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Review

Energy Inequality Indicators: A Comprehensive Review for Exploring Ways to Reduce Inequality

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Abstract: Society faces challenges in achieving a climate-neutral society due to deepening energy inequality. The pandemic led to reduced emissions but also caused an economic downturn. Geopolitical tensions since 2022 raised energy prices, affecting affordability. To address these issues, this research aims to conduct a systematic literature review to explore the content, conceptualization, and distinguishing factors of energy inequality compared to similar concepts as well as to identify energy inequality dimensions and its indicators and explore ways to reduce it. A systematic literature review explored recent publications on energy inequality from 2019 to 2023, encompassing both pre-pandemic and pandemic-affected periods. This review analyzed 203 articles, with 61 of them directly focusing on energy inequality indicators. This research is conducted in several stages. Firstly, this article clarifies the concept of energy inequality and highlights its differences from related terms. Secondly, this study investigates the effects of energy inequality taking into account its diverse dimensions, and it categorizes these dimensions and their respective indicators based on their specific contexts. Thirdly, recommendations are provided for potential approaches to reduce energy inequality. The methodology integrates an examination of macroeconomic energy inequality statistics. The resulting findings hold the potential to significantly contribute towards cultivating a more environmentally conscious trajectory. Moreover, these outcomes play a pivotal role in advancing energy justice and effectively tackling the multifaceted challenges posed by energy inequality.

Keywords: energy inequality; energy justice; climate-neutral society; systematic literature review (SLR)

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1. Introduction

The background. In recent years, society has encountered numerous challenges that have tested its resilience. The pandemic and geopolitical conflicts induced substantial energy demand shifts, supply chain disruptions, and investment setbacks, while their lasting effects on low-carbon energy transitions and climate change mitigation remain uncertain [1]. One of the significant obstacles in the path towards a climate-neutral society is the deepening energy inequality. Achieving a climate-neutral society is a pressing and critical task that seeks to create opportunities for prosperity for future generations. It involves finding a balance between economic development, technological advancements, ecological sustainability, social well-being, and psychological growth in the present. The transition to a climate-neutral society is a central objective of Europe's green agenda, which aligns with the commitments made under the Paris Agreement. It recognizes the global importance of addressing climate change and emphasizes the need to reduce inequality as a crucial component of achieving Sustainable Development Goals. By tackling energy inequality and ensuring fair access to clean and sustainable energy, societies can guarantee the well-being and quality of life for everyone.

The year 2020 showed contrasting shifts in various aspects of life due to the global pandemic's impact. On one hand, there was a notable reduction in emissions as industrial activity slowed down. However, this was accompanied by a severe economic downturn. Since 2022, geopolitical tensions have contributed to a significant increase in energy prices, posing a major challenge to energy affordability for society. This situation highlights the need to address crucial questions regarding the transition towards a climate-neutral society. It is essential to effectively coordinate environmental sustainability and economic prosperity while ensuring energy justice and reducing energy inequality. Balancing these objectives requires careful consideration and strategic planning to achieve a sustainable and equitable energy future.

While the concept of energy inequality is not new, it has gained significant attention in recent years. The recognition of energy inequality as a critical issue has prompted discussions and actions to address the disparities in access to reliable and affordable energy services. Energy inequality is a global problem that affects a large part of the world's population, as evidenced by these facts.

- ✓ Approximately 733 million people, or one in ten people worldwide, still lack access to electricity. Additionally, around 2.4 billion people, or one-third of the global population, do not have access to clean cooking facilities [2].
- ✓ The top 10% of income earners consume approximately 20 times more energy than the bottom 10% as the study that examined energy inequality among income classes in 86 countries shows. It also emphasized the unequal distribution of energy footprints across countries. For instance, a notable finding is that the poorest 20% of the UK's population consumes more than five times the energy per person compared to the bottom 84% in India [3].
- ✓ Rising fuel prices contribute to a significant increase in the average costs of electricity generation worldwide. This has led to a concerning trend where the number of people without access to modern energy is increasing for the first time in a decade. Approximately 75 million individuals who recently gained access to electricity are at risk of losing it due to affordability issues, and 100 million people may resort to using traditional biomass for cooking [4].
- ✓ In the European Union, approximately 31 million households were unable to adequately heat their homes in 2021. This figure is equivalent to about 7% of the EU population. Particularly affected by this are Bulgaria and Lithuania with 23.7% and 22.5% of the population, respectively [5].
- ✓ In theEuropean Union, almost 29 million people (6.2% of the EU population) reported arrears on their utility bills in 2021. Greece has the highest share in the EU with 26.3% of the population facing arrears, followed by Bulgaria with 19.2% [6].

The term energy inequality is closely linked to justice. Ensuring energy justice is one of the main highlights of tackling energy inequality and economic inequality as well as one of the key challenges in moving towards a climate-neutral society, protecting the environment, and promoting a green economy. The concept of energy justice is a multifaceted one that needs to be addressed in a contemporary context and the possibilities of a "fair" distribution and use of energy, with a commitment to non-discrimination, need to be examined in depth. The justice issues extend to how we represent the interests of future generations and how the needs of future generations are spoken for and represented now [7]. By involving everyone in energy-related matters and including all stakeholders in these processes, we can clearly work towards achieving a sustainable global energy system, while also promoting fairness and equal decision-making.

Research questions. The facts and data presented above illustrate the depth of energy inequality as a worldwide concern. This article addresses the following research questions. What constitutes the content of energy inequality? How do researchers conceptualize energy inequality compared to similar concepts? What are the key distinguishing factors that set energy inequality apart from other related concepts, and how do these differences impact research approaches? What are the dimensions of energy inequality as a global issue? What are the indicators used to measure energy inequality?

Research objectives. Reflecting the depth and substance of the issue, this research aims to conduct a systematic literature review to explore the content, conceptualization, and distinguishing factors of energy inequality compared to similar concepts. It also seeks to identify the dimensions of energy inequality as a global issue and the indicators used for its measurement. In addition, this article aims to justify the necessary conditions that are essential to find effective strategies to reduce energy inequality and promote energy justice. It is evident that achieving energy justice, promoting consumer awareness, embracing sustainability in all aspects of life, and transitioning to a climate-neutral society will be incomplete without addressing energy inequality. It is crucial to conduct research to identify effective measures that can minimize energy inequality and ensure energy justice for all.

Research methods. This research aims to comprehensively understand energy inequality by exploring its various aspects and implications. A systematic literature review was conducted to examine recent research, identifying dimensions, indicators, evaluation criteria, and gaps in addressing inequality reduction. The use of this method revealed the challenges in conceptualizing energy inequality and its confusion with related terms. Consequently, the concept of energy inequality in this article encompasses both quantitative and qualitative aspects of the research problem, facilitating the conceptualization of its content, identification of key distinguishing factors, exploration of dimensions grouped by context, and review of commonly used measurement indicators.

The relevance of the research. Despite the growing role of energy inequality, the use of the term is confusing. The term energy inequality is used synonymously with energy poverty and is often equated or even confused with other similar terms. The relevance of the article is that it raises the issue of the correct use of terminology, highlighting the diversity of terms used, the wide range of their components, and the multiplicity of measurement indicators.

The practical implication. The novelty and the practical implication of the article are based on the fact that it identifies the differences between the terminology of energy inequality and energy poverty and proposes definitions of these terms. This article proposes that the scientific community should agree on a common terminology and attributes of the phenomena under study. This is an extremely important task, because only if common definitions and concepts are agreed upon, only then is it possible to analyze their dimensions, identify relevant indicators, and develop strategies for reducing energy inequality.

2. Theoretical Basis

A systematic literature review was conducted to explore recent publications on energy inequality, aiming to identify key indicators, assessment criteria, and research gaps in addressing inequality reduction. This review utilized the Web of Science database, covering the period from 2019 to 2023, including both pre-pandemic and pandemic-affected periods. The keywords "energy inequality indicators" were used to gather relevant scientific papers. This analysis included a total of 203 articles, out of which 61 articles were directly relevant to the subject matter, focusing on the analysis of energy inequality indicators. The remaining articles were partially relevant, addressing specific elements or aspects of the topic. The collected publications were exported to the Zotero bibliography program, which facilitated the initial screening and in-depth analysis of the articles. This review aimed to provide insights into the current state of research on energy inequality and identify areas for further investigation and development.

It should be noted that the majority of articles are published in the journals "*Energy Economics*" (13%) and "*Energy Research & Social Science*" (11%) from the total sample of 61 targeted articles. Slightly fewer articles (5% each) were published in the journals "*Sustainability*", "*Journal of Cleaner Production*", and "*Environmental Science and Pollution Research*". Further analysis reveals that 3% of the articles in the considered sample were published in journals such as "*Nature Energy*", "*Energy Policy*", "*Environmental Science & Policy*", "*Energy and Buildings*", and "*Technological Forecasting and Social Change*". A more detailed distribution of the articles across various journals is presented in Table 1, highlighting notable diversity.

Table 1. Distribution of journals in which targeted articles have been published.

Journal	Number of Articles	Share
Energy Economics	8	13.11%
Energy Research & Social Science	7	11.48%
Sustainability	3	4.92%
Journal of Cleaner Production	3	4.92%
Environmental Science and Pollution Research	3	4.92%
Nature Energy	2	3.28%
Energy Policy	2	3.28%
Environmental Science & Policy	2	3.28%
Energy and Buildings	2	3.28%
Technological Forecasting and Social Change	2	3.28%
Energies	1	1.64%
Energy	1	1.64%
Applied Energy	1	1.64%
Global Sustainability	1	1.64%
Energy for Sustainable Development	1	1.64%
Environmental and Sustainability Indicators	1	1.64%
Renewable & Sustainable Energy Reviews	1	1.64%
Environmental Development	1	1.64%
Journal of Environmental Protection and Ecology	1	1.64%
Sustainable Production and Consumption	1	1.64%
Frontiers in Energy Research	1	1.64%
Frontiers in Public Health	1	1.64%
Frontiers in Sustainable Cities	1	1.64%
Environmental Research Letters	1	1.64%
Proceedings of the National Academy of Sciences of the United States of America	1	1.64%
International Journal of Environmental Research and Public Health	1	1.64%
Proceedings of the Institution of Civil Engineers-Engineering Sustainability	1	1.64%
Applied Sciences-Basel	1	1.64%
One Earth	1	1.64%
Buildings	1	1.64%
Data & Policy	1	1.64%
Regional Statistics	1	1.64%
Lancet Global Health	1	1.64%
Applied Geography	1	1.64%
SSM-Population Health	1	1.64%
BMC Pediatrics	1	1.64%
Geoforum	1	1.64%

The key bibliometric and model information from each of the 61 articles, which are directly relevant to the subject matter, were meticulously recorded and are summarized in Table 2. The bibliometric details encompassed the research types (research articles or review articles), topics, keywords, purpose, and key findings examined in each paper. The research scales spanned global, regional, national, and local levels, encompassing a wide range of countries, multiple countries or economies, individual countries, and specific regions within countries. The geographic locations of the research areas were distinguished based on the respective regions—Europe, North America, Australia, Asia, Africa, or global. The model information was thoroughly examined, including the types and methods utilized. Three distinct model purposes were identified: ex-ante analysis, which involves estimating future trends; ex-post analysis, which analyzes past data and assesses the impact of events, behaviors, or politics; and relationships exploration, which focuses on examining quantitative relationships between energy inequality or related factors across different scenarios or measuring its influence. Furthermore, the dimensions used to assess energy inequality and the specific indicators employed for measurement were also analyzed.

Table 2. Key information recorded.

Key Information	Meta-Indicator	Description
Bibliometric information	Authors, titles, publication date, etc.	-
	Research topics, keywords, purpose, findings, etc.	-
	Publication types	Research articles or review articles.
	Research scales	Global, regional, national or local.
	Geographic locations	Differentiated by region (Europe, North America, South America, Australia, Asia, Africa, or global).
Model information	Model types and methods used	-
	Model spatial range	Global, regional, national, or local.
	Model purposes	Ex-ante analysis, ex-post analysis, relationships exploration.
	Dimensions	Dimensions (approaches) through which energy inequality are assessed.
	Indicators	Indicators (variables) proposed to measure energy inequality.

It is worth noting that the majority of articles included in the scope of the literature review are research articles, with only a few being review articles. In terms of model purposes, a significant portion of the articles (61%) focus on ex-post analysis, analyzing historical data. Another third of the articles (30%) concentrate on relationship exploration, examining quantitative relationships between energy inequality or related factors across different scenarios or measuring their influence. The remaining 10% of the articles analyze ex-ante scenarios, estimating future trends and potential impacts (Table 3). In terms of research scales, most studies (43%) analyze the national context, while 41% examine the global context. Regional and local contexts account for 8% each (Table 4). Regarding geographic locations, 36% of the studies compare multiple countries in a global analysis, with 25% focusing on Asian countries, 18% on Europe, 10% on North America, 5% on Africa, and 3% each on Australia and South America (Table 5). While a detailed analysis of the content, dimensions, and indicators of energy inequality is presented in subsequent sections, it is worth mentioning that accessibility and availability dimensions are frequently assessed in the context of research in Asia and Africa, affordability is studied in Europe, North America, and Australia, and development is explored in global research.

Table 3. Distribution of articles analyzed in the SLR according to the model purpose.

Model Purpose	Number of Articles	Share
Ex-post analysis	37	60.66%
Relationships exploration	18	29.51%
Ex-ante analysis	6	9.84%

Table 4. Distribution of articles analyzed in the SLR according to the model spatial range.

Model Spatial Range	Number of Articles	Share
Regional	26	42.62%
Global	25	40.98%
National	5	8.20%
Local	5	8.20%

Table 5. Distribution of articles analyzed in the SLR according to the geographic locations.

Geographic Locations	Number of Articles	Share
Global	22	36.07%
Europe	15	24.59%
North America	11	18.03%
South America	6	9.84%
Africa	3	4.92%
Australia	2	3.28%
Asia	2	3.28%

The results of the systematic literature review that are presented below in detail provide a comprehensive examination of the findings. This review delves into the conceptual challenges associated with energy inequality, explores its potential consequences, identifies the dimensions and indicators used to measure energy inequality, and proposes actionable recommendations to alleviate this issue by implementing strategies to reduce energy inequality.

3. Results

3.1. The Concept

Energy inequality has become a significant research topic due to its social, economic, and environmental implications. Researchers from a wide range of disciplines, including social sciences, economics, public policy, and even engineering, are now exploring different aspects of energy inequality, such as the factors that contribute to energy inequality, the economic and social impacts of energy inequality [8–15], the impact on health [13,16–23], the impact on vulnerable members of the society [24–29], the impact on environmental quality [30–36], and the policies and strategies that can help to promote energy access and equity. Recent advancements in data collection and analysis have also enabled researchers to better understand the magnitude and distribution of energy inequality across different regions and populations. As a result, there is growing recognition that addressing energy inequality is essential for achieving Sustainable Development Goals, promoting energy and social justice, and mitigating climate change.

This systematic literature review has identified that various terms are used to address similar aspects of *energy inequality* (see Figure 1) [17], including *energy poverty* [9,14,18,20,21,26,32,37], *energy insecurity* [17,38], *fuel poverty* [39–43], *environmental inequality* [34], *carbon inequality* [44], and *environmental degradation* [13,31,36]. To achieve the objective of this study, which is to identify energy inequality dimensions and their indicators and explore ways to reduce them, it is crucial to establish a common understanding and terminology. Resolving the differences between these concepts is the first step in the research process. By agreeing on common definitions and concepts, it becomes possible to analyze their dimensions (components), identify relevant indicators, and develop strategies for reducing energy inequality.

The systematic review of the literature highlights a common source of confusion between the concepts of energy inequality and energy poverty. It is evident that these terms are often used interchangeably or synonymously. Energy inequality is characterized by an uneven distribution of access to energy resources and the ongoing challenge of affordability in meeting utility expenses [17].

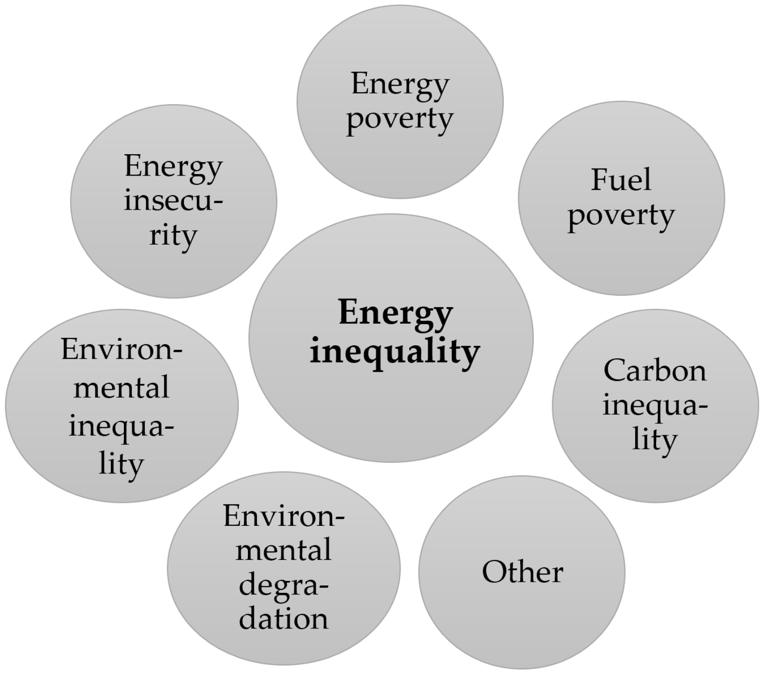

Figure 1. Diverse terminology for the concepts of energy inequality.

It is important to highlight that energy poverty is described using closely related language and energy poverty is conceptualized as follows:

- ✓ a condition in which a household is unable to secure a socially and materially needed level of energy services in the home [45];
- ✓ a constraint in access and affordability of modern forms of energy, especially electricity [29];
- ✓ a situation where a household is unable to meet the socially and materially necessary level of energy services within their home [37];
- ✓ the inability of families to have enough and affordable high-quality energy to survive and satisfy their development needs [14];
- ✓ a situation of inability to realize the essential capabilities due to insufficient choice in accessing affordable, reliable, adequate, quality, and safe energy services in a reasonable manner [28];
- ✓ inadequate alternative energy types and inappropriate circumstances for accessing energy adequately, affordably, in constant supply, in an uninterrupted manner, and through environmentally sustainable new energy services that contribute to attaining economic and human advancement [9].

It is important to recognize that the term energy inequality is often associated with the concept of (in)security as this issue is an integral part of the broader concept of energy justice. Energy security, from a generic perspective, refers to an economy's ability to ensure a sustainable and continuous energy supply, as well as stable energy prices that support the normal functioning of the economic system [10]. This concept encompasses the interplay between energy and various economic factors, including environmental security, social stability, and income security. The lack of equitable access to energy and the financial burden it poses contribute to the complex dynamics of energy inequality and insecurity, necessitating attention and action within the framework of energy justice [17]. In the context of household, energy insecurity refers to a household's struggle to pay energy bills and exposure to inadequate residential energy services, which is a widespread problem across the world [38]. Households experiencing energy insecurity face challenging choices every day as they try to balance the need to keep their power on and maintain safe indoor temperatures, while also meeting other essential needs like food and healthcare.

Energy inequality, characterized by the unequal distribution of energy resources, has significant implications for resilience. It could be defined as the ability of a system to recover from a disturbance or disruption [46] or as the capacity to adapt to changing circumstances. Energy inequality limits access to reliable energy for vulnerable populations, hindering their ability to cope with and bounce back from challenges. In this context, Zaman, R., van Vliet, O., and Posch A. (2021) explore the concept of livelihood resilience and define it as the capacity of an individual to sustain as well as to improve his or her social well-being and livelihood opportunities in the face of socio-economic, political, and environmental disturbances and shocks [29]. Chen, S., Wu, J., Zhou, K., and Li, R. (2023) consider the livelihood resilience concept as a three-dimensional structure, which includes buffer capacity, self-organization capacity, and learning capacity dimensions and examines different factors associated with these dimensions, such as housing conditions, income diversity, and ecological environment measurements [47], providing evidence that energy justice and its associated constructs are linked to resilience.

Tiwari, S., Schelly, C., Ou, G., Sahraei-Ardakani, M., Chen, J., and Jafarishiadeh, F. (2022) suggest to improve and expand the concept of resilience and define it as the ability to sustain and bounce back after an adverse event, in realizing essential functioning through the means of *affordable*, *reliable*, and safe energy services *access*, while accounting for alternative means to further strengthen those functioning in ways that improve equity through energy services access [48]. Such conceptualization acknowledges the central role of electricity services in supporting various capabilities and underscores their importance in promoting resilience. It embraces a multidimensional perspective that considers both functioning and capabilities, recognizing that different individuals and communities have diverse needs for services even when access to electricity is available as a shared commodity. Hasselqvist, H., Renstrom, S., Stromberg, H., and Hakansson, M. (2022) propose a framework for household energy resilience as an interwoven part of everyday life; household energy resilience means to ensure a good life by adjusting what activities are performed, when they are performed, and how they are performed in the face of expected and unexpected power outages and shortages as well as to prepare for future adjustments of activities and to more fundamentally change to reduce the need for adjustments [49]. By challenging the perception of electricity demand as non-negotiable, this framework highlights the potential for households to shape the future energy system and contribute to its resilience. It also suggests that household energy resilience can play a role in enhancing the acceptance of renewable energy systems with variable supply and managing power disruptions associated with climate change. According to this perspective, resilience can play a significant role in driving the transformation of society towards becoming climate neutral. By enhancing the ability of individuals, communities, and systems to withstand and recover from adverse events, resilience can create a foundation for sustainable change. Resilience allows societies to adapt and respond to the challenges and disruptions associated with climate change, enabling them to transition towards cleaner and more sustainable energy sources.

Expanding upon the range of options available to describe aspects related to energy inequality, it is essential to analyze the terms *fuel poverty* and *environment (ine)quality*. Fuel poverty refers to a condition where households are unable to afford and maintain an adequate level of energy services, particularly warmth, within their homes [18]. In the literature concerning natural resources and environmental quality, ecological footprints and CO_2 emissions are commonly utilized to assess environmental quality [30]. However, this environmental quality has significantly deteriorated due to greenhouse gas emissions and a substantial ecological deficit [50]. As fuel inequality and environment (ine)quality refers to a form of inequality that goes beyond income-related factors and encompasses the inability to meet the energy requirements necessary for a comfortable, healthy, and sustainable environment, it can be considered synonymous with the concept of energy inequality.

This systematic literature review has revealed a significant challenge in the field of energy inequality, which is the use of diverse terms to address similar aspects of the problem. Terms such as energy poverty, energy insecurity, fuel poverty, carbon inequality, environmental inequality, and environmental degradation are used interchangeably or in related contexts. This inconsistency in terminology poses a hurdle in understanding and addressing the issue effectively. To address this challenge, it is crucial to establish a clear and precise definition of the concept of energy inequality. This involves identifying the distinct boundaries that differentiate it from other similar terms. By defining the specific components of energy inequality, researchers and policymakers can gain a better understanding of its nature and develop targeted strategies to mitigate it. Therefore, the first step in addressing energy inequality is to establish a comprehensive and unambiguous definition that encompasses its various dimensions. This will enable researchers and stakeholders to identify the root causes, assess the magnitude of the problem, and explore appropriate approaches to reduce energy inequality and its associated impacts.

3.2. The Impact

A systematic literature review has brought attention to the multidimensionality of energy inequality, revealing that its impact varies according to research findings.

Social and economic impact. Energy inequality has significant socio-economic consequences, which include a decline in social cohesiveness due to limited social engagement and increased isolation [9]. It also leads to a reduction in social interaction and exclusion [14]. Addressing energy inequality could have a positive impact on reducing gender inequality, especially in areas such as education, health, and employment [11].

The findings suggest that environmental degradation has a significant negative impact on life satisfaction [13]. Additionally, the research from Ashenafi, B. (2022) reveals that greenhouse gas emissions contribute to widening income inequality [8]. Consequently, the types of energy used for heating purposes become significant within the context of energy poverty and inequality. Higher availability of energy is associated with a decrease in energy poverty, which, in turn, leads to lower income inequality [14]. Moreover, the analysis by Szep, T., Toth, G., and LaBelle, M. (2022) establishes a positive relationship between residential energy use per capita and human well-being [15].

The research conducted by Lee, C., Xing, W., and Lee, C. (2022) confirms that energy security has an impact on income inequality through multiple channels. Energy security can reduce income inequality by providing access to sustainable energy, stabilizing prices, and promoting economic growth. It enables low-income individuals to access modern energy, frees up their time, and increases disposable income. Stable energy prices benefit low-income households, and energy security supports economic growth [10]. The impact of energy security on income inequality can vary depending on the level of economic development. In developed countries, energy security can reduce income inequality, while in developing countries, it can promote both economic growth and lower income inequality levels [10]. The findings emphasize the importance of considering the economic context when examining the relationship between energy security and income inequality.

Impact on health. Energy inequality, characterized by inadequate and unequal access to sufficient, affordable, and high-quality energy for meeting basic survival needs and supporting development, poses a distinct challenge in maintaining essential energy services. This disparity in resource availability and uneven distribution has significant implications for public health [22]. Additionally, energy inequality and insecurity in households have adverse effects on well-being and health, impacting behavioral, physical, and social-psychological aspects of health [17]. Research indicates that elderly individuals often face higher levels of energy inequality in their daily lives, leading to increased stress and anxiety [21]. Also, consequences of energy poverty for the elderly include vulnerability to health problems exacerbated by cold and heat and more time spent at home [20]. This heightened energy inequality can negatively impact their mental well-being, potentially exacerbating feelings of depression and reducing overall life satisfaction among older adults [21]. Therefore, it can be argued that energy insecurity has significant impacts on the health and well-being of communities, especially vulnerable populations [23].

Fuel poverty, which refers to the inability of households to access an adequate level of energy services, has wide-ranging impacts on health and well-being, including increased risks of cardiovascular disease, inflammation, and lower levels of mental health [18]). Additionally, a study by Frostad, J. et al. (2022) reveals that household air pollution, a consequence of inadequate energy services, contributed to approximately 205,000 deaths among children under the age of 5 in 2018 due to lower respiratory tract infections [19]. Also, carbon emissions, a significant contributor to environmental degradation, pose one of the greatest environmental health risks globally [13]. The impact of carbon emissions extends beyond environmental concerns and directly affects various aspects of people's lives, including social welfare, health, and overall happiness.

Addressing energy inequality has a positive effect on reducing gender inequality, especially in education, health, and employment. Improved access to energy resources enhances women's enrollment in education, reduces mortality rates, and opens up more job opportunities for women, contributing to gender equality [11].

Impact on vulnerable members of society. Energy inequality is a global issue that affects a significant portion of the population, particularly vulnerable individuals. Its consequences include unhealthy indoor conditions, inadequate heating during winter months, financial hardships, and limitations on social activities with relatives [26]. The research findings further support the notion that low-income households face heightened levels of energy insecurity. Additionally, the research conducted by Konisky, D., Carley, S., Graff, M., and Memmott, T. (2022) highlights significant socio-demographic disparities, such as race, income, household composition, reliance on electronic medical devices, and the physical conditions of dwellings [25].

The study conducted by Ssennono, V., Ntayi, J., Buyinza, F., Wasswa, F., Aarakit, S., and Mukiza, C. (2021) reveals that energy inequality is unevenly distributed among different subgroups, with high levels of inequality based on residence and regional location. The vulnerabilities arising from energy inequality disproportionately affect millions of rural individuals living in poverty in developing countries [28]. This situation severely limits their ability to escape the cycle of poverty and effectively cope with environmental challenges [29]. The research by Konisky, D., Carley, S., Graff, M., and Memmott, T. (2022) indicates that households with people of color, very low income, children aged five years and younger, someone relying on an electronic medical device, and those living in inadequate housing conditions are more likely to experience energy insecurity [25]. Moreover, the study by Ssennono, V., Ntayi, J., Buyinza, F., Wasswa, F., Aarakit, S., and Mukiza, C. (2021) highlights that energy poverty is more prevalent among women, individuals in the lowest wealth quintile, and those employed in agriculture [28]. Therefore, reducing energy poverty has a positive impact on reducing gender inequality, particularly in education, health, and employment. Access to energy resources improves women's enrollment in education, reduces women's mortality rates, and creates more job opportunities for women [11].

The vulnerability of society is closely intertwined with the climate crisis [24,27]. The consequences of climate change will have the most immediate and severe effects on billions of impoverished individuals, particularly those whose livelihoods depend on agriculture and subsistence activities and who are directly influenced by changing weather patterns. Among those disproportionately affected by these challenges are women, youth, the elderly, and ethnic and racial minorities, as well as indigenous and rural populations in underdeveloped and developing nations [27]. It is worth mentioning that these vulnerable communities are indeed impacted by climate change, and these impacts have implications for community resilience or vulnerability. The Perez-Pena, M., Jimenez-Garcia, M., Ruiz-Chico, J., and Pena-Sanchez, A. (2021) study emphasizes the importance of understanding factors such as income, activity choices, and sustainable livelihood capitals in shaping the resilience of these communities [27]. By considering these factors, strategies can be developed to enhance resilience and reduce vulnerability in the face of climate change.

Impact on environmental quality. The primary obstacles hindering the socioeconomic and environmental advancement of both developed and developing economies for decades are the intertwined issues of inequality and environmental degradation, in particular, climate change [31,33]. Climate change is undeniably linked to economic inequality, as it is considered a disaster primarily driven by the greenhouse gas emissions of those who are more privileged, which disproportionately affects the most vulnerable populations. Jain, M. and Kaur, S. (2022) describe it as a disaster that is driven by the greenhouse gas emissions of the "haves" and has the most severe consequences for the "have-nots" [33].

The research indicates that energy inequality could be influenced by economic development and income inequality across various dimensions. The study conducted by Igawa, M. and Managi, S. (2022) highlights that lower levels of economic development lead to increased energy poverty in terms of accessibility and reliability. On the other hand, a middle level of economic development and a higher income inequality exacerbate energy poverty in terms of affordability [32]. Similarly, the research by Uzar, U. and Eyuboglu, K (2022) suggests that the rise in the Gini coefficient, which measures income inequality, significantly contributes to environmental degradation [36]. High levels of income inequality diminish ecological awareness among the population, as economic and future concerns take precedence over environmental issues. This lack of environmental awareness further contributes to social disunity and a disregard for environmental damage. Neglecting the long-term effects of economic activities prioritizes short-term economic interests for both the wealthy and the poor. Furthermore, the study by Jain, M. and Kaur, S. (2022) highlights the complex relationship between income inequality and CO2 emissions. It suggests that moderate income inequality is associated with higher emissions [33], indicating the environmental implications of unequal resource distribution. However, interestingly, high income inequality appears to have a negative association with emissions, suggesting that reducing income disparities may contribute to better climate outcomes. The study of Ata et al. (2022) emphasizes that the most important reasons for inequality are CO2 emissions, changes in the economy, and incomes [51]. These findings emphasize the need for comprehensive approaches that address economic development, income inequality, and energy poverty while promoting sustainable practices.

According to the findings of Ahmad, F., Draz, M., Chandio, A., Ahmad, M., Su, L., Shahzad, F., and Jia, M. (2022), various factors such as the use of natural resources, economic development, urbanization, industrialization, income inequality, nonrenewable energy, and population growth have a negative effect on long-term environmental quality. On the other hand, technological progress, environmental regulations, and the use of renewable energy sources have been found to enhance environmental quality [30]. Additionally, Jiang, S., Mentel, G., Shahzadi, I., Ben Jebli, M., and Iqbal, N. (2022) found a positive association between income inequality and ecological footprint as well as a negative association with renewable energy consumption [34]. This suggests that reducing income inequality could potentially lead to a decrease in ecological footprint and an increase in renewable energy consumption, which would be beneficial for the environment. Mehmood, U., Agyekum, E., Tariq, S., Ul Haq, Z., Uhunamure, S., Edokpayi, J., and Azhar, A. (2022) also support the idea that reducing income inequality can contribute to an increase in renewable energy consumption [35].

Traditionally, the causes of energy poverty have been attributed to the combination of low incomes, high energy prices, and low levels of residential energy efficiency [45]. Despite studies suggesting that energy poverty is perceived as a multifaceted problem caused by the transition to low-carbon energy [52], the systematic literature review underscored the complex nature of energy inequality and unveiled their diverse effects across different research outcomes. It becomes evident that energy inequalities have far-reaching socio-economic consequences, implications on health, vulnerabilities of marginalized groups, and impacts on environmental quality. This emphasizes the significance of addressing energy inequality with heightened attention, further research, and dedicated efforts towards mitigation.

3.3. The Dimensions

A systematic literature review has highlighted the variation in the analysis of energy inequality and its dimensions (see Figure 2) across different countries, including both developing and developed nations as well as low- and high-income contexts. The studies reveal distinct concerns regarding the *accessibility* and *affordability* of energy services. In low-income (developing) countries, the focus is on addressing limited access to basic energy services among marginalized populations, such as electricity and clean cooking fuels. Efforts are directed towards improving infrastructure and expanding energy networks to ensure that everyone has greater accessibility to these essential services. In high-income (developed) countries, where access to energy services is generally available, the challenge lies in affordability. Many households, despite having access to energy, struggle to afford the increasing costs associated with energy consumption, especially for heating and cooling purposes. This affordability challenge can result in energy inequality, adversely affecting individuals, where a major concern is the affordability of adequate indoor heating, which can lead to negative health effects such as respiratory illnesses, increased mortality during winter months, and mental health issues due to the stress of managing limited resources. The study by Rafi, M., Naseef, M., and Prasad, S (2021) highlights the critical importance of affordable and reliable energy access for sustainable human capital development [53]. The findings reveal that the accessibility and affordability of energy have a significant influence on individuals' health, including premature mortality, self-reported health, and life expectancy. The study by Reames, T., Daley, D., and Pierce, J. (2021) emphasizes the importance of addressing energy justice and mitigating energy burdens to achieve health equity [22]. To effectively address energy inequality on a global scale, it is crucial to tackle both dimensions of accessibility and affordability. This requires targeted strategies that aim to improve access for marginalized populations in low-income countries and enhance affordability for households in high-income countries. By addressing these two dimensions, policymakers and interventions can work towards reducing energy inequality and its adverse impact.

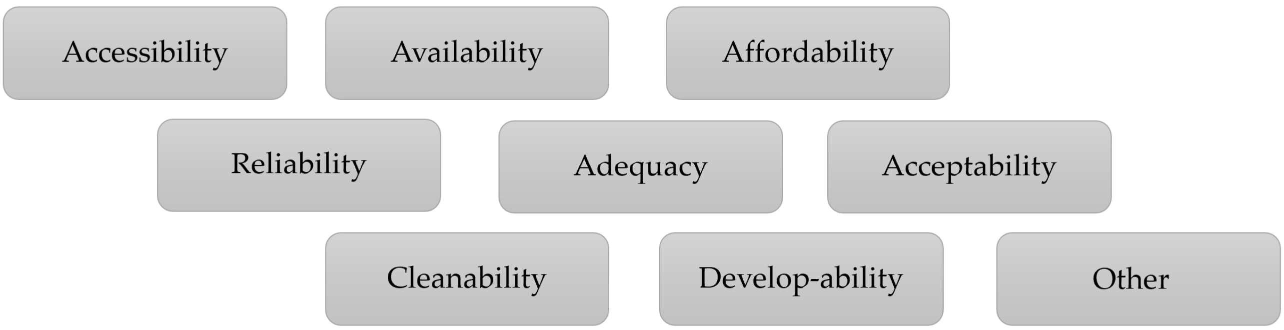

Figure 2. A diverse array of energy inequality dimensions.

Indeed, in addition to the accessibility dimension, some scholars also include the *availability* dimension when discussing energy inequality [23]. While accessibility refers to the physical access and availability of energy services to individuals and communities, availability focuses on the overall supply and availability of energy resources within a given region or country. The availability dimension of energy inequality encompasses factors such as energy resource availability, energy infrastructure development, and energy production and distribution systems. It considers the extent to which energy resources are accessible and reliably provided to meet the energy needs of individuals and communities. Including the availability dimension in the analysis of energy inequality provides a more comprehensive understanding of the challenges and disparities related to energy access and availability. The study conducted by Shapira, S., Shibli, H., and Teschner, N. (2021) emphasizes the significance of energy infrastructure availability and accessibility as a core element of community resilience—a concept that characterizes a community's ability to promote health and well-being and to cope with and recover from adversity [23]. Meanwhile, Igawa, M., and Managi, S. (2022) include a *reliability* dimension alongside accessibility and affordability and highlight the importance of considering the reliability of energy systems [32]. Reliability encompasses various aspects of the electricity grid, such as the frequency and duration of power outages and the stability of voltage. Reliable access to electricity is crucial for individuals and communities to meet their energy needs consistently and without interruptions.

In response to today's context and the need for a transformation towards a climate-neutral society, some authors emphasize the importance of considering not only the availability and affordability dimensions but also the *cleanability of energy* [9,14]. Cleanability refers to the cleanliness of the energy sources and technologies used. It acknowledges the crucial role of transitioning to clean and renewable energy sources to mitigate climate change and minimize the negative environmental impacts associated with energy production and consumption. However, the study by Rao, F., Tang, Y., Chau, K., Iqbal, W., and Abbas, M. (2022) confirms that energy affordability had the strongest relationship with energy inequality, followed by energy availability and energy cleanability [14].

However, it is important to highlight that one approach that is particularly relevant to addressing current issues and comprehensively capturing energy inequalities is the consideration of four dimensions: *availability*, *accessibility*, *affordability*, and *acceptability*. Lee, C., Xing, W., and Lee, C. (2022) adopt this approach and refer to these dimensions as energy security dimensions [10]. Availability refers to a country's capacity to meet its energy requirements through domestic energy production, including the exploration and utilization of primary energy sources. Affordability encompasses two aspects: the ability to acquire energy from foreign sources at a reasonable cost and the affordability of domestic energy prices for the population. However, in the context of affordability, Best, R., Hammerle, M., Mukhopadhaya, P., and Silber, J. (2021) include an additional dimension—*adequacy*—and consider whether households face difficulties in heating and cooling their homes due to financial constraints [39]. Acceptability focuses on energy utilization and includes aspects such as energy efficiency and the composition of energy consumption. Accessibility refers to the ability to access energy supplies through imports [10]. In recent years, the concept of energy sustainability has expanded to encompass the consideration of negative externalities associated with energy production and consumption. Studies have emphasized the developmental aspect of energy security as a crucial element of overall energy sustainability, particularly in relation to environmental concerns linked to energy production and consumption within an economy.

Indeed, some researchers include *developability* as an additional dimension when measuring energy inequality [10]. This dimension considers the capacity of individuals and communities to develop and utilize energy resources effectively and sustainably. It takes into account factors such as the technical knowledge, skills, infrastructure, and institutional support necessary for energy development. Including developability as a dimension of energy inequality recognizes that access to energy alone is not sufficient. The ability to harness energy resources and utilize them in a way that supports economic, social, and environmental development is crucial. It acknowledges that disparities in technical capabilities and institutional support can contribute to energy inequalities, particularly in developing regions.

The uneven treatment of energy inequality and its dimensions, along with the urgent need to transition towards a climate-neutral society and address associated risks, emphasizes the importance of continuously seeking and developing appropriate dimensions and indicators to measure energy inequality in today's context. It is crucial to identify the most relevant dimensions that capture the multifaceted nature of energy inequality and align them with the goals of reducing energy inequality and combating climate change. Efforts should be directed towards finding effective ways to measure and monitor energy inequality, taking into account the specific challenges and priorities of different regions and populations. This includes considering factors such as *availability*, *accessibility*, *reliability*, *affordability*, *adequacy*, *cleanability*, *acceptability*, *developability*, and other dimensions that are crucial in assessing and addressing energy inequality. By developing comprehensive frameworks and indicators, we can gain a better understanding of the complexities of energy inequality and its relationship with climate change.

3.4. The Indicators

The study of energy inequality is motivated by multiple factors, including the lack of consensus on measuring energy inequality, the significant scale of the challenge, the importance of devising measurement methods, and the necessity of finding solutions to tackle energy inequality. To comprehensively understand and address energy inequality, it is crucial to establish standardized measures similar to those used for income inequality. Currently accepted measures of income inequality, such as the Gini coefficients, Palma ratio, Theil index, and Atkinson index, provide valuable insights into the extent of income disparities. Similarly, developing comparable measures for energy inequality will enable a more accurate assessment of its magnitude and facilitate the identification of appropriate strategies to alleviate it. Establishing agreed-upon measures for energy inequality is an important step towards effectively addressing this issue.

A systematic literature review has revealed a wide range of indicators used to assess energy inequality, indicating a lack of consensus and standardization in the field. This diversity of indicators points to the limitations of the existing framework for understanding and measuring energy inequality.

Some researchers argue that *energy consumption* can serve as an appropriate measure of energy inequality [9,15,54–58]. They contend that disparities in energy consumption patterns reflect underlying socioeconomic inequalities within a society. Wu, S., Li, C., and Wei, C. (2022) propose electricity consumption as an appropriate indicator for measuring inequality [58]. The analysis shows that it provides a reliable and informative measure of inequality, reflecting service flows and durable goods. While there are limitations such as coverage, accuracy, and external factors, the authors argue that electricity consumption has unique properties that complement existing literature on inequality measurement [58]. By analyzing differences in energy consumption levels across different population groups or regions, researchers can gain insights into the distribution of energy resources and access. Energy consumption is considered a comprehensive indicator that captures the combined effects of various factors, such as income, infrastructure availability, and energy access. Higher energy consumption is often associated with improved living standards, access to modern amenities, and economic development. Conversely, lower energy consumption is indicative of limited access to energy services, which can be a result of income disparities, inadequate infrastructure, or energy poverty. By focusing on energy consumption, researchers can identify groups or regions that are disproportionately burdened by energy inequality. According to Reames, T., Daley, D., and Pierce, J. (2021), *energy burden* can be considered as one measure of energy inequality [22] as it refers to the proportion of household income that is allocated to pay for energy utilities, such as electricity and heating. It reflects the affordability aspect of energy access and consumption.

Indeed, another part of the scientific community recognizes the significance of *carbon emissions* in assessing energy inequality [8,9,13,56,57,59–64]. Carbon emissions are closely linked to energy production and consumption patterns, and they play a crucial role in climate change mitigation efforts. Several studies argue that carbon emissions can be used as an indicator of energy inequality as they reflect disparities in energy use and environmental impact across different population groups and regions. By examining carbon emissions, researchers can identify the distributional aspects of energy consumption and its associated environmental consequences. Considering carbon emissions as a measure of energy inequality helps shed light on the environmental justice dimension of energy disparities. It highlights the unequal distribution of climate change impacts and the potential burden on disadvantaged communities that may be more vulnerable to the effects of global warming.

It can indeed be argued that *energy expenditure* is a significant indicator of energy inequality [26,38]. Energy expenditure refers to the amount of money households or individuals allocate towards meeting their energy needs, such as electricity, heating, and transportation fuel. It reflects the financial burden and affordability of accessing and utilizing energy services. Higher energy expenditures relative to income can indicate a greater energy burden on households, particularly those with limited financial resources. This can be attributed to various factors such as inefficient housing, lack of access to affordable energy options, and disparities in income levels. Indeed, the *housing situation* is commonly examined as an indicator of energy inequalities [47,54]. The quality, type, and efficiency of housing can significantly impact energy consumption and access to energy services. Factors such as insulation, heating and cooling systems, and energy-efficient appliances play a crucial role in determining energy usage and costs within households. Disparities in housing conditions, particularly among marginalized populations, can contribute to energy inequalities by influencing energy consumption patterns and affordability.

Considering a systematic literature review, the following dimensions of energy inequality have been identified: availability, accessibility, reliability, affordability, adequacy, cleanability, acceptability, and developability. Table 6 presents indicators categorized according to these dimensions and other relevant factors.

Measuring energy inequality is a complex task, and, currently, there is no standardized approach to doing it. Some researchers use the multidimensional energy poverty index [9,14,53] or indices like the disease outbreak resilience index [68], livelihood resilience index, or livelihood vulnerability index [24]. However, there is no consensus on the suitability of these measures for capturing energy inequality. Therefore, the development of an effective indicator system is necessary to measure energy inequality [9]. Given the multidimensional nature of energy inequality, including dimensions such as availability, accessibility, reliability, affordability, adequacy, cleanability, acceptability, and developability, it is challenging to encompass all these dimensions in a single indicator evaluation approach. Nevertheless, it is crucial to seek measures and take action to address energy inequality.

Table 6. Dimensions and indicators of energy inequality according to the systematic literature review.

Dimension	Type	Indicator
Accessibility [14,23,24,32,65–68], etc.	Objective	Electricity accessibility (% of population).
		Electricity accessibility in urban areas.
		Electricity accessibility in rural areas.
		Household accessibility.
		Access to basic services.
		Distance to water.
		Per capita water resources.
		Per capita water consumption.
		Urbanization rate.
		Sewage treatment rate.
		Water utilization rate.
		Water consumption.
		Waste water emission.
		Drinking water: source of water, water treatment.
	Subjective	Dissatisfaction with electricity supply conditions.

Table 6. *Cont.*

Dimension	Type	Indicator
Availability [10,21,23,26,53,66–69], etc.	Objective	Energy availability.
		Water availability.
		Food availability.
		Energy source and kitchen appliances.
		Lighting and electrical appliances.
		Domestic hot water system.
		Type of refrigerator associated with its energy efficiency.
		Lack of adequate energy services, including electricity, modern cooking fuels, entertainment, education, telecommunications, and electric appliances, along with high indoor pollution levels.
		The ownership of electric appliances (lamps, fans, televisions, radios, mobile phones, landline phones, fridges, microwaves, personal computers, washing machines, and air conditioners).
		Improved sanitation: toilet facility, handwash, shared toilets.
		Housing conditions: floor, roof, walls.
		Primary energy production per capita.
	Subjective	Participants were asked to indicate their household’s primary source(s) of energy for daily use and requirements (e.g., cooking, boiling water, heating, and lighting) using a checklist of the following: (a) direct connection to a power grid; (b) connection to power grid via other client; (c) self-installed solar panels and batteries; (d) diesel generators; and (e) wood and other combustion material.
Reliability [26,32], etc.	Objective	System average interruption duration index.
		System average interruption frequency index.
		Supply capacity.
		Voltage oscillations.
	Subjective	Experience of electric outages in daily lives.
Affordability [14,18,20,22,25,32,37,40,41,61,69,70], etc.	Objective	Energy burden: the county-level average proportion of income spent on housing energy bills for low- and moderate-income households.
		Energy price: world annual average crude oil price.
		Minimal energy production costs.
		Inability to pay an energy bill.
		Receipt of a shutoff or service termination notice.
		Actual disconnection from service.
		Ability to face an unexpected expense.
		Required energy expenditure over the national median and a residual income below the official poverty line.
		Required energy expenditure over the national median and a residual income below the poverty line.
		Fuel costs above the median level and residual equivalized income after fuel expenditure below the official poverty line.
		Net residual income, after housing costs, that is insufficient to cover their energy expenses after covering other minimum living costs.
		Average share of energy billings (including charges for electricity/gas/water/kerosene/gasoline) out of monthly household income, calculated using the energy expenditure approach.
		Indicator of whether the budget share exceeded 10%, a traditional measure of energy poverty.

Table 6. *Cont.*

Dimension	Type	Indicator
Affordability [14,18,20,22,25,32,37,40,41,61,69,70], etc.	Objective	Annual expenditure on energy (electricity, gas, and other heating fuel) as a proportion of annual household disposable income (budget share).
		Identifies households that cannot afford to maintain the dwelling at an adequate temperature during the cold months.
		Identifies households that cannot afford to maintain the dwelling at an adequate temperature during the hot months.
		Identifies households that had one or more arrears in utility bills in the last 12 months.
		The percentage of households within a county that are overcrowded or lack kitchen or plumbing facilities.
		Identifies dwellings with leaks, dampness in walls, floors, ceilings, or foundations, and/or rot in floors, window frames, or doors.
		Identifies dwellings without means of heating or with central heating or room-heating appliances but not used when necessary.
		Identifies dwellings without an air conditioner or with an air conditioner but not used when necessary.
		The low income–high cost (LIHC) indicator of energy poverty, taking into account income and energy cost circumstances.
	Subjective	Inability to heat the home due to a shortage of money.
		Inability to pay electricity, gas, or phone bills on time due to a shortage of money.
		Feelings about electricity costs, specifically focusing on households selecting "very expensive".
Adequacy [39], etc.	Objective/subjective	Consider whether households face difficulties in heating and cooling their homes due to financial constraints.
Cleanability [8,9,14,30,54,59–64,70–76], etc.	Objective	Energy use.
		Energy demands.
		Energy intensity.
		CO_2 emission.
		Methane emission.
		PM2.5 air pollution.
		Exceedance of air quality limit.
		Relationship between GDP per capita and the greenhouse gases—carbon dioxide, nitrous oxide, and methane.
		Minimal use of fresh water through reusing.
		Forest area.
		Biodiversity.
		Fossil fuel energy consumption.
		Electricity production from renewable sources, excluding hydroelectricity.
		Final energy consumption by uses in residential and service sectors.
		Urban waste generation.
		Urban waste recovery.
		Clean fuels accessibility and technologies for cooking.
		Investment in environmental pollution control as a percentage of GDP.
		Renewable capacity trend installation.
		Threshold for the peak power.
		Minimal total non-processing energy.
		Minimal number of setup machines to avoid emissions.

Table 6. *Cont.*

Dimension	Type	Indicator
Cleanability [8,9,14,30,54,59–64,70–76], etc.	Objective	Final energy consumption by mode of transport.
		Vehicle fleet.
		Km travelled by mode of transport and activity.
		De-installation of conventional thermal plants.
		Sectoral decarbonization.
		Energy ecological footprint.
		Energy ecological pressure index.
		Energy ecological support coefficient.
Acceptability [10,14,49,61,73], etc.	Objective	Energy intensity level of primary energy.
		Non-fossil to total energy consumption.
		Sustainable transportation.
		Energy-efficient buildings.
		Renewable energy consumption (measured as a share of total final energy consumption).
		More efficient appliances and systems (needs to be combined with sufficient capacity).
		Energy biocapacity.
		Per capita energy biocapacity.
Developability [10,13,14,35,77], etc.	Objective	Investment in renewable energy.
		Renewable power generation.
		Renewable energy: terawatt hours of solar, wind power, and geothermal and biomass generation.
		Primary energy consumption per capita
		Innovation.
		Low-carbon technology innovation.
		Exogenous technological progress.
		Energy innovation.
		Environmental innovation/green technology.
		Renewable energy technology innovation.
		Eco-innovation.
		Green technology innovation.
		Clean technology innovation.

4. Discussion

The challenge today is to reduce poverty and inequalities while preserving the vitality of natural ecosystems and ensuring inclusive economic growth and wellbeing, both now and in the future, thus including future generations [78].

The concept. Although a systematic literature review has highlighted the disagreements between the two concepts, particularly regarding their common use as interchangeable terms, it is crucial to recognize that energy inequality and energy poverty are distinct phenomena. Energy inequality refers to disparities in energy access, distribution, and utilization among different individuals, households, communities, or regions. It recognizes that not everyone has equal opportunities to access and benefit from energy resources, and there can be significant variations in energy accessibility and affordability as well as quality across different population groups. Energy inequality focuses on understanding and addressing the unequal distribution of energy resources and services, with an emphasis on social, economic, and environmental factors that contribute to these disparities.

On the other hand, energy poverty refers to the lack of access to modern and reliable energy services required for basic human needs and well-being. It is characterized by inadequate access to electricity, clean cooking fuels, heating, cooling, and other essential energy services. While there are some similarities between energy inequality and energy poverty, both relate to access to energy resources and services. Specifically, both concepts highlight the challenges of providing equitable access to energy resources and services to all individuals and communities, particularly those that are disadvantaged or marginalized. Additionally, both energy inequality and energy poverty can have negative impacts on human well-being, economic development, and environmental sustainability. However, energy poverty highlights the socio-economic consequences of energy deprivation, such as limited educational opportunities, compromised health and safety, reduced productivity, and restricted socio-economic development. While energy inequality and energy poverty are related, they each capture different aspects of the energy access challenge. Energy inequality focuses on the unequal distribution of energy resources and services, whereas energy poverty emphasizes the lack of basic energy services necessary for a decent standard of living. Understanding the distinctions between these concepts is important for accurately diagnosing energy-related challenges and developing targeted interventions.

To effectively address both energy inequality and energy poverty, it is crucial to establish a shared understanding and consensus on their definitions and usage. This will facilitate the development of appropriate strategies and interventions to tackle these challenges comprehensively. By recognizing the distinctions between these concepts and using the terms accurately and consistently, we can work towards mitigating energy inequalities and alleviating energy poverty.

The dimensions. A systematic literature review has identified availability, accessibility, reliability, affordability, adequacy, cleanability, acceptability, and developability as determinants of energy inequality. These dimensions provide a comprehensive framework for analyzing energy inequality, but there are still gaps that need to be addressed. One potential gap is the consideration of environmental sustainability. This proposal party aligns with the suggestion made by Urquiza, A., Amigo, C., Billi, M., Calvo, R., Labrana, J., Oyarzun, T., and Valencia, F. (2019) to incorporate an energy quality dimension in measuring energy inequality [69]. Urquiza, A., Amigo, C., Billi, M., Calvo, R., Labrana, J., Oyarzun, T., and Valencia, F. (2019) highlight that the existing indicators often do not explicitly consider energy quality and its relationship to the unique socio-cultural and territorial contexts; therefore, it is important to recognize the significance of local factors in establishing standards for energy quality, equity, and affordability [69]. On the other hand, transitioning towards a climate-neutral society should be a shared objective for all nations, and it should not be treated differently or pursued with varying approaches in different countries. Therefore, it is justified to include the dimension of environmental sustainability in the measurement of energy inequalities. This addition is particularly crucial to fulfill our responsibilities towards future generations and to work towards a common goal in alignment with the Sustainable Development Goals. By considering environmental sustainability as a dimension, we can better address the long-term implications of our energy choices and make progress towards a more sustainable and equitable energy system.

It is important to note that the dimensions of availability and accessibility together with the reliability dimension have similar content (this is proven by the content examined in the latter dimensions and their indicators) and could be combined into a single dimension. This systematic literature review highlights the significance of affordability together with the adequacy dimension as a crucial dimension in measuring energy inequality. Additionally, the dimensions of cleanability, acceptability, and developability are equally important but may only partially address the current situation and the goal of achieving a climate-neutral society. To address these gaps, it is appropriate to combine the dimensions of cleanability, acceptability, and developability and expand their content to encompass the concept of environmental sustainability (see Figure 3).

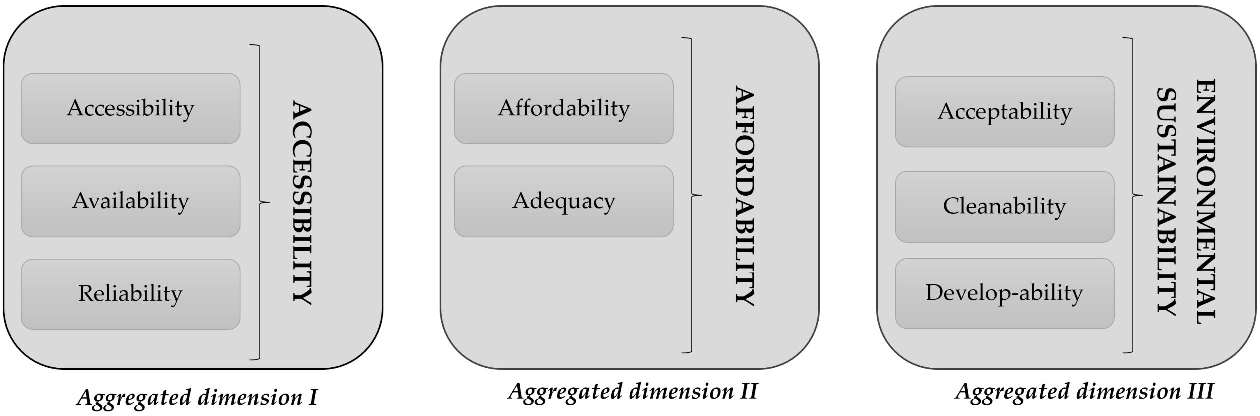

Figure 3. A structured and systematic framework for assessing energy inequality dimensions: addressing specifics of content and research gaps.

Environmental sustainability refers to the ability to meet present energy needs without compromising the ability of future generations to meet their own needs. This dimension includes considerations such as greenhouse gas emissions, air and water pollution, and resource depletion. By incorporating environmental sustainability as a dimension, we can gain a better understanding of the long-term implications of our energy choices and work towards a more sustainable and equitable energy system. This expanded framework allows us to analyze energy inequality from a comprehensive perspective that considers social, economic, and environmental aspects, enabling us to make informed decisions and pursue effective strategies for addressing energy inequality and achieving sustainability goals.

The introduction of the environmental sustainability dimension is indeed necessary, especially in response to Sustainable Development Goals: SDG 1—end poverty in all its forms everywhere; SDG 6—ensure availability and sustainable management of water and sanitation for all; SDG 7—ensure access to affordable, reliable, sustainable, and modern energy for all; SDG 10—reduce inequality within and among countries; SDG 11—make cities and human settlements inclusive, safe, resilient, and sustainable; SDG 12—ensure sustainable consumption and production patterns; and SDG 13—take urgent action to combat climate change and its impacts [79]. By incorporating the environmental sustainability dimension into the framework for analyzing energy inequality, we align our efforts with the mentioned Sustainable Development Goals.

Environmental sustainability addresses the urgent need to combat climate change, reduce greenhouse gas emissions, protect natural resources, and promote sustainable consumption and production patterns. It recognizes that achieving social and economic goals must go hand in hand with preserving the environment for current and future generations. Considering the Sustainable Development Goals in the context of energy inequality underscores the importance of adopting a holistic approach that integrates social equity, economic development, and environmental protection. By addressing energy inequality while prioritizing environmental sustainability, we can work towards a more just, resilient, and sustainable future that promotes poverty eradication, equitable access to basic services, and the protection of our planet's resources.

The indicators. Scientists must reach a consensus regarding the terminology used in the field. It is important to establish that energy inequality refers to the unequal distribution of access to energy resources, infrastructure, and services within a country or region, while energy poverty pertains to the lack of access to affordable and reliable energy services necessary to meet basic needs. Reaching a consensus on the terminology used in the field of energy research is important. Standardizing definitions and understanding the nuances between different terms, such as energy inequality and energy poverty, can improve clarity and facilitate effective communication among researchers, policymakers, and practitioners. By incorporating energy sustainability as a dimension within the framework of accessibility, affordability, and energy sustainability, a more comprehensive understanding of energy inequality can be achieved. This recognizes the need to address not only immediate energy access and afford issues but also the long-term sustainability and environmental implications of energy systems. Ongoing research and collaboration are crucial for identifying suitable indicators and measurement approaches for these dimensions. By developing robust indicators, researchers and policymakers can gain insights into the extent of energy inequalities and design effective strategies and interventions to address them. This can include measures to improve energy infrastructure, promote renewable energy sources, enhance energy efficiency, and ensure equitable access to energy services for all. Ultimately, reaching a consensus on terminology, defining key dimensions, and developing suitable indicators are important steps in advancing our understanding of energy inequality and devising targeted solutions to reduce disparities and promote sustainable energy access and use.

The ways for inequality reduction. Global challenges have become increasingly prevalent, and these challenges have significant implications for our planet and society. Addressing these challenges will require global cooperation and innovative solutions to ensure a sustainable future for all. Efforts to transition towards urban sustainability and resilience are confronted with strong inequalities [80].

Understanding the concept, dimensions, and indicators of energy inequality is crucial for effective policy implementation. By addressing energy inequality, significant progress can be made towards achieving the Sustainable Development Goals. A systematic literature review has highlighted the analysis of the concept of energy inequality, its dimensions, indicators, and its impact on vulnerable individuals, health, and social and economic aspects. To tackle energy inequality, the following points should be considered (Figure 4).

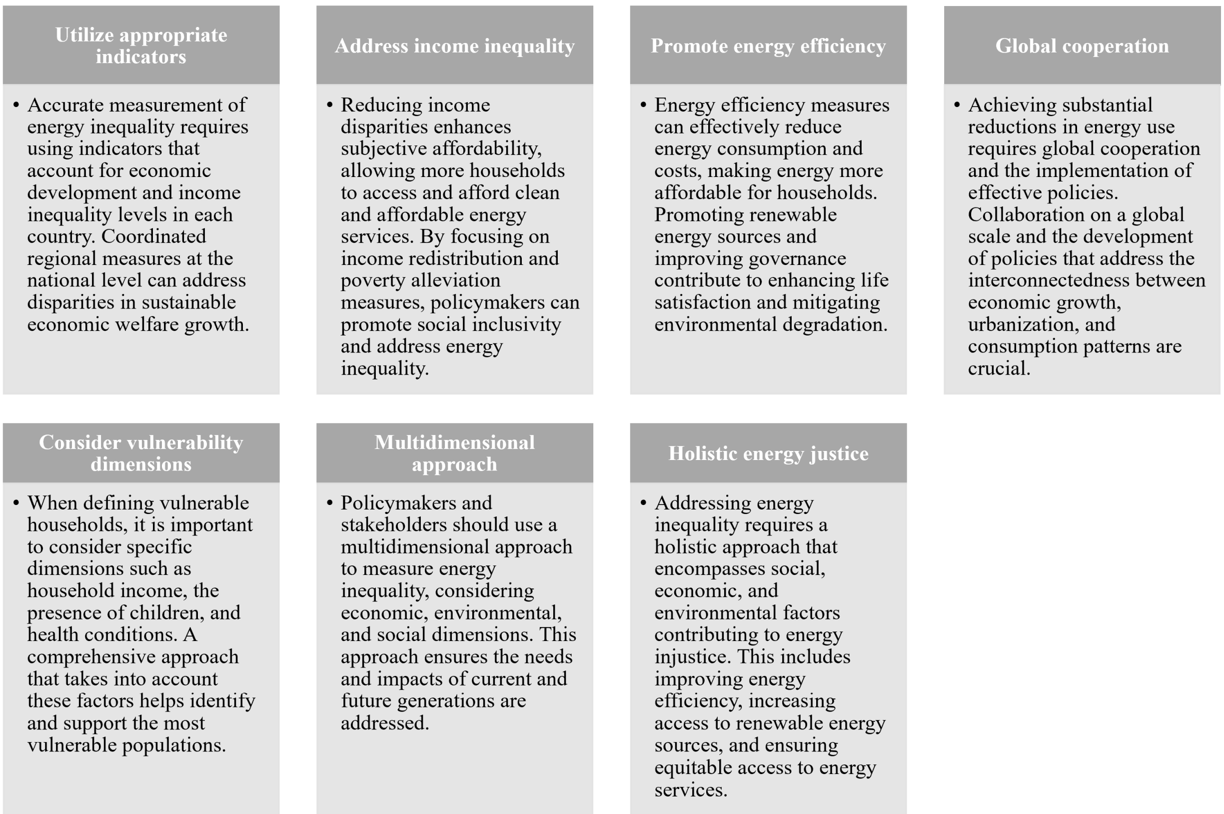

Figure 4. The ways for energy inequality reduction.

Firstly, utilizing appropriate indicators that account for economic development and income inequality levels in each country is crucial for accurately measuring energy inequality and guiding effective policy responses. According to a study by Liu, Y., Zhu, X., and Wang, Y. (2022), there is significant inequality in the development level, which is primarily driven by gaps between regions. This highlights the need for coordinated regional measures at the national level to address disparities in sustainable economic welfare growth [81]. The study recommends reducing the national income gap, stimulating household consumption, increasing infrastructure construction expenditures, investing in public health and education, mitigating environmental pollution to improve well-being and social welfare, and addressing inequality in sustainable economic welfare development. Additionally, addressing inequality remains a critical aspect of global development, particularly in low-income countries [64]. A study by Selseng, T., Linnerud, K., and Holden, E. (2022) emphasizes the significance of decreasing inequality to foster sustainable development [64]. Furthermore, a study by Jiang, S., Mentel, G., Shahzadi, I., Ben Jebli, M., and Iqbal, N. (2022) recommends that governments should prioritize reducing income inequality and promoting the use of renewable energy to achieve Sustainable Development Goals [34]. By implementing these measures, policymakers can effectively address energy inequality, promote inclusive and sustainable economic welfare, and contribute to global development.

Secondly, it is crucial to address income inequality in order to enhance subjective affordability for all households. By reducing income disparities, more households will have the financial resources to access and afford clean and affordable energy services. The narrowing of income gaps can contribute to creating a more equitable energy landscape, where energy services are accessible to a larger segment of the population. This approach aligns with the findings of various studies highlighting the importance of income redistribution and poverty alleviation measures in combating energy inequality. By focusing on reducing income inequality, policymakers can enhance the affordability aspect of energy access and ensure that energy services are not disproportionately burdensome for low-income households. This, in turn, contributes to promoting social inclusivity and addressing energy inequality on a broader scale.

Thirdly, it is crucial to not only consider the varying levels of economic development and income disparities among different countries but also to focus on assessing extreme poverty [82] or excessive inequality [83]. Extreme poverty and excessive inequality can lead to significant damage in terms of the economy, quality of life, especially for marginalized groups, and the environment [83]; additionally, extreme poverty and excessive inequality can lead to significant damages in terms of the economy. Therefore, special attention should be given to understanding and addressing these extreme forms of inequality to mitigate their adverse impacts and promote a more equitable and sustainable society.

Fourth, economic growth and energy demand have been closely linked in the last century. As economies develop rapidly, their need for energy increases. Industries, transportation, and infrastructure all require energy to function. Conversely, constraints in energy supply can hinder economic growth. However, efforts are being made to decouple economic growth from energy consumption through energy efficiency and renewable energy. Balancing economic growth with sustainable energy practices is a key challenge for policymakers.

Fifth, giving priority to energy efficiency is essential as it can effectively reduce energy consumption and costs. This approach has multiple benefits, including making energy more affordable for households and contributing to environmental sustainability. Research conducted by Omri, A., Omri, H., Slimani, S., and Belaid, F. (2022) highlights the positive effects of renewable energy and good governance on life satisfaction and their ability to mitigate the adverse impacts of environmental degradation [13]. Therefore, promoting renewable energy sources and improving governance can enhance life satisfaction and counteract the negative effects of environmental degradation.

While many countries account for a significant share of global energy consumption, their utilization of renewable energy remains relatively low, indicating the need for greater adoption of sustainable energy practices [36]. However, achieving substantial reductions in energy use requires global cooperation and the implementation of effective policies. It is crucial to address the interconnectedness between economic growth, urbanization, and consumption patterns to break the cycle of increasing energy demand. Efforts should be made to mitigate the rebound effect, where gains in energy efficiency are offset by increased consumption [54]. To promote energy efficiency and transition to renewable energy sources, countries must collaborate on a global scale and develop and implement effective policies. This approach aligns with the findings of Ajide, K. and Ibrahim, R. (2022) who suggest policy directions such as reducing income gaps, scaling up social welfare programs, investing in private business ideas, implementing government interventions to regulate exploitative activities of private investors, increasing awareness of the environmental consequences of consumption, and providing tax incentives for environmentally friendly goods and services [31]. Additionally, it is important to examine the conditioning role of institutions in mediating the relationship between income inequality and environmental degradation, which calls for further research.

Lastly, it is important to consider specific dimensions of vulnerability when defining vulnerable households, including household income, the presence of children, and the prevalence of illness or health conditions. By adopting a comprehensive approach that takes into account these specific factors, we can ensure that the most vulnerable populations are identified and provided with the necessary support to overcome energy inequality. This approach aligns with the findings of various studies that emphasize the importance of considering multiple dimensions of vulnerability in addressing energy inequality [84–91]. By understanding the unique challenges faced by vulnerable households, policymakers and stakeholders can develop targeted interventions and support mechanisms to improve their access to affordable and reliable energy services.

By considering these factors, policymakers and stakeholders can work towards reducing disparities in access to affordable and reliable energy services, promoting sustainability, and supporting vulnerable populations [28]. It is essential to use a multidimensional approach to measure energy poverty and include a broad range of indicators to accurately assess the problem. Governments and associated bodies should promote financial development, human development, and bio-capacity to achieve long-term economic growth while discouraging ecological footprint and income inequality [92]. Sustainable system development requires considering the economic, environmental, and social dimensions of sustainability, ensuring the needs and impacts of current and future generations [70]. Addressing energy inequality and the negative impacts of energy inequality requires a comprehensive approach that encompasses social, economic, and environmental factors contributing to energy injustice. This includes improving energy efficiency in buildings, increasing access to renewable energy sources, and ensuring equitable access to energy services. By adopting a holistic approach to energy justice, a more sustainable and equitable energy system can be established, benefiting all members of society [17].

In summary, the following points can be highlighted that show that the challenge of reducing energy inequality while preserving natural ecosystems and promoting inclusive economic growth and well-being is a key concern. Energy inequality and energy poverty are two related but distinct phenomena that need to be understood and addressed. Energy inequality refers to disparities in energy access, distribution, and utilization, emphasizing the unequal distribution of energy resources and services among different population groups. Energy poverty, on the other hand, pertains to the lack of access to reliable and affordable energy services necessary for basic human needs. To effectively tackle energy inequality and energy poverty, a shared understanding and consensus on their definitions and usage are essential. It is important to establish key dimensions for analyzing energy inequality, such as availability, accessibility, reliability, affordability, adequacy, cleanability, acceptability, and developability. Environmental sustainability should also be integrated into this framework to ensure long-term energy solutions that do not compromise future generations' needs. In addressing energy inequality, it is crucial to consider indicators that account for economic development, income inequality levels, and subjective affordability. Policies should focus on reducing income disparities, promoting energy efficiency, and transitioning to renewable energy sources. Global cooperation, effective governance, and comprehensive approaches that consider vulnerability dimensions and social, economic, and environmental factors are necessary for reducing disparities in access to energy services, promoting sustainability, and supporting vulnerable populations. By addressing energy inequality, policymakers can make significant progress towards achieving Sustainable Development Goals and contribute to a more just, resilient, and sustainable future. Standardizing definitions, understanding key dimensions, and developing suitable indicators are crucial steps in advancing our understanding of energy inequality and devising targeted solutions to reduce disparities and promote sustainable energy access and use.

5. Conclusions

This study emphasizes the importance of establishing a common understanding and terminology to effectively address energy inequality. While energy inequality refers to the unequal distribution of access to energy resources, infrastructure, and services within a country or region, energy poverty refers to the lack of access to affordable and reliable energy services to meet basic needs. Resolving the differences between energy inequality and energy poverty is the first step towards identifying its dimensions and indicators and exploring strategies to reduce it.

The multidimensionality of energy inequality is evident, with impacts ranging from social and economic aspects to health implications and environmental quality. To comprehensively analyze energy inequality, dimensions such as availability, accessibility, reliability, affordability, adequacy, cleanliness, acceptability, and developability must be considered. While it is challenging to encompass all these dimensions in a single indicator evaluation approach, efforts should be directed towards developing comprehensive frameworks and indicators. This will enable a better understanding of the complexities of energy inequality and its interconnection with climate change. Additionally, the inclusion of environmental sustainability as a dimension of energy inequality deserves further attention. By identifying the most relevant dimensions, aligning them with the goal of reducing energy inequality, and prioritizing actions such as addressing income disparities, promoting energy efficiency, and considering vulnerability factors, policymakers and stakeholders can work towards reducing disparities in access to affordable and reliable energy services. This not only promotes sustainability but also supports vulnerable populations.

The findings underscore the need for a multidimensional approach to measure and monitor energy inequality, considering the specific challenges and priorities of different regions and populations. Collaboration on a global scale, along with the implementation of effective policies, is necessary to achieve greater energy sustainability, reduce environmental impact, and create a more resilient and equitable future.

Limitations and further research directions. This research analyses the energy inequality concept and its content. However, this article has several limitations. Firstly, the research is grounded in a systematic literature review of scientific articles from the past five years. While this study enabled the conceptualization of energy inequality, identification of its content components, and proposal of potential measures, further research is necessary to empirically validate the reliability and validity of the proposed aggregated sets of dimensions. Secondly, one of the significant challenges in achieving a climate-neutral society is energy inequality. Future research should not only analyze the concept of energy inequality but also empirically investigate the indicators that contribute to its exacerbation. Additionally, there is a need to measure and identify effective actions empirically to reduce energy inequality and ensure energy equity for everyone. By addressing these issues, we can strive towards a more equitable and sustainable energy future. Thirdly, new computational methodologies based on artificial intelligence (AI) can revolutionize energy inequality research. AI-driven algorithms can analyze vast datasets to uncover deeper insights into the drivers and impacts of energy inequality. Predictive modelling can simulate scenarios and test strategies to address energy inequality, leading to evidence-based policy recommendations. AI's natural language processing can streamline literature reviews and the synthesis of information. AI also contributes to optimizing energy distribution, forecasting energy demands, and promoting renewable energy integration for a more sustainable and equitable energy future.

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