing and ultimately promoting fairness and equity throughout the transition from fossil fuels (McCauley and Heffron, 2018).

This expansive perspective on the just transition is embraced in this research by employing a paradigm to integrate household energy consumption inequality into the just transition. As explained in subsequent sections, this is accomplished by utilizing the energy justice framework as an intermediary element.

The third perspective on the concept of a "just transition" conceptualizes it as a socio-technical transition. In this context, socio-technical transitions refer to profound structural changes within systems, entailing intricate and enduring reconfigurations of technology, policy, infrastructure, scientific knowledge, and societal and cultural norms (Newell and Mulvaney, 2013). This perspective posits that technological transitions are most likely to occur inseparably with radical shifts in society's framework, values, and utilization of technology. Consequently, the socio-technical transition framework engages with these transitions' intricate and uncertain nature, acknowledging their potential to bring about fundamental changes in individual lives and society (Lachman, 2013).

Geels et al. (2018) noted that adopting a socio-technical transitions perspective is better suited to addressing the details of the challenges involved in transforming energy service systems to mitigate global carbon emissions. This perspective contrasts with dominant analytical viewpoints rooted in neoclassical economics and social psychology and primarily focuses on incremental changes. These prevailing viewpoints offer limited guidance on facilitating the transformative shifts necessary for addressing the energy transition's complexity and scale.

Numerous analytical frameworks related to socio-technical transitions have been applied to various aspects of the energy transition discourse, such as sustainable development and the transition to low-carbon energy sources (Andrews-Speed, 2016; Geels, 2002; Geels et al., 2018; Kemp et al., 2005). However, these approaches have faced criticism for their noticeable lack of attention to political dynamics, a pivotal element within the transition's framework (Healy and Barry, 2017). Instead, they focus narrowly on policy management, often focusing on specific energy technologies or energy fuels (Healy and Barry, 2017).

Moreover, given that energy transitions entail systemic shifts, they inherently carry the risk of unequal distribution of benefits and losses. Consequently, this unequal distribution is fundamental to ensuring system transitions are more sustainable and just (Williams and Doyon, 2019).

Moving towards a governance-oriented perspective of the just transition, scholarly literature explores how the injustice of transition processes is influenced by the prevailing political context. The concept of a just transition necessitates decision-making procedures that are participatory and inclusive. The formation of coalitions involving diverse stakeholders, cultivated through engagement with social movements and community representatives, plays a pivotal role in crafting an alternative vision and facilitating financing of what we can term 'just energy' (Newell and Mulvaney, 2013). Consequently, the conceptualization of just transition governance predominantly unfolds within the framework of democratic systems, wherein the significance of networked and participatory governance mechanisms is greatly emphasized (Wang and Lo, 2021).

A robust coalition comprises a diverse range of actors, serving to mitigate conflicts among stakeholders with varying interests and fostering open and democratic participation while reducing exclusion and inequality, thereby ensuring that all voices are heard (Sovacool et al., 2019). However, it is essential to note that just transitions do not inherently occur in democratic regimes; instead, democracies possess certain institutional advantages that, to some extent, facilitate the realization of a just transition due to their political system (Sovacool et al., 2019).

In contrast, as Huang and Liu (2021) explained, energy transition processes in authoritarian governance models adopt a top-down approach that prioritizes policy efficiency while affording limited room for participatory decision-making and context-specific policy adjustments. This divergence necessitates a call for more nuanced and long-term perspectives on the social injustices that arise during energy transitions within authoritarian regimes.

Finally, a substantial body of academic literature characterizes the concept of a just transition as a perspective rooted in public perceptions and support for energy transitions. Examining public attitudes toward energy transition becomes crucial, given its pivotal role in seamlessly implementing renewable energy projects and policies (Bauwens and Devine-Wright, 2018). Public view is increasingly recognized as a potential obstacle to realizing renewable energy sources. Despite a general inclination towards renewables, specific projects often encounter negative sentiments, leading to conflicts between the public and project leaders (Karasmanaki and Tsantopoulos, 2021).

Public opinions and attitudes toward energy transition and renewable energy initiatives are subject to many influences. These inclinations may be fueled by environmental values and concerns, particularly regarding climate change (Karasmanaki and Tsantopoulos, 2021). Participation in community energy initiatives also plays a significant role. It is observed that members exhibit considerably more favorable attitudes toward renewable energy than their non-member counterparts (Bauwens and Devine-Wright, 2018). Procedural fairness emerges as another vital determinant, as it enhances community engagement, thereby reducing tensions and enabling more effective deliberative processes that can secure public support (Mundaca et al., 2018).

Additionally, visual appeal and economic benefits significantly influence public opinions and attitudes toward transitioning to alternative energy sources. Empirical findings (Olson-Hazboun et al., 2016) suggest that public support for renewable energy is less closely tied to environmental beliefs and is instead influenced by factors such as economic benefits and concerns over landscape alterations. For example, the degree of support for renewable energy among individuals in the Rocky Mountain region of the United States is closely linked to how often they witness nearby wind turbines, regardless of their actual proximity to them.

Within the EU Member States, the public exhibits a widespread awareness of and positive attitude toward renewable energy in a comprehensive manner. However, a distinct preference for solar energy is evident, coupled with significant doubt regarding wind energy, mainly stemming from its perceived impact on the natural environment (Karasmanaki and Tsantopoulos, 2021). Other variables, including dependence on fossil fuels, also come into play. The Visegrad four countries (Czechia, Hungary, Poland, and Slovakia) are often characterized as lagging in climate action within the EU, given their domestic energy policies' emphasis on fossil fuels and large generation units, which occasionally diverge from the EU's ambitious energy-climate agenda (Surwillo and Popovic, 2021).

The "just transition" concept presents a multifaceted and evolving framework that transcends its origins in labor movements to encompass broader environmental, energy, and climate justice dimensions. It underscores the complex interplay between societal values, technological shifts, and governance structures in pursuing equitable and sustainable energy transitions. Moreover, public perceptions and attitudes cannot be underestimated when shaping the trajectory of renewable energy projects and policies. As the discourse surrounding the just transition continues to evolve, it offers invaluable insights and perspectives that can guide policymakers, researchers, and advocates toward a more inclusive and equitable approach to navigating the global transition away from fossil fuels.

Energy Transition Index (ETI)

The Russia-Ukraine war revealed the vulnerabilities of energy security systems, forcing countries to take emergency measures to maintain energy supply. Europe avoided energy shortages through solid policies, alternative fuel supply agreements, LNG infrastructure development, demand management, and regional collaboration. However, the global energy crisis highlighted issues of inclusiveness, with poor households suffering the most from high energy prices and food inflation. Energy market volatilities also impacted the competitiveness of energy-intensive industries and raised concerns about employment in local communities (World Economic Forum, 2023).

In response to the crisis, global investments in low-carbon energy technologies reached a record $1 trillion in 2022 (BloombergNEF, 2023). The introduction of significant legislative proposals, such as the US Inflation Reduction Act and the EU Net-Zero Industry Act, accompanied this. The electric vehicle market saw remarkable expansion, recording over 10 million unit sales and electric vehicles constituting 14% of new car purchases (IEA, 2023). Additionally, as of June 2022, 702 of the world's largest corporations have pledged to achieve net-zero targets (NewClimate Institute, 2022).

Given these developments, countries must accelerate their energy transition in a balanced manner that addresses equity, sustainability, and security. Policies play a central role in shaping this transition by promoting investments in clean energy, fostering innovation, encouraging energy efficiency, and ensuring that the benefits are spread across all segments of society.

The Energy Transition Index (ETI), developed by the World Economic Forum, offers a structured approach to assessing and comprehending the efficacy of energy systems and the preparedness for energy transition across nations. Established in 2014, this annual index evaluates system performance through the lens of the energy triangle, which emphasizes equitable access, security, and sustainability. Equity endeavors to ensure the affordability of modern and clean energy for all, while security aims at diversifying energy sources, trade partners, and electricity generation methods. Sustainability focuses on reducing CO2 and methane intensity in energy production, promoting responsible consumption with lower per capita energy and emissions footprints, and increasing the utilization of clean energy in final demand (World Economic Forum, 2023).

Transition readiness measures the advancement of the energy transition by evaluating the capacity to establish a robust enabling environment. This environment relies on a solid regulatory framework and the ability to attract and mobilize significant capital investments. Transition readiness encompasses five key dimensions: Regulations and political commitment, Finance and investment, Education and human capital, Infrastructure, and Innovation (World Economic Forum, 2023). Figure 5 illustrates the framework of the ETI.

The Energy Transition Index (ETI) ranges from zero to one hundred, with higher scores indicating better energy transition performance within a country. Over the last decade, global ETI scores have seen a 10% improvement, reaching an average of 56.3 globally in 2023. This improvement is driven by a 19% increase in transition readiness scores but only a 6% increase in system performance scores (World Economic Forum, 2023). Table 2 presents the ETI values for the 27 EU Member States in 2014 and 2023. Nordic countries such as Sweden, Denmark, and Finland consistently maintain top rankings, achieving high system performance and transition readiness scores. In 2023, Sweden, the highest-ranked country, attained a system performance score of 81.0, while Denmark, the second-ranked country, achieved the highest transition readiness score of 79.8.

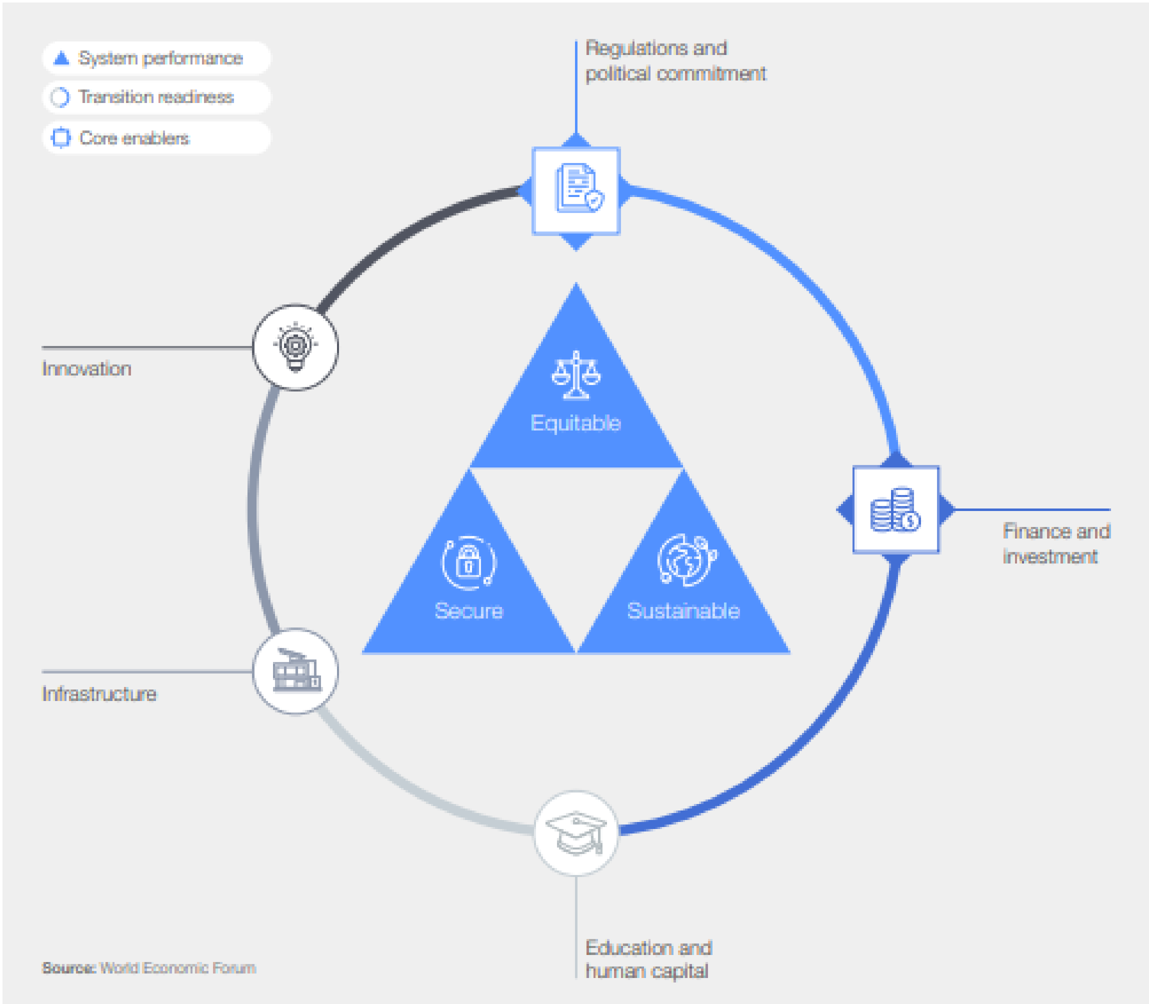

Figure 5 Energy Transition Index (ETI) framework
Source: World Economic Forum (2023)

Eastern and Southern European countries recorded the lowest ETI scores in 2023, including Malta with 54.9, Cyprus with 56.4, and Romania with 56.8. Malta ranked 61st globally and was the only state with a score below the global average in 2023. Regarding progress in energy transition, Hungary demonstrated the highest increase in ETI from 2014 to 2023, with a 23.2% rise, followed by Malta with 22% and Lithuania with 21.4%. Conversely, Romania, Denmark, and Germany exhibited the lowest percentage increases, with 3.1%, 5.1%, and 6%, respectively.

The table illustrates the leading and lagging performers in energy transition within the EU, revealing a clear correlation between ranking and the economic development of Member States. Most top-ranked states are economically more developed. However, exceptions such as Belgium and Ireland exist; these states are highly developed economically but display relatively weak energy transition performance.

Table 2 Energy Transition scores for the 27 EU Member States in 2014 and 2023

Country	ETI 2014	ETI 2023	Global Rank 2023	System Performance 2023	Transition Readiness 2023	ETI Increase (%)
Sweden	72.1	78.5	1	81.0	74.8	8.9
Denmark	72.4	76.1	2	73.7	79.8	5.1
Finland	63.1	72.8	4	68.9	78.6	15.4
France	64.2	70.6	7	73.3	66.5	10.0
Austria	62.5	69.3	8	69.2	69.5	10.9
Netherlands	59.4	68.8	9	65.7	73.5	15.8
Estonia	57.6	68.2	10	74.2	59.2	18.4
Germany	63.7	67.5	11	64.6	71.9	6.0
Portugal	57.8	65.8	15	66.7	64.5	13.8
Spain	56	65	16	65.1	64.7	16.1
Hungary	52.2	64.3	18	68.8	57.5	23.2
Luxembourg	56.5	64.2	20	61.5	68.2	13.6
Latvia	55.2	63.4	26	69.0	55.1	14.9
Slovenia	56	62.6	29	68.0	54.4	11.8
Croatia	54.9	62	33	67.0	54.4	12.9
Lithuania	50.4	61.2	36	62.0	60.1	21.4
Greece	53.4	60.9	37	60.3	61.7	14.0
Italy	54.3	60.6	38	63.9	55.6	11.6
Poland	49.2	59.7	40	63.0	54.7	21.3
Ireland	53.9	59.3	41	61.3	56.3	10.0
Belgium	55.1	59.2	42	59.6	58.5	7.4
Slovakia	51	58.8	44	64.9	49.7	15.3
Czech Republic	52.8	58.6	45	66.2	47.2	11.0
Bulgaria	53.9	57.2	48	62.8	48.9	6.1
Romania	55.1	56.8	49	65.8	43.3	3.1
Cyprus	48.3	56.4	52	61.7	48.4	16.8
Malta	45	54.9	61	61.5	45.1	22.0

Source: Author's compilation based on World Economic Forum (2023)

2.2.3 Energy justice

Ideas and theories about equity and justice have been central to profound intellectual and ethical debates across many generations (Cowell, 2009). Despite occasional interchangeable usage, it is essential to recognize that equity and justice are separate and distinct concepts (Enschede et al., 2018). Accurate equity suggests that to promote fairness, a person or group may need to encounter or obtain something unequal (Romero-Lankao and Nobler, 2021). Conversely, justice involves the removal of barriers that impede equity, intending to establish a system that grants individuals and groups equitable access to resources, choices, and opportunities to achieve their life goals (Silva, 2009).

Energy justice refers to establishing equity within the energy infrastructure's societal and economic dimensions while mitigating the social, economic, and health disparities experienced by historically disadvantaged populations because of the energy system. It aims to enhance energy accessibility, affordability, and environmental sustainability for all communities (Baker et al., 2019). As McCauley et al. (2013) articulated, energy justice is a conceptual framework that aspires to furnish every individual, regardless of geographic location, with secure, cost-effective, and ecologically sound energy solutions. This framework serves as a valuable tool for examining the challenges inherent in the global energy system. It offers guidance for making more equitable energy investment decisions, both in the public and private sectors (McCauley et al., 2019).

2.2.3.1 Energy justice and energy trilemma

Understanding the complex network of factors in global energy analysis depends on three essential elements: production, consumption, and disposal. A prominent energy disparity within contemporary society emerges from its heavy reliance on fossil fuel-based production systems, deeply rooted in history, to meet rising energy demands. According to McCauley (2018), humanity faces three significant challenges arising from the global energy system. First, there is a need to secure the necessary resources to meet the increasing energy demand, all while ensuring that the shift from fossil fuels to renewable sources does not compromise the satisfaction of basic energy requirements. Second, it is crucial to guarantee universal access to energy, acknowledging its essential status comparable to basic needs such as food and clean water. Third, an immediate commitment to the sustainable and long-term extraction, generation, and management of energy resources globally is imperative. These three challenges converge to form what is commonly referred to as the "energy trilemma," depicted in Figure 6. This trilemma embodies the interplay between security, poverty alleviation, and climate considerations, with the prospect of mitigating these challenges through the lens of energy justice.

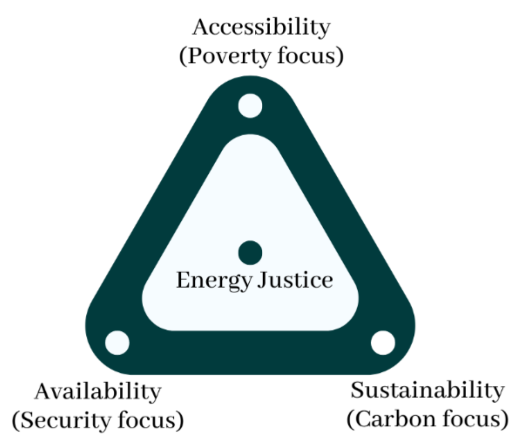

Figure 6 Energy Trilemma
Source: Author's compilation based on (McCauley, 2018)

The contemporary energy security concept is different from the classic concept. In the 1970s and 80s, energy security primarily meant ensuring a stable supply of inexpensive oil amidst exporters' threats of embargoes and price manipulations (Yergin, 1988). However, present-day challenges extend beyond oil and encompass broader issues (Yergin, 2006), intertwining energy security with concerns like equitable access to modern energy and addressing climate change (Goldthau, 2011).

In academia, various conceptualizations of energy security have emerged, including the "four A's of energy security" introduced in 2007 by the Asia Pacific Energy Research Centre (APERC, 2007). These four A's – availability, accessibility, affordability, and acceptability – frequently serve as the starting point for contemporary energy security studies. Notably, availability and affordability, two of the four As, have been central in classic energy security studies and remain integral to the International Energy Agency's definition of energy security as "the uninterrupted availability of energy sources at an affordable price" (Cherp and Jewell, 2014). The remaining two, accessibility and acceptability, have a more intricate history, initially outlined in the World Energy Council's Millennium Declaration (WEC, 2000) but only linked to energy security in the 2007 APERC report.

For energy to be secure, sources must be consistently available without adverse environmental impacts and accessible to producers and consumers at an affordable cost. Security discussions predominantly focus on the availability of energy supplies, stemming from the dynamics of resource abundance or scarcity globally. Balancing the often-conflicting goals of producers and consumers requires placing justice at the forefront of policy solutions (Boersma, 2015). Decision-makers should prioritize providing access to energy to combat poverty, ensuring that the most vulnerable global populations have heating and electricity (Chidebell-Emordi, 2015). Additionally, decision-makers must consider how current and future energy investments can facilitate or impede progress.

To establish a just global energy system, the endeavor to secure resources must extend beyond net suppliers and consumers to encompass those who currently lack access. The long-term consequences of our energy decisions must also be considered. It is impossible to ignore rising carbon emissions. If low- or zero-carbon energy solutions are provided by sustainable energy, a just global energy system entails rebalancing all three pivotal facets: accessibility, availability, and sustainability.

2.2.3.2 Energy justice concept

The concept of "energy justice" emerged because of a maturing comprehension of the interconnections between social justice and energy issues. As it evolved, it integrated existing literature on environmental and climate justice (Hall, 2013). However, the enduring and worsening instances of environmental shortcomings underscore the inadequacy of the influence of environmental and climate justice principles on decision-making processes. These persistent failures have highlighted the growing imperative to identify alternative, more precise justice models explicitly focusing on energy-related challenges. Energy justice represents one such outcome (Jenkins, 2018). Nevertheless, it maintains a close and interconnected relationship with climate and environmental justice.

Due to compelling evidence highlighting the disparities in environmental burdens faced by communities of color, coupled with the limited protective impact of recent environmental legislation, the concept of environmental justice emerged in the early 1980s, serving both as an activist initiative and an academic discipline (Bullard et al., 2007). Environmental justice seeks to ensure the fair distribution of environmental risks and access to natural resources for all while promoting meaningful involvement in decision-making processes and equitable treatment in the distribution of benefits (Schlosberg, 1999). This concept inspired the climate justice concept, explicitly addressing the pressing challenges of climate change that disproportionately impact communities of color and working-class regions. The origin of climate justice can be traced back to the late 1990s and early 2000s, driven by the recognition that individuals in the Global South, despite contributing minimally to the origins of the climate change issue, would bear a disproportionately heavy burden of its consequences (Jenkins, 2018).

Throughout its extensive historical development, energy justice emerged during the 2010s. A prevailing vision of a just energy society involves the equitable distribution of benefits and burdens related to the production and consumption of energy services and the equitable treatment of individuals and communities in energy-related decision-making processes (Baker et al., 2019). Examining the distinct contributions of energy justice that set it apart from environmental and climate justice is crucial. According to Jenkins (2018), energy justice has at least three unique characteristics that distinguish it from existing environmental and climate justice scholarship and enhance its legitimacy. First, energy justice has more potential to impact policy due to its focus on particular systems and subject matter. Second, in contrast to environmental and climate justice, energy justice originated as an academic concept, affording it a well-defined strategy and content. Finally, it is underpinned by a robust methodological tradition, showcasing a wide range of applications in both academic research and policy-relevant contexts. Figure 7 illustrates the timeline and key environmental, climate, and energy justice claims.

In the theoretical realm, the term 'energy justice' began garnering increased attention in early 2013 and emerged as a subject of scholarly inquiry. In this era, scholars defined it as a concept and constructed theoretical frameworks (Heffron and McCauley, 2017). The literature dedicated to energy justice heavily relies on two prominent theoretical paradigms (Lacey-Barnacle et al., 2017).

Firstly, the 'three core tenets' framework initially articulated by McCauley et al. (2013) encompasses procedural justice, distributional justice, and *recognition* justice. Furthermore, a fourth dimension, restorative justice, was recently introduced by Heffron and McCauley, 2017. This addition draws inspiration from principles of remediation found in legal theories related to criminal justice and aims to address perceived instances of injustice in the energy context.

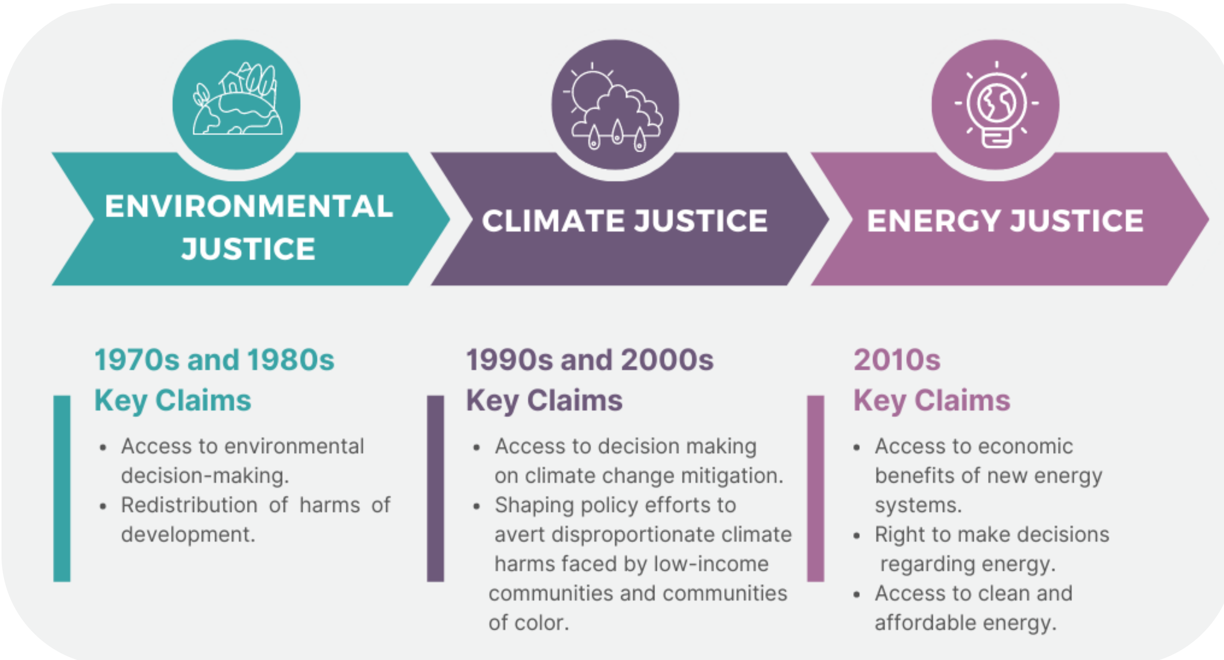

Figure 7 Timeline and key claims of environmental justice, climate justice, and energy justice
Source: Author's compilation based on (Baker et al., 2019)

Secondly, given the nature of energy justice as a field rooted in addressing a central 'problem' concerning energy, much of its scholarly endeavors have been dedicated to shaping policy outcomes. In this regard, the 'eight-principle decision-making framework,' articulated by Sovacool and Dworkin (2015), seeks to offer policymakers a comprehensive toolkit. This toolkit involves considerations such as availability, affordability, transparency and accountability, sustainability, intra-generational equity, inter-generational equity, and responsibility to guide policy formulation and implementation in energy justice.

Drawing from the initial definition and conceptual framework, distributional, *recognition*, and procedural justice are the three fundamental principles of energy justice. Distributional justice addresses the unequal physical distribution of environmental benefits and burdens and the unequal assignment of related responsibilities (Walker, 2009). Since specific resources are often distributed unjustly, justice calls for combining evidence of these inequalities with arguments for fair treatment (Eames and Hunt, 2013). Consequently, exploring the extent to which the location of energy infrastructure influences distributional disparities becomes a promising avenue for empirical research. Furthermore, the concept of energy justice extends to issues surrounding physical access to power and heating, raising questions about the degree of personal freedom (Jenkins et al., 2016).

The issue of energy inequality, encompassing disparities in energy supply, distribution, access, and end-use, falls within the principle of distributional justice. Solutions aimed at promoting energy justice encompass measures to enhance energy service accessibility, reduce the cost of energy infrastructure, and ensure that energy systems are designed and implemented with the needs and interests of all communities and groups in mind.

The second principle, *recognition* justice, extends beyond mere tolerance and calls for ensuring that individuals have full and equal access to political rights, fair representation, and protection from physical harm. It involves acknowledging diverse perspectives based on social, cultural, ethnic, racial, and gender distinctions (Schlosberg, 2003). The third principle, procedural justice, advocates for fair processes that engage all stakeholders inclusively (Bullard, 2005). It asserts that every group should be able to participate in decision-making, with their input receiving due consideration. Both government and business entities are expected to engage impartially, provide comprehensive information, and be accountable (Davies, 2006). *Recognition* justice and procedural justice share some conceptual common ground, mainly since *recognition* justice demands equal representation for all individuals. Furthermore, it can be argued that the enforcement of *recognition* justice is a prerequisite for any notion of procedural justice. Equitable participation in decision-making becomes impossible without acknowledgment, and discrimination prevails.

The central challenge within the energy justice domain involves applying these three principles to energy policy across the entire energy system. To address this challenge, Jenkins et al. (2016) advocate for a fusion of social science perspectives on energy policy with natural scientific insights. This approach broadens the exploration of distributional, procedural, and *recognition*-based justice in energy production and consumption contexts. Globally, initiatives are underway to develop energy justice as an emerging study area as societies actively shape energy policies and reshape global energy systems (McCauley et al., 2013).

As previously indicated, this research utilizes a paradigm rooted in the concept of a just transition, which is intertwined with various justice-related domains, including environmental, energy, and climate justice. The primary objective is to incorporate the consideration of inequality in household energy consumption into the just transition framework. This is achieved by employing the energy justice framework as an intermediary element.

The concept of a just transition, which promotes aspects of equity and justice in addressing energy, environmental, and climate challenges, has been gaining recognition within the scholarly community (Kenfack, 2018; Newell and Mulvaney, 2013; Snell, 2018; Stevis and Felli, 2015). Given that energy consumption equality plays a pivotal role in advancing the distributional dimension of energy justice, and energy justice is an integral aspect of the just transition framework, it becomes evident that energy consumption equality is essential for a just transition. Figure 8 shows the employed paradigm that connects energy consumption equality and the just transition.

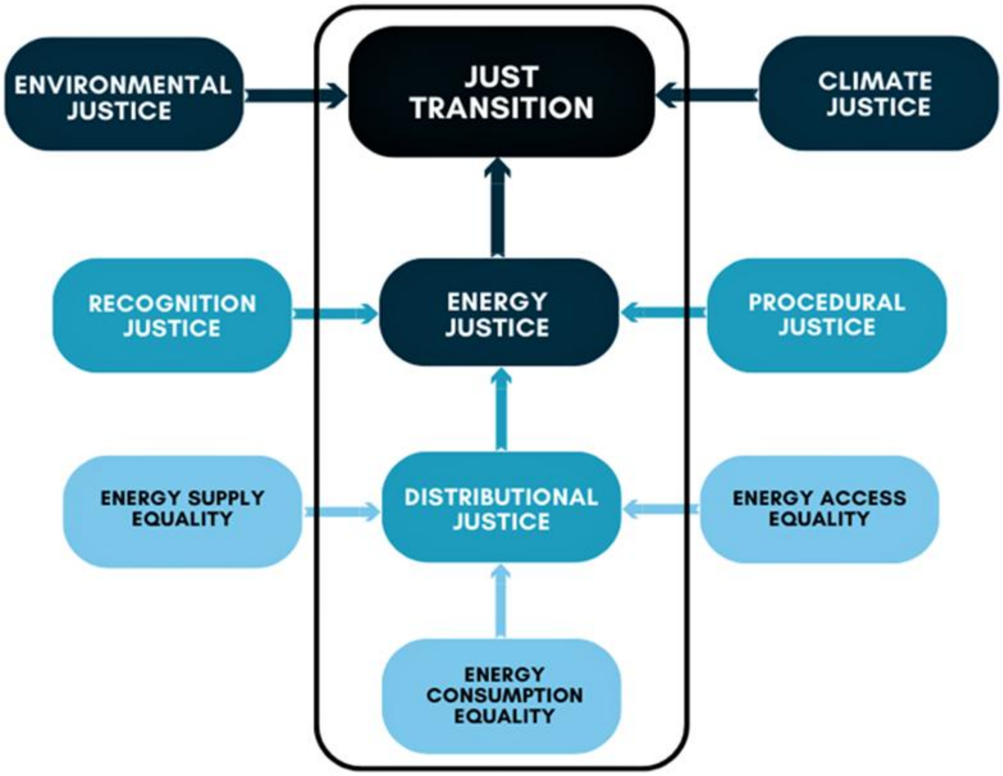

Figure 8 Energy consumption equality in relation to the just transition
Source: Author's compilation

2.3 Literature review and research hypotheses

This section discusses the literature on the relationship between human development and energy consumption, the drivers of energy inequality, and the relationship between energy prices and energy consumption. Additionally, it outlines the hypotheses to be tested later in the study.

2.3.1 Development and energy consumption

Development is a complex and ongoing process that results in significant and enduring enhancements through economic and societal changes (Schaffner, 2014). The primary objective of development is the enhancement of human well-being. Given that well-being is a multifaceted concept with implications for prioritization and trade-offs, the definition of development in the context of the social requirements and aspirations of individuals, groups, or nations is a matter of national and personal choice (De Janvry and Sadoulet, 2016).

De Janvry and Sadoulet (2016) assert that the extent and speed of growth in per capita income is the foremost measure of development. Income is derived from producing goods and services and is distributed as wages or returns on capital and entrepreneurship. Economic growth, which is the expansion in the worth of all goods and services produced within an economy, is another indicator. Economic growth is necessary for sustainable development. However, it does not guarantee improvements in material living standards for all individuals, and an increase in income does not always lead to improved well-being. Non-income aspects like health and future opportunities can also affect living standards (Schaffner, 2014).

For ecological economists, there is a realization that economic growth does not necessarily go hand-in-hand with an increase in the well-being of people. Standard measures of economic output, such as Gross National Product (GNP), do not reflect the growing disparity between rich and poor in most nations or the environmental degradation that diminishes the health of people, communities, ecosystems, and the economy (Daly and Cobb, 1989).

The emphasis on human needs and well-being as central development objectives has been reinforced by Streeten (1994) and the United Nations Development Program (UNDP), mainly through its Human Development Report initiated in 1990 (UNDP, 2023). They argue that a nation's true wealth resides in its people, not just capital accumulation. UNDP's Human Development Index (HDI), incorporating health and education indicators, underscores the importance of basic needs in enhancing well-being, as access to health and education significantly contributes to development.

In an academic context, human development can be understood as increasing individuals' capacity to achieve what they find valuable and have reasonable grounds to value. It transcends mere financial well-being and clearly distinguishes between the means and the ultimate objectives of development (Conceição et al., 2021). Health and education possess inherent worth beyond their role in improving productivity. When combined with income, they collectively constitute the components of the HDI (Conceição et al., 2021).

Among the essential human needs, access to energy stands out as a critical factor in daily life and is a prerequisite for human development. Reliable energy sources like electricity and clean cooking fuels are fundamental for sustaining a high quality of life and facilitating access to healthcare (Acheampong et al., 2021). Consequently, energy consumption can also measure human development or, at the very least, show a correlation with it.

Nonetheless, it is noteworthy that linking increased energy consumption to higher human development has undergone revision due to mounting concerns over climate change and the imperative of energy efficiency. While energy is essential for a wide range of activities, it is also a primary contributor to greenhouse gas emissions, which pose significant environmental threats. In addition, as nations progress, the correlation between energy consumption and HDI becomes less robust, and the significance of human development diminishes (Wu et al., 2010). Therefore, in the case of the most developed nations, the phenomenon known as "saturation" occurs, where an increase in energy consumption no longer leads to a corresponding increase in human development.

The intricate interplay between energy consumption and human development has garnered significant attention in scholarly circles since the 1990s, notably with C.E. Suarez's initial investigation into the correlation between HDI and energy usage (Ediger and Tatlıdil, 2006). More recent studies, exemplified by Martínez and Ebenhack (2008) and Wu et al. (2012), have affirmed a non-linear relationship between energy consumption and HDI, with noteworthy disparities across countries.

In developed nations' contexts, Wu et al. (2010) advocate reducing energy consumption through enhanced efficiency to sustain a high standard of living while mitigating environmental impacts. Conversely, constrained by resource limitations, developing nations often need to increase energy demand to boost human development.

Pîrlogea (2012) contributes nuanced insights by outlining the differential impacts of fossil fuel and renewable energy consumption on HDI across European nations. Their findings underscore the complex relationship between energy choices, economic development, and human well-being, reflecting that responses to energy consumption effects can shape development trajectories. According to this study, although energy consumption enhances economic development, it does not necessarily contribute to human development. Moreover, it adversely affects the environment, negatively impacting health and well-being.

Beyond the macro-level dynamics, the HDI's components—life expectancy, education level, and GNI—offer a nuanced understanding of development's multifaceted nature. Energy consumption emerges as a crucial determinant, even though with varied implications. For instance, energy-related air pollution poses significant health risks, negatively impacting life expectancy (Sarkodie et al., 2019; Wang et al., 2020). Yet, the type of energy source matters; clean energy fosters positive health outcomes (Wang et al., 2019; Nkalu and Edeme, 2019).

Education's relationship with energy consumption exhibits intricate patterns dependent on the development level. Developed countries witness declining energy use as technology enhances educational efficiency, whereas in developing contexts, expanding education may drive energy demand (Inglesi-Lotz et al., 2017).

Similarly, the nexus between energy consumption and income or GNI unfolds in complex ways. While energy expenditure may increase with rising income, this relationship is not strictly linear and may remain steady beyond certain thresholds (Cayla et al., 2011). Moreover, the causal linkages between electricity consumption and income exhibit bidirectional relationships, with the nature of these relationships dependent on specific socio-economic contexts (Dey, 2019; Chen et al., 2022b).

The literature underscores the nuanced and context-dependent relationship between energy consumption and human development. Acknowledging the multidimensional facets of development and the diverse impacts of energy choices is crucial for formulating effective policies that promote sustainable and inclusive progress.

The first two hypotheses emphasize the significance of human development in relation to residential energy consumption. They examine the impact of the Human Development Index (HDI) and its components—life expectancy, education, and Gross National Income (GNI)—on residential energy consumption across the 27 EU Member States from 2010 to 2020, using the Least Squares Dummy Variables (LSDV) model for analysis.

H1	H2
Regardless of their energy transition efforts, HDI values for the 27 EU Member States are still dependent on household energy consumption, and variation in HDI values can increase energy consumption inequality.	A significant and positive correlation exists between HDI components (life expectancy, education index, and GNI) and household energy consumption across EU Member States.

2.3.2 Energy inequality drivers

Inequalities are usually discussed and analyzed in terms of income or a related monetary measure. Research that explores the inequalities in energy access and consumption is lacking. Moreover, studies on this topic usually focus on individual countries. Global or cross-country comparisons are still limited to addressing carbon inequality rather than energy inequality (Hubacek et al., 2017). This could be due to global comparisons' limitations on comprehensive analysis (the latter is challenging because countries have different energy systems). However, Jacmart et al. (1979) were pioneers in examining energy inequality among nations. They applied the Lorenz curve to a study period of 25 years and observed a gradual decline in inequality in commercial energy consumption. Lawrence et al. (2013) used different methods to measure energy consumption inequality for all world countries. They found that the top one-third of the world's population consumes two-thirds of the energy. They also found that the Gini coefficient decreased from 0.66 in 1980 to 0.55 in 2010, indicating a decrease in inequality, which they attributed to the globalization of the world economy. However, the study did not measure the impact of globalization on energy consumption inequality.

The most recent studies to address global energy consumption inequality were implemented by Duan and Chen (2018), Yao et al. (2020), and Oswald et al. (2020). In the first study, Duan and Chen (2018) used the Lorenz curve and the Gini coefficient to assess the inequality of indirect energy consumption among consumers in 121 countries worldwide. The results showed that the global Gini coefficient declined from 0.602 in 2000 to 0.501 in 2013. The US, where energy consumption per capita is significantly higher than in all other countries, has always been at the top of the Lorenz curve. Yao et al. (2020) calculated the impact of the inequality of different energy sources on environmental quality in 57 countries between 1995 and 2018. The results showed that energy inequality degrades environmental quality. Oswald et al. (2020) calculated the final energy footprints of 86 countries and analyzed the energy intensity of goods and services used by different income groups for 2011. They found that inequality in the distribution of the energy footprint varies according to goods and services. Energy-intensive goods tend to be more elastic, resulting in a larger energy footprint for high-income individuals. In addition, they calculated the inequality of international energy footprints. Results showed significant inequality insofar as the consumption share of the half of the population with the lowest incomes is less than 20% of the final energy footprint and less than the consumption of the wealthiest 5%.

Some studies have highlighted the use of Lorenz curves and Gini coefficients for measuring inequality in energy consumption. Although these techniques are most commonly used to quantify inequality, they are more typically used to calculate income than energy inequality. Jacobson et al. (2005) applied the Lorenz curve and the Gini coefficient to measure inequality in household electricity consumption in five countries with various energy profiles. The authors highlighted the need to address the distributional aspects of energy consumption, particularly in light of rising energy demand and the need for energy access in emerging economies. They also underlined the effectiveness of the Lorenz curve technique for calculating the distributional aspects of energy consumption. Its general application can significantly influence scientific and policy discussions about the role of energy equality in combating climate change and deregulating electricity generation.

Lorenz curves and Gini coefficients, along with other inequality methods, were also used by Pascual-S´aez et al. (2017) to measure inequality in gross inland energy consumption per capita for the EU-15 from 2005 to 2014. Inequality in gross inland energy consumption decreased from 2005 to 2014, and the value of the Gini coefficient declined from 0.44 to 0.42 during this period. The study examined inequality within and between geographical clusters to explain this result without considering the factors driving inequality. However, this was the first study to measure disparities in inland energy consumption for EU Member States.

In Europe, the findings in the literature dealing with energy consumption inequality between countries are vague. They also do not sufficiently consider the socioeconomic disparities between EU Member States regarding this form of inequality. Bouzarovski and Tirado Herrero (2017) investigated the relationship between the energy transition in Europe and socioeconomic and regional disparities by examining geographical and temporal changes in the prevalence of energy poverty. The results showed that the typical economic development gap between the core and periphery also applies to energy poverty, which is much more significant in Southern and Eastern European EU Member States. Nevertheless, the study examined territorial disparities between EU Member States using measures of energy poverty rather than energy consumption.

Regarding energy consumption inequality, Szép et al. (2022b) divided the 27 EU Member States into old and new (post-communist) Member States. They measured the contribution of both groups to inequality in 2000, 2008, and 2018. The results showed that the contribution of the old Member States was twice as significant as that of the post-communist Member States. Another classification method was employed by Bianco et al. (2019) to categorize the 28 EU Member States based on their GDP per capita and geographical location. The authors weighted different sources of primary energy consumption by GDP and population and decomposed inequality between and within groups. They found that inequality between groups had the most significant impact when GDP was used as a weighting factor. They attributed this to the different economic structures and energy mixes of countries.

All of the studies mentioned above examined the inequality of energy consumption between countries, not within countries. On the other hand, more recent studies have examined inequality in household energy consumption and other socioeconomic and demographic factors within countries. According to Baltruszewicz et al. (2021), income inequality differed from energy footprint inequality in Zambia in 2015. Only high-income urban households had a significant indirect energy footprint related to expenditure on goods and services, while the lower-income half of households had similar energy footprints. This is perhaps because the latter exist below the poverty line and cannot increase their energy expenditure. In this context, Wang et al. (2023) assessed the impact of the rapid energy transition in China between 2013 and 2017 (which involved replacing traditional solid fuels with modern, clean energy) on the household energy burden. The researchers found that 43.0% of the surveyed households had switched from using traditional solid fuels to a cleaner energy source. However, 56.1%– ~61.0% of them were highly low-income or low-income households, raising serious concerns about the impact of the increasing energy burden on households. As a result, the proportion of households experiencing energy poverty had increased from 30.1% to 34.2%. The results also showed that urban households spend a smaller and declining share of their income on energy. In contrast, the energy burden of rural households has increased due to the dramatically rising cost of renewable energy. For urban households in China, Zhang et al. (2023) measured the energy consumption of different income categories in 2012, 2015, and 2017. The regional environment inequality index was used to quantify inequality between provinces, while Gini coefficients were used to measure inequality within each province. They found that between 2012 and 2017, the level of inequality in the provinces steadily decreased, while inequality in energy consumption between the provinces gradually increased, and high-income groups consumed ten times more energy than low-income groups.

In most cases, the reviewed literature highlighted the role of socioeconomic factors in energy inequality by showing that developed countries or high-income groups consume more energy than developing countries or low-income groups. Some of the former compared inequality in energy consumption with inequality measured using socioeconomic parameters. Nevertheless, none of these studies (as summarized in Table 3) disaggregated household energy consumption inequality according to its socioeconomic driving factors. The significance of this study is that it is one of the few studies to examine energy consumption inequality between EU Member States and the only one to demonstrate the role of the socioeconomic gap between them concerning this inequality by calculating the contribution of each socioeconomic factor to overall inequality.

Table 3 Summary of studies about inequality in energy consumption

Study	Indicator	Unit of Observation	Period	Inequality Measure
Jacmart et al., 1979	Commercial energy consumption	174 countries	1950–1975	Lorenz curves and Gini coefficients
Jacobson et al., 2005	Household electricity consumption	Norway, USA, El Salvador, Thailand, and Kenya.	1997	Lorenz curves and Gini coefficients
Lawrence et al., 2013	Energy consumption and CO_2 emissions	Around 220 countries	1980–2010	Lorenz curves, Gini coefficients, cumulative probability distribution, and the law of 1/3
Pascual-Sáez et al., 2017	Gross inland energy consumption	EU-15	2005–2014	Lorenz curves, Gini coefficients, generalised entropy indices, and Atkinson
Duan and Chen, 2018	Embodied energy consumption – overall, renewable, and non-renewable	121 countries	1990–2013	Lorenz curves and Gini coefficients
Bianco et al., 2019	Primary energy consumption and CO_2 emissions	EU-28	2008–2016	Theil index
Yao et al., 2020	Oil, coal, natural gas hydroelectricity, and renewable energy consumption	57 countries	1995–2018	Theil index
Oswald et al., 2020	Household indirect energy consumption	86 countries	2011	Energy and expenditure extended input-output model and Gini coefficient
Baltruszewicz et al., 2021	Household indirect energy consumption	Zambia	2015	Gini coefficients and environmentally extended input-output analysis
Szép et al., 2022b	Household energy consumption	EU-27	2000, 2008, 2018	Gini coefficients and Hoover index
Wang et al., 2023	Household energy burden	China	2013–2017	Lorenz curves and Gini coefficients
Zhang et al., 2023	Urban household energy consumption	China	2012, 2015, 2017	Regional environment inequality index and Gini coefficients

Source: Sources listed in the table

The third, fourth, and fifth hypotheses explore inequality in household energy consumption across the 27 EU Member States between 2010 and 2020 within the context of the European energy transition. These hypotheses also investigate the factors driving this inequality in highly developed and least developed Member States by analyzing the decoupling of energy consumption from economic growth within these groups.

As mentioned earlier, climate change and the transition to sustainable energy are the most significant long-term challenges for the EU. Even with the Social Fund's support, the transition process will have social and economic effects that are difficult to assess in advance (EU, 2023). While extending the EU ETS to the household sector is an excellent tool for mitigating climate change, it will reduce household energy consumption (LaBelle et al., 2022), hitting Member States where less energy is consumed per household harder. Those who can afford carbon-reducing technologies are also expected to invest in them instead of paying for carbon permits. This will increase the price of fossil fuels, which are more likely to be used by low-income households, increasing inequality within countries and pushing more people into energy poverty.

Moreover, absolute decoupling between economic growth and resource use is a goal of the EGD to achieve a just transition. Breaking the link between environmental pressures and economic or social drivers such as economic growth, GDP, and the HDI is called decoupling (Yu et al., 2017). The old Member States have decoupled their economic growth from household energy consumption, whereas this has not been the case in all post-communist Member States (LaBelle et al., 2022). Failure to achieve complete decoupling between EU Member States could hinder the European just transition.

It is noteworthy to mention that the concept of decoupling is not entirely successful when considering broader environmental implications. Specifically, while some progress may have been made in decoupling economic activity from resource use or environmental damage (like reducing emissions), other forms of natural resource use, such as ongoing material accumulation, still pose challenges. The shift toward new, often environmentally friendly technologies can also come with ecological trade-offs. These trade-offs include the extraction of rare materials, energy-intensive production processes, or the generation of electronic waste.

H3	H4	H5
The socioeconomic divide among EU Member States contributes significantly to the inequality in household energy consumption across states.	GDP is the socioeconomic factor contributes most to inequality in household energy consumption in EU Member States.	Decoupling between economic development and household energy consumption has not been achieved in all Member States.

2.3.3 Energy price impact on energy inequality

Traditionally, price fluctuations, whether they rise or fall, influence the demand and supply of goods. When the price of a product increases, it raises the opportunity cost as less money is left for spending on other goods and services (Zweifel et al., 2017). Economists gauge the impact of price changes on demand using the concept of price sensitivity or price elasticity of demand, which examines how a product's price influences consumers' purchasing decisions and, consequently, demand.

In the energy sector, understanding the price elasticity of energy demand has become increasingly essential for assessing the socioeconomic and environmental implications of energy policies or events that affect energy product prices. Since the 1970s, numerous scientific studies have employed various models, datasets, and methodologies to estimate short- and long-term price elasticity for different countries (Sickles and Huntington, 2008). These studies, conducted by researchers like Al-Sahlawi (1989), Basso and Oum (2007), Bohi and Zimmerman (1984), Dahl (2012), Drollas (1984), Graham and Glaister (2004), Kouris (1983), Szép and Kashour (2023), and Taylor (1975), analyze the elasticity for energy products such as electricity, natural gas, gasoline, and vehicle fuels. In most instances, short-run demand elasticity is deemed inelastic. In contrast, long-run elasticity is somewhat elastic, suggesting that significant time is needed before observing a considerable energy demand response to price changes.

However, employing diverse methodologies for elasticity measurement can lead to disparate outcomes. For example, Drollas (1984) utilized time series and cross-sectional models to assess gasoline demand's short- and long-term price elasticity across 37 highly developed and extremely low-income nations. Their results revealed that gasoline demand is relatively inelastic in the short run (within 1 or 2 years). Conversely, long-term time series models suggest elasticity comparable to unity, while cross-sectional models indicate potential elasticity surpassing unity. The choice of method, coupled with factors such as timeframe, composition of price fluctuations, sectoral breakdown, and regulatory frameworks, influences the elasticity of energy demand (Kouris, 1983). Notably, variations in short- and long-term energy demand elasticities are evident across different sectors. For instance, research has demonstrated that natural gas consumption in the industrial sector responds more significantly to income changes than in the residential and commercial sectors (Al-Sahlawi, 1989). Furthermore, distinct outcomes can emerge across different income groups. Szép and Kashour (2023) discovered that the elasticity of energy demand in Hungary is notably higher for the first two income deciles than others, indicating that these deciles are most sensitive to price fluctuations.

A modest decrease in energy consumption signifies high price elasticity of demand, which can be advantageous in specific scenarios. According to Kouris (1983), this suggests the economy's long-term resilience against rising energy prices. Although price shocks have substantial short-term inflationary and recessionary impacts, they do not hinder long-term economic growth. Conversely, weak price elasticity implies a feeble response to rising energy prices, leading to adverse effects on output and inflation in the long run.

The sixth hypothesis expands the previous three hypotheses(3, 4, and 5), which centered on incorporating energy consumption inequality within the context of the European just transition. Capitalizing on the 2021-2022 energy crisis as a proxy for the anticipated crisis that may arise in the future due to the extension of the EU ETS to encompass the household sector, this hypothesis aims to examine the outcomes of the energy crisis, notably the surge in energy prices (electricity prices), on inequalities in energy consumption, GDP, and the HDI. The main aim is to substantiate that the increasing energy prices will disproportionately affect the post-communist Member States compared to the old ones, consequently exacerbating inequalities in the variables above.

H6

The increase in electricity prices that transpired across the 27 EU Member States between 2021 and 2022 led to a more pronounced decline in household energy consumption, per capita GDP, and HDI for the new Member States compared to the old ones, thereby intensifying disparities in these variables.

3 Methodology and data

This chapter provides a detailed description and justification of the study variables and the methods employed to calculate them. It then outlines the research hypotheses and explains the statistical testing methods, offering a rationale for their selection. The chapter concludes by discussing the study's limitations, including the scope of the data and the methodological constraints.

3.1 Study variables

Several variables are used in this study to test the hypotheses. Table 4 provides information on the variables and databases used. The climate-corrected household energy consumption per capita (CEC) is calculated to eliminate the effect of the different Member States ' climate conditions on energy consumption by using the following equation:

$$CEC = \frac{EC}{(HDD + CDD)} \quad [1]$$

Where EC: household energy consumption per capita.

Figure 9 shows the values of energy consumption per capita (EC) in (kgoe) and climate-corrected energy consumption per capita (CEC) in (kgoe/degree day) for the Member States in 2020. The two cases show a noticeable variation in how the residential energy consumption values are distributed among the Member States. A different distribution exists when the degree days values are considered. The Western states still consume more energy than the Eastern states, but the gap between the Northern and Southern states is diminishing. These values reflect the energy states would have consumed if they had experienced the same weather circumstances. When calculating energy inequality, they produce more precise results.

Table 4 Data description

Variable	Unit	Description	Source
CEC	A kilogram of oil equivalent per degree day (kgoe/dd).	Annual climate-corrected household energy consumption per capita	Author's compilation, based on World Bank (2021), Eurostat (2023a), and Eurostat (2023b)
POP	Number of individuals	The number of individuals living in a specific area.	World Bank (2021)
HDD CDD	Celsius (°C)	A simplification of outside air temperature data. They come with a base temperature and measure how much (in degrees) and for how long (in days) the outside temperature was below or above that base temperature.	Eurostat, 2023a
HDI	Unity	A composite of the three dimensions of human development, life expectancy, education index, and gross national income per capita adjusted for the country's price level.	HDR, 2020
EI	Unity	An average of years of schooling for adults and expected years of schooling for children.	HDR, 2020
LE	Years	The mean number of years still to be lived by a person who has reached a certain age and is subjected to current mortality conditions throughout the rest of their life (age-specific probabilities of dying).	Eurostat, 2021
GDP	Constant 2015 USD	Annual per capita gross domestic product	World Bank, 2022
EES	Unity	An average of the three scores obtained for 'energy efficiency level, a moving average of the last three years,' 'energy efficiency progress based on the trend indicator since 2000', and 'energy efficiency policies.'	Odyssee-mure, 2021
GNI	USD PPP (purchasing power parity)	The aggregate income of a country, converted to international dollars using PPP rates, and divided by the number of population.	HDR, 2020
EP	EUR	Electricity prices for medium-sized households (annual consumption between 20 and 200 GJ)	Eurostat, 2022c

Source: Sources are listed in the table

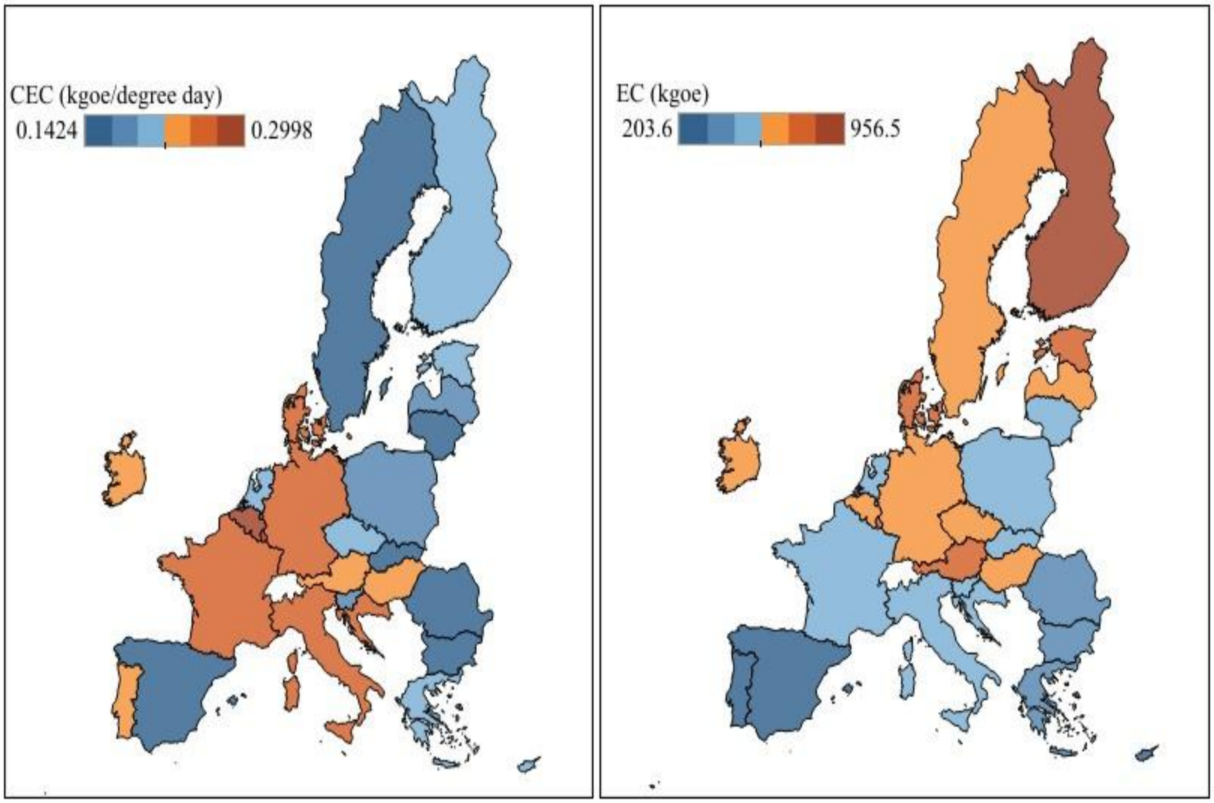

Figure 9 Typical and climate-corrected residential energy consumption per capita for the 27 EU Member States in 2020
Source: Author's compilation based on Eurostat (2023b)

3.2 Panel regression – Least Squares Dummy Variable (LSDV) Model

The Panel regression – Least Squares Dummy Variable (LSDV) model is used to test the first two hypotheses. Figure 10 shows the hypotheses and testing method.

Panel data are a combination of time series and cross-sectional data. Panel regression is a method that analyses the relationship between independent variables and one dependent variable in the panel data. It considers the effect of each independent variable adjusted to account for differences in other independent variables. The general formula for panel regression is (Brugger, 2021):

$$Y_{it} = \beta 1 X_{it} + \alpha i + u_{it} \quad [2]$$

Where Y_{it}: The dependent variable, where i = entity and t = time; α_i: Unknown intercept for each entity; X_{it}: One independent variable; β1: Regression coefficient for the independent variable; u_{it}: The error term.

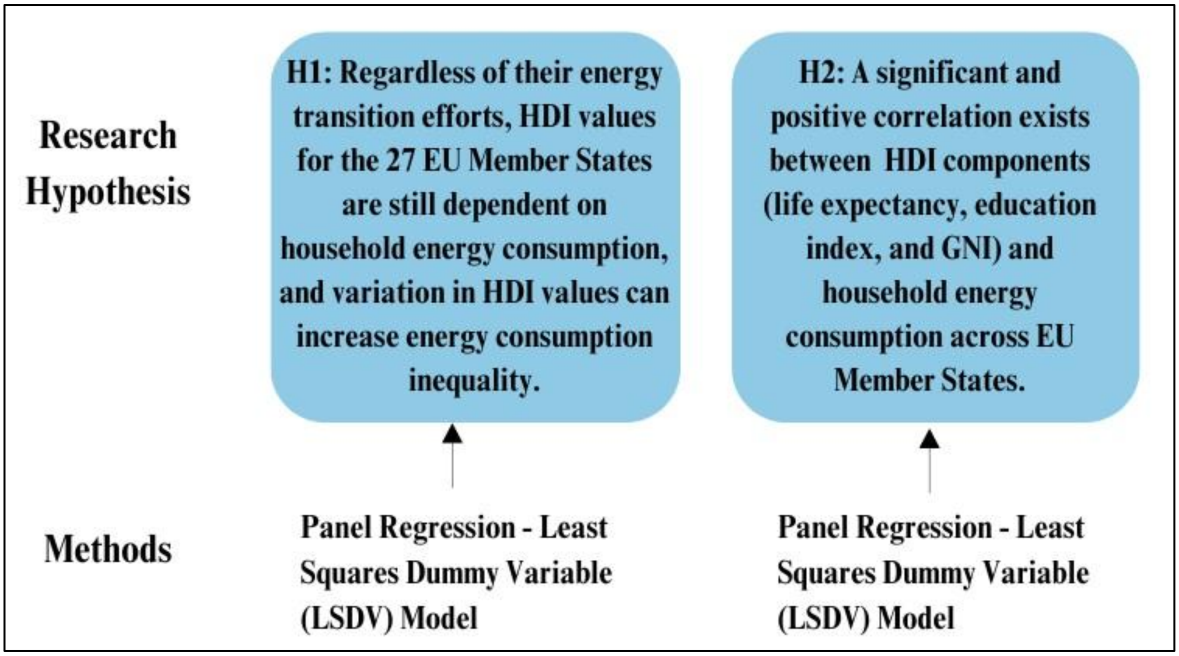

Figure 10 Research hypotheses (H1 and H2) and testing method
Source: Author's Compilation

The dependencies of unobserved independent variables (unknown intercepts) on a dependent variable, leading to biased estimators in traditional linear regression models, can be controlled by panel regression. The method can address the problems of heterogeneity and endogeneity that lead to such results. Heterogeneity is the existence of the unobserved dependency of other independent variables, and endogeneity is the correlation between independent and unobserved independent variables.

There are three main types of regression for panel data: pooled Ordinary Least Squares (OLS), Fixed Effects (FE), and Random Effects (RE). Pooled OLS can be described as a simple OLS model performed on panel data. It ignores time and individual characteristics and focuses only on the dependencies between individuals. However, simple OLS requires no correlation between unobserved and independent variables. Consequently, pooled OLS is inappropriate for panel data. The existence of time series and cross-sectional data poses various problems, such as heteroskedasticity and autocorrelation. Several estimation models address one or more of these problems, but the most prominent are the FE and RE models (Gujarati et al., 2003).

The FE model determines the individual effects of unobserved independent variables as constant over time. Endogeneity can exist within FE models. The FE model assumes alpha as a constant and subtracts the mean values from each equation term. In this way, alpha becomes zero and is neglected. However, heterogeneity can exist within the model because it can be controlled. RE models determine the individual effects of unobserved independent variables as random variables over time. They can switch between OLS and FE and focus on the dependencies between and within individuals.

An alternative to the FE model is the LSDV model, in which dummy variables represent fixed individual effects. This model yields the same results as the FE model. The LSDV model is selected to investigate the impact of the HDI and its components, education index, GNI, and life expectancy on climate-normalized residential energy consumption per capita. The natural logarithm transformation for all variables is used to measure relative elasticity. The LSDV model is selected for more than one reason. According to (Gujarati et al., 2003):

1. If the number of time series units (T) is small, the number of cross-sectional units (N) is large, and the cross-sectional units are not random selections from a larger sample, then the FE model is appropriate. If the cross-sectional units in the sample are regarded as random selections, then the RE model is applicable. In this regard, the Member States are not randomly selected from a larger sample.

2. If endogeneity exists, then the RE model estimators are biased, whereas those obtained from the FE model are unbiased. The null hypothesis of the Wald test is rejected for the four regressors, indicating that they are endogenous.

3. The Hausman test is used to ensure proper selection. The Hausman test's null hypothesis, that is, the covariance between independent variables and unknown intercepts is zero, is rejected, indicating that the FE model is preferable to the RE model.

After selecting the LSDV model, the following assumptions are tested (Hanck et al. 2021):

1. Significant outliers are unlikely to exist.
2. There is no perfect multicollinearity.
3. The error terms are normally distributed.
4. The error terms are not correlated (no autocorrelation).
5. The error variance is constant (no heteroscedasticity).

3.3 A multi-method approach to energy inequality

Regarding the third, fourth, and fifth hypotheses, several statistical analysis techniques are used. First, cluster analysis is employed to classify Member States based on household energy consumption, GDP, HDI, and electricity prices. Second, Gini and Theil's indices measure each cluster's inequality of household energy consumption. Third, the Theil index decomposes overall inequality by subclusters. Finally, the regression-based inequality decomposition decomposes overall inequality according to its determinants. Figure 11 shows each research hypothesis and the respective test methods.

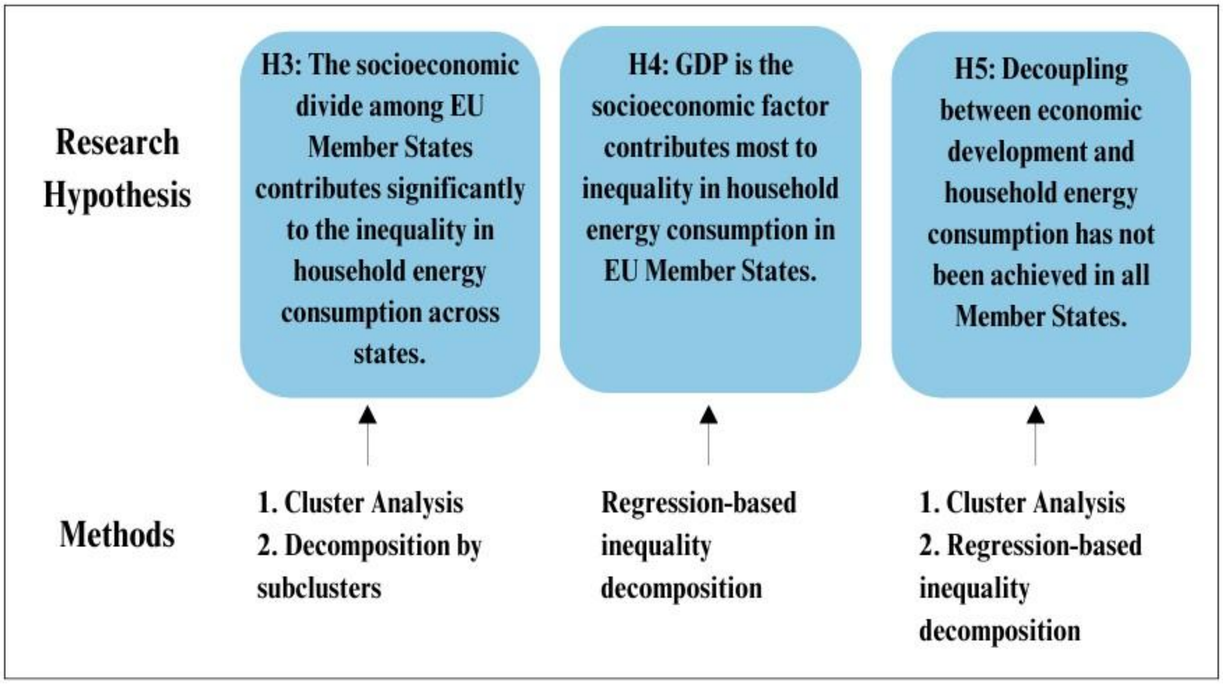

Figure 11 Research hypotheses (H3, H4, and H5) and testing methods
Source: Author's compilation

3.3.1 Cluster analysis

Cluster analysis refers to a set of techniques used to classify cases into homogeneous groups based on the values of several variables. The two main types of cluster analysis are hierarchical (agglomerative and divisive) and non-hierarchical. Hierarchical cluster analysis is based on a tree-like approach and is more suitable for smaller data sets. With this type, cases are divided into groups so that cases in one group are similar to each other and different from cases in other groups. The process is iterated at various levels to create a hierarchy that shows how the clusters are created (Clatworthy et al., 2005). The iteration can be bottom-up (agglomerative) or top-down (divisive). The most commonly used approach is agglomerative because it employs a simple algorithm (Setyaningsih, 2012). Alternatively, non-hierarchical clustering does not follow a hierarchal approach to determine new clusters but instead divides or combines existing clusters. Unlike hierarchical clustering, non-hierarchical clustering techniques require the user to specify the number of clusters in advance (Clatworthy et al., 2005). The algorithms K-Means and K-Medoids are the two best-known non-hierarchical clustering algorithms. K-Means is based on centroids, while K-Medoids is based on medoids. K-Means' centroids are defined as the average values of the units assigned to the clusters, while the medoids are the most observed units for each cluster (Giordani et al., 2020).

K-Means is a distance-based clustering method that works only with continuous variables. Its fundamental concept involves working with an initial clustering arrangement that may not be optimal. The approach entails moving each data point to its closest new center, subsequently revising the cluster centers by determining the mean of component data points. This sequence of relocating and updating is reiterated until convergence benchmarks, such as a predetermined iteration count or a specific threshold in distortion function variation, are met (Jin and Han, 2011). The K-Means clustering method is used to classify the 27 EU Member States according to their climate-adjusted per capita household energy consumption (CEC), GDP, HDI, and electricity prices. The ideal number of clusters is determined by the trial-and-error method.

3.3.2 Territorial disparity

The Lorenz curve and Gini index are used primarily to measure income inequality by dividing the country's population into equal deciles based on income and then measure each decile's income share related to its population share. In recent years, these methods have been used to measure different types of inequality, such as energy consumption, GDP, and CO_2 emissions. The Lorenz curve is a plot where the y-axis shows the cumulative percentage of the variable whose inequality is to be measured, and the x-axis shows the cumulative percentage of the population of countries, cities, areas, and deciles. It is a curve with a straight diagonal line representing perfect equality, where all countries or deciles would have an equal share of the variable. The Gini index is a standard measure of inequality, defined as the area between the Lorenz curve and the equality line divided by the triangle beneath the equality line area (Ramzai, 2020). The Gini index equation used with the Lorenz curve to calculate inequality in typical energy consumption values in 2020 is extracted from Kashour (2023).

$$G = 1 - \Sigma i \left(Ppi \, x \left(ECpi + 2 \times (1 - CECpi) \right) \right) \quad [3]$$

Where Ppi: Population percentage of country i; ECpi: Energy consumption percentage of country i; CECpi: Cumulative energy consumption percentage of country i.

This study also measures the inequality in residential energy consumption per capita for all EU Member States from 2010 to 2020, following the equation of Araar and Duclos (2009) provided to measure the Gini index.

$$\mathrm{G} = 1 - \frac{\xi}{\mu} \quad [4]$$

Where:

$$\xi = \sum_{i=1}^{n} \left[\frac{(V_i)^2 - (V_{i-1})^2}{(V_1)^2} \right] y_i \text{ and } V_i = \sum_{h=i}^{n} w_h \text{ and } \mu = \frac{\sum_{i=1}^{n} w_i \, y_i}{\sum_{i=1}^{n} w_i} \text{ and}$$

$$y_1 \geq y_2 \geq \cdots y_{n-1} \geq y_n$$

y: the variable of interest, i: observation number, y_i: the value of the variable of interest for observation I, w_i: the sampling weight for observation I multiplied by the size of observation I, and n: sample size.

The Gini index is the most commonly used inequality measure (Allison, 1978; Anand, 1983; Maxwell, 1990; Asada, 2005; Foster and Wolfson, 2009; Castillo, 2020). It was developed in 1912 by the Italian statistician Corrado Gini (Sitthiyot and Holasut, 2020) and was initially created as a standardized measure of statistical dispersion for understanding income distribution. However, it has also been used to measure inequality associated with wealth distribution, access to education and health care, gender parity, and environmental issues (Charles et al., 2022).

The Gini index is the most commonly used indicator because it is easy to interpret. However, it has a limitation: it is less sensitive to population stratification than individual value differences (Liao, 2006). Moreover, the Gini index cannot be wholly decomposed into subgroups because it usually has a residual value. It can be perfectly decomposable (residual = 0) if the rankings of the subgroups do not overlap (Bellù and Liberat, 2006). Other inequality measures, such as generalized entropy measures, are perfectly decomposable and have no residual term. These measures exhibit additive decomposability and can be decomposed by subgroups. They depend on a parameter (θ) that defines how sensitive the index is to different distribution segments. When the value of θ equals 1, this is known as the Theil index (Costa and P´erez-Duarte, 2019). The Theil index was introduced in 1967 by the Dutch econometrician Henri Theil. It measures the entropic distance of the population from the condition of perfect equality.

Unlike the Gini index, the Theil index value has no upper limit. It is zero when there is perfect equality, and the value increases when the distribution is unequal. Since its values cannot always reflect the relative inequality between different population sizes, researchers often use it because of its decomposability (Trapeznikova, 2019). The energy inequality in household energy consumption is also calculated using Theil index (T). The following equation is extracted from Araar and Duclos (2009) to measure the Theil index:

$$\mathrm{T} = \frac{1}{\sum_{i=1}^{n} w_i} \sum_{i} \frac{w_i y_i}{\mu} log\left(\frac{y_i}{\mu}\right) \quad [5]$$

Where $\mu = \frac{\sum_{i=1}^{n} w_i \; y_i}{\sum_{i=1}^{n} w_i}$ and y: the variable of interest, i: observation number, y_i: the value of the variable of interest for observation i, w_i: the sampling weight for observation i multiplied by the size of observation i, and n: sample size.

3.3.3 Inequality decomposition analysis

There are two different decomposition approaches: additive and multiplicative. The additive approach measures absolute change, while the multiplicative approach measures relative change (Weiner and Szép, 2022). The decomposition of inequality has been undertaken many times. However, it is not commonly used to address energy consumption. Most previous studies have dealt with income inequality. Such empirical studies have attempted to decompose the functional sources of income (labor, capital, and land) using the additive decomposition approach (Rao, 1969) to understand the impact of income components on income inequality. In Western Europe, growing income inequality in the 1980s and 1990s inspired research into the underlying factors. As a result, new methods for decomposing income inequality into its components were developed (Rani and Furrer, 2016). One decomposition method was introduced by Shorrocks (1982) to understand better the proportional contribution of individual income sources to overall income inequality. Two years after this, Shorrocks (1984) decomposed subsequent income inequality by population subgroups and proposed a method for calculating the effects of inequality between and within subgroups.

The decomposition of the Theil index by subclusters is used to measure the impact of energy consumption inequality within and between the resulting subclusters on the overall inequality of the 27 EU Member States. In the case of the Theil decomposition, the additive approach is used. The following equation is extracted from Bellù and Liberat (2006) to decompose the Theil index by subclusters. The first term in the equation represents the 'within' part of the decomposition, and the second represents the 'between' part.

$$\mathrm{T} = \sum_{k=1}^{m} \left[\frac{n_k}{n}\frac{\bar{y}_k}{\bar{y}}\right] T_k + \sum_{k=1}^{m} \frac{n_k}{n}\left[\frac{\bar{y}_k}{\bar{y}}\right] ln \left[\frac{\bar{y}^k}{\bar{y}}\right] \quad [6]$$

Where m: the number of subgroups, n: the total population, n_k: the population of subgroup k, $\bar{y}$: the total mean energy consumption, $\bar{y}_k$: the mean energy consumption for subgroup k, and T_k: the Theil index of subgroup k.

The above methods measure the contribution of different variable sources or segments of the population to variable inequality, but they do not measure the factors that determine it. Unlike earlier approaches, the regression-based technique has the advantage of going beyond simply decomposing inequality into discrete population categories or components. It can account for any factor that might be responsible for observed inequality. Initially proposed by Blinder (1973) and Oaxaca (1973), the regression-based approach gained little attention until it was further advanced by Morduch and Sicular (2002) and Fields (2003), who developed a regression-based approach to decompose inequality based on income determinants (Manna and Regoli, 2012).

Regression-based inequality decomposition is used to decompose the Gini index according to its socioeconomic determinants (GDP per capita, HDI, and electricity prices). The decomposition is based on the Shapley value introduced by Shorrocks (2012). The Shapley value is a principle from game theory that measures how much each player influences the game's outcome (Shapley, 1953). The Shapley approach is based on the idea that the contribution of a single component can be measured as the difference between the total inequality and the inequality that would exist if that element were eliminated from the group of factors. Consequently, the marginal effect of each component is determined by estimating a series of regression models, starting with a specification that includes all regressors and then removing each one. The average of the marginal effects of each variable is then used to calculate the total marginal contribution of each variable. Since the contribution of each factor depends on the order in which the factors appear in the elimination sequence, this average is calculated over all possible elimination sequences (Manna and Regoli, 2012). The following equations are extracted from Wicaksono et al. (2017) and used to calculate the contribution of each driving factor to total inequality. The regression model chosen to estimate the energy-consumption generating function, which assigns energy consumption to some explanatory variables, is calculated separately for each year:

$$y = \alpha + \sum_{i=1}^{n} \beta_i X_i + \varepsilon \quad [7]$$

where y: climate-corrected households energy consumption, α: intercept, n: number of explanatory variables, β_i: regression coefficient for explanatory variable i, X_i: explanatory variable i, and ε: residual.

The Shapley value decomposition is applied after the value of actual energy consumption Y is predicted ($\hat{Y}$), and the contribution of residuals (e) is determined as follows:

$$Y = F(X) + e \quad [8]$$

$$Y = \hat{Y} + e \quad [9]$$

Therefore, the inequality in energy consumption can be decomposed as follows:

$$I(Y) = I(\hat{Y}|X_1, X_2, \dots, X_n) + I_e \quad [10]$$

Where $I(Y)$: the actual energy consumption inequality, $I(\hat{Y}|X_1, X_2, \dots, X_n)$: the predicted energy consumption inequality, and I_e: the contribution of residuals, which represents the unexplained inequality.

The residual term is considered the other driving factor but is excluded from the regression. Not considering the residual term means throwing away valuable information about the excluded determinants, leading to the decomposition results' bias (Hua Wan, 2002).

After suppressing the effect of the intercept, since it has a negligible value, the inequality calculated for the predicted energy consumption is described as the sum of each explanatory variable contribution (C), as follows:

$$\mathrm{I}\left(\hat{\mathrm{Y}} \middle| \mathrm{X}_1, \mathrm{X}_2, \ldots, \mathrm{X}_n\right) = \mathrm{C}_1 + \mathrm{C}_2 + \ldots + \mathrm{C}_n \quad [11]$$

The Shapley principle states that the contribution of an explanatory variable is equal to the difference between total inequality and inequality when that variable is removed by replacing it either with its mean or with zero. In this study, the mean is used. Consequently, the contribution can be expressed by the following equation:

$$C_i = \frac{1}{n!} \sum\nolimits_{\pi \epsilon \Pi_n} \left[I\left(\hat{\mathrm{Y}} \middle| B(\pi, X_i) \cup \{X_i\}\right) - I\left(\hat{\mathrm{Y}} \middle| B(\pi, X_i)\right) \right] \quad [12]$$

Where $I(\hat{\mathrm{Y}}|X)$: the inequality measured for the predicted energy consumption values, Π_n: the set of all possible permutations of the n variables, and $B(\pi, X_i)$: the set of variables preceding X_i in the given order π.

The Shapley share of each explanatory variable contribution S_i to the total inequality of energy consumption can be determined as follows:

$$S_i = \frac{C_i}{\mathrm{I(Y)}} \quad [13]$$

3.4 Bivariate analysis

Regarding the sixth hypothesis, the analytical approach applied to assess the impact of escalating energy prices on disparities in energy consumption, GDP, and HDI across the 27 EU Member States involves bivariate analysis. This methodology entails the utilization of connected scatterplots, illustrating the relationships between pairs of variables. The validation of results is ensured by applying the Gini index. Figure 12 shows the sixth hypothesis and the testing method.

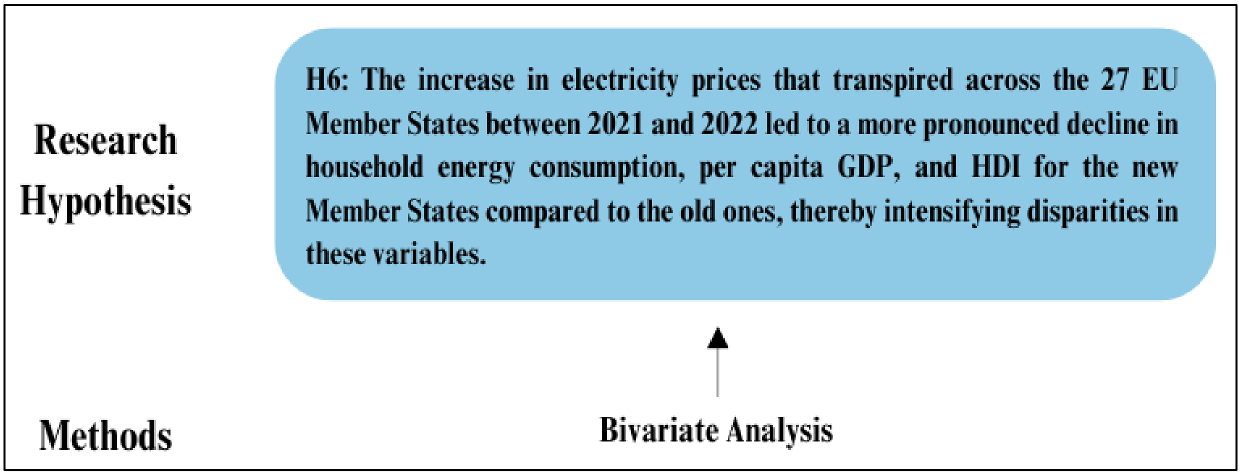

Figure 12 Research hypothesis (H6) and testing method
Source: Author's compilation

3.5 Limitations

The study has some limitations regarding literature, data, and methods. Previous research on energy consumption inequality between countries is relatively sparse in the literature, especially regarding EU Member States. Therefore, this study contributes to this area of research.

The analytical time frame is limited due to restricted data accessibility and availability. Collecting data for all EU Member States before 2010 proved difficult.

The Gini index has limitations in measuring inequalities. It has a sample size bias, and in some cases, it can have the same value for countries with different income distributions but equal income levels.

The selected electricity prices apply solely to medium-sized households with annual consumption of between 20 and 200 GJ. This limited scope can lead to biased results. Nevertheless, no electricity price index covers all consumption ranges.

The climate-corrected energy consumption calculation does not consider the heating and cooling shares for a typical year, as it is difficult to collect such data for each Member State.

Finally, the technique used to investigate the decoupling, regression-based inequality decomposition, is perhaps inappropriate. However, its use is consistent with the study's primary objective, which is to examine inequality in energy consumption and its causes to mitigate it.

4 Results and discussion

4.1 Final energy consumption by sector of 27 EU Member States

Final energy consumption by sector measures the amount of energy consumed by each sector: industry, transport, commercial, and household separately. Table 5 shows the values of the final energy consumption of EU-27 for each sector from 2010 until 2020 in thousand tons of equivalent oil, and Figure 13 shows the average percentage share of energy consumption by each sector over the 2010-2020 period.

Table 5 Research hypotheses - H1 and H2 - and testing methods

Year	Sector			
	Commercial	**Household**	**Industrial**	**Transport**
2010	139,982	278,937	243,873	279,992
2011	128,305	251,901	244,296	278,951
2012	131,147	263,019	239,703	269,188
2013	132,725	266,099	236,749	265,450
2014	123,435	234,643	233,298	268,809
2015	128,519	245,035	233,508	272,463
2016	130,171	250,873	237,799	278,736
2017	133,882	251,709	240,064	284,509
2018	131,662	249,744	242,466	285,945
2019	128,567	248,182	239,240	288,723
2020	121,210	248,122	230,923	251,440
Average	129,964	253,479	238,356	274,928

Source: Author’s compilation based on Eurostat (2022)

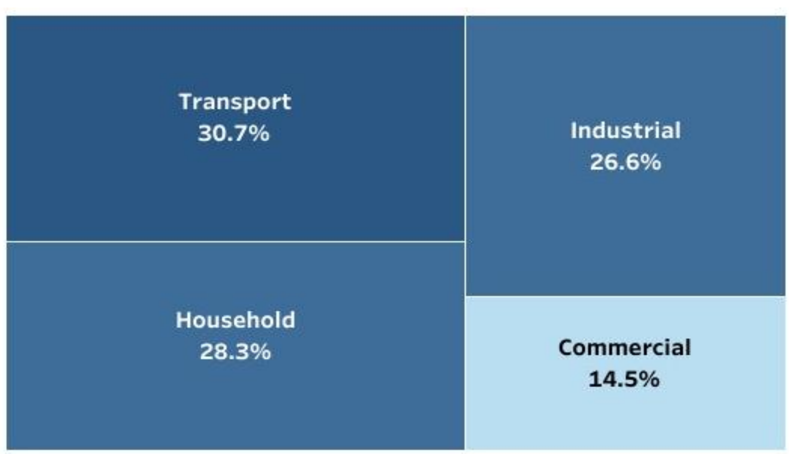

Figure 13 Average energy consumption by sector for EU-27 over the period 2010-2020 (%)
Source: Author’s compilation based on Eurostat (2022)

4.1.1 Industry, transport, and commercial sectors

The industry sector accounted for 26.6% of the EU final energy consumption in 2010-2020, with a 238.36 (Mtoe) average value. Notably, the energy consumption of the industrial sector experienced a decline of 4.6% between 2010 and 2014, likely attributable to the economic recession and the transition towards less energy-intensive manufacturing industries. However, it rebounded with a 3.98% increase between 2014 and 2018, mainly due to the sustained growth of the EU economy, which outweighed any energy-saving measures within the industrial sector. Subsequently, it decreased by 4.8% between 2018 and 2020.

The transport sector is the biggest energy consumer among all sectors, with a 30.7% share of the EU's final energy consumption in 2010-2020 and a 274.93 (Mtoe) average value. Notably, the energy consumption within this sector experienced a 5.1% reduction between 2010 and 2013, primarily attributed to the economic recession. However, between 2013 and 2018, there was a gradual increase of 7.9% in energy consumption, signaling both an economic recovery and growth in air and road passenger transport. This upward trend was subsequently interrupted, as the value declined by 12.1% between 2018 and 2020, possibly influenced by the impact of the COVID-19 pandemic.

The commercial sector has the lowest energy consumption, with a 14.5 % share of the EU final energy consumption in 2010-2020 and a 129.96 (Mtoe) average value. Notably, the energy consumption of the commercial sector experienced fluctuations throughout this period, with a 7.9% decrease from 2010 to 2011, followed by a 3.3% increase from 2011 to 2013, a 7% decrease from 2013 to 2014, a 9.6% rise from 2014 to 2017, and a 1.5% decrease from 2017 to 2018. These fluctuations may be attributed to the variability in winter and summer temperatures and the annual economic activities. Furthermore, in 2020, energy consumption in the commercial sector dropped by 7.9% due to the impact of the COVID-19 pandemic.

4.1.2 Household

The household sector is the second biggest energy consumer among all sectors, with a 28.3% share of the EU final energy consumption in 2010-2020 and an average value of 253.48 (Mtoe). Notably, energy usage within households exhibited fluctuating patterns during this period. There was a 10% decrease from 2010 to 2011, followed by a 5.7% increase between 2011 and 2013, an 11.8% decrease from 2013 to 2014, a 7.3% increase from 2014 to 2017, and a 2.4% decrease between 2017 and 2018. These fluctuations may be attributed to the variability in summer and winter temperatures from year to year.

In the broader context, the energy consumption of the EU's household sector registered a significant 12.2% reduction from 2010 to 2018, primarily driven by enhancements in household energy efficiency. Remarkably, the household sector experienced the most negligible impact from the COVID-19 pandemic, with a minimal 0.06% decline in energy consumption between 2018 and 2020.

This research places particular emphasis on household energy consumption, as it represents the most relevant sector concerning the issue of energy inequality due to its high energy expenditure and the escalating levels of energy poverty within specific demographic groups.

4.2 Energy inequality and HDI

To better understand inequalities, this study employed the Lorenz curve and Gini index (from Equation 3) to divide the Member States into three groups based on the per capita household energy consumption values (unadjusted for climate) in 2020. See Table 6 and Figure 14. The first group accounts for 22.7% of the total population and consumes only 14.3% of total household energy. The second group of countries accounts for 48.9% of the total population and consumes 49.0% of total household energy. The third group of countries accounts for 28.4% of the total population and consumes 36.7% of the total household energy. The highest per capita energy consumption values measured in kilograms of oil equivalent are 956 in Finland, 790 in Luxembourg, 781 in Austria, and 735 in Denmark. Meanwhile, the lowest values are 208 in Malta, 293 in Portugal, 294 in Cyprus, and 307 in Spain. A Gini index of 0.139 in these results generally suggests an acceptable level of energy inequality among the 27 EU Member States.

Notably, most countries in the first group are in southern Europe, and most countries in the third group are in northern Europe. As long as the weather in northern Europe is colder than that in the south, those countries in the north consume more energy for residential heating spaces than those in the south. This is one possible factor contributing to these results.

The other possible factor is the human development level of the country; it is evident that all countries in the third group are the most developed in the EU. Table 6 also shows that the average HDI value for the first group of countries that consume a low amount of energy is 0.867; for the second group of countries that consume a moderate amount of energy, it is 0.891; and for the last group of countries that consume a high amount of energy, it is 0.924. This result shows how much these two variables correlate with each other.

Table 6 Population, typical household energy consumption shares, and average HDI in 2020 for the EU-27 Member States

EU Member States	Population (%)	Household Energy Consumption (%)	Average HDI
Malta, Portugal, Cyprus, Spain, Bulgaria, Greece, Romania, Slovakia	22.7	14.3	0.867
Lithuania, Italy, Slovenia, Netherlands, Poland, Croatia, France, Latvia, Hungary, Ireland	48.9	49.0	0.891
Czech Republic, Belgium, Sweden, Germany, Estonia, Denmark, Austria, Luxembourg, Finland	28.4	36.7	0.924

Source: Author's analysis

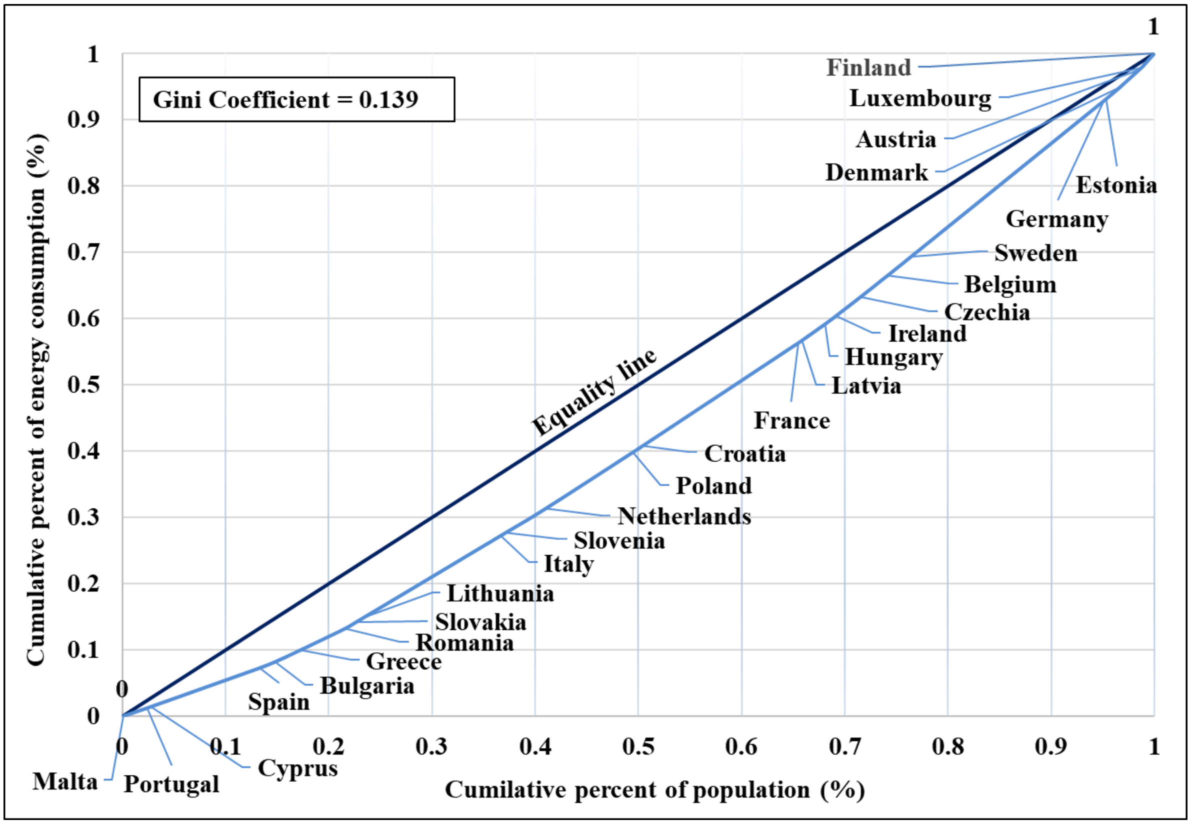

Figure 14 Lorenz curve and Gini coefficient for the typical household energy consumption for the EU-27 Member States in 2020
Source: Author's analysis

To examine the impact of the HDI on energy consumption, Table 7 presents the results of the LSDV model for climate-adjusted residential energy consumption per capita and HDI values for the 27 EU Member States from 2010 to 2020, with Malta identified as an outlier. The panel regression is conducted using the variables' natural logarithmic transformation to address normality and heteroskedasticity issues while estimating relative elasticity (percentage change). The results of normality and autocorrelation tests support the null hypothesis, confirming that the error terms follow a normal distribution and exhibit no autocorrelation. The null hypothesis for the heteroskedasticity test is rejected, suggesting that the error variance is not constant across units. The table indicates a positive relationship between energy consumption and HDI, with a 1% increase in HDI corresponding to a 3.17% rise in climate-adjusted energy consumption (CEC). The first hypothesis is accepted. Figure 24 in the Appendix provides an overview of the distribution and trends in the pooled data, highlighting the relationship between CEC and HDI.

Table 7 LSDV model for climate-corrected residential energy consumption and the HDI values for the EU-27 Member States from 2010 to 2020

Dependent variable: log_CEC Robust (HAC) standard errors				
Variable	**Coefficient**	**Std. Error**		p-value
Constant	−1.24078	0.0338873		3.05e-023 ***
log_HDI	3.17344	0.278205		2.11e-011 ***
Effects Specification				
LSDV R-Squared		0.350	**Durbin–Watson**	2.116
Joint test on named regressors - Test statistic: F(1, 25) = 130.115 with p-value = P(F(1, 25) > 130.115) = 2.11259e-11				
Distribution free Wald test for heteroskedasticity - Null hypothesis: the units have a common error variance Asymptotic test statistic: Chi-square(26) = 45.9284 with p-value = 0.036837				
Test for normality of residual - Null hypothesis: error is normally distributed Test statistic: Chi-square(2) = 5.41019 with p-value = 0.0668639				
Wooldridge test for autocorrelation in panel data - Null hypothesis: No first-order autocorrelation (rho = -0.5) Test statistic: F(1, 25) = 0.20747 with p-value = P(F(1, 25) > 0.20747) = 0.652689				
Hausman test - Null hypothesis: GLS estimates are consistent Asymptotic test statistic: Chi-square(1) = 0.151778 with p-value = 0.696842				

*Significant at 10% **Significant at 5% ***Significant at 1%

Source: Author's analysis

4.3 The influence of HDI components on energy consumption

For an in-depth analysis, the relationship between climate-corrected residential energy consumption and the three HDI components for the EU-27 Member States from 2010 to 2020 is shown in Table 8. The climate-corrected energy consumption is the dependent variable, whereas the HDI components are the independent variables. The variables values are transformed to natural logarithms to measure the relative elasticity. Considering the individualism of each Member State, Malta and Luxembourg are detected outliers in the data. The correlation matrix in the table shows no robust correlations between the independent variables, and the Variance Inflation Factors are less than 3, indicating no harmful multicollinearity. The null hypothesis for the normality and autocorrelation tests is accepted, indicating that the error is normally distributed and there is no autocorrelation. In addition, the null hypothesis for the heteroskedasticity test is rejected, indicating that the units do not have a common error variance. The table shows positive regression coefficients between energy consumption and the three HDI components. Except for the education index, the probability values for the independent variables are less than 0.05, indicating a significant relationship with energy consumption. The R-squared value is 0.487, which is acceptable in social science, meaning that the independent variables can explain 48.7% of the variation in the dependent variable. The second hypothesis is partially accepted. Figures 25, 26, and 27 in the Appendix provide an overview of the distribution and trends in the pooled data, highlighting the relationships between each pair of independent and dependent variables.

A high life expectancy means that people live more and consume more energy. A study by Steinberger et al. (2020) showed that the increase in energy consumption in 70 countries (80% of the world population) between 1971 and 2014 accounted for a 25% increase in life expectancy. Another study confirmed these results by presenting two variables moving in the same direction for four developing countries (China, India, Brazil, and Indonesia) over 50 years (Lloyd, 2017). Consistently, the results showed a positive relationship between energy consumption and life expectancy. This result is highly dependent on the energy mix used in the Member States. The greener energy is used, the more the direction of the relationship is shifting from negative to positive. This is mainly because high life expectancy requires an advanced health system and a green environment with fewer pollutants and emissions.

Regarding education, the literature has shown that the education level in developed countries might have an adverse effect on energy consumption, as improving technology in education will lead to declining energy use (Inglesi-Lotz et al., 2017). Most EU Member States are developed countries with high-quality educational systems. Furthermore, education influences the behavior of households to become more energy-conservative (Liu et al., 2015). However, the results show that education in Europe does affect residential energy consumption, but the effect is not significant.

Consistent with the works of Cayla et al. (2011) and Chen et al. (2022b), GNI positively impacts energy consumption. The cumulative reduction in EU energy consumption from a combination of outsourcing activities and efficiency gains since 1990 has been significant, resulting in approximately 40% less energy use, half of which is due to deindustrialization (Moreau and Vuille, 2019). Therefore, prospects for decoupling economic growth and energy are limited. Given the non-achievement of absolute decoupling and for a specific income range, the more income households have, the more they will spend on energy and use it.

Table 8 LSDV model for climate-corrected residential energy consumption and the three HDI components for the EU-27 Member States from 2010 to 2020

Dependent variable: log_CEC Robust (HAC) standard errors			
Variable	**Coefficient**	**Std. Error**	p-value
Constant	−17.2694	1.34481	3.03e-012 ***
log_Life Expectancy	3.20392	0.398372	2.87e-08 ***
log_Education Index	0.0679350	0.137380	0.6254
log_GNI	0.136732	0.0348794	0.0006 ***

Effects Specification

LSDV R-Squared	0.487	**Durbin–Watson**	1.857

Joint test on named regressors -
Test statistic: F (3, 24) = 106.826
with p-value = P (F (3, 24) > 106.826) = 5.09814e-14

Distribution free Wald test for heteroskedasticity -
Null hypothesis: the units have a common error variance.
Asymptotic test statistic: Chi-square (25) = 42.9235
with p-value = 0.043493

Test for normality of residual -
Null hypothesis: error is normally distributed
Test statistic: Chi-square(2) = 0.582292
with p-value = 0.747407

Wooldridge test for autocorrelation in panel data -
Null hypothesis: No first-order autocorrelation (rho = -0.5)
Test statistic: F(1, 24) = 0.309493
with p-value = P(F(1, 24) > 0.309493) = 0.583142

Hausman test -
Null hypothesis: GLS estimates are consistent
Asymptotic test statistic: Chi-square(3) = 6.38931
with p-value = 0.0941315

Correlation coefficients,
5% critical value (two-tailed) = 0.1138 for n = 275

	log _LifeE	log _GNI	log _EducationI
log_EducationI	0.5397	0.4733	1.0000
log _GNI	0.7860	1.0000	
log _LifeE	1.0000		

Variance Inflation Factors
Minimum possible value = 1.0
Values > 10.0 may indicate a collinearity problem

log_LifeE	2.890
log_EducationI	1.424
log_GNI	2.640

*Significant at 10% **Significant at 5% ***Significant at 1%

Source: Author's analysis

4.4 Energy efficiency and HDI

The decoupling of economic growth and energy consumption can be achieved using different tools, one of which is to improve the energy efficiency of buildings and appliances. Figure 15 displays the average HDI values for the study period (2010–2020) and the residential energy efficiency scores for all Member States. This score varies from 0 to 1 and combines three energy efficiency measures: current level, performance since 2000 (trend), and strength of policies. Energy efficiency is a critical factor that should be considered when examining the effects of human development on energy consumption. It reduces the energy required to deliver a product or a service. At the same time, it offers a range of other benefits, including improved economic performance and competitiveness, job growth, energy security, and better health. As a result, it helps reduce energy consumption and increase human development.

Figure 15 shows that old Member States have a higher energy efficiency score than post-communist Member States. Ireland, Finland, France, Netherlands, and Germany have the highest energy efficiency scores. All these states are amongst the highest energy consumers in the EU. If all the states had a similar efficiency level, the residential energy use gap between these states and others would be more significant. In addition, most of these states have very high HDI values and per capita incomes.

On the left side of the graph, Croatia, Poland, Italy, Estonia, and Hungary have the lowest energy efficiency scores. These states have relatively lower HDI values and income per capita than the first group, and their households, except Estonia, consume less energy.

Finally, the last group in the middle of the graph has average energy efficiency scores. These countries have moderate HDI and income values and consume more energy than the second group.

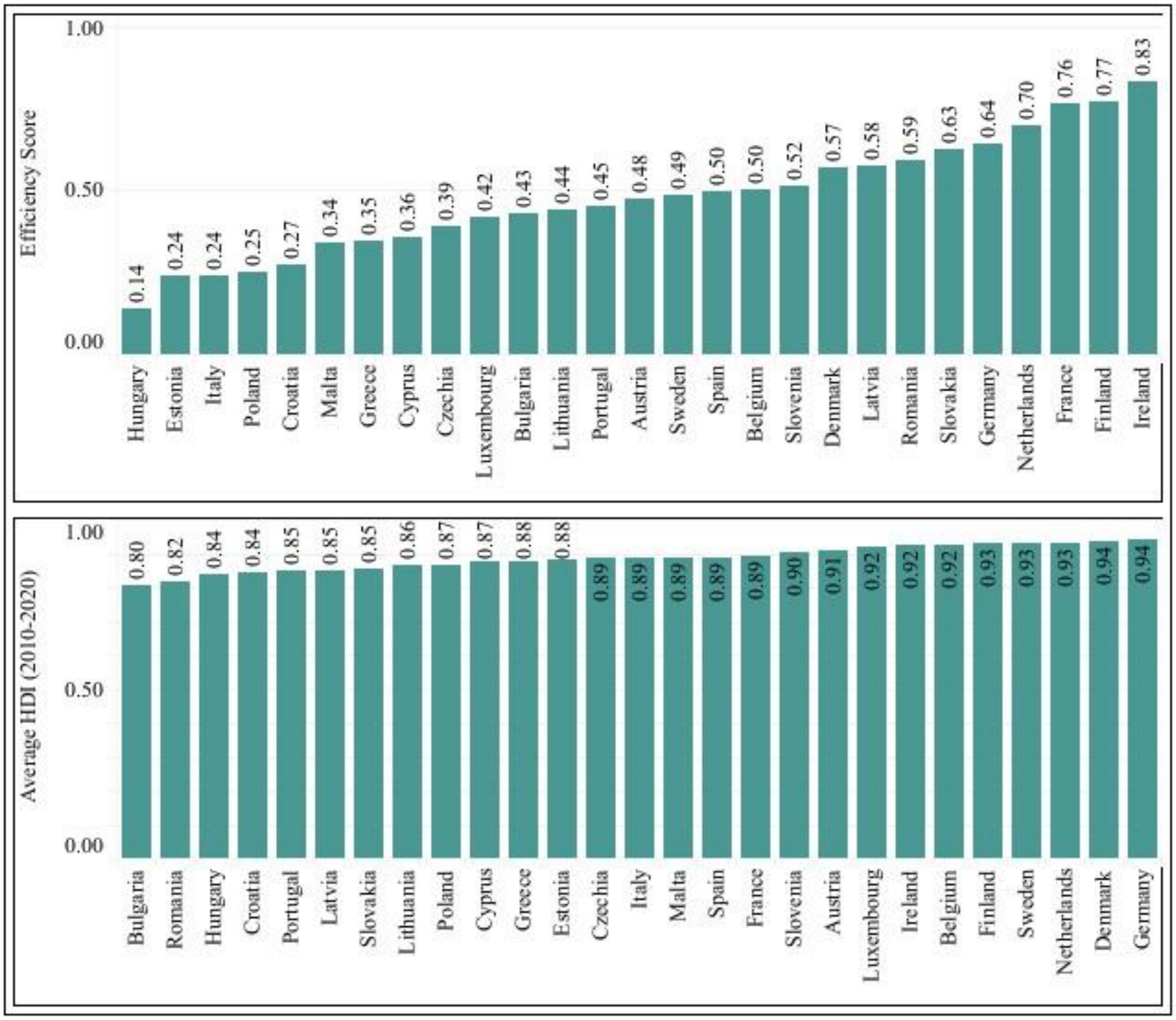

Figure 15 Average HDI value for the study period (2010–2020) and residential energy efficiency scores for all Member States
Source: Author's analysis

4.5 The impact of the socio-economic gap on energy inequality

The main objective of using cluster analysis is to capture the socioeconomic differences between the Member States to test the third hypothesis. The 27 EU Member States are classified based on the average values of CEC, GDP per capita, HDI, and electricity prices during the study period in Table 9. All Member States are included in the analysis except Luxembourg, which is an outlier. The Member States were classified into four subclusters: A, B, C, and D. Subcluster A includes states with the highest values. The values decrease from subclusters A to D, so the states in subcluster D have the lowest values. Based on these results, the Member States can be divided into two major clusters. The first group is called "Leaders" and consists of subclusters A and B, while the second is called "Laggards" and consists of subclusters C and D. The table also includes the average ETI value for states in each subcluster in 2020. Subcluster B boasts the highest ETI at 65.1, followed by A at 64.5, C at 57.6, and D at 57.1. The cluster analysis outcomes align with the

ETI metrics the World Economic Forum provided and reflect the system performance and readiness for energy transition. Because of Ireland and Belgium's underperformance or deviation from expectations in energy transition, subcluster A is not clinching the highest ETI score. However, the gap in the scores between Leaders and Laggards is evident.

Table 9 K-Means clustering for the EU Member States based on their average values for climate-adjusted per capita household energy consumption (CEC), GDP per capita, HDI, and electricity prices over the period 2010–2020

Cluster	Subcluster	Member States	Average ETI 2020
Leaders	A	Belgium, Denmark, Germany, and Ireland	64.5
	B	Austria, Cyprus, Finland, France, Italy, Netherlands, Spain, and Sweden	65.1
Laggards	C	Croatia, Czech Republic, Estonia, Greece, Hungary, Malta, Poland, Portugal, and Slovenia	57.6
	D	Bulgaria, Latvia, Lithuania, Romania, and Slovakia	57.1

Source: Author's analysis, ETI data is extracted from World Economic Forum (2023)

The average standardized scores (Z-scores) for the variables in each subcluster are shown in Figure 16. For each variable, the Z-scores represent the difference between the mean of the variables in the subcluster and the mean in the whole sample. All differences are measured in standard deviations. The zero line in the figure shows the mean values of the variables for the 26 Member States included in the analysis. The Z-scores for subclusters A and B (Leaders) are above the zero line, and those for subclusters C and D (Laggards) are below. Based on this result, the distinction between the two clusters (Leaders and Laggards) was made.

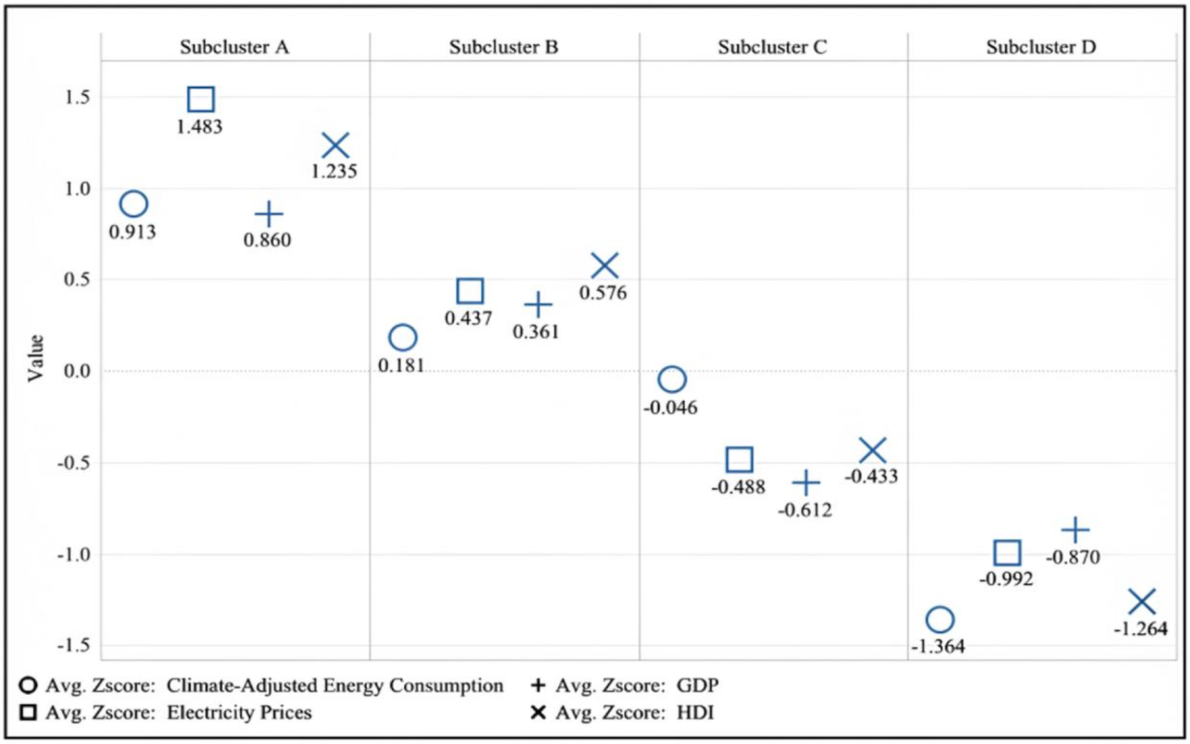

Figure 16 Average standardized scores (Z-scores) for climate-adjusted per capita household energy consumption (CEC), GDP per capita, HDI, and electricity prices in each subcluster
Source: Author's analysis

To examine the impact of socioeconomic differences between Member States on inequality in energy consumption, inequality within each subcluster is calculated, and the share of inequality within and between subclusters of overall inequality is compared. Gini and Theil values are shown in Figures 17 and 18, respectively. The figures show the same inequality fluctuations and trends with different values. Since the Theil values, unlike the Gini values, have no upper limit, they cannot provide helpful information on how profound inequality is.

The trend lines (dashed lines) in Figures 17 and 18 are downward sloping to varying degrees for the EU-27 Member States and all subclusters, indicating a downward trend in energy consumption inequality over this period. While the pattern of inequality values in subclusters A and B is almost stagnant, the significant downward trend for the EU-27 Member States could be related to the patterns in subclusters C and D (Laggards). In these states, the values of energy consumption converge. However, knowing the values and patterns of inequality within each subcluster does not indicate how much each contributes to overall inequality. To determine the contribution of inequality of each subcluster to overall inequality, the Theil index is decomposed by subclusters, as shown in Figure 19. Inequality *between* subclusters contributed the most in all years, with an average of 60%. In other words, the leading cause of overall inequality is inequality *between* subclusters, not inequality *within* subclusters. This result suggests that the socioeconomic gap between the Member States significantly impacts energy consumption inequality.

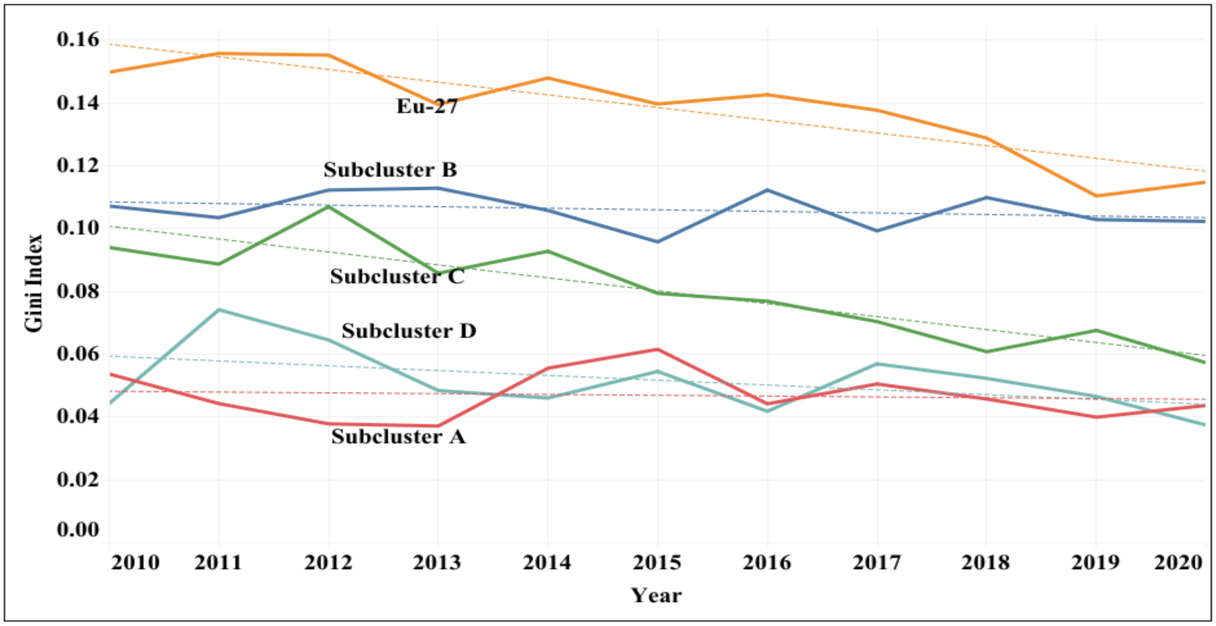

Figure 17 Inequalities in climate-adjusted per capita household energy consumption (CEC) for the EU-27 Member States and subclusters from 2010 to 2020, measured using the Gini index
Source: Author's analysis

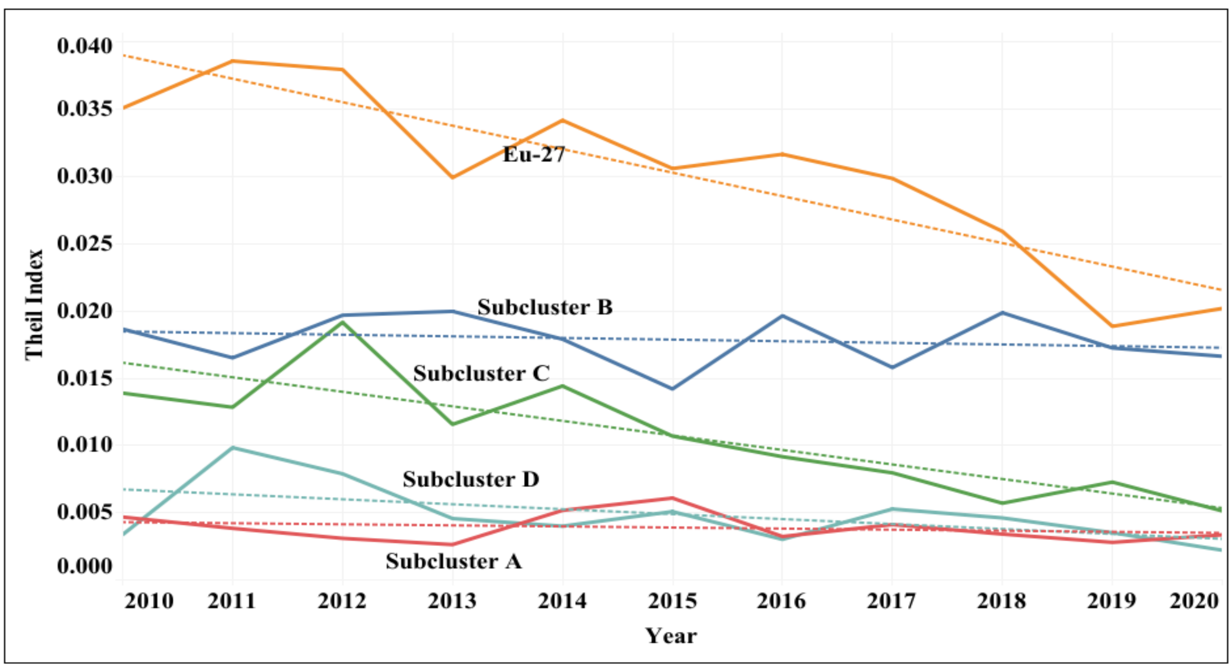

Figure 18 Inequalities in climate-adjusted per capita household energy consumption (CEC) for the EU-27 Member States and subclusters from 2010 to 2020, measured using the Theil index
Source: Author's analysis

Moreover, the highest share was 64.4% in 2011, and the lowest was 50.3% in 2019. The highest and lowest levels of energy consumption inequality were recorded in these years across the EU-27 Member States(from Figures 17 and 18), confirming the significant impact of inter-subcluster inequality on overall inequality. On the other hand, the average contribution share of intra-subcluster inequality is around 40% over the whole study period, indicating a less measurable impact.The third hypothesis is accepted.

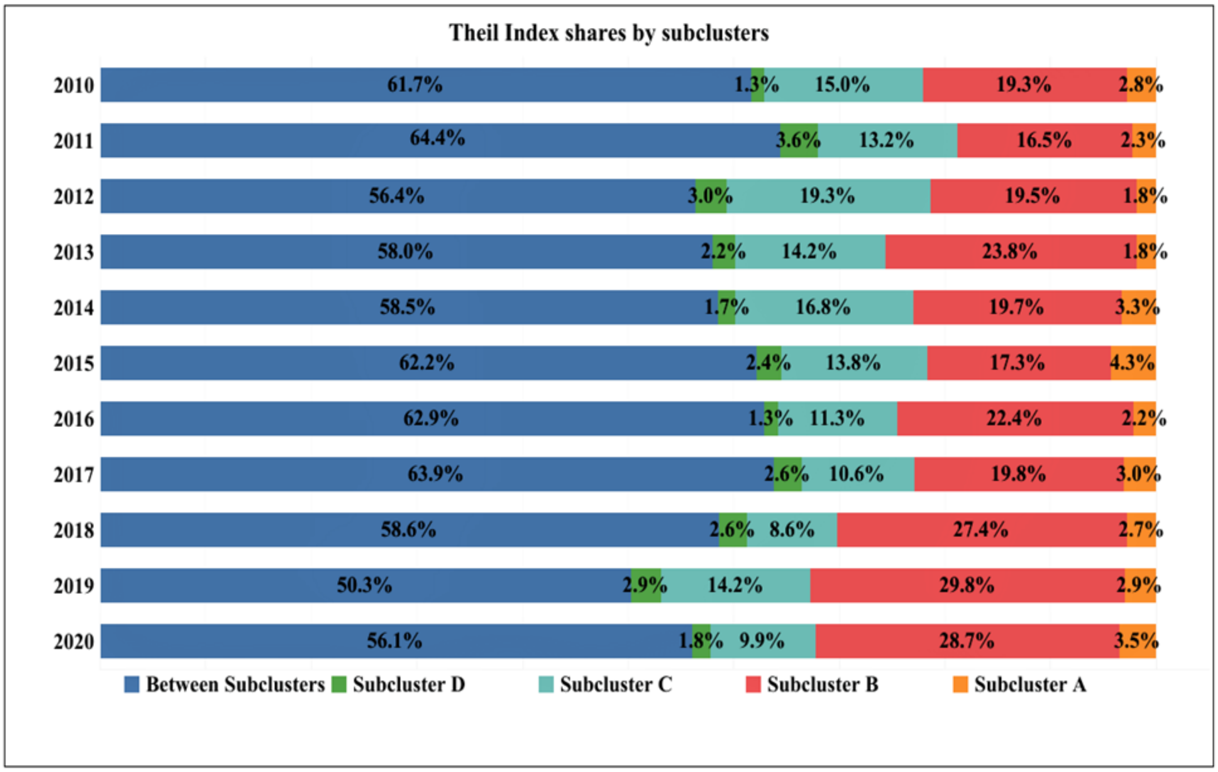

Figure 19 Shares of inequality within and between subclusters of overall inequality from 2010 to 2020
Source: Author's analysis

4.6 Contributions to energy inequality

Regression-based inequality decomposition is used with the Shapley value framework to test the fourth research hypothesis (which socioeconomic factor contributes most to inequality in household energy consumption in the EU Member States). Table 10 shows the socioeconomic factors' relative and absolute contributions for the 27 EU Member States from 2010 to 2020.

The main contributor to this inequality is GDP, the factor responsible for the largest share in most years. The most significant contribution was 52.8% in 2011, and the smallest was 20.79% in 2019, the same years when energy consumption inequality was the highest and lowest. This shows that GDP has a significant impact on energy consumption inequality. To a lesser extent, HDI and electricity prices contribute to inequality in energy consumption. The fourth hypothesis is accepted.

Table 10 Relative and absolute contributions of climate-adjusted per capita energy consumption (CEC) inequality determinants (GDP, HDI, and EP) for the EU-27 Member States from 2010 to 2020

Year	*Contribution*	*GDP*	*HDI*	*EP*	*Unexplained Inequality (Other Variables)*	*Overall Inequality (Gini Index)*
2010	Absolute	0.0621	0.0166	0.0166	0.0545	0.1499
	Relative	41.47%	11.07%	11.06 %	36.40%	100%
2011	Absolute	0.0823	0.0175	0.0057	0.0503	0.1558
	Relative	52.80%	11.26%	3.64%	32.30%	100%
2012	Absolute	0.0756	0.0182	0.0038	0.0575	0.1553
	Relative	48.72%	11.75%	2.47%	37.06%	100%
2013	Absolute	0.0550	0.0175	0.0118	0.0551	0.1395
	Relative	39.44%	12.56%	8.49%	39.51%	100%
2014	Absolute	0.0563	0.0148	0.0244	0.0525	0.1480
	Relative	38.05%	10.03%	16.47 %	35.45%	100%
2015	Absolute	0.0564	0.0161	0.0154	0.0518	0.1397
	Relative	40.38%	11.50%	11.06 %	37.06%	100%
2016	Absolute	0.0557	0.0158	0.0167	0.0545	0.1427
	Relative	39.02%	11.09%	11.69 %	38.20%	100%
2017	Absolute	0.0580	0.0147	0.0193	0.0458	0.1377
	Relative	42.08%	10.67%	13.99 %	33.25%	100%
2018	Absolute	0.0443	0.0154	0.0184	0.0507	0.1289
	Relative	34.35%	11.98%	14.31 %	39.36%	100%
2019	Absolute	0.0230	0.0153	0.0243	0.0478	0.1104
	Relative	20.79%	13.87%	22.01 %	43.33%	100%
2020	Absolute	0.0336	0.0166	0.0176	0.0470	0.1148
	Relative	29.29%	14.49%	15.32 %	40.89%	100%

Source: Author's analysis

Cumulatively, these socioeconomic factors explain more than 59% of inequality in all years. In contrast, other determinants explain the remaining unexplained inequality. Household energy consumption is influenced by several demographic, social, and energy-related factors in addition to economic ones. Factors such as urbanization rate (Nie et al., 2018), health status (Longhi, 2015), age, gender, marriage (Frederiks et al., 2015), family composition (Mansouri et al., 1996), household size (Kialashaki and Reisel, 2013), and house type (Zhao et al., 2016) influence household energy consumption. Nevertheless, the economic and social factors included in the analysis have the most significant influence. This result shows how much these factors influence the inequality of energy consumption in the 27 EU Member States. However, do they influence inequality equally in leading and lagging states?

To answer this question and test the fifth research hypothesis, Figure 20 presents a more comprehensive overview. It shows the average contribution (share) of socioeconomic factors in energy consumption inequality for the EU-27 Member States, Leaders, and Laggards. For more detailed data, Tables 12 and 13 in the Appendix show the contributions of Leaders and Laggards clusters in each year. Back to Figure 20, socioeconomic factors explain 18.02% of overall inequality in Leaders and 41.94% in Laggards. Since leading states have better economic conditions and higher living standards, the disparities in GDP, HDI, and electricity prices have little impact on the inequality values in energy consumption. Other factors are the main determinants of this inequality. As lagging states may further develop, the contribution of socioeconomic factors to their energy consumption inequality is more significant. Given the economic and social differences between these two groups of countries, the contributions of GDP, HDI, and electricity prices to energy consumption inequality are the greatest when all Member States are considered.

Furthermore, for all Member States, variations in GDP contribute 38.76% to energy consumption inequality, variation in HDI 11.84%, and variation in electricity prices 11.86%. These figures imply that GDP is the primary determinant of European household energy consumption and that decoupling has not yet been achieved in all Member States. For Leaders, the contribution of GDP is the smallest of all the determinants at 2.58%, confirming that these states have decoupled their energy consumption from their economic growth. In contrast, it is highest for Laggards at 17.58%, most likely because they have not yet achieved absolute decoupling. The fifth hypothesis is accepted.

Finally, the HDI and electricity prices are secondary determinants due to their average contributions. In all Member States, inequalities in HDI and electricity prices contribute almost equally to inequality in energy consumption. Regarding human development, the contribution of HDI is relatively small for the Leaders and Laggards and relatively large for all Member States, highlighting the economic and social gap between the two groups of countries. The contribution of electricity prices to the energy consumption inequality for Laggards is the largest among all country groups at 16.71%, illustrating the energy price sensitivity of households in these states.

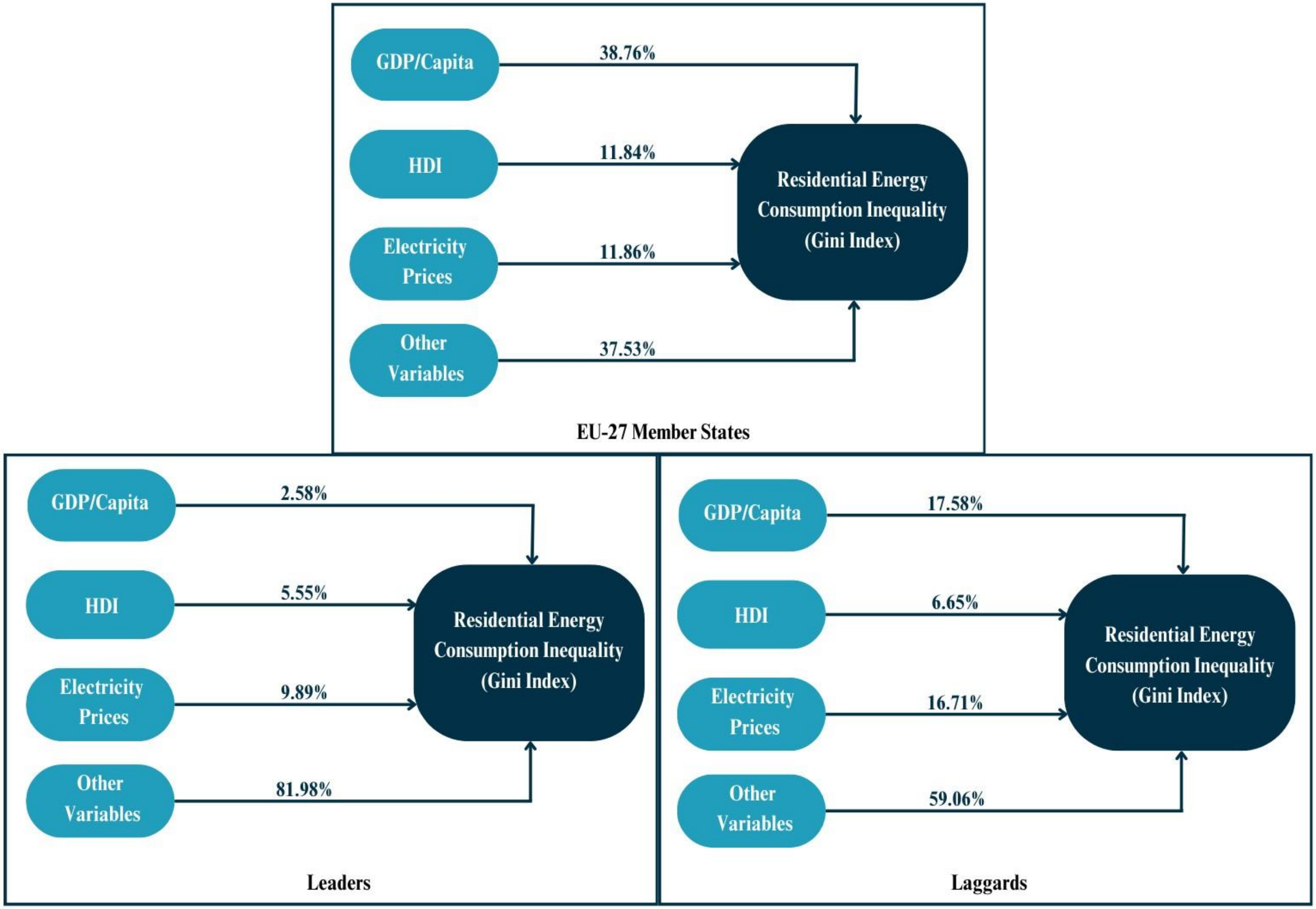

Figure 20 Average contribution of GDP, HDI, and electricity prices to the inequality of climate-adjusted per capita energy consumption for the EU-27 Member States, Leaders, and Laggards
Source: Author's analys

4.7 Analyzing the impact of the rise in electricity prices on energy inequality

While a year may not comprehensively analyze the correlation between rising energy prices and other variables, valuable insights can be gained into how this price surge in 2021-2022 impacts old and new Member States differently. It should be noted that the analyses assume the price increase is the sole driver for changes in other variable values. Additionally, Malta was excluded from the analyses due to a decrease in electricity prices between 2021 and 2022.

Regarding the relationship between electricity prices and energy consumption, a decrease in energy consumption across all EU Member States is anticipated due to the higher electricity prices. Figure 21 illustrates the trends in these variables for the EU Member States during 2021 and 2022, with Luxembourg and Finland excluded as outliers. Initially, electricity prices were relatively similar across all states in 2021, with an inequality measure (Gini index) of 0.134. This homogeneity is attributed to the liberalized energy market in the EU. Beginning in the 1990s, the EU and its Member States agreed to gradually liberalization their national gas and electricity markets, progressively opening them to competition. This process underwent various phases from 1996 until 2022 (European Parliament, 2024). However, by 2022, price increases varied significantly among states, resulting in a rise in the Gini index to 0.217. States that experienced less pronounced price hikes in 2022 tended to have lower prices in 2021, such as Hungary, Poland, and Bulgaria. This discrepancy is attributed to differing state interventions during the energy crisis. Following the Russian invasion of Ukraine and the disruption of gas supply to Europe, the EU implemented REPowerEU to address the crisis, incorporating exceptional and structural measures in the electricity and gas markets (European Parliament, 2024). In exceptional circumstances, the EU permitted Member States to establish retail prices for households and micro-enterprises, resulting in different electricity prices among the Member States.

Energy consumption values also fluctuated, decreasing Gini values from 0.125 in 2021 to 0.113 in 2022. Countries like Greece, Croatia, Portugal, and Cyprus witnessed increased energy consumption despite higher electricity prices, potentially attributed to their warmer climates. It's essential to acknowledge that energy consumption values are not climate-adjusted, which may explain these countries' rise in energy use.

Unexpectedly, the rise in electricity prices did not correspond to an increase in energy inequality, as energy consumption values tended to converge irrespective of price hikes. However, this convergence occurred due to varying degrees of price increases, leading to a significant rise in price inequality between the two years. Generally, states with higher energy consumption witnessed more substantial decreases, possibly because they experienced greater price hikes. These states might have had energy overconsumption before the price surge. Conversely, except for Southern states that increased their energy use despite significant price hikes, most states with low energy consumption experienced minimal price increases, indicating their inability to cope with substantial price hikes and lack of energy overconsumption. Consequently, the price increase in the EU contributed to reducing energy inequality among the states.

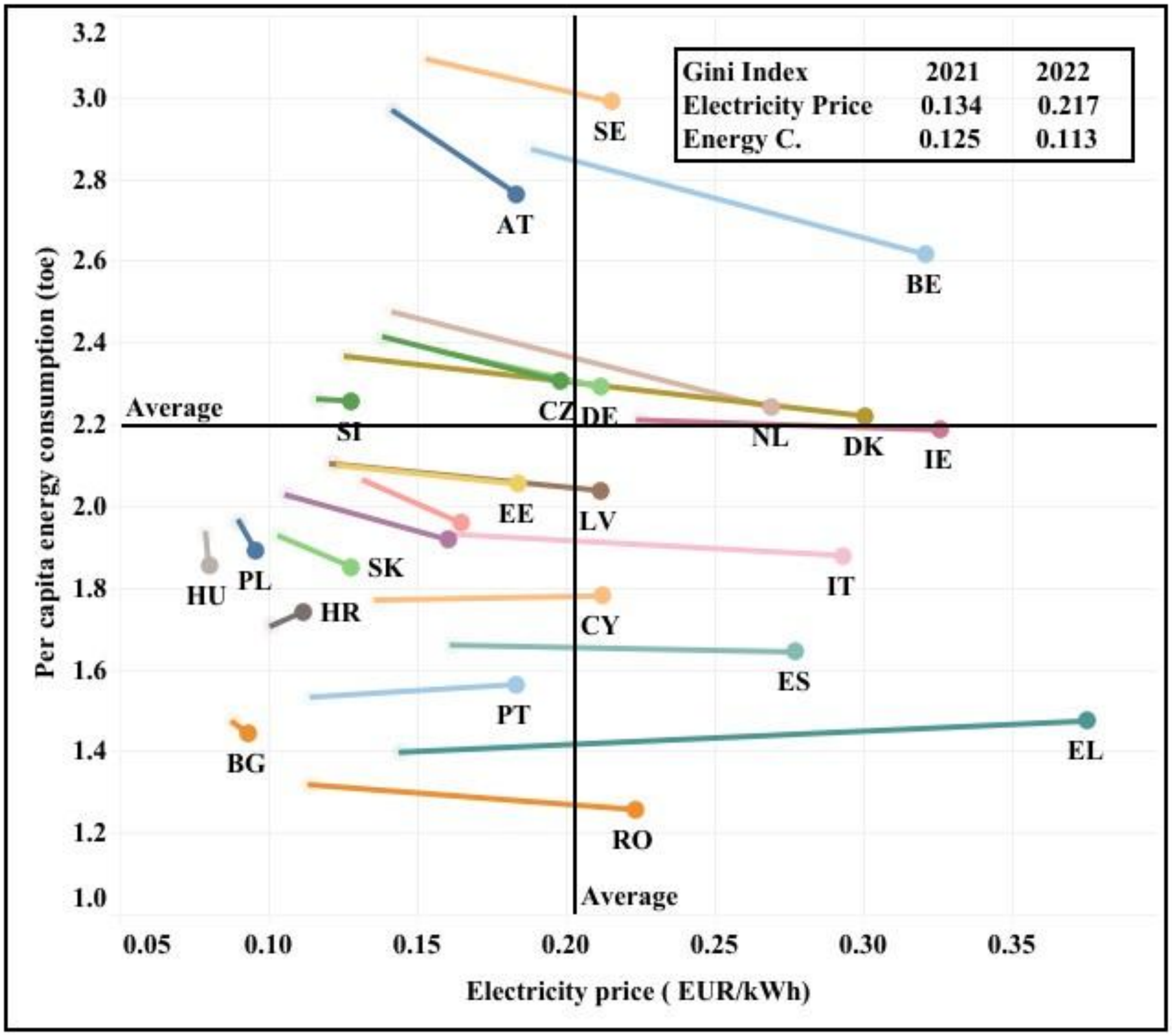

Figure 21 Electricity prices and per capita household energy consumption for the EU Member States in 2021 and 2022
Source: Author's Compilation

Regarding the relationship between electricity prices and GDP, Figure 22 displays the EU Member States' values in 2021 and 2022, with Luxembourg and Ireland excluded as outliers. The inequality in GDP decreased from 0.268 in 2021 to 0.251 in 2022, indicating a more significant decline in more developed states than less developed ones. Notably, this decline was observed primarily in states with higher GDP values, such as the old Member States, while those with lower values, such as the new ones, saw an increase. Similarly to energy consumption trends, more developed states experienced a more significant price increase, potentially explaining the decrease in their GDP values. Conversely, despite considerable price hikes, most Southern states experienced increased GDP values. Another group, including Hungary, Poland, and Bulgaria, faced relatively minor price increases, resulting in minimal impact on GDP. Their GDP values also increased. However, it was unexpected that GDP values increased for these states despite reduced energy usage. This suggests a weak connection between energy and GDP for these states compared to more developed ones. This observation contradicts the conclusions drawn earlier.

Nonetheless, it's crucial to note that this analysis covers only one year, overlooks climatic factors, and assumes electricity prices are the sole driver of other variables. Moreover, the drop in energy consumption and GDP values for the most developed states in one year does not hinder long-term economic growth. It suggests the economy's long-term resilience, as mentioned in the literature review. Therefore, including more years after the price shock in the analysis is recommended for more precise and comprehensive conclusions.

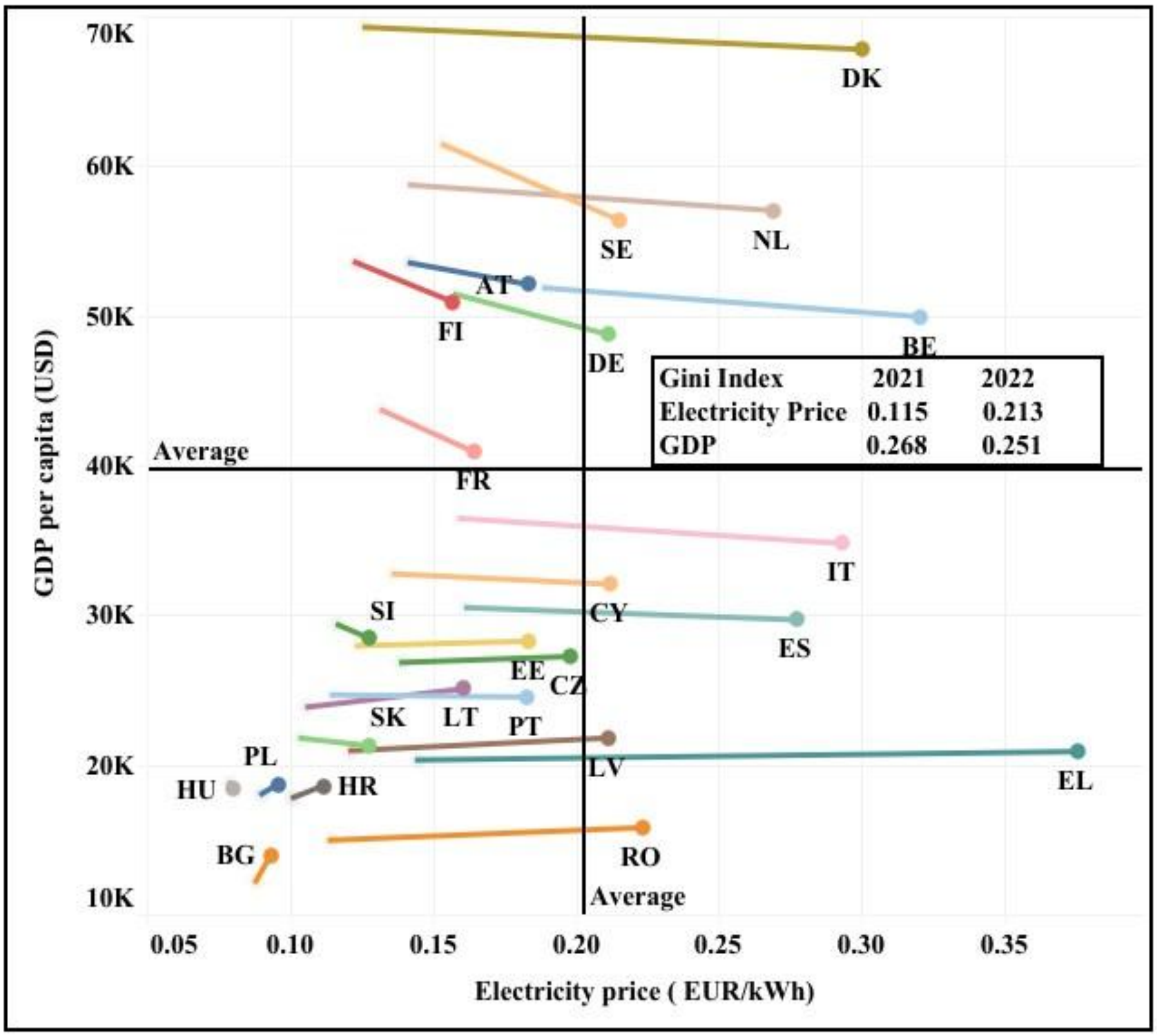

Figure 22 Electricity prices and per capita GDP for the EU Member States in 2021 and 2022
Source: Author's Compilation

For electricity prices and HDI, Figure 23 shows the values for the EU Member States between 2021 and 2022, excluding Romania and Bulgaria as outliers. Interestingly, all countries witnessed an uptick in their HDI values despite rising energy prices. However, the degree of HDI increase varied among countries, leading to a slight decrease in inequality from 0.205 to 0.195. Notably, nations with higher HDI values, including Denmark, Sweden, Germany, and Ireland, exhibited less pronounced increases than those with lower HDI values. This phenomenon suggests that these countries might have approached a saturation point where significant further increases in HDI become challenging to achieve. Overall, the data depicted in the figure indicates a lack of correlation between electricity prices and HDI across the EU Member States. The sixth hypothesis is rejected.

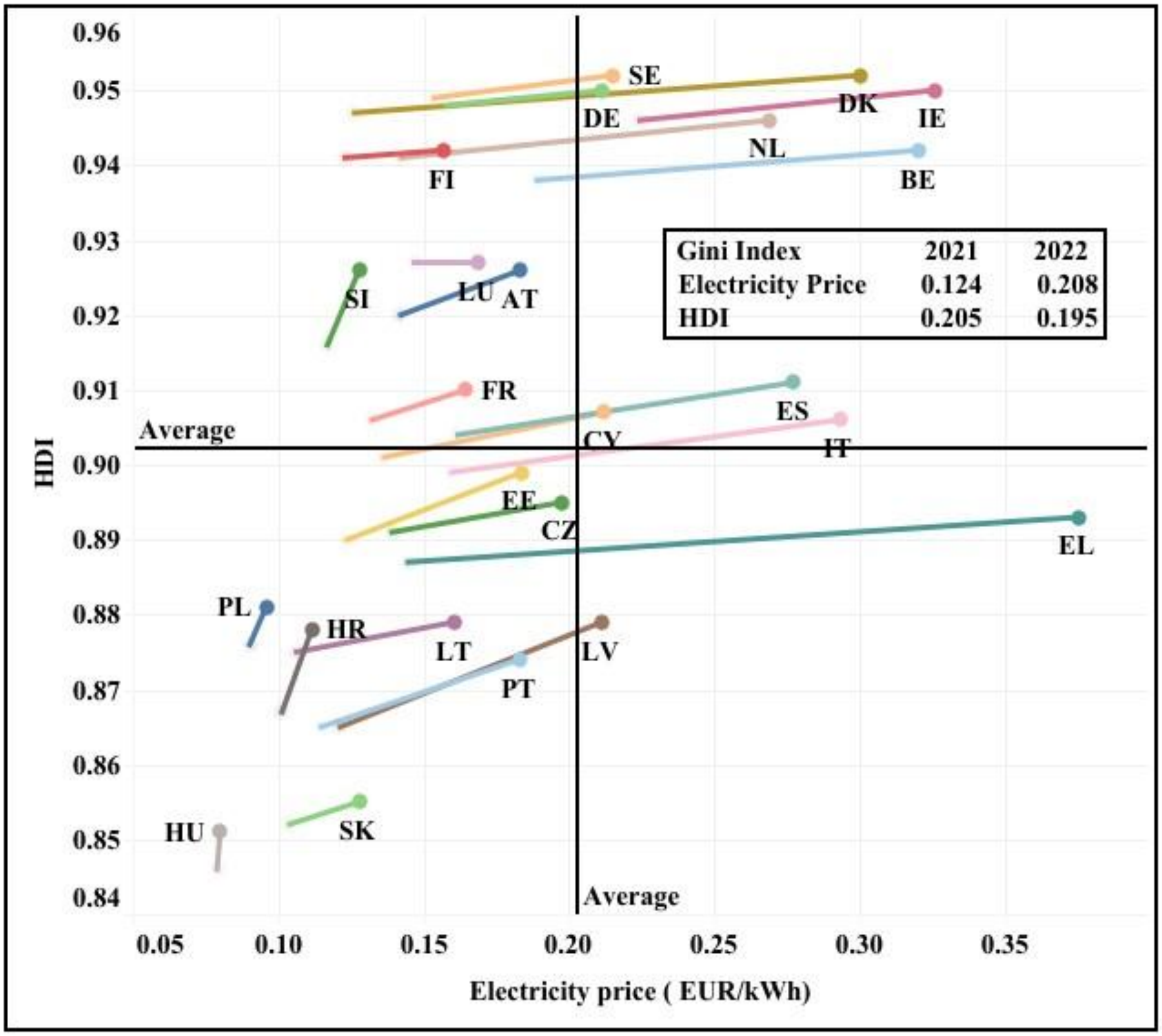

Figure 23 Electricity prices and HDI for the EU Member States in 2021 and 2022
Source: Author's Compilation

5 Conclusion and recommendations

This chapter presents the conclusions drawn from the results and the theses developed as a result. It also offers policy recommendations and provides a theoretical reflection on the proposed paradigm.

5.1 Hypotheses One and Two

Human development is mandatory for citizens' well-being and quality of life. The provision of affordable and clean energy sources can improve this process. Thus, energy consumption plays a vital role in increasing a nation's level of human development. Nonetheless, the relationship between the two variables is nonlinear and depends on the energy consumed. The panel regression result showed that the HDI and its components positively correlate with household energy consumption. Thus, decision-makers in each state, particularly those with HDI values less than 0.9, and the EU should consider the influence of human development on energy inequality for the household sector by improving the education and health sectors and putting more effort into decoupling economic growth and energy consumption.

Energy efficiency should be considered when considering the decoupling process and raising the level of human development. Three groups of countries resulted based on the energy efficiency scores and HDI values of the 27 EU Member States. The first group, Ireland, Finland, France, the Netherlands, and Germany, has high energy efficiency scores and HDI values. Consequently, it is preferable to introduce the extended EU ETS as a pilot system in these states. These nations consume more energy, have higher energy efficiency levels, and have a higher income per capita than the other Member States. Hence, it is better to start reducing their high household energy consumption. In addition, households in such states can withstand the predictable increase in energy prices and utility bills as they have a high income.

The second group, Croatia, Poland, Italy, Estonia, and Hungary, has low energy efficiency scores and relatively low HDI values. Policymakers in such states should put more effort into improving their energy efficiency performance with the help and support of the EU. The EU ETS for the residential sector should not be applied in these states to avoid energy poverty and ensure energy justice because households here cannot handle rising energy prices.

The third group, which comprises the rest of the countries, has average energy efficiency scores and HDI values. To reduce their residential energy consumption and reach climate policy goals, they should improve their energy efficiency performance and strengthen their energy taxation framework. This could be achieved by changing the current minimum tax rates for the states under the Energy Taxation Directive and modifying the fuel type.

The correlation between increased energy consumption and higher human development has undergone reevaluation in light of mounting concerns about climate change and the imperative of energy efficiency. While essential for a wide range of activities, energy is also a primary contributor to greenhouse gas emissions, posing significant environmental threats. Consequently, the energy mix a nation uses plays a pivotal role in determining the direction of this relationship. For the EU Member States, there appears to be a trend towards higher-quality energy products over time, particularly aided by climate and energy policies. As a result, the quality of energy has reached a level where increased household energy consumption positively impacts the HDI and its components. This indicates that energy usage within the EU contributes more to advancing human development than it does to environmental degradation.

Furthermore, as nations progress, the correlation between these factors becomes less robust, and the significance of human development may diminish. In the context of the 27 EU Member States, it is evident that HDI positively impacts household energy consumption. States with higher HDI values tend to exhibit greater energy consumption in households.

The positive correlation between the HDI components and household energy consumption reinforces this relationship. Households in states with higher life expectancy, education indices, and GNI tend to consume more energy. The following theses are concluded:

T1	T2
HDI values are still dependent on residential energy consumption among the 27 EU Member States and its variation increases energy consumption inequality. This observation supports the conservative and growth hypotheses.	The correlation between the HDI and residential energy consumption is substantiated by the positive impact of specific HDI components, life expectancy, education index, and GNI, on residential energy consumption within the 27 EU Member States. Nevertheless, the conservative hypothesis is partially supported, as the education index exhibited a non-significant correlation.

5.2 Hypotheses Three, Four, and Five

The distribution of energy resources can lead to significant social, environmental, and economic inequalities. A major challenge for policymakers worldwide is how to distribute the costs and benefits of policies to address such problems (Wu et al., 2012). In Europe, the just transition approach is used to address this challenge. This approach aims to eliminate greenhouse gas emissions by 2050, decouple economic growth from resource consumption, and ensure no individual or region is left behind. Although the transition process entails a reduction in household energy consumption, the differences in household energy consumption across Member States and their social and economic consequences are often not considered in the context and regulatory framework of the just transition. To this end, this study assesses the role of socioeconomic differences between EU Member States in this inequality, calculates the share of each determinant (GDP per capita, HDI, and electricity prices) in overall inequality, and examines the decoupling between economic development and energy consumption.

To test the third hypothesis, the study divided the Member States into four subgroups and two main groups based on socioeconomic factors and energy consumption: Leaders (concentrated in the West and North) and Laggards (concentrated in the East). Leaders typically have better economic conditions and a higher standard of living than Laggards. Households in this group consume more energy than the EU average, while households in Laggards consume less energy than the EU average. The results show that inequality *between* subclusters contributes more to overall inequality than inequality *within* subclusters (the former accounting for the largest average contribution share in all years, at around 60%). This finding highlights the gap between the states allocated to these subclusters, leading to greater energy consumption inequality. In other words, the socioeconomic gap between EU Member States significantly impacts energy consumption inequality. This makes it necessary to consider this gap in all policy decisions. A multi-pronged strategy based on the sufficiency principle – the idea that everyone must have enough, not an equal share of benefits and burdens (Shields, 2019) – should be pursued to ensure that the lagging states with relatively low per capita energy consumption are treated differently. Referring to an earlier proposal of the present author, introducing the EU ETS as a pilot system in states with higher energy consumption, higher energy efficiency, and higher per capita income would be a viable short-term solution if applied to the EU leading Member States.

National governments can also adopt this strategy to reduce inequality in energy consumption at the country level. Hungary is an excellent example in this respect. The utility cost reduction program initiated by the Hungarian government to keep utility prices low in 2013 resulted in an additional consumption of 13.2 PJ by 2018 (Weiner and Szép, 2022). However, the latter was unevenly distributed across income deciles. Low energy prices favored members of the higher-income deciles more than those of the lower-income deciles, who often use low-quality market fuels and live in inefficient housing (Weiner and Szép, 2022). Nevertheless, in response to the energy price storm in 2022, the Hungarian government revised the program to specify an official price for gas and electricity for every consumer to the national household average consumption level. Beyond this level, everyone must pay the market price. The Hungarian government's multi-tier pricing strategy, designed to alleviate the budgetary pressure caused by the energy crisis, is expected to reduce the inequality of household energy consumption between Hungarian population groups.

Regarding the contribution to overall inequality, variation in GDP per capita has the most significant impact, followed by electricity prices and the HDI. The average contribution shares of these variables to overall inequality are 38.76%, 11.86%, and 11.84%, respectively, showing that GDP significantly impacts energy inequality. Therefore, decoupling GDP and energy consumption could be the most effective strategy for reducing inequality in household energy consumption in the EU Member States. For Leaders, the contribution share of GDP is the smallest of all variables, with a negligible value of 2.58%. In contrast, it is highest for Laggards at 17.58%. This result confirms that the decoupling of economic growth from household energy consumption has not been achieved in all Member States. Two primary strategies can be pursued to attain absolute decoupling:

First, lagging states may strive to increase their energy consumption, increasing their level of economic development. This would enable these states to better align their economies with those of the Leaders, which have already achieved decoupling.

Alternatively, the energy efficiency of buildings in lagging states could be increased, thereby decreasing energy consumption. This strategy would ensure that any decline in energy consumption would not merely be a reaction to rising energy prices, which impede economic development.

Given the consequences of the 2021-2022 energy crisis, which raised questions about energy security and the urgency of reducing fossil fuel imports, the second proposal is more realistic, especially as it aligns with European climate and energy policy goals. According to a report by the European Commission in 2021, about 75% of buildings in the EU are energy inefficient (EC, 2021). Accordingly, it is proposed to prioritize renovating old buildings in lagging states to improve energy efficiency. Addressing the preexisting problems of energy inequality that could widen the gap between the two groups of countries and disproportionately affect lagging states would be a step towards a just transition in the EU.

The fifth hypothesis aligns with the conservative hypothesis to examine the relationship between energy and growth. It also neither rejects nor endorses the growth hypothesis. Concerning the connection between energy consumption and GDP, despite advancements in energy quality and technological improvements, such as increased energy efficiency levels within the EU, there remains a connection between energy usage and GDP in some Member States. Complete decoupling has yet to be attained across all Member States, confirming the viewpoint of opponent economists. The following theses are concluded:

T3

The pronounced socioeconomic disparities among EU Member States, as reflected in differences in GDP, HDI, and energy prices, play a pivotal role in shaping the disparities in household energy consumption across these states. The empirical evidence supports the conservative hypothesis.

T4

GDP is the primary driver of inequality in household energy consumption within the EU Member States. This analysis underscores the pronounced economic-centric nature of development within the EU, as evidenced by GDP's significant impact on household energy consumption.

T5

The decoupling of economic development from household energy consumption remains elusive in all Member States. This analysis disproves the neutrality hypothesis yet underscores the enduring link between GDP and household energy consumption.

Theory reflection

In the theoretical realm, the most recent and comprehensive just transition concept was presented by McCauley et al. (2023), who adopted a multifaceted approach encompassing the integration of distributional, procedural, and restorative tenets. They expanded the distributional justice tenet to include not only inequalities in fossil fuel dependency but also inequalities in health, education, gender, and income. However, their approach overlooked inequality in energy consumption as a form of energy inequity. In contrast, the paradigm employed in the theoretical background (Chapter Two) sought to integrate this inequality into the just transition by leveraging the energy justice framework as a mediating element. Energy justice emphasizes addressing justice-related concerns within energy systems and their associated policy frameworks during the transition (Hartwig et al., 2023).

Consequently, integrating energy consumption equality into the just transition requires adaptations in the energy justice framework. The framework addresses issues directly related to energy, such as inequality in the access to, supply, and consumption of energy. Still, it does not explicitly address the complicated political and economic forces often leading to energy injustice (Lee and Byrne, 2019). In this way, it focuses on identifying injustices rather than solving them (Lee and Tieslau, 2019). The energy justice framework should additionally consider the preexisting structural causes of injustice in energy markets and broader socioeconomic factors to ensure that the current low-carbon transition wave does not create new injustices and vulnerabilities (Sovacool et al., 2019).

Nevertheless, energy inequality should be acknowledged first. *Recognition* justice has been described differently by numerous scholars, for it is the most challenging concept to grasp. One group of definitions claims that it involves recognizing a specific issue or problem by pointing out that it exists and/or needs more attention (Van Uffelen, 2022). If *recognition* justice is limited to this interpretation, inequality in energy consumption should first be recognized as an injustice by researchers, and even more so by policymakers, before the causes are addressed. Some specialist theorists (Dworkin, 2000; Sayer, 2012; Young, 2010) employ the criterion that inequalities are only acceptable if they are the result of differences in individual choices, while those that are due to factors outside the individual's control are unjust (Bouzarovski and Simcock, 2017). As long as the results show that socioeconomic differences beyond the control of the individual contribute, on average, to more than 60% of the inequality in energy consumption in the EU Member States, it is essentially not due to differences in individual choices. The latter is, therefore, an injustice that should be addressed in the just transition.

In terms of future research, there is a lack of sophisticated empirical studies because scholars in the field seem more interested in creating various analytical frameworks for the just transition than in applying these frameworks through empirical studies (Wang and Lo, 2021). However, policymakers need empirical evidence before paying more attention to these inequities in the context of the just transition. Creating a decomposable and unrestricted measure of inequality, incorporating other factors that contribute to it, and developing historically based future scenarios that analyze inequalities and their underlying causes would be a valuable task for future research.

5.3 Hypothesis Six

Despite the growing disparities in income and access to energy, initiatives like the EGD aim to facilitate a fair transition away from fossil fuels. However, challenges remain in transforming energy supply and demand to achieve decarbonization while ensuring a decent standard of living for all. The old Member States, major carbon emitters, are urged to lead the transition to sustainable energy sources, considering their more significant financial resources. The sixth hypothesis explores the impact of rising energy prices on energy consumption, GDP, and the HDI for EU Member States, aiming to validate the hypothesis that economically weaker states are more adversely affected.

Notably, the surge in electricity prices did not uniformly translate into reduced energy consumption across the region, with differing degrees of price increases contributing to varying outcomes. Moreover, the findings regarding the relationship between electricity prices and GDP reveal unexpected nuances, particularly in states with lower energy consumption. Despite minimal price hikes, these states experienced GDP increases, highlighting a potentially weak link between energy consumption and economic output compared to more developed counterparts. However, it's essential to interpret these findings within the context of the study's limitations, including its focus on a single year, oversight of climatic factors, and the assumption of electricity prices as the primary driver of change.

All in all, the increase in energy prices due to the energy crisis in 2021-2022 decreased the inequality in energy consumption, GDP, and HDI, mainly because the increase was not uniform among the states. As a result, the sixth hypothesis is rejected. To get more precise results, further analysis is required by calculating and comparing the variables’ change rates between the states and including more years after the price shock in the study. Still, this result confirms that every state must have enough, not an equal share of benefits and burdens. That is why the higher increase in energy prices in the old Member States led to a decrease in energy inequality in the EU.

6 Synthesis of findings, policy impacts, and research opportunities

This chapter summarizes the key findings and concludes with a table of the hypotheses, their testing outcomes, and the resulting theses. It then examines the policy implications of these findings for EU energy and climate strategies. The chapter concludes by highlighting opportunities for future research and outlining potential directions for further exploration.

6.1 Summary

Energy is a significant concern with far-reaching impacts on the environment, society, and economy. This includes effects on climate change, poverty alleviation, productivity in various sectors, and the well-being of ecosystems and human populations. Our energy usage influences the environment, with greenhouse gas emissions being a key factor. Therefore, developing sustainable energy strategies without degrading the environment is one of the most pressing challenges of our time. To address this challenge, it's essential to reduce energy demand, enhance energy efficiency, and promote the use of renewable sources. Addressing energy challenges also includes increasing energy access in developing nations and encouraging individuals to conserve energy. Achieving this requires involvement from governments, scientists, local communities, and consumers.

The distribution of energy resources creates social, environmental, and economic inequalities. Policymakers globally face the challenge of equitable distribution of costs and benefits in addressing these issues. The EU employs the just transition approach to tackle this challenge, striving for zero greenhouse gas emissions by 2050 and decoupling economic growth from resource consumption. However, the inequality in household energy consumption and its social and economic implications are often neglected in the EU just transition's regulatory framework. Understanding energy consumption inequality and its determinants is crucial to address this challenge effectively.

Economic growth emerges as a prominent determinant, with scholars identifying four key elements influencing the energy-growth nexus: substitutability of energy and capital, innovation in energy efficiency, changes in energy input composition, and output shifts. While economic growth is vital for sustainable development, its benefits do not automatically translate into improved living standards for all individuals, necessitating a comprehensive approach that prioritizes human well-being. The development process brings about not only economic but also societal changes that result in lasting improvements. Its main aim is to enhance human well-being. Since the HDI includes health and education indicators, it is widely regarded as the leading measure of human well-being, emphasizing the essential role of basic needs in enhancing quality of life.

This research evaluates inequalities in household energy consumption across the 27 EU Member States from 2010 to 2020. It examines the underlying economic and social factors contributing to these inequalities (GDP, HDI, and electricty prices). Additionally, it investigates the impact of electricity price increases between 2021 and 2022 on energy inequality and the progress of just transition.

Regarding the energy-HDI relationship, the results indicate that HDI exhibits a positive correlation with residential energy consumption among the 27 EU Member States between 2010 and 2020. As a result, the first hypothesis is accepted. This observation supports the conservative hypothesis and does not reject/support the growth hypothesis.

The correlation between the HDI and residential energy consumption is substantiated by the results that showed that all HDI components, life expectancy, education index, and GNI, positively correlate with household energy consumption. Nevertheless, the conservative hypothesis is partially accepted, as the education index exhibited a non-significant correlation.

The conservative hypothesis suggests a unidirectional causality from economic growth to energy consumption, implying that policies aimed at reducing energy use may not adversely affect economic growth. However, the growth hypothesis, which establishes energy as a crucial input for output and suggests that increased energy consumption causes economic growth, has not been tested. Panel regression measures the strength and direction of the relationship between the dependent variable (energy consumption) and independent (HDI) and does not measure the causality. So, according to the results, the policies aimed to reduce energy consumption impact economic growth. Decision-makers in each state, particularly those with HDI values less than 0.9, and the EU should consider the influence of human development on energy inequality for the household sector by improving the education and health sectors and putting more effort into decoupling income and energy by improving energy efficiency figures.

The energy mix a nation uses plays a pivotal role in determining the direction of the energy-HDI relationship. For the EU Member States, there appears to be a trend towards higher-quality energy products over time, particularly aided by climate and energy policies. As a result, the quality of energy has reached a level where increased household energy consumption positively impacts life expectancy. This indicates that energy usage within the EU contributes more to advancing human development than it does to environmental degradation.

Regarding investigating energy inequality and its driving factors in the EU, including more socioeconomic factors to the HDI, such as GDP and electricity prices, the study divided the Member States into two main clusters (Leaders and Laggards) and four subclusters based on energy consumption and these socioeconomic variables. The results show that the socioeconomic divide contributes significantly to the inequality in household energy consumption, as the inequality *between* subclusters is higher than the inequality *within* subclusters. As a result, the third hypothesis is accepted.

This empirical evidence supports the conservative hypothesis and again does not support/reject the growth hypothesis. The study primarily investigates energy inequality and suggests that further research into the precise relationship between energy and socioeconomic factors, including causality analysis, could be beneficial. However, the current research only aims to identify the factors driving energy inequality for mitigation purposes. Consequently, it underscores the importance of considering the socioeconomic gap among EU Member States in all policy decisions. A comprehensive approach should address this issue, mainly treating lagging states differently.

Among these socioeconomic factors, the per capita GDP is the main contributor to the energy inequality in the EU, with an average contributing share of 38.76%, followed by electricity prices and HDI, with contributing shares of 11.86% and 11.84%, respectively. This validates the fourth hypothesis and means that the economic aspects of development in the EU have a more robust connection to energy than the social aspects, and decoupling GDP and energy consumption could be the most effective strategy for reducing inequality in household energy consumption.

In leading states, GDP contributes the least among all variables, accounting for 2.58% of the total. Conversely, it holds the highest share in lagging states at 17.58%. This finding confirms that the decoupling of economic growth from household energy consumption has not been achieved in all Member States. This analysis rejects the neutrality hypothesis but reinforces the conservative hypothesis and the persistent correlation between GDP and household energy consumption. As a result, the fifth hypothesis is accepted.

In theory, energy justice framework adaptations are required to incorporate energy consumption equality into the just transition fully. While the framework addresses energy access, supply, and consumption issues, it does not explicitly address the political and economic forces that often lead to energy injustice. To prevent the creation of new injustices and vulnerabilities during the low-carbon transition, the energy justice framework should consider the preexisting structural causes of injustice in energy markets and broader socioeconomic factors. Also, researchers and policymakers should recognize energy inequality as an injustice. The criterion for acceptable inequalities suggests that those resulting from factors beyond an individual's control are unjust. Since socioeconomic differences beyond individual choices contribute to over 60% of the inequality in energy consumption in EU Member States, it is an injustice that should be addressed in the just transition.

Regarding the impact of the energy price rise that occurred during the 2021-2022 energy crisis on energy inequality, the increase in electricity prices caused a more notable decrease in household energy consumption, per capita GDP, and HDI in the old Member States compared to the post-communist ones, thereby mitigating inequalities in these indicators. Consequently, the sixth hypothesis is rejected. This unforeseen outcome is linked to the more significant price increase experienced by the old Member States, leading to a more substantial reduction in these indicators.

Moreover, the findings regarding the relationship between electricity prices and GDP reveal unexpected nuances, particularly in states with lower energy consumption. Despite minimal price hikes, these states experienced GDP increases, highlighting a potentially weak link between energy consumption and economic output compared to more developed counterparts. This outcome challenges the fifth hypothesis's conclusion, positing that GDP in old Member States contributes less to energy consumption than in new ones. However, it's crucial to contextualize these results within the study's limitations, which include a focus on a single year, oversight of climatic influences, and the assumption that electricity prices are the only driver of change. Consequently, further analysis is warranted to obtain more precise insights by calculating and comparing variable changes across regions over multiple years following the price shock.

The relationship between household energy consumption and GDP in the EU presents an intriguing aspect. The connection between these variables is expected to be robust for other sectors, particularly the industrial one, given that GDP primarily reflects production activities. However, the findings revealed a strong correlation for the household sector, despite the consideration of direct energy use only. The embodied energy in goods and services is not calculated. Considering energy quality variations and including other variables in the model, causality analysis between these two variables is advisable for future research. The research concludes with Table 11, which comprehensively summarizes the research outcomes.

Table 11 Comprehensive summary of research outcome

#	Hypothesis	Result	Thesis
1	Regardless of their energy transition efforts, HDI values for the 27 EU Member States are still dependent on household energy consumption, and variation in HDI values can increase energy consumption inequality.	Accepted	HDI values still dependent on residential energy consumption among the 27 EU Member States, and their variation increases energy consumption inequality. This observation supports the conservative and growth hypotheses.
2	A significant and positive correlation exists between HDI components (life expectancy, education index, and GNI) and household energy consumption across EU Member States.	Partially Accepted	The correlation between the HDI and residential energy consumption is substantiated by the positive impact of specific HDI components, life expectancy, education index, and GNI, on residential energy consumption within the 27 EU Member States. Nevertheless, the conservative hypothesis is partially supported, as the education index exhibited a non-significant correlation.
3	The socioeconomic divide among EU Member States contributes significantly to the inequality in household energy consumption across states.	Accepted	The pronounced socioeconomic disparities among EU Member States, as reflected in differences in GDP, HDI, and energy prices, play a pivotal role in shaping the disparities in household energy consumption across these states. The empirical evidence supports the conservative hypothesis.
4	GDP is the socioeconomic factor contributes most to inequality in household energy consumption in EU Member States.	Accepted	GDP is the primary driver of inequality in household energy consumption within the EU Member States. This analysis underscores the pronounced economic-centric nature of development within the EU, as evidenced by GDP's significant impact on household energy consumption.
5	Decoupling between economic development and household energy consumption has not been achieved in all Member States.	Accepted	The decoupling of economic development from household energy consumption remains elusive in all Member States. This analysis disproves the neutrality hypothesis yet underscores the enduring link between GDP and household energy consumption.
6	The increase in electricity prices that transpired across the 27 EU Member States between 2021 and 2022 led to a more pronounced decline in household energy consumption, per capita GDP, and HDI for the new Member States compared to the old ones, thereby intensifying disparities in these variables.	Rejected	None

Source: Author's analysis

6.2 Policy implications for the EU: Insights from research

The current conceptual and regulatory framework of the EU just transition lacks a focus on inequality in household energy consumption. While the EU's just transition acknowledges carbon dependency considerations, a socioeconomic gap among EU Member States is often overlooked in policy formulation and decision-making processes. This socioeconomic gap significantly influences energy consumption inequality, necessitating its incorporation into all policy decisions.

A multifaceted approach based on the sufficiency principle should address this issue and ensure that the lagging states with relatively low per capita energy consumption are treated differently. National governments can also implement similar strategies to mitigate energy consumption disparities domestically. For instance, the Hungarian government's response to the 2022 energy price surge through a multi-tier pricing strategy exemplifies the application of the sufficiency principle.

In this context, findings revealed that the liberalization of national gas and electricity markets among EU Member States initially led to a reduction in energy price disparities from the 1990s until the 2021-2022 energy crisis. However, by 2022, price hikes varied considerably among states due to differing interventions, resulting in increased energy price inequality. Notably, prices rose more in leading states than in lagging ones, prompting a more substantial decline in household energy consumption in the former. Consequently, this led to decreased energy consumption inequality, serving as another manifestation of the sufficiency principle. Given their overconsumption of energy, leading states have the priority of curtailing their energy consumption.

The EC proposed reforming the electricity market design on March 14, 2023, in response to the energy crisis (European Parliament, 2024). The reform aims to reduce the dependency of electricity prices on fossil fuel costs and enhance consumer protection by expanding the availability of fixed-price and fixed-term contracts. It also allows consumers to choose dynamic pricing with multiple or combined contract options. Additionally, the reform ensures that governments can better regulate household retail prices to protect vulnerable consumers. Furthermore, it seeks to streamline the integration of renewable energy sources into the system. This initiative aims to maintain price stability and achieve ambitious climate targets simultaneously. The reform addresses national-level policy implications but overlooks the socioeconomic disparities among EU Member States.

The EU ETS was implemented in the industrial and power generation sectors in various phases, commencing with the first phase from 2005 to 2007, which served as a pilot phase for system testing. During this phase, most carbon allowances were distributed free of charge, with Member States retaining autonomy over the allocation process. However, after the first year of operation and the publication of real-world emission data, it became evident that an excess of allowances had been issued, resulting in a surplus and subsequent decline in their price. The following phases saw a tightening of the emissions cap and a consequent rise in allowance prices.

At the beginning of phase three in 2012, changes were made to allocating carbon allowances. While the power generation sector transitioned to an auction-based allocation system, the industrial sector continued to receive allowances free of charge, determined by a benchmark linked to the installation's output or input. Initially, installations were granted 80% of the allowances according to the benchmark allocation, gradually decreasing annually to 30% by 2020 (Chandreyee and Velten, 2021). Industries vulnerable to carbon leakage, wherein production relocates from regions with strict climate policies to areas with less stringent regulations, were allocated 100% of allowances throughout the trading period. As a result, this allocation approach led to a more pronounced reduction in greenhouse gas emissions within the power generation sector than in the industrial sector by the end of the phase in 2020.

The phased implementation of the EU ETS, starting with an initial pilot phase, is recommended when the system is extended to the household and transport sectors. Furthermore, the differentiation in the allocation methods of the carbon allowances between the power generation and industrial sectors is also recommended to be applied to the leading and lagging states based on the amount of energy households consume.

Regarding the goal of decoupling energy consumption from economic growth, the study affirmed that leading states have successfully achieved this, whereas not all lagging states have. Consequently, two main strategies can be pursued to achieve absolute decoupling. Firstly, lagging states could aim to increase their energy consumption, thereby boosting their economic development to align more closely with leading states. Alternatively, improving the energy efficiency of buildings in lagging states could reduce energy consumption, ensuring that any decrease in consumption is not solely due to rising energy prices, which can hinder economic growth.

Considering the consequences of the 2021-2022 energy crisis and the imperative to enhance energy security while reducing fossil fuel imports, the latter proposal appears more feasible. With approximately 75% of buildings in the EU identified as energy-inefficient, there is a suggestion to prioritize renovating older buildings in lagging states to enhance energy efficiency.

6.3 Future research plan

The following research concepts and ideas are proposed for future exploration.

1. Investigating the household energy-GDP nexus in the EU using causality analysis and incorporating a model that includes energy quality considerations and other determinants such as capital, labor, and technical change.
2. Investigating the energy-GDP nexus for all sectors in the EU while assessing the just transition progress by analyzing the shifts in the autonomous energy efficiency index.
3. Assessing the feasibility of the EU's climate policy targets by constructing future scenarios based on historical data, projecting energy inequality and its underlying drivers.
4. Conducting comparative analyses between energy inequality trends and policy responses within the EU and other regions or countries worldwide.
5. Investigating the long-term impact of energy prices in the EU on household energy use and other socioeconomic factors.
6. Developing a conceptual framework to explore the relationship between energy inequality and energy poverty in the EU, supported by empirical investigation.

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Appendix

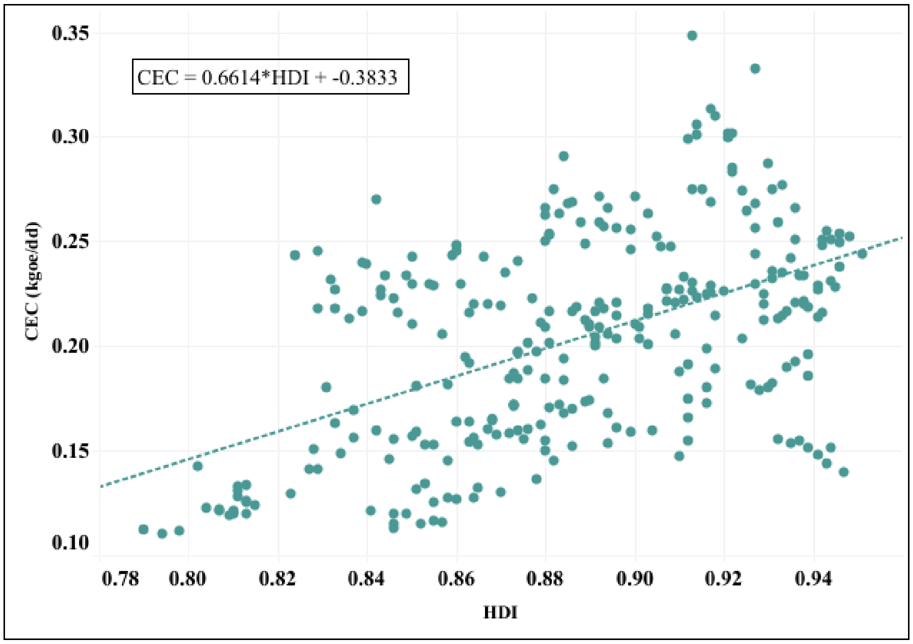

Figure 24 CEC versus HDI for the EU Member States excluding Malta (2010 - 2020)
Source: Author's Compilation

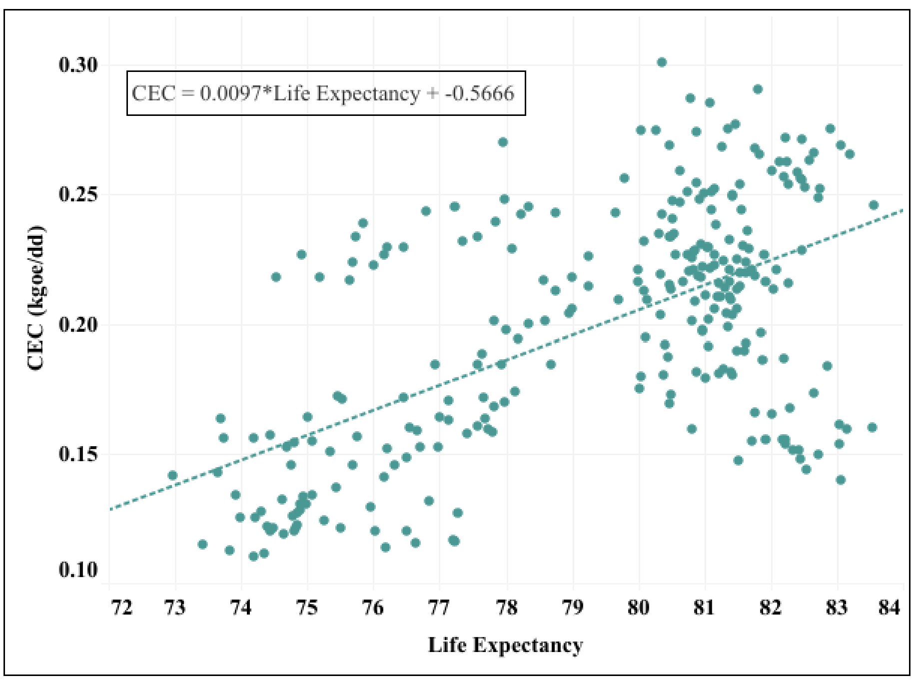

Figure 25 CEC versus life expectancy for the EU Member States excluding Luxembourg and Malta (2010 - 2020)
Source: Author's Compilation

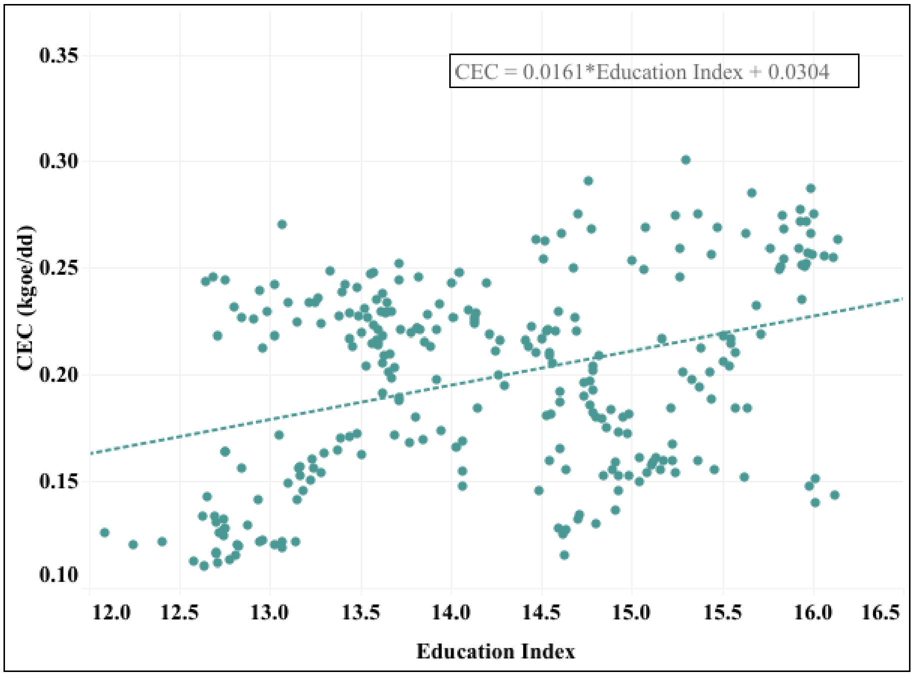

Figure 26 CEC versus education index for the EU Member States excluding Luxembourg and Malta (2010 - 2020)
Source: Author's Compilation

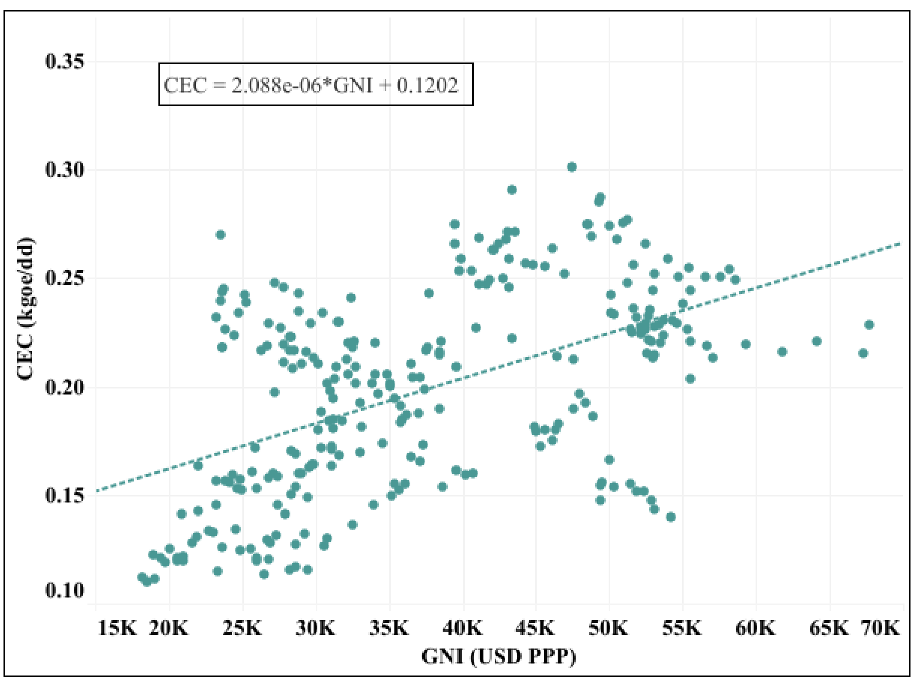

Figure 27 CEC versus GNI for the EU Member States excluding Luxembourg and Malta (2010 - 2020)
Source: Author's Compilation

Table 12 Relative and absolute contributions of climate-adjusted per capita energy consumption (CEC) inequality determinants (GDP, HDI, and EP) for Leaders from 2010 to 2020

Year	*Contribution*	*GDP*	*HDI*	*EP*	*Unexplained Inequality (Other Variables)*	*Overall Inequality (Gini Index)*
2010	Absolute	0.0102	0.0034	0.0078	0.0749	0.0963
	Relative	10.63%	3.50%	8.13%	77.74%	100%
2011	Absolute	0.0043	0.0045	0.0020	0.0858	0.0966
	Relative	4.50%	4.69%	2.05%	88.76%	100%
2012	Absolute	0.0011	0.0072	0.0022	0.0894	0.0999
	Relative	1.06%	7.23%	2.19%	89.52%	100%
2013	Absolute	0.0001	0.0083	0.0039	0.0868	0.0991
	Relative	0.06%	8.35%	3.98%	87.61%	100%
2014	Absolute	0.0060	0.0019	0.0136	0.0763	0.0978
	Relative	6.15%	1.97%	13.90%	77.98%	100%
2015	Absolute	0.0029	0.0038	0.0098	0.0769	0.0934
	Relative	3.11%	4.07%	10.47%	82.35%	100%
2016	Absolute	0.0001	0.0071	0.0126	0.0803	0.1001
	Relative	0.08%	7.06%	12.60%	80.26%	100%
2017	Absolute	0.0002	0.0066	0.0085	0.0783	0.0936
	Relative	0.18%	7.07%	9.11%	83.65%	100%
2018	Absolute	0.0010	0.0046	0.0130	0.0791	0.0978
	Relative	1.06%	4.73%	13.26%	80.95%	100%
2019	Absolute	0.0012	0.0061	0.0148	0.0721	0.0942
	Relative	1.26%	6.43%	15.75%	76.57%	100%
2020	Absolute	0.0002	0.0058	0.0169	0.0745	0.0974
	Relative	0.25%	5.97%	17.38%	76.41%	100%

Source: Author's analysis

Table 13 Relative and absolute contributions of climate-adjusted per capita energy consumption (CEC) inequality determinants (GDP, HDI, and EP) for Laggards from 2010 to 2020

Year	***Contribution***	***GDP***	***HDI***	***EP***	***Unexplained Inequality (Other Variables)***	***Overall Inequality (Gini Index)***
2010	Absolute	0.0856	0.0085	-0.00004	0.0532	0.1473
	Relative	58.12%	5.76%	-0.03%	36.15%	100%
2011	Absolute	0.0728	0.0085	0.0012	0.0628	0.1453
	Relative	50.10%	5.83%	0.81%	43.25%	100%
2012	Absolute	0.0370	0.0113	0.0007	0.0951	0.1441
	Relative	25.67%	7.87%	0.47%	65.99%	100%
2013	Absolute	0.0173	0.0127	0.0039	0.0895	0.1234
	Relative	14.02%	10.30%	3.14%	72.54%	100%
2014	Absolute	-0.0001	0.0078	0.0441	0.0882	0.1399
	Relative	-0.10%	5.58%	31.50%	63.02%	100%
2015	Absolute	0.0138	0.0106	0.0131	0.0939	0.1314
	Relative	10.48%	8.06%	9.98%	71.48%	100%
2016	Absolute	0.0296	0.0108	0.0063	0.0883	0.1351
	Relative	21.95%	7.98%	4.69%	65.39%	100%
2017	Absolute	-0.0006	0.0053	0.0442	0.0745	0.1234
	Relative	-0.52%	4.27%	35.85%	60.39%	100%
2018	Absolute	0.0069	0.0093	0.0234	0.0751	0.1148
	Relative	6.05%	8.06%	20.42%	65.47%	100%
2019	Absolute	0.0047	0.0036	0.0421	0.0478	0.0982
	Relative	4.76%	3.69%	42.86%	48.69%	100%
2020	Absolute	0.0027	0.0055	0.0327	0.0549	0.0959
	Relative	2.83%	5.77%	34.12%	57.27%	100%

Source: Author's analysis