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Review

Energizing the Now: Navigating the Critical Landscape of Today's Energy Challenges—An In-Depth Review

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Abstract: Today's energy challenges are multifaceted. Over the past 30–40 years, energy issues have been discussed and published on an extensive scale. The green transition involves concrete actions related to increasing energy efficiency, replacing fossil fuels with alternative fuels, producing energy using renewable resources, creating various means of transport that use electric motors, identifying technical solutions that generate an increased energy yield in the case of buildings, and waste reduction, reuse and recycling. In order to attain a climate-neutral environment, it is mandatory to impose regulations, measures and actions to help decarbonize the energy sector. The analysis of published articles on these issues is the subject of this large and information-dense review. Concretely, the transition to climate neutrality will generate obvious advantages at an economic, social and technological level, for example, the opportunity for economic growth, new business models and new markets, and the generation of new jobs or technological development. At the same time, this paper underscores the need for a multifaceted approach, integrating technological innovation, policy intervention and global cooperation for an effective energy transformation. The review suggests future issues and research directions, focusing on viable strategies for energy transition and its socio-economic environmental impacts.

Keywords: energy transition; renewable energy; competitiveness of economies; resilience of energy markets; energy efficiency; greenhouse gas (GHG) emissions; decarbonization; climate neutrality; energy security; energy poverty

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1. Introduction

Energy is the essential engine of human progress and social development and a fundamental pillar in the fabric of every society.

Energy is the ability of a system to produce mechanical work, heat, light, sound or radiation. Energy is also an economic good, which is produced, consumed, traded and regulated in local, regional or global markets. Energy is also a social factor, influencing quality of life, access to basic services, human rights and civic participation. Finally, energy is an environmental factor, affecting the environment, biodiversity, climate and human health.

Energy systems have evolved in a dynamic and complex manner throughout history, depending on resource availability, energy demand, technological progress, political interests and environmental pressures. Globally, the energy system is dominated by fossil fuels (oil, natural gas, coal), which account for over 80% of primary energy consumption and greenhouse gas emissions. At the regional level, there are significant differences between continents and economic blocs in terms of energy mix, degree of integration, level of development and energy security. At the national level, each country sets its own objectives, strategies and measures to manage energy resources, production, transport, distribution and consumption, according to its specific context and national interests.

The energy transition (green transition) refers to the process of transforming energy systems from a predominantly fossil fuel base to a predominantly renewable energy base, providing cleaner, secure and affordable energy for all. The energy transition is driven by several factors, such as the depletion of fossil fuel resources, increasing energy demand, environmental pollution and climate change, but also by opportunities such as technological development, innovation, competitiveness, cooperation and participation. The energy transition entails profound technical, economic, social and political changes, bringing challenges but also benefits for all actors involved.

Facilitating the energy transition requires a shared vision, an integrated strategy and coordinated action at all levels: global, regional, national and local. A holistic and multidimensional approach is needed, taking into account all aspects of energy: resources, technologies, markets, policies, actors and impact. From infrastructure and storage to efficient integration into existing networks, from fighting energy poverty to ensuring a just transition, from regulatory framework content to financing packages and techniques, these new energy sources require innovative solutions and sustainable strategies to become the main source of power for our society in the future. This requires the active and responsible involvement of all stakeholders: governments, institutions, companies, organizations, researchers, consumers and citizens. A massive and sustainable investment is needed in energy research, development, innovation, education, information and awareness-raising. There is a need for the constant monitoring, evaluation and reporting of progress and results achieved in the energy transition.

While this paper does not aim to cover the subject exhaustively, it focuses on analyzing the approaches, evolution and future prospects of energy, illustrating a complex and dynamic landscape in which research, technology, economics and policy intersect to shape the future direction and impact of this fundamental resource. In fact, the primary research problem is to understand and address the critical challenges in today's energy sector, focusing on the integration of renewable energy sources, improving energy efficiency and ensuring energy security. The objectives include discovering new challenges and trends on the issue of energy, exploring innovative solutions to overcome barriers in the transition to sustainable energy practices, assessing the impact of technological advancements (especially AI) on energy systems and proposing strategies for a holistic approach to energy policy and management. Despite extensive research in the field of energy, there remains a gap in understanding how to effectively integrate AI and other emerging technologies into the energy sector for optimal efficiency and sustainability. Furthermore, there is a need for a comprehensive analysis that bridges the technological, socio-economic and environmental aspects of energy policy, particularly in the context of the latest international climate action discussions and agreements. This revised focus will provide a unique contribution to the field by blending technology with policy and socio-economic considerations, offering a multidimensional perspective on energy challenges. Although many studies have been published in this field regarding energy issues, as far as we know, there are no review papers that summarize the four major directions that reflect this vast field. Therefore, it can be stated that this study is the first in this sense, which also constitutes the novelty of this paper.

The outline of this paper includes a very comprehensive search of representative articles and studies related to the issue of energy; subsequently, it describes the bibliometric approach and data sources, presents key findings from the literature review, interprets the results and their implications, and finally summarizes the in-depth study and suggests areas for further research.

2. Literature Review

2.1. Renewable Sources of Energy

In recent decades, renewables have become a major topic of interest because of their potential to help reduce carbon emissions and transition to a more sustainable energy system. These alternative energy sources are key pillars towards a sustainable energy transition and a lower dependence on fossil fuels. Solar, wind, hydro, geothermal and biomass have been investigated in detail by researchers, highlighting the benefits and challenges of each.

Although each renewable energy source has its specific benefits and challenges, collectively, they offer considerable potential to meet the world's energy needs while reducing environmental impacts and addressing climate change.

Researchers' concerns with these issues are not new. With regard to the role and impact of wind energy on the energy sector, between 1980 and 2005, technological developments in the field of wind turbines generated a 5% annual increase in energy production from such sources [1]. The main challenges in wind energy have been and remain the same: the reliability of wind turbine components [1,2]; the complexity of the mathematical models required, which include an array of variables such as meteorological models for selecting suitable locations; the design of turbines according to site characteristics [1–5]; the cost–benefit analysis [6]; the impact of wind farms on economic, social and environmental sustainability [7]; and the often diverging interests of various governmental and non-governmental organizations [6,7].

Solar energy is not a new field of study either. Guangul and Chala, 2019, perform a classical SWOT analysis of the development and use of solar energy systems [8]. They identify, on the one hand, strengths and opportunities (versatility of the systems, low long-term costs, environmental compatibility) and, on the other hand, weaknesses and threats (high initial costs, low efficiency, possibility to store only a small part of the energy produced, conventional fossil fuel energy systems in use and operation). In another study, Eroğlu and Cüce, 2021, point out other weaknesses (dependence on daylight hours and large areas required for panel installation) but also the vulnerability to unforeseen external environmental factors (the COVID pandemic increased photovoltaic (PV) panel prices from USD 0.228/W to USD 0.27/W) [9]. Okkerse and van Bekkum, 1999, [10] point to solar energy as the main source that will enable the transition from a fossil fuel-based economy to a plant-based economy, a model that will be able to provide food, energy and materials for the planet's needs in the medium and distant future. However, the authors identify the major challenge of such a system as the actual limits of available agricultural land.

Presently, there are several possible applications of the third generation of solar PV technologies. Obaideen et al. analyze the following [11]: large-scale solar PV power plants (solar farms); residential applications for solar PV systems (PV-powered units for HVAC-heating, ventilation and air conditioning; PV-water pumps); green hydrogen; water desalination; and transportation.

More recent studies examine the impact of AI on solar energy systems. In a study conducted by Mohammad and Mahjabeen in 2023, they argue that artificial intelligence has a revolutionary impact on PV systems [12]. By utilizing large volumes of data, including climate patterns, solar radiation levels and geographic data, along with machine learning algorithms, AI facilitates decision making in the design phase of PV systems. This includes the development of smart, orientationally mobile PV panels for optimal solar radiation exposure. Additionally, through the analysis of market data such as price developments and consumption trends, AI contributes to market balance and the more efficient integration of PV systems into the energy system.

Green hydrogen is an energy carrier that can aid in the decarbonization and defossilization of various sectors, including transport, industry and power generation. Several methods exist for producing green hydrogen, but the most common and promising is water electrolysis. This process involves breaking down water into hydrogen and oxygen by applying an electric current. Water electrolysis can be achieved using different types of electrolytes, each of which has advantages and disadvantages in terms of efficiency, cost, sustainability and scalability. A comparative study of these technologies was conducted by Osman et al., 2022, who concluded that PEM (proton exchange membrane) electrolysis has the greatest potential for large-scale green hydrogen production due to its high efficiency, high power density and operational flexibility [13]. However, there are different methods of combining hydrogen and renewable energy sources throughout the energy sector. Hassan et al. identifies and studies the following [14]: energy-to-energy, energy-to-gas, energy-to-fuel and energy-to-feedstock.

The cost of green hydrogen production depends largely on the cost of electricity produced from renewable sources, which varies according to location, resources, infrastructure and policies. Currently, the cost of green hydrogen is still higher than that of hydrogen produced from fossil fuels. However, this gap is expected to narrow in the future, due to the falling costs of renewables and electrolytes, as well as their increasing efficiency and performance. IRENA 2022, for example, estimates that the cost of green hydrogen could fall from USD 3–6/kg in 2020 to USD 1.5–2.6/kg in 2030 and USD 0.8–1.6/kg in 2050 [15].

There are several options for storing and transporting green hydrogen, such as storage under pressure, storage in liquid form, storage in porous or metallic materials, storage in geological formations, or conversion into derived energy carriers such as ammonia, methanol or synthetic hydrocarbons. Each of these options has advantages and disadvantages in terms of efficiency, cost, safety and technological maturity. A review of these options was carried out by Osman et al., 2022, who found that storing hydrogen in geological formations, such as depleted natural gas reservoirs or salt caverns, is the most suitable for long-term storage and for balancing renewable energy supply and demand [13].

The environmental impact of green hydrogen depends on how it is produced, stored, transported and used. Green hydrogen produced from renewable energy has a much lower environmental impact than hydrogen produced from fossil fuels because it does not generate direct emissions of greenhouse gases or air pollutants. However, green hydrogen still has an indirect environmental impact due to the consumption of resources, such as water, metals or land, which are needed to build and operate facilities to produce, store, transport and use hydrogen. It is therefore important to carry out a Life Cycle Assessment (LCA) to assess the environmental impact of green hydrogen across the value chain compared to other energy alternatives. An example of an LCA for green hydrogen production by water electrolysis using solar, wind or hydropower was carried out by Terlouw et al., 2022, who showed that green hydrogen has a lower environmental impact than hydrogen produced from natural gas or coal, but it is higher than that of direct renewable electricity [16].

Marine energy is a renewable source generated in a variety of ways from the natural movement of water, including ocean currents, tides, river currents, waves, as well as the heat transfer from deep cold water to surface water.

In a comparison of tidal and wave energy, Chen, 2023, points out the development, the applications and the advantages and disadvantages of using these sources [17]. The author shows that while there are only a few places in the world where wave energy can be used on a large scale and profitably, tidal energy offers a significant opportunity for increasing global renewable energy production capacity. However, researchers must focus on reducing prices, developing equipment that can withstand ocean forces, and minimizing environmental impacts.

Tidal energy has the advantage of being predictable, constant and clean, but it also has disadvantages, such as high costs, its impact on the environment and marine biodiversity, its dependence on geographical and climatic conditions, and its intermittent production.

Tidal energy conversion technologies can be classified into two main categories: dam-based technologies (the oldest and most developed, with the iconic Rance power plant in France, which has been in operation since 1966 and has an installed capacity of 240 MW, as an example) [18] and turbine-based technologies (less widespread, but with great potential for development, with the MeyGen project in Scotland, which aims to install 269 turbines with a total capacity of 398 MW, as an example) [19].

Most scientific work on tidal energy focuses on economic, social and environmental analysis. The economic analysis of tidal energy reveals very high investment costs due to the complexity and size of projects, involving feasibility studies, design, construction, transport and installation. For example, the MeyGen project is estimated to have had an investment cost of around GBP 51 million [20]. Operation and maintenance costs are lower but depend on environmental conditions and equipment reliability. The lifetime of tidal energy conversion technologies is estimated at 20–30 years, depending on wear and degradation. Efficiency is variable, depending on the tidal cycle, current speed, turbine efficiency and transmission losses.

Tidal energy can have positive social impacts such as creating jobs, boosting the local economy, diversifying energy sources and reducing greenhouse gas emissions. For example, the MeyGen project is estimated to have created over 100 direct and indirect jobs and contributed to the development of the region's shipbuilding and metallurgical sectors [21]. Tidal energy can also have negative impacts, such as affecting the landscape, cultural heritage, tourism, fishing and navigation [18].

From an environmental perspective, tidal energy can be considered a clean energy source, producing no greenhouse gas emissions, radioactive waste or other pollution. For example, it is calculated that the MeyGen project will avoid the emission of over 300,000 tons of CO_2 during its lifetime [20]. However, tidal energy can also have negative effects on marine ecosystems, such as altering the hydrological regime, salinity, temperature and sedimentation; destroying or breaking up habitats; disturbing or killing species; interfering with migration or reproduction; and generating noise or electric currents. For example, the Rance power plant was found to have affected the biodiversity of the area, reducing the number and diversity of fish, crustaceans, mollusks, algae and bird species, and altering the balance between native and invasive species [18].

2.2. Energy Efficiency

Energy efficiency is a complex and multidimensional issue, involving many factors and actors, with important implications for the economy, for society, for the environment and for development.

Energy efficiency can be defined as the ratio of energy services obtained to the energy consumed to produce them [22]. Energy efficiency is an important way to reduce energy consumption and waste, improve energy supply security, reduce greenhouse gas emissions, boost economic competitiveness and ensure a transition to a low-carbon economy [22,23]. Energy efficiency is also a strategic principle of the Energy Union, which aims to create an integrated and diversified internal energy market in the EU [23].

The existing literature on energy efficiency covers a wide range of issues, including ways, techniques and tools to promote energy efficiency at the national and global levels. It explores the short-, medium- and long-term benefits and costs of energy efficiency for various industries, sectors and entities. The literature also addresses barriers and challenges in implementing and monitoring energy efficiency, along with indicators and methodologies for measuring energy efficiency. Moreover, it examines the impact of energy efficiency implementation on the environment, health, the common good, quality of life and sustainable development. Additionally, the literature explores the role of innovation, digitalization and artificial intelligence in increasing energy efficiency, and it provides forecasts of future scenarios for energy efficiency.

Energy efficiency can be studied from very different perspectives. A large range of studies [24–28] approach the relation between energy efficiency, rural activities and the agriculture sector. Some other studies are trying to show the impact of some financial issues on energy efficiency: access to credit [29], digital finance [30] and green bonds [31,32]. Lately, a new approach has arisen: the energy efficiency of cloud computing systems [33,34].

An example of a study that examines measures and instruments to promote energy efficiency is that of Bertoldi and Rezessy, which compares energy efficiency policies and programs in EU countries and the US [35]. The authors identify the main types of instruments used, such as regulations, standards, labeling, audits, certificates, subsidies, taxes, tariffs, energy performance contracts, energy efficiency funds, energy savings obligations, white certificate trading schemes, and information and education campaigns. The authors assess the impact and effectiveness of these instruments as well as the synergies and complementarities between them. They conclude that there is no single solution for promoting energy efficiency, but rather an optimal mix of instruments tailored to the specific context of each country.

Ürge-Vorsatz et al., 2012, assess the benefits and costs of energy efficiency and estimate the economic impact of energy efficiency at global, regional and sectoral levels [36]. The authors use a methodology based on input–output analysis and macroeconomic modeling to calculate the direct and indirect effects of energy efficiency on output, income, employment, investment, consumption and trade balance. They show that energy efficiency has a net positive effect on the economy, generating economic growth, job creation, poverty reduction and improved competitiveness. They also stress the importance of considering the multiplier and rebound effects of energy efficiency, which can mitigate or amplify economic benefits.

Another approach is offered by Gynther et al., 2015 that identifies barriers and challenges in implementing and monitoring energy efficiency and examines the experience and practices of EU countries in reporting energy efficiency progress [37]. The authors review the methodologies and indicators used by Member States to measure and evaluate energy efficiency and the difficulties and uncertainties associated with them. They highlight the need to improve the quality and comparability of data, harmonize methodologies and indicators, set clear and realistic objectives and targets, ensure the transparency and verifiability of reports, involve all relevant actors and encourage the exchange of best practices and cooperation between countries.

In a synthesis exploring the results of over 100 scientific studies on the subject, Ryan and Campbell, 2012, review the impact of energy efficiency on the environment, health, quality of life and sustainable development [38]. The researchers demonstrate that an enhanced energy efficiency yields a multifaceted array of societal advantages. These include the diminution of greenhouse gas emissions, alongside a concomitant reduction in air, water and soil contaminants. Further, there is an amelioration in both indoor and outdoor air quality. Health risks and mortality rates associated with pollution and climatic alterations are observed to decrease. Additionally, there is an elevation in thermal and acoustic comfort levels. Economic benefits are evidenced through a decrease in energy-related expenditures and an augmentation in the accessibility of energy services. This improvement in energy efficiency contributes to a heightened energy security and resilience. It also acts as a catalyst for innovation and technological advancement. The employment sector benefits from the creation of job opportunities and fosters local development. Collectively, these factors play a pivotal role in the advancement towards achieving sustainable development goals.

One report investigating the role of innovation and digitization in increasing energy efficiency is that by the IEA, which presents trends and opportunities offered by digital technologies for energy efficiency [39]. The authors analyze the impact of digitization on different energy sectors such as buildings, transport, industry, electricity, oil and gas. They identify the main digital technologies that can enhance energy efficiency, such as sensors, the internet, data analytics, artificial intelligence, automation, digital platforms and the blockchain. They estimate the potential energy savings and emission reductions associated with digitization, as well as the challenges and risks involved, such as cybersecurity, data protection, access to digital infrastructure, and digital skills. This report makes policy recommendations to support the digital transition to energy efficiency.

Future prospects and scenarios for energy efficiency are summarized in a report produced by the EEA in 2023, which explores possible ways forward for energy efficiency in Europe up to 2050 [40]. The authors use an energy optimization model to construct four alternative scenarios, based on different assumptions on the evolution of energy demand, the energy mix, energy prices, energy efficiency investments, energy policy and climate targets [40]. They compare the results of the scenarios in terms of energy consumption and production, energy intensity, CO_2 emissions, economic costs and benefits, energy dependency, health and environmental impacts, etc. They conclude that energy efficiency is essential to achieve a significant reduction in CO_2 emissions and to ensure a fair and sustainable transition of the European energy system.

2.3. Energy Security

Energy security is a complex and dynamic issue that requires a multidisciplinary and multilateral approach. Addressing the issue requires different perspectives: conceptual, geopolitical, geo-economic, geostrategic, legal and institutional. Energy security is a highly topical and important issue for the European Union, which faces major challenges in securing affordable energy supplies, promoting energy efficiency and protecting the environment.

Furfari, 2017 provides a comprehensive and up-to-date analysis of EU energy security, taking into account historical, political, economic, technological and legal developments. The author explains how the EU has developed a common energy policy based on three main objectives: security of supply, competitiveness and sustainability. This book also examines the challenges and opportunities presented by the energy transition, climate change, the internal energy market, the diversification of sources and routes of supply, regional and international cooperation, and the role of the European institutions in the energy field [41].

Klare, 2008 presents a challenging perspective on the new geopolitics of energy, which is marked by the increasing energy demand from emerging powers such as China, India and Brazil; declining conventional hydrocarbon reserves; intensifying competition for access to the remaining energy resources; and increasing risks of conflict and instability [42]. This book also examines how these trends affect the energy security of the US and its allies, and the possibilities for cooperation and dialogue to avoid a global energy confrontation.

Goldthau and Sitter, 2015 take an original view of the EU's role in the global political economy of energy, arguing that the EU is a liberal actor in a realistic world [43]. The authors argue that the EU has used its normative and regulatory power to influence the behavior of other energy actors, such as producer states, multinational companies, international organizations and civil society. This book also examines how the EU has responded to energy security challenges such as import dependence, price volatility, regional instability and climate change.

Van de Graaf and Sovacool, 2016 successfully attempt another comprehensive and in-depth approach in the form of a collection of 28 chapters covering a wide range of topics related to the international political economy of energy [44]. This book addresses issues such as the history and evolution of the global energy system, key actors and institutions, current issues and policies, and future prospects and scenarios. This book provides a comprehensive and interdisciplinary view of energy security, integrating economic, political, social, environmental and technological perspectives.

Scholl and Westphal, 2018 critically examine the EU's energy security strategy and policy, highlighting the contradictions and tensions between the diverging objectives and interests of Member States, European institutions, external partners and non-state actors [45]. This report also examines how the EU has responded to changes in the global energy environment, such as the emergence of new players, transforming markets, developing technologies and growing environmental concerns. This report proposes a number of recommendations to improve the coherence and effectiveness of European energy policy.

A more recent study conducted by Dogan et al., 2023, explores some fundamental questions using data for the new industrialized countries (China, Brazil, India, Malaysia, Indonesia, Mexico, the Philippines, Thailand, South Africa and Turkey) [46]: "How do energy use and energy security concerns affect carbon emissions that may impact the strategy on developing a cleaner production trajectory? How do financial development and institutional quality coordinate in clarifying the negative effects of resource consumption on environmental sustainability? Is there any association between global economic uncertainty and carbon emissions?. . .”

2.4. Energy Poverty

Energy poverty is a relatively new concept in academic research, which has started to be addressed in the last two decades, particularly in the context of climate change and the energy transition. The academic literature mainly analyzes three key issues: causes of energy poverty, measurement indicators and ways to combat it.

There is no universally accepted definition of energy poverty, but rather several approaches and indicators that attempt to measure and characterize this complex and multidimensional phenomenon. In terms of indicators, most studies identify three categories [47–49]: energy burden, which is the percentage of household income that is spent on energy bills; energy under-consumption, which refers to the situation where households consume less energy than the minimum needed for a decent living; and housing quality, access to modern energy services, residents’ satisfaction and thermal comfort, and health and environmental impacts.

Energy poverty is determined by several factors, which can be grouped into three main categories [50–52]: factors related to household income and socio-economic status, factors related to energy price and availability, and factors related to energy efficiency and housing quality. These factors interact with each other and can generate a vicious cycle of energy poverty. For example, low-income households may have to choose between paying energy bills or other essential needs such as food, health or education. This can lead to an under-consumption of energy, which can affect the comfort and health of residents, as well as their school or work performance. At the same time, low-income households may live in old, uninsulated buildings that require more energy to heat or cool. This can lead to a high energy burden, which can further reduce households’ ability to save and invest. Low-income households may also have limited access to modern and renewable energy sources, which could reduce costs and greenhouse gas emissions. This can lead to a reliance on traditional and polluting energy sources such as wood, coal or gas, which can affect air quality and the environment. A study conducted by Cheikh et al., 2023, states that an increase in GDP per capita is necessary but not enough for reducing energy poverty [53]. In order to have a positive effect, the income needs to be more equally distributed.

In conclusion, energy poverty is a major challenge for the sustainable and equitable development of society, which requires an integrated and multidisciplinary approach, taking into account local and national specificities [54]. To effectively combat energy poverty, cooperation is needed between different actors such as governments, local authorities, energy suppliers, civic organizations, researchers, media and citizens. There is also a need for the constant monitoring and evaluation of the phenomenon through the collection and analysis of relevant and up-to-date data [55].

2.5. Energy Transition—Challenges

Energy transition is a necessity and an opportunity for the world’s economic, social and environmental development, but it also involves a number of challenges at local, national, regional and global levels. All the issues listed above, energy security, energy efficiency, energy poverty, and increasing the share of renewable energy sources (wind, solar) in the energy mix, are major challenges in making the energy transition a reality. But they are not the only ones.

A just transition is a challenge and a process to ensure a fair and inclusive transition to a carbon-neutral economy that minimizes negative impacts on regions, sectors, workers and communities dependent on fossil fuels. One of the main initiatives of the European Green Pact is the Just Transition Mechanism, a financial instrument designed to mobilize at least EUR 150 billion over the period of 2021–2027 to support regions and Member States with the greatest energy transition challenges. The Just Transition Facility has three main pillars: the Just Transition Fund, which provides grants for investments in infrastructure, innovation, environment and social development; the Investment Plan for Europe, which provides guarantees to attract private investment in areas such as renewable energy, energy efficiency and sustainable mobility; and the European Investment Bank, which provides public loans for energy transition projects [56].

A just transition is not only a technical or economic issue, but also a social and political one, requiring the active involvement of all those affected, especially the most vulnerable or marginalized. In a 2020 study, the authors propose a theoretical and practical framework for understanding and implementing a just transition based on four principles: solidarity, participation, coherence and anticipation [57].

In another paper on the same topic, the authors outline the origin and evolution of the concept, which was initially adopted by the US labor movement, then by the environmental and climate justice movement, and finally by international climate negotiations [58]. They also provide an analytical framework to describe the range of definitions and perspectives of the different actors involved in a just transition. One of the key aspects is scope, which includes both distributional impact—i.e., who and what is affected by the transition—and intention (ideological preference between reforming or transforming existing political and economic systems). The other aspect is social inclusion, which refers to the degree of recognition and procedural justice for various groups. The framework does not seek to identify a single "correct" definition of the just transition, but rather to capture a range of ideologies and approaches to the concept. The final section of this paper suggests that the next stage of the work of a just transition will be to advance solutions and apply lessons learned. The authors list several priorities for future research, including concrete tools and strategies, more developing country case studies, more effective social engagement and new funding methods.

One of the major difficulties facing the energy transition process is how to measure and evaluate the state of transition. Singh et al., 2019 produce a synthesis of aggregated indicators constructed with the aim of providing an overview of the phenomenon [59]. One of the most relevant such indicators is considered to be the ETI (Energy Transition Index) [60].

It should also be remembered that there is no consensus on the viability of a system that produces electricity using 100% renewable sources. Some authors consider the feasibility of such a system to be a myth [61].

Other authors focus on the effects of recent crises on the energy transition process. Neacsa et al., 2022 identify the effects of the COVID pandemic crisis such as the delay and cancellation of investment projects; the volatility in oil, gas and energy prices; and job insecurity for millions of energy workers [62]. Skalamera, 2023, analyses the mutations of energy geopolitics after Russia's invasion of Ukraine, identifying the repositioning of energy interdependencies, the transformation of indigenous clean energy production into an instrument of energy security, and the vulnerability of supply chains from China with specific green energy technologies [63]. European Union countries should leverage renewable energy to boost their economies. Renewable energy not only generates new job opportunities but also cuts down energy import dependence, stimulating the economy. The EU needs to carry out deeper and wider research in renewable energy, implement more effective energy policies and foster economies of scale for a unified European energy market [64].

3. Data and Methodology

Regarding current energy, we encountered four different directions: renewable sources of energy, energy efficiency, energy security and energy poverty. In order to capture the image of these issues reflected through renewable energy transition, we used bibliometric analysis by considering the literature provided by the Web of Science database. Considering the association of the words "energy transition", "fossil fuels", "renewable energy" and "energy efficiency" resulted in 559 articles from 1994 to 2023.

Bibliometric analysis is a quantitative method to study the bibliographic material in order to provide a general picture of a research topic [65], representing an integral part of the research evaluation methodology, especially in the scientific and applied fields [66]. This approach is quantitative and is aimed at studying bibliographic materials to provide a general overview of a research topic.

Bibliometric analysis is defined as the measurement of texts and information [67]. Using bibliometric analysis, hidden patterns are identified by classifying information [68–71]. Bibliometric methods provide quantitative analysis using the extant literature, being related to "infometrics" [72,73] and "scientometrics" [74].

Bibliometric analysis identifies the literature content for a subject area, evaluating the scientific production [66]. Thus, the bibliometric analysis can be seen as a state of the art, including parts from all scientific domains [75]. This meticulous approach enabled the authors to categorize and understand the broad concept of energy transition, highlighting the most analyzed topics in the field. The document thus offers a detailed and structured overview of the current state of research in energy transition, emphasizing renewable energy sources, energy efficiency, energy security and energy poverty.

To identify the main topic of the content, we used the word clouds considering the words with the highest frequency. The relationships between words can be determined by investigating which words tend to follow others immediately, or which tend to co-occur within the same documents. If the word network reveals which word pairs co-occur most often, the correlation network reveals which words appear more often [76].

We identified the clusters regarding the most correlated groups of words, identifying the most frequent and strongest links at the level of the words encountered in our sample of articles selected according to the key words of our interest. These are our most analyzed topics regarding the broad concept of energy transition.

4. Empirical Results

The concept of energy has evolved over time, from the use of fossil fuels, such as oil, gas and coal, to the use of alternative fuels, such as nuclear energy and renewable resources. The renewable resources most encountered are solar energy, wind energy, geothermal energy, hydro energy, energy created by biomass, and hydrogen energy. Based on this transformation, the renewable energy transition is taking place, which aims to reduce greenhouse gas emissions, increase energy efficiency, achieve the goal of climate neutrality, ensure energy security and protect the environment, as well as achieve the objectives of sustainability, resilience and competitiveness at the micro- and macro-economic levels.

A total of 559 articles reflected the literature on renewable energy transition provided by the WOS database for the period 1994–2023. As can be observed in Figure 1, both the number of published papers and the number of citations in the area reflect a progression. A large jump is registered regarding the number of publications after 2019, as well as a significant rise regarding the number of citations after 2016. Thus, interest in renewable energy transition increased in the last decade, being reflected by the research in this field.

Although many studies have been written in this field regarding energy issues, as far as we know, there are no review papers that summarize the four major directions that reflect this vast field. Therefore, we can say that this study is the first in this sense, which also constitutes the novelty of this paper.

At the same time, based on the research, the most cited paper in the field was identified (Table 1).

By far, the first article has an impressive number of citations and deserves comment. This article provides an extensive analysis of CO_2-related issues. Key topics include the rise in atmospheric CO_2 concentrations, energy challenges and strategies for CO_2 utilization. It discusses various technical approaches for CO_2 conversion, thermodynamic considerations and the importance of industrial and government commitments. This paper emphasizes using CO_2 in environmentally friendly ways, producing useful chemicals and materials, and the potential of converting CO_2 using renewable energy sources for sustainable development [77]. The basic and conclusive ideas of this article confirm that a significant challenge for numerous nations is the escalating atmospheric carbon dioxide levels, mainly driven by energy consumption and economic growth. The primary energy sources contributing to this are fossil fuels, including coal, oil and natural gas, which significantly increase CO_2 emissions. There is currently a constant concern in capturing CO_2 using various technologies with the aim of reducing the levels generated in the atmosphere.

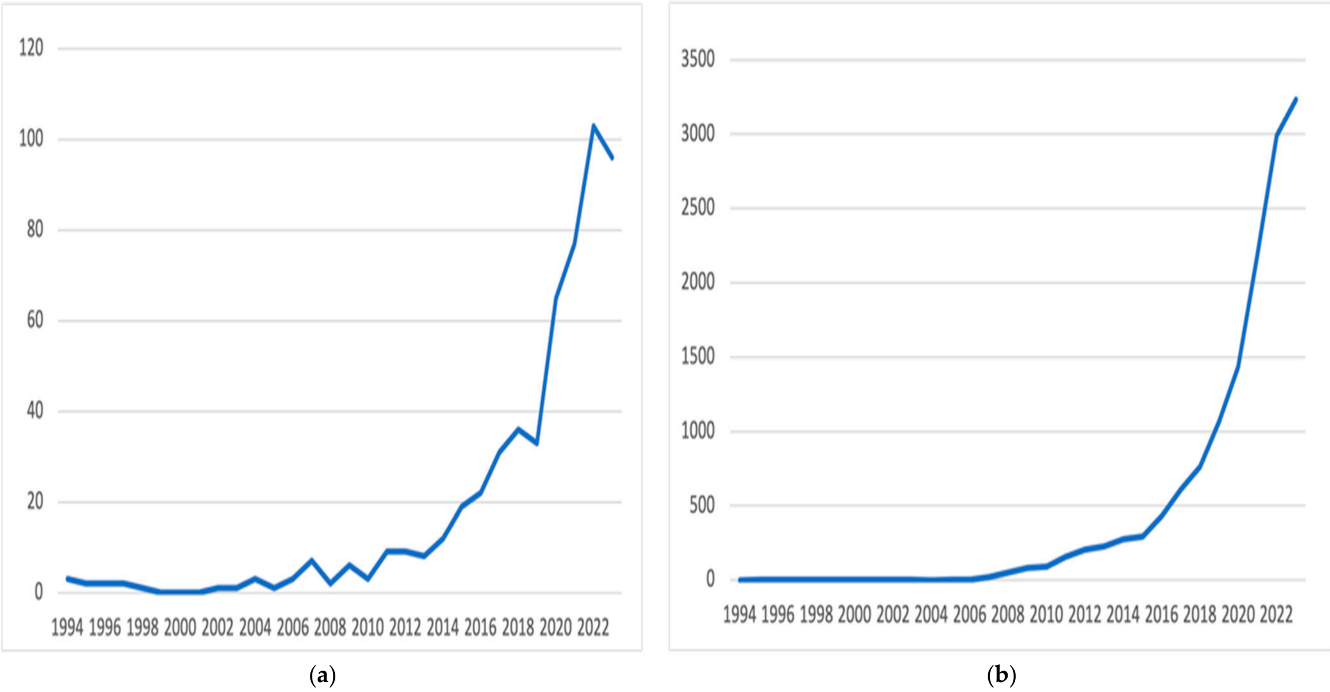

Figure 1. Dynamics on (**a**) publications and (**b**) citations in the field. Source: authors' selection from the WoS database, based on selected words and using Excel 2016.

Table 1. The highest cited papers in the field.

Number	Article	Number of Citations
1	Song, C. Global challenges and strategies for control, conversion and utilization of CO_2 for sustainable development involving energy, catalysis, adsorption and chemical processing. *Catal. Today* **2006**, *115*, 2–32.	14,227
2	Wang, L.; Xia, M.; Wang, H.; Huang, K.; Qian, C.; Maravelias, C.T.; Ozin, G.A. Greening ammonia toward the solar ammonia refinery. *Joule* **2018**, *2*, 1055–1074.	518
3	Wong, W.Y.; Ho, C.L. Organometallic photovoltaics: a new and versatile approach for harvesting solar energy using conjugated polymetallaynes. *Acc. Chem. Res.* **2010**, *43*, 1246–1256.	405
4	Zhang, G.; Xiao, X.; Li, B.; Gu, P.; Xue, H.; Pang, H. Transition metal oxides with one-dimensional/one-dimensional-analogue nanostructures for advanced supercapacitors. *J. Mater. Chem. A* **2017**, *5*, 8155–8186.	357
5	Han, N.; Liu, P.; Jiang, J.; Ai, L.; Shao, Z.; Liu, S. Recent advances in nanostructured metal nitrides for water splitting. *J. Mater. Chem. A* **2018**, *6*, 19912–19933.	352
6	Huisingh, D.; Zhang, Z.; Moore, J.C.; Qiao, Q.; Li, Q. Recent advances in carbon emissions reduction: policies, technologies, monitoring, assessment and modeling. *J. Clean. Prod.* **2015**, *103*, 1–12.	266

Table 1. *Cont.*

Number	Article	Number of Citations
7	Armaroli, N.; Balzani, V. Solar electricity and solar fuels: status and perspectives in the context of the energy transition. *Chem.–A Eur. J.* **2016**, *22*, 32–57.	265
8	Iris, Ç.; Lam, J.S.L. A review of energy efficiency in ports: Operational strategies, technologies and energy management systems. *Renew. Sustain. Energy Rev.* **2019**, *112*, 170–182.	214
9	Jensen, S.H.; Graves, C.; Mogensen, M.; Wendel, C.; Braun, R.; Hughes, G.; Gao, Z.; Barnett, S.A. Large-scale electricity storage utilizing reversible solid oxide cells combined with underground storage of CO_2 and CH_4. *Energy Environ. Sci.* **2015**, *8*, 2471–2479.	202
10	Chandrasekhar, K.; Lee, Y.J.; Lee, D.W. Biohydrogen production: strategies to improve process efficiency through microbial routes. *Int. J. Mol. Sci.* **2015**, *16*, 8266–8293.	193

Another issue that represents important information for this review is related to the most productive institutes in this field (Table 2).

Table 2. The most productive institutes in the field.

Number	Institutes Most Productive in the Field	Number of Research Papers/Studies/Articles
1	Swiss Federal Institutes of Technology Domain	11
2	Helmholtz Association	10
3	Lappeenranta Lahti University of Technology Lut	10
4	Chinese Academy of Sciences	9
5	United States Department of Energy Doe	9
6	Aalborg University	8
7	Indian Institute of Technology System Iit System	8
8	Centre National de la Recherche Scientifique Cnrs	6
9	Shanghai Jiao Tong University	6
10	University of New South Wales Sydney	6
11	Xiamen University	6
12	Consiglio Nazionale Delle Ricerche Cnr	5
13	Ecole Polytechnique Federale de Lausanne	5
14	Eth Zurich	5
15	Imperial College London	5

As can be observed, besides university entities, research centers and institutes or scientific research associations are also involved, highlighting the importance and the impact of this topic currently. In addition, the geographical heterogeneity of the entities involved in this research can be observed, perhaps with a small plus for the European continent. This heterogeneity reflects a worldwide interest, not just in certain areas. However, the institutes with the most research papers in this field are from Switzerland (11 studies), followed by Germany and Finland (10 studies), and China and the USA (9 studies).

The trend regarding the transition to renewable energy is encountered worldwide, with each country taking measures in this endeavor. This is also reflected by the many studies in this field. However, there are countries that show a greater interest in this field. Considering our sample, we clustered the countries according to the interest in this field (Figure 2). The result highlighted four clusters, with the countries from cluster 1 (light blue color) registering the fewest studies in the field and the countries from cluster 4 (dark blue color) registering the most studies in the field. The countries from cluster 4, with the most studies in this field, are China (90 papers) and the USA (87 papers). The five countries with the most studies from cluster 3 are Germany (41 papers), Italy (40 papers), England (35 papers), Australia (33 papers) and India (30 papers). All this information can be seen in Figure 2.

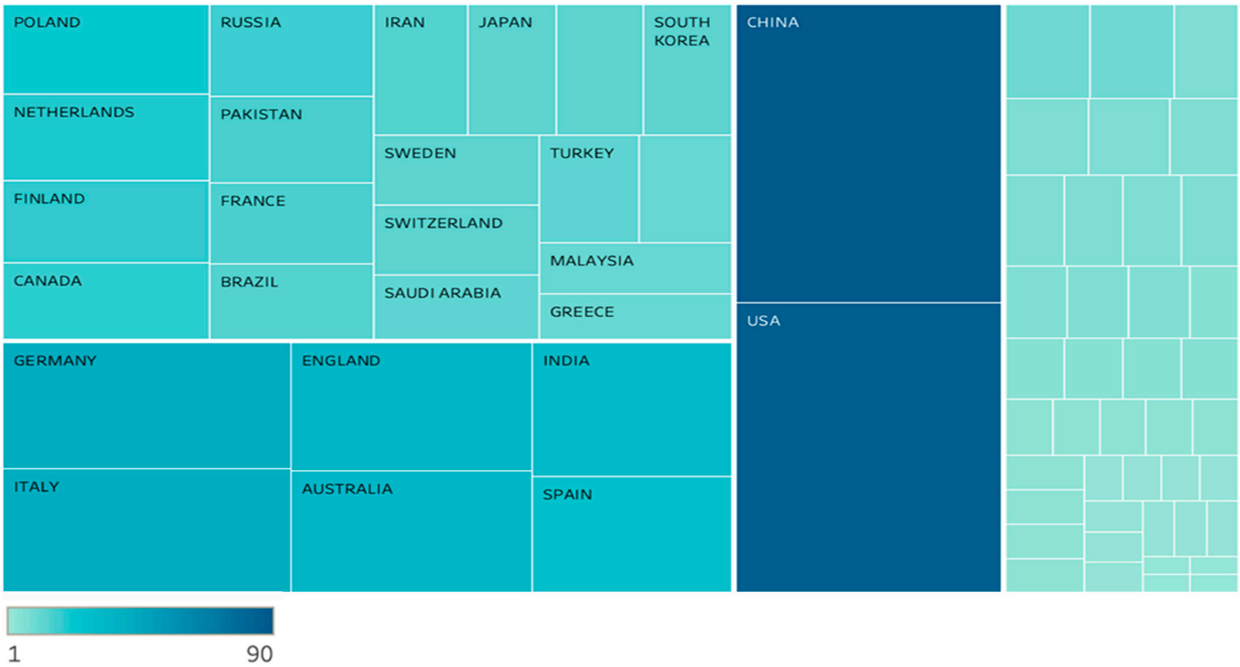

Figure 2. Country analysis regarding the studies in the field. Source: authors' selection from the WoS database, based on selected words, using the visualization TreeMap Chart.

Considering the research area of the studies, most of the papers were published in areas such as Energy Fuels (263), Environmental Sciences/Ecology Science (147 papers), Technology/Other Topics (145 papers), Engineering (136 papers), Chemistry (77 papers) and Business Economics (49 papers). This division of papers can be seen in Figure 3. Although most studies are included in the energy–technological field, as is obvious, the Business and Economics field also appears with many papers. This fact shows that this topic has a significant impact on the economy, but also in the business area, being included not only in the technical areas. This is an extension of the fact that in order to achieve sustainable development, the energy transition occupies a very important place.

Considering the information provided by the 559 scientific articles, we identified the most common words. Investigating the co-occurrence of the words the authors used in the publications, we used a frequency of at least 5 times, a correlation degree greater than 0.5 and a threshold of 0.5. The analysis was conducted using the VOS program.

Figure 4 presents the most encountered words in this field, except the keywords used: security, energy use, reduction, demand, renewable source, innovative technology, heating and low carbon energy transition.

In order to achieve renewable energy transition, according to research in the extant literature, security is the key word. Currently, energy security means more than just safeguarding access to resources. It implies ensuring reliable and affordable energy supplies, while protecting economies from exposure to price volatility. In this context, it is increasingly clear that the energy transition will be an enabler of energy security.

Considering the most correlated words within the selected articles, the combinations of the most encountered words were detected. The empirical results (Figure 5) highlighted seven significant clusters of the most common combinations in the selected studies in the field.

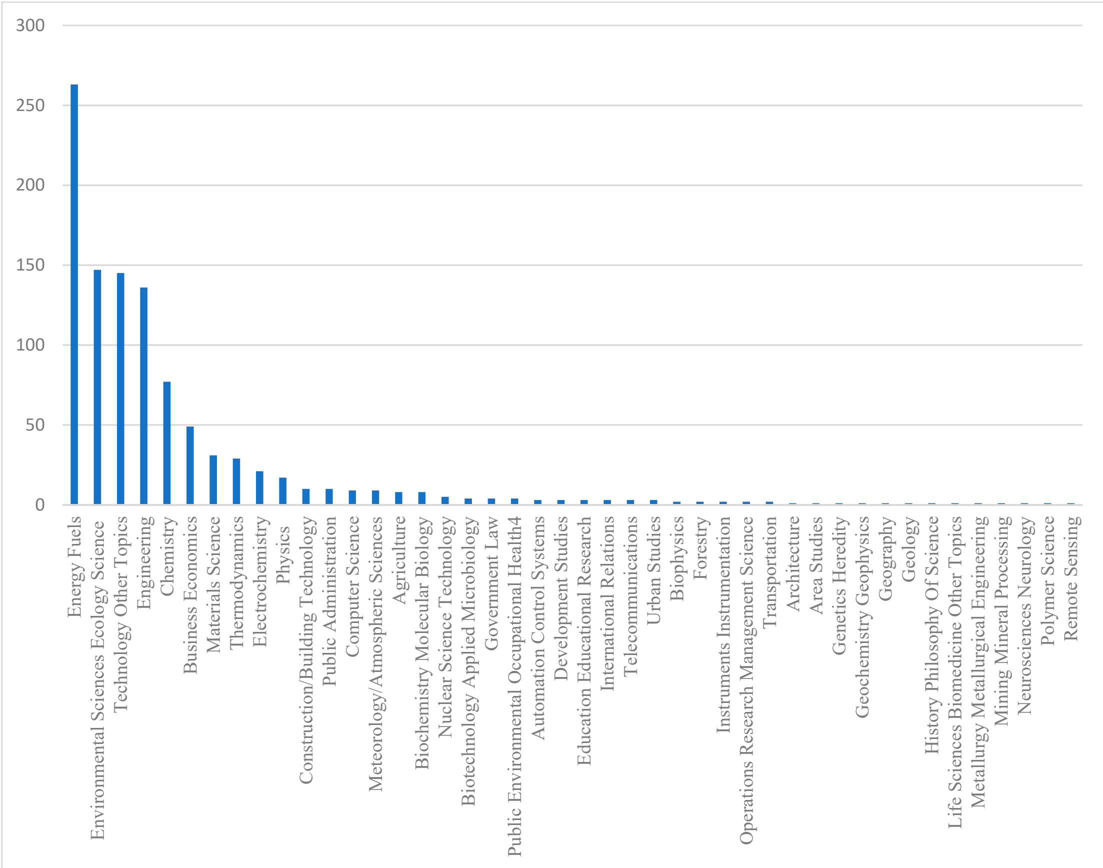

Figure 3. The division of the papers based on research area.

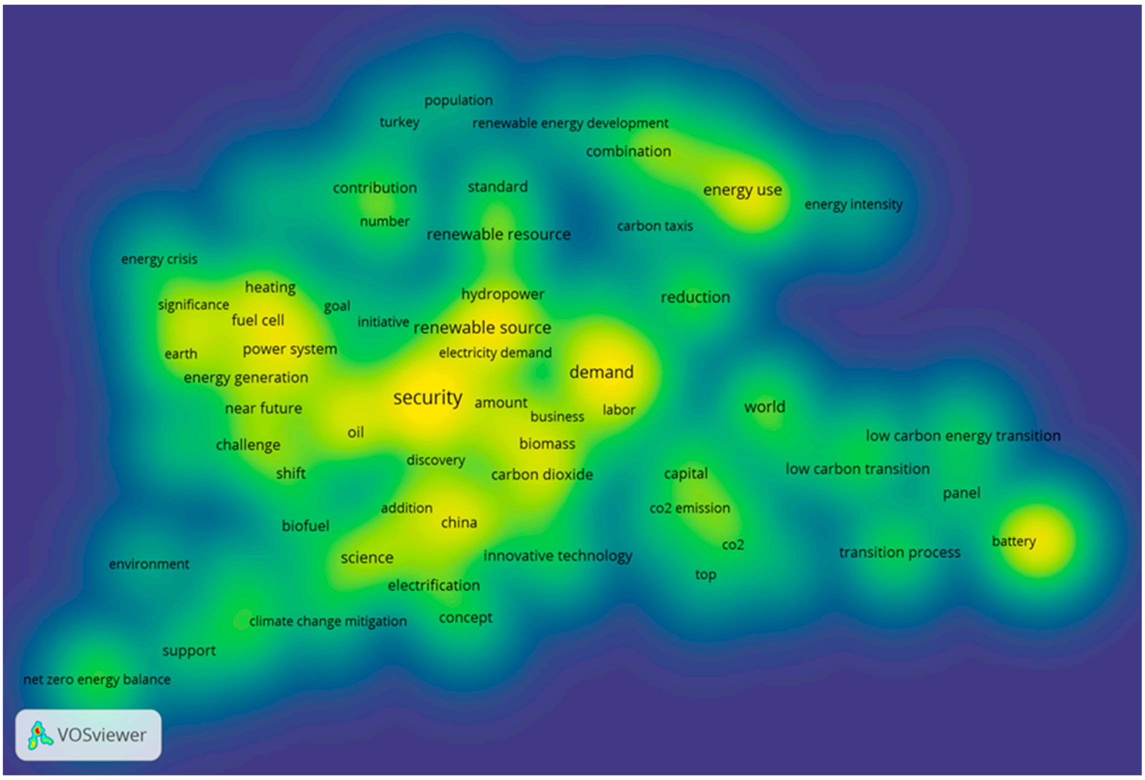

Figure 4. Most common words in the field. Source: authors' selection from the WoS database, based on selected words, using the VOSviewer_1.6.18 program.

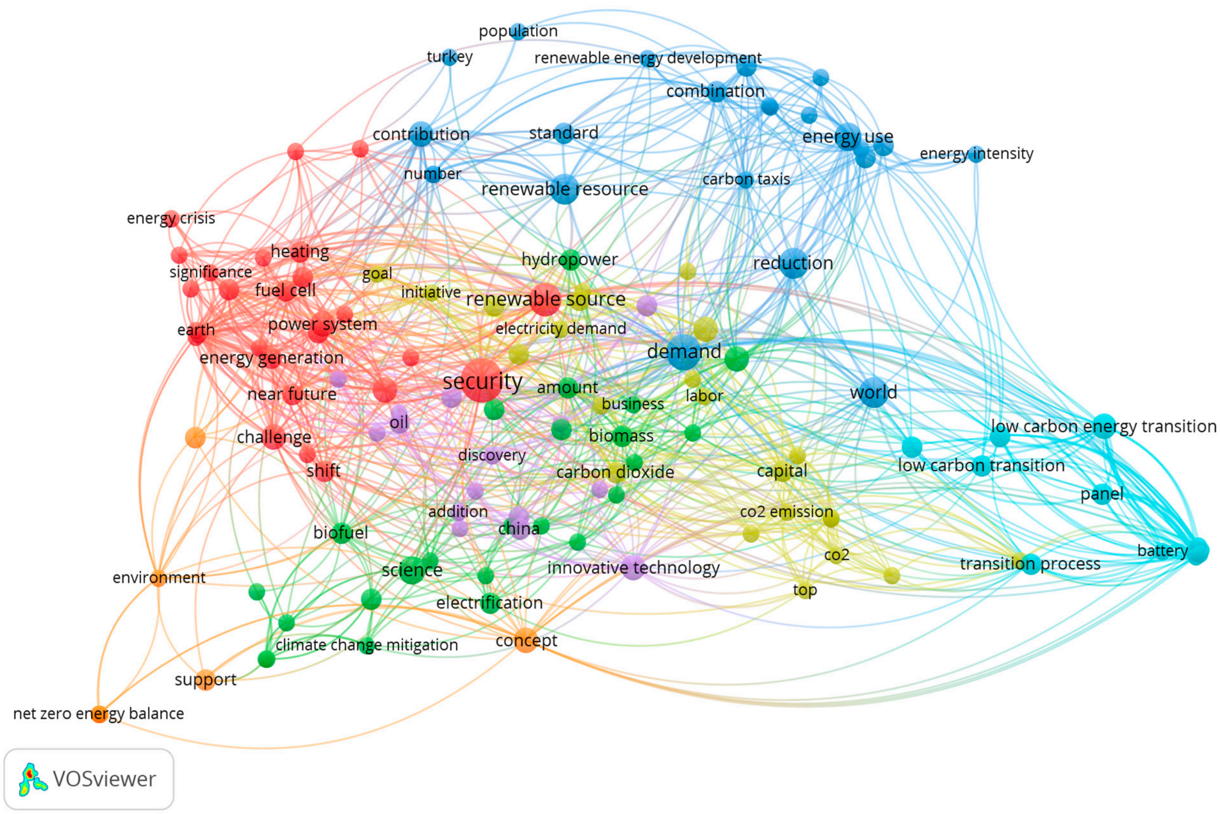

Figure 5. Most common words and the word network in terms of scientific publications' content. Source: authors' selection from the WoS database, based on selected words, using the VOSviewer_1.6.18 program.

These clusters include the following common words:

Cluster 1 (red color): challenge, clean energy, contraction, earth, electricity generation, energy crisis, energy generation, energy potential, energy sector, fuel cell, heating, hydrogen economy, implementation, importance, job, near future, pollutant, power system, renewable fuel, renewable source, security, shift, significance, sustainable transition, transportation, utilization and water;

Cluster 2 (green color): alternative fuel, amount, assumption, biofuel, biomass, business, carbon budget, carbon dioxide emission, climate change mitigation, decarbonization, electrification, energy return, evidence, forerunner, ghg, ghg emission, hydropower, operational strategy, quantity, region, renewable electricity, science and solar photovoltaic;

Cluster 3 (blue color): barrier, capita, carbon capture, carbon taxis, combination, demand, energy conservation, energy intensity, energy use, land use, nuclear energy, population, reduction, renewable energy development, renewable energy resources, renewable resource and world;

Cluster 4 (light green color): capital, carbon dioxide, CO_2, CO_2 emission, electricity demand, energy dependence, environmental quality, environmental sustainability, fossil fuel energy, goal, initiative, input, labor, non renewable energy, policy maker, renewable energy system, risk, solar energy and trade openness;

Cluster 5 (magenta color): addition, advance, China, depletion, discovery, environmental issue, innovative technology, local renewable resource, natural gas, renewable energy transition, oil, Russia and Japan;

Cluster 6 (blue light color): battery, carbon, clean energy transition, energy efficiency measure, international agreement, Kyoto protocol, low carbon energy transition and transition process;

Cluster 7 (orange color): environment, net zero energy balance, rural area, smart rural, support and sustainable development.

Based on the review data and on the analyzed contents of the clusters, representative names are proposed for each cluster (Figure 6).

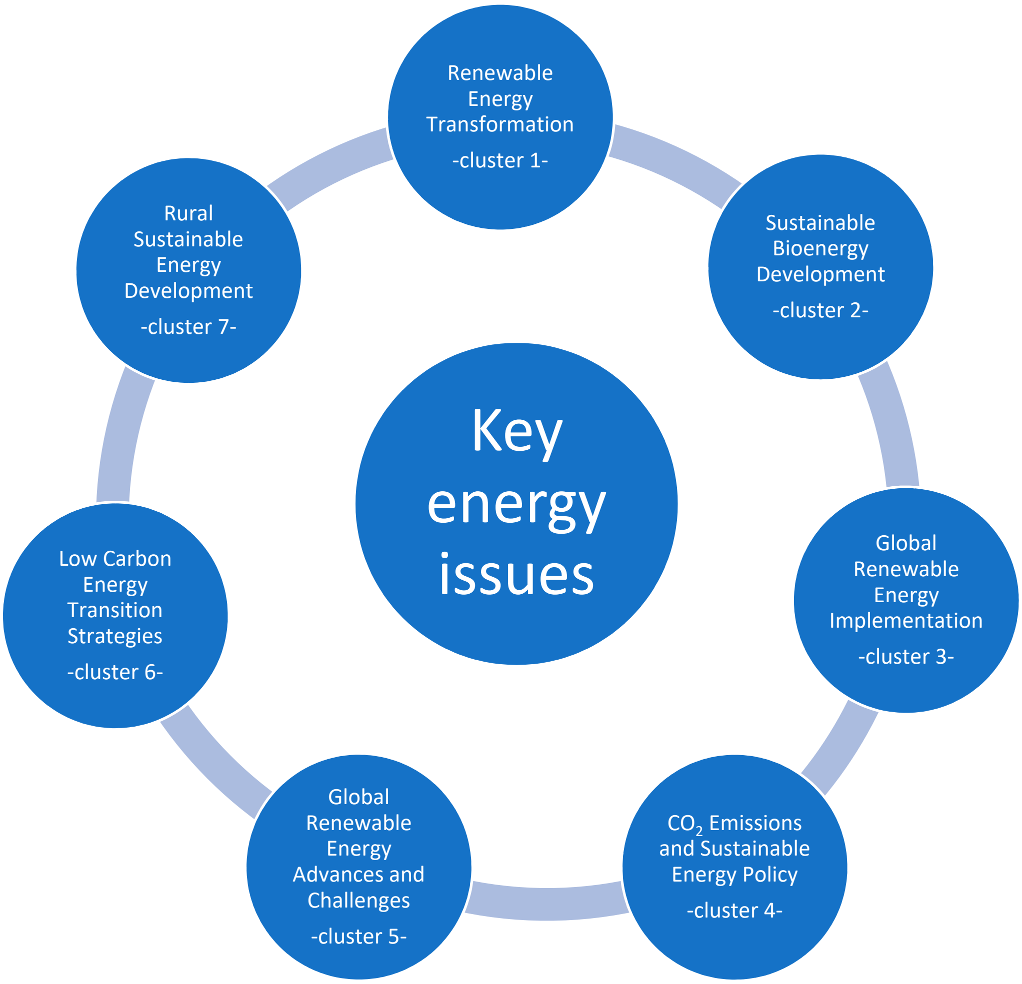

Figure 6. The approach proposed by the authors in relation to the analysis of the main items and challenges regarding energy issues.

Furthermore, a table was designed containing detailed information regarding the key features of each cluster (Table 3). These key features represent the overall findings from the in-depth review based on the literature review and bibliometric analysis.

Table 3. Key features of clusters related to current energy sector challenges.

Cluster No.	Cluster Name	Sources	Key Features, General Findings and Ideas
1	Renewable Energy Transformation	[1],[4],[5],[7],[8],[10],[11],[13],[17–21],[23],[29],[32–34],[36],[38],[43],[44],[48],[52],[55],[56],[58],[62–64],[78]	Transition from fossil fuels to renewables Investment in renewable infrastructure Policy and regulatory support Technological innovation and research Public awareness and education Energy storage solutions Decentralized energy systems Market incentives and financial models International collaboration and agreements Socio-economic integration

Table 3. *Cont.*

Cluster No.	Cluster Name	Sources	Key Features, General Findings and Ideas
2	Sustainable Bioenergy Development	[10],[13],[14],[24],[25],[27],[28],[56],[58],[77],[79]	Sustainable biomass sourcing transition Advanced biofuel technologies Lifecycle emission analysis innovation Integration with agricultural practices Policy support and incentives Public–Private partnerships Local community engagement Diversification of energy sources Research and Development Environmental impact assessments
3	Global Renewable Energy Implementation	[1],[2],[5],[7],[12],[15],[20–23],[29–31],[35–37],[39–43],[45–47],[50],[53],[54],[56],[59–61],[64],[79–81]	Policy frameworks and incentives Infrastructure development Public and private investments Technology advancement and accessibility Capacity building and training Public awareness and engagement International collaboration Sustainable development goals alignment Market integration and deregulation Adaptation to local contexts
4	CO_2 Emissions and Sustainable Energy Policy	[6],[13],[15],[29],[31],[37],[40],[42],[43],[46],[51],[55],[59],[77],[79],[81]	Emissions reduction targets climate policy Renewable energy incentives Energy efficiency standards Carbon pricing mechanisms Sustainable transportation policies Green building regulations Research and development funding Public awareness and education International cooperation and agreements Monitoring and reporting systems
5	Global Renewable Energy Advances and Challenges	[3],[6],[7],[14],[15],[21],[23],[28–30],[32],[33],[35],[38],[41],[44],[45],[47],[52],[56],[60–62],[64],[77],[78],[81]	Technological innovation Cost reductions Grid integration and infrastructure Market and policy support Energy access and equity Intermittency and reliability Resource availability and location constraints Environmental and social impacts Global collaboration and knowledge sharing Investor confidence and financing
6	Low-Carbon Energy Transition Strategies	[7],[11],[15–17],[20],[23],[24],[26],[37],[38],[41],[43],[46],[55–58],[60],[62],[69],[70],[77],[78],[81]	Renewable energy integration Energy efficiency improvements Carbon pricing and taxes Investment in clean technologies Policy and regulatory frameworks Public and Private partnerships Consumer behavior and demand management Decentralized and Smart Energy Systems Sustainable transportation International collaboration and agreements
7	Rural Sustainable Energy Development	[2],[5],[10],[13],[14],[16],[21],[22],[24–28],[32],[33],[36],[37],[40],[42],[45],[47–50],[54],[55],[60],[61],[63],[79],[81]	Small-Scale renewable energy sources Energy efficiency in rural homes Community-Based Energy Projects Sustainable agricultural practices Infrastructure development Specific education and training Policy support and incentives Technology adaptation and innovation

So, cluster 1 encapsulates a comprehensive approach towards transforming the global energy landscape into one that is sustainable, resilient and predominantly powered by renewable energy sources. Then, cluster 2 contains a holistic approach to developing bioenergy sustainably, balancing environmental concerns with the need for renewable energy sources. The third cluster highlights a comprehensive approach towards global renewable energy implementation, addressing technological, economic, policy and social aspects to achieve a sustainable and inclusive energy future. The fourth cluster underscores the multifaceted approach required in policymaking to address CO_2 emissions effectively, balancing environmental goals with economic and social considerations. Cluster 5 highlights the dynamic landscape of renewable energy, marked by rapid advancements and complex challenges that require integrated solutions across technological, policy and social dimensions. The sixth cluster includes a comprehensive approach to transitioning towards a low-carbon economy, aimed at mitigating climate change while promoting sustainable growth. Finally, the seventh cluster refers to the sustainable development of rural areas, balancing environmental conservation with the energy needs of rural communities.

Based on general ideas and key features, a certain content of general findings can be identified within Table 3, identifiable in fact to several clusters. Thus, the issues recognized by the analysis carried out encompass challenges and strategies that are widely applicable across the energy sector. They often involve broad themes like the transition to renewable energy sources, the integration of policy frameworks and incentives, and the development of sustainable energy policies. Common issues typically address global trends and patterns, such as the need for renewable energy infrastructure investment, policy and regulatory support, technological innovation, public awareness and international collaboration. They reflect the shared challenges faced by multiple countries and regions in transitioning towards sustainable energy practices. On the other hand, singular issues are more specific and may pertain to particular aspects or unique scenarios within the broader energy context. These could include specific technological innovations like advanced biofuel technologies or particular strategies for rural sustainable energy development. Singular issues often involve detailed considerations of a certain aspect of energy transition, such as the integration of sustainable practices in agricultural sectors or the development of small-scale renewable energy sources for rural areas. They represent the specific challenges and solutions that might be relevant to particular contexts or sub-domains within the broader field of energy transition.

As can be observed, the energy transition reflects a total of seven subdomains, showing the diversity of this topic. At the same time, it presents numerous stakeholders, both in the technical and economic areas. Considering the amplitude of this topic, we can justify the lack of works that incorporate all these directions.

5. Discussion

Based on the previous research [78,79] and on the present review, six critical issues related to the energy topic can be declared: renewable energy and transition; technological advancements; energy efficiency; energy security; energy poverty and socio-economic aspects; and environmental sustainability. Therefore, the transition to renewable energy involves replacing fossil fuels with renewable sources. Key challenges include technological feasibility, cost-effectiveness and infrastructure development. The transition not only aims at reducing environmental impacts but also at enhancing energy security and fostering sustainable economic growth. Then, technological innovation and integration emphasize the significant impact of technological advancements, particularly in AI, in renewable energy systems. This encompasses the development of smart grids, efficient energy storage solutions and improved forecasting methods for renewable energy generation, as well as the fast and efficient transition from Industry 4.0 to Industry 5.0 in order to support the energy issues and challenges.

Moving on to the energy efficiency and sustainability issue, it is important to focus on optimizing energy use in order to minimize waste and maximize output. Efficient energy use reduces the environmental impact, lowers costs and contributes to sustainability. Discussions include advancements in technology, policy initiatives and consumer behavior influencing efficiency. Then, global energy security entails ensuring a reliable and uninterrupted supply of energy at affordable prices. Geopolitical dynamics, resource availability and international trade influence this item. Energy security is integral to economic stability and national security. This relates to the impact of energy policies on society and environment. Energy policies have far-reaching effects on societal development and environmental health. The focus is on creating policies that balance economic growth with environmental protection, ensuring equitable access to energy and promoting sustainable practices.

A less treated and discussed aspect has to do with the energy rehabilitation of buildings and the creation of "green" buildings. This aspect appeared with the development of urban areas, with the increase in the energy requirement and its price. An eloquent example of topic analysis focuses on sustainable energy performance in green building design [80]. It examines the key aspects of sustainability, the role of renewable energy in green buildings and the challenges associated with sustainable energy performance. This paper emphasizes the importance of integrating sustainable energy solutions in green buildings and discusses various technological and design approaches to enhance their energy efficiency. This study underlines the significance of green buildings in achieving sustainable development and addresses both the current achievements and the ongoing challenges in this field.

Related to the future of energy and in relation to the last notable events organized at the international level, it is worth commenting on the discussions and topics on the agenda of COP28 (World Summit for Climate Action) from 1 to 2 December 2023. So, the document "COP28: Key Takeaways for Investors from the Global Climate Summit", by MSCI Inc., outlines the critical outcomes of the COP28 summit, focusing on climate change mitigation, adaptation and financial implications [81]. It highlights the historic agreement to move away from fossil fuels, emphasizing the role of renewable energy, energy efficiency and reducing methane emissions. The formal document discusses the challenges and opportunities for investors in the light of the summit's decisions, including transition risks, asset repricing and the role of carbon markets. The document underscores the urgency for governments and businesses to act on these commitments for sustainable development.

As energy transition reflects a sum of seven subdomains, it is considered a very broad and vast topic, with numerous stakeholders involved. Thus, the lack of papers including all these aspects is obvious. As further directions, we also consider a more detailed analysis on each subdomain divided by time periods.

Another critical point refers to the relationship between socio-economic development and technological change, in the context of energy issues. To review and reflect more on this relationship, several key aspects can be considered (Table 4):

Table 4. Key issues defining the relationship between socio-economic development and technological change, in the context of energy challenges.

No.	Component/Item Issue	Comments
1	Historical Perspective	Historically, technological advancements in energy production and consumption have significantly influenced socio-economic development. The Industrial Revolution is a prime example, where the advent of steam power and, later, electricity transformed economies and societies. These changes brought about improved productivity, urbanization and a shift from agrarian to industrial societies.
2	Energy Accessibility and Economic Growth	Access to affordable and reliable energy is a fundamental driver of economic growth and development. Technologies that provide efficient and cost-effective energy solutions can significantly impact the socio-economic status of a region. This is particularly evident in developing countries, where access to energy can improve living standards, enhance education and healthcare services, and stimulate economic activities.

Table 4. *Cont.*

No.	Component/Item Issue	Comments
3	Sustainable Development and Renewable Energy	With the growing awareness of climate change and environmental sustainability, there is a shift towards renewable energy technologies like solar, wind and hydroelectric power. This shift is not just a technological change but also a socio-economic transformation. Renewable energy can reduce the dependency on fossil fuels, decrease pollution and create new job opportunities, contributing to sustainable socio-economic development.
4	Technological Innovation and Energy Efficiency	Technological advancements have led to more energy-efficient appliances, industrial processes and transportation systems. Improvements in energy efficiency can reduce costs, lower energy consumption and decrease environmental impacts, all of which are beneficial for socio-economic development.
5	Digitalization and Energy Systems	The integration of digital technologies in energy systems, such as smart grids and Internet of Things (IoT) devices, has revolutionized how we manage and consume energy. These technologies enable more efficient energy use and better resource management, and facilitate the integration of renewable energy sources, which can support sustainable socio-economic development.
6	Policy and Regulatory Frameworks	Governmental policies and regulatory frameworks heavily influence the relationship between socio-economic development, technological change and energy. Policies that support innovation, provide incentives for renewable energy and regulate emissions play a crucial role in shaping this relationship.
7	Global Inequalities and Energy Access	There are significant global inequalities in energy access and consumption. While developed nations have high-energy consumption and access to advanced technologies, many developing countries struggle with energy poverty. Addressing these inequalities is crucial for global socio-economic development.
8	Economic and Social Challenges	Transitioning to new energy technologies is not without its challenges. There can be economic implications such as job losses in traditional energy sectors and the cost of new technologies. Socially, there is a need for skill development and education to adapt to these changes.
9	Future Trends and Innovations	Looking ahead, emerging technologies like artificial intelligence, battery storage and hydrogen fuel cells may further revolutionize the energy landscape. The continuous evolution of technology will likely have profound implications for future socio-economic development.

6. Conclusions

This comprehensive analysis focuses on various aspects of the current energy landscape. It discusses topical and critical subjects such as renewable energy sources, energy efficiency, energy security, energy poverty and the challenges of energy transition.

This paper emphasizes the crucial role of energy in human progress and societal development. It discusses the dynamic evolution of energy systems, influenced by factors like resource availability, demand, technological progress and political interests. This review covers the global dominance of fossil fuels and highlights regional differences in the energy mix and security. It delves into the concept of energy transition, driven by factors like resource depletion, environmental concerns and technological innovations, stressing the need for an integrated strategy and coordinated action across levels. In fact, this article collectively emphasizes the importance of transitioning to renewable energy sources for a sustainable future, considering the challenges of energy poverty and security. They suggest the need for a multi-faceted approach, incorporating technological innovation, policy intervention and global cooperation, to effectively manage and transform the world's energy systems. Future research could focus on exploring viable strategies for this transition, considering the socio-economic and environmental impacts.

The review addresses renewable energy sources (solar, wind, hydro, geothermal, biomass and green hydrogen) and their benefits and challenges, and it emphasizes the role of technological advancements, particularly the impact of AI on solar energy systems and the production and use of green hydrogen. Also, it emphasizes the impact of renewable energy sources on reducing greenhouse gas emissions, achieving the goal of climate neutrality and achieving the objectives of sustainability, resilience and competitiveness. This study also delves into the economic, social and environmental aspects of tidal energy and discusses energy efficiency in depth, covering its influence on the economy, society, environment and development. The concept of energy security is explored from various perspectives, including geopolitical and institutional aspects. Additionally, this paper examines energy poverty and its causes, measurement indicators and solutions. Moreover, it discusses the necessity of energy transition, its challenges and the importance of a just transition for a carbon-neutral economy. The analysis discovered the need for a multidisciplinary approach to tackle energy poverty and calls for cooperation among various actors for effective solutions.

The focus areas for the current energy challenges include:

- Renewable energy sources, through the importance of solar, wind, hydro, geothermal, biomass and green hydrogen as key to the energy transition. The emphasis is on their potential to address energy security and mitigate climate change impacts.
- Energy efficiency and sustainability: Energy efficiency emerges as a critical issue. The integration of sustainable practices in energy consumption and production is deemed essential for a greener future.
- Social inclusion: the notion of social inclusion is pivotal in transitioning to sustainable energy systems.
- ESG (environmental, social and governance) practices: these practices are fundamental in driving the transition to a sustainable energy future.
- Policy and regulatory frameworks: The need for supportive policy frameworks and regulations that facilitate this energy transition is a common theme. Policies should encourage innovation, invest in renewable technologies and ensure equitable access to energy.
- Challenges and future directions: Through the review, challenges are identified such as economic constraints, technological limitations and social acceptance. At the same time, future directions are proposed like increased research, cross-sector collaborations and global coordination for an effective energy transition, taking into account the rising cost of capital discouraging the investment and underinvestment in related fields, the uneven geographic adoption of renewables, the implications for renewables developers who have the means and funding to drastically accelerate deployments, or the lack of policy clarity.

An important contribution of this study is the countries cluster scheme according to their interest in the transition to renewable energy. We identified four clusters that recorded the countries with the fewest studies in the field to those with the most studies such as China (90 papers) and the USA (87 papers). These clusters are related to actionable knowledge, which allows a better understanding of the energy field. Also, the empirical results highlighted another seven clusters based on the analysis of the main challenges related to energy aspects to which the authors proposed an innovative approach, giving different names according to the main features of each cluster which are detailed in this paper. The following paragraphs summarize the defining ideas of each cluster. The first cluster addresses the comprehensive shift in energy paradigms, underscoring the need for a systemic change that goes beyond mere technological upgrades. It reflects the multifaceted nature of the energy transition, requiring societal and economic adaptation alongside technological advancements. The second cluster delves into the nuanced balance of developing bioenergy sources while ensuring environmental sustainability. It highlights the complexity of integrating bioenergy with existing agricultural practices and the critical role of community involvement in such initiatives. The third cluster emphasizes the scale and scope of renewable energy implementation on a global level, recognizing the diverse challenges and opportunities across different geographical and socio-economic contexts. The fourth cluster focuses on the policy-driven aspects of energy transition, particularly how regulatory frameworks can incentivize or accelerate the move towards lower carbon emissions. This cluster underlines the interconnectedness of policy, technology and behavioral changes. The fifth cluster acknowledges both the strides made in renewable energy technologies and the persistent challenges that hinder seamless integration into existing energy systems. This cluster is a reminder of the ongoing journey in renewable energy advancement. The sixth cluster is about the strategic approach towards a low-carbon future. It encompasses not just technology, but also the economic and behavioral aspects, underscoring the comprehensive approach needed for a successful transition. The last cluster, the seventh, highlights the unique challenges and opportunities in rural energy development. It emphasizes the importance of tailoring sustainable energy solutions to the specific needs and contexts of rural areas, often overlooked in broader energy discussions.

As a major contribution to the field, this paper presents a detailed framework for transitioning to sustainable energy practices, considering all aspects reflected by energy transition. It outlines strategies such as transitioning from fossil fuels to renewables, investing in renewable infrastructure and developing supportive policies and regulations. Emphasis is placed on technological innovation and public awareness for renewable energy.

Taking into account all information generated in the entire article, based on the content in tables and summarizing all findings, a very useful table can be generated that includes the key points and the challenges for the energy future (Table 5).

Table 5. Key issues defining the points and the challenges for the energy future.

No.	Key Issue	Comments
1.	Integrated Approach to Energy Transition	The present review emphasizes the need for an integrated approach towards the energy transition, which includes renewable energy sources, energy efficiency and sustainability. The data and figures in this paper highlight the critical role of these elements in transforming the energy landscape.
2.	Technological Innovation and AI	The present research acknowledges the significant impact of technological advancements, particularly the role of artificial intelligence in enhancing solar energy systems and green hydrogen production. This study underscores the importance of continuous innovation for a successful energy transition.

Table 5. *Cont.*

No.	Key Issue	Comments
3.	Socio-Economic and Environmental Considerations	The conclusions draw attention to the socio-economic aspects and environmental sustainability within the energy sector. This paper suggests that future energy policies should balance economic growth with environmental protection and social equity.
4.	Role of Policy and Regulatory Frameworks	This particular study highlights the necessity of supportive policy frameworks and regulations to facilitate the energy transition. It points out that policies should encourage innovation and investment in renewable technologies and ensure equitable access to energy.
5.	Global Collaboration and Future Research Directions	This paper concludes with a call for increased global collaboration and coordination for an effective energy transition. It suggests that future research should delve into detailed analyses of each subdomain within the energy sector, split by time periods, to gain a more comprehensive understanding.

The review article also highlights the importance of energy storage solutions, decentralized energy systems, market incentives, international collaboration and socio-economic integration. Additionally, it covers sustainable bioenergy development, public–private partnerships and environmental impact assessments. Aligning renewable energy initiatives with sustainable development goals and adapting to local contexts are also key components of this holistic approach.

Author Contributions: Conceptualization, C.P. and S.A.A.; methodology, C.P. and S.A.A.; software, S.A.A.; validation, C.P., S.A.A., I.G.R., J.D.M. and A.G.B.; formal analysis, C.P., S.A.A., I.G.R. and J.D.M.; investigation, C.P., S.A.A., I.G.R., J.D.M. and A.G.B.; resources, C.P., S.A.A., I.G.R., J.D.M. and A.G.B.; data curation, C.P., S.A.A., I.G.R., J.D.M. and A.G.B.; writing—original draft preparation, C.P., S.A.A., I.G.R., J.D.M. and A.G.B.; writing—review and editing, C.P. and S.A.A.; visualization, C.P., S.A.A., I.G.R., J.D.M. and A.G.B.; supervision, C.P.; project administration, C.P.; funding acquisition, C.P., I.G.R., J.D.M. and A.G.B. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflicts of interest.

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