





Energy Futurology: The Renewable Energy Revolution and the Future of Global Energy Supply

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Abstract

The world is on the brink of a significant transformation in the energy sector. Rising concerns about climate change and the depletion of fossil fuel resources have accelerated the transition towards renewable energy sources. This study focuses on examining the global upward trend in adopting renewable technologies such as solar, wind, and hydropower. Findings indicate significant progress in the production and increased share of renewable energy in the global energy mix, attributed in part to domestic and international regulations and commitments to sustainable energy provision, as well as a growing trend in demand. Several critical factors influence this transition, including government support policies, investments, and technological innovations, which play a substantial role in creating economic opportunities, generating employment, and impacting the environment and local communities. However, despite these significant advances, challenges such as financial, technological, regulatory, and policy limitations persist, requiring targeted planning and special attention.

Keywords: *Renewable Energy, Clean Energy, Solar Energy, Wind Energy, Futurology.*

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1. Introduction

Humans rely on energy for daily needs such as cooking, heating, lighting, and transportation. Some of these needs, like heating and cooking, are classified as essential. Currently, one of the most critical goals of developing countries is energy provision, as there is a direct relationship between economic growth and energy supply [1, 2]. Competition among countries to access more energy has resulted in environmental pollution, which is one of the most significant global challenges caused by greenhouse gas emissions. Accordingly, developing countries such as China and India play a major role in greenhouse gas emissions. These countries primarily rely on fossil fuels (e.g., oil, gas, and coal) to meet their energy needs. Today, the use of fossil fuels for energy provision is the primary cause of greenhouse gas emissions, and the impacts of these emissions must be mitigated by utilizing alternative energy sources [1, 2].

In addition to greenhouse gases, climate change has emerged as another critical challenge of the 21st century, garnering global attention. Rising global temperatures, changes in rainfall patterns, and extreme weather events are all indicators of these changes. One of the main drivers of climate change is the uncontrolled release of greenhouse gases resulting from fossil fuel consumption, exacerbating existing concerns and necessitating the use of systems based on renewable energy sources. Renewable energies are an acceptable alternative to fossil fuels because they are clean, can be utilized in most parts of the world, and play a vital role in addressing climate change, environmental degradation, and energy security [3].

Currently, there is a wide range of renewable energy sources, such as hydropower, wind energy, solar energy, and biomass energy. However, despite the potential of these sources to meet energy demands, their utilization remains limited, with only a few countries, such as China, Germany, and the United States, making significant investments in renewable energy development. The rest of the world continues to exploit fossil fuels for energy provision. The primary reason for the limited popularity of renewable energy sources may lie in the complexity of renewable energy systems and the high costs of implementation. Unlike renewable energy systems, fossil fuels can be transported to a reactor to generate heat, which can then produce steam to rotate turbines and generate electricity. Nevertheless, the use of renewable energies is on the rise, while the reliance on fossil fuels is declining. Scientists are actively seeking ways to reduce costs and enhance energy efficiency in renewable

energy systems. These advancements have encouraged more countries to adopt renewable energy systems for power generation [4].

Studies show that the annual increase in global renewable energy capacity is reaching unprecedented levels. In 2023, this capacity grew by approximately 50%, reaching nearly 510 gigawatts, the fastest growth rate in the past two decades. Notably, 2023 marked the 22nd consecutive year of record-breaking increases in renewable energy capacity. Solar energy accounted for three-quarters of the total renewable energy capacity. Among nations, China's performance stands out; in 2023, the country installed as many solar panels and plants as the entire world did in 2022. The United States, Europe, and Brazil also set new records [5].

Thus, a technological revolution is underway in the field of renewable energy to meet future global energy demands, profoundly transforming energy usage and the structure of global energy systems. This transition stems from pressing environmental concerns, particularly climate change, and the need to reduce dependence on fossil fuels. As countries grapple with the impacts of energy crises and the dire consequences of inaction, the adoption of renewable technologies such as solar, wind, hydro, biomass, and geothermal energy has accelerated, marking a pivotal moment in the pursuit of sustainable energy solutions [6].

Today, significant advancements have positioned renewable energies as a key component of the global energy mix, with projections suggesting they could account for nearly 50% of electricity generation by 2030 [7, 8]. However, this transition is not without challenges, including issues such as energy storage, grid integration, and financing. Studies indicate that renewable energy faces significant obstacles, such as the intermittent nature of renewable resources, technological limitations, and the need for supportive regulatory frameworks to facilitate integration into existing energy infrastructures. These challenges complicate accurate projections of future energy needs and production [9, 10], underscoring the necessity of employing scientific methods like futurology in the energy sector to identify future needs in light of current problems and trends.

Futurology plays a vital and decisive role in the field of renewable and clean energy. This scientific approach helps us analyze current trends, make more accurate future predictions, and consequently make better decisions regarding investments, policymaking, and planning in this field. Designing a sustainable energy plan requires

identifying and managing uncertainties, as not all uncertainties can be eliminated. Ignoring current and future conditions and uncertainties in this process will hinder an organization's ability to take corrective actions and achieve a stable position [11].

Given the crucial role and importance of renewable energy in future global energy provision, this study aims to gain a comprehensive understanding of its current status and future trends, addressing critical questions such as: What are the benefits and challenges of utilizing renewable energy? What are its impacts on the economy, environment, and society? What policies and strategies can effectively promote and develop these energies? The primary objective of this research is to provide a comprehensive overview of renewable energy, its benefits, challenges, and opportunities, and to propose recommendations for accelerating the transition to a sustainable energy system. The study employs a documentary and library-based method for data collection and adopts an analytical-descriptive approach.

2. Conceptual Framework of the Research

2.1. Renewable Energy and Its Sources

Energy exists in various forms, including heat, light, mechanical, electrical, chemical, and nuclear energy. We use energy for diverse activities, ranging from cooking our favorite meals to sending astronauts into space. The food we consume contains chemical energy, which our bodies store and release during activities such as exercise or work. The energy sources we use daily come in various forms and are stored in different ways. These sources are divided into two categories: renewable (energy sources that regenerate over a short period) and non-renewable (energy sources that are depleted and cannot regenerate quickly). Renewable energy sources can be replenished within a short time frame, making them easily replaceable after use. These energy types have been a global focus for over three decades, with both developed and developing countries including the expansion of renewable energy in their national energy portfolios as part of their development plans. Additionally, environmental concerns, coupled with the rising and irreversible costs of oil, have led to increased growth and the establishment of regulations encouraging the utilization and commercialization of renewable resources [12].

Renewable energies are primarily derived from natural resources that can be replenished faster than they are

consumed. Five commonly used renewable energy sources include:

A. Solar Energy

Solar energy is derived from sunlight and can be converted into electricity through two primary technologies: photovoltaic (PV) and concentrated solar power (CSP). The more common method, solar photovoltaic, uses solar panels to convert sunlight into electrical energy, which can then be stored in batteries for various applications. Over the past decade, the cost of solar energy has dropped by approximately 90%, making it a more accessible option for energy generation. Innovations in photovoltaic technology have led to the development of lighter and more flexible solar panels that maintain efficiency even in low-light conditions [8].

B. Wind Energy

Wind energy is generated by harnessing the kinetic energy of wind through turbines. This clean and sustainable energy source has been utilized for centuries and holds significant potential, particularly with advancements in offshore wind technology. The International Energy Agency (IEA) predicts that wind power generation will more than double by 2028. For instance, China's renewable energy market is expected to grow by 66% in 2023 alone. Programs such as the U.S. initiative to deploy 30 gigawatts of floating offshore wind energy by 2030 aim to boost energy supply and reduce reliance on fossil fuels [8].

C. Hydropower

Hydropower utilizes the movement of water, such as river flows and tidal forces, to generate electricity. This natural resource remains the largest provider of clean energy globally and is expected to maintain its leading position through 2030. Innovations in small-scale hydropower technologies have enabled renewable energy generation in rural and remote areas while minimizing environmental impacts and offering sustainable energy solutions [8].

D. Biomass Energy

Biomass energy is produced from organic materials such as plants and algae. While debates on its sustainability exist, modern bioenergy methods result in nearly zero emissions, making it a crucial component of the renewable energy landscape. Biofuels derived from biomass are essential for carbon reduction in the transportation sector, particularly in aviation and road transport, as they can be integrated into existing infrastructure with minor modifications [6].

E. Geothermal Energy

Advanced Geothermal Systems (EGS) represent an exciting development in geothermal energy, enabling the

extraction of heat from beneath the Earth's surface in areas previously deemed unsuitable for geothermal production. This technology has the potential to provide large quantities of clean, low-cost energy worldwide [8].

As the global energy landscape evolves, integrating these diverse renewable energy sources will be crucial to addressing climate change and ensuring a sustainable energy future.

2.2. Goals of Renewable Energy

Some studies indicate that most major countries worldwide, including the largest greenhouse gas emitters, lack comprehensive and specific economic goals for transitioning to renewable energy across all sectors. Only five G20 members—the European Union (EU-27), France, Germany, Italy, and the United Kingdom—set 2020 targets for achieving specific shares of renewable energy in final energy consumption. However, some countries were clearly not on track to meet their goals by the end of the year.

Overall, 165 countries implemented targets for achieving specific levels of renewable energy by 2020. Most of these targets, however, were limited to the electricity sector. Additionally, these predefined targets were not always met by 2021.

Approximately 80 targets for 2020 were reportedly achieved, while most (134) remained unmet based on the latest available data. Even when countries fulfilled their commitments, they did not always establish new, ambitious goals for the future. Only half of the countries with 2020 targets set more ambitious goals by the end of the year. More concerningly, most countries that failed to establish new targets had not even met their initial goals. In summary, countries are missing the mark and failing to plan for enhanced ambitions [13].

The following chart illustrates the shares and targets of renewable energy among G20 countries between 2009 and 2019. In this chart, TTEC refers to Total Final Energy Consumption. Data for the Russian Federation and Saudi Arabia correspond to 2018 and 2017, respectively.

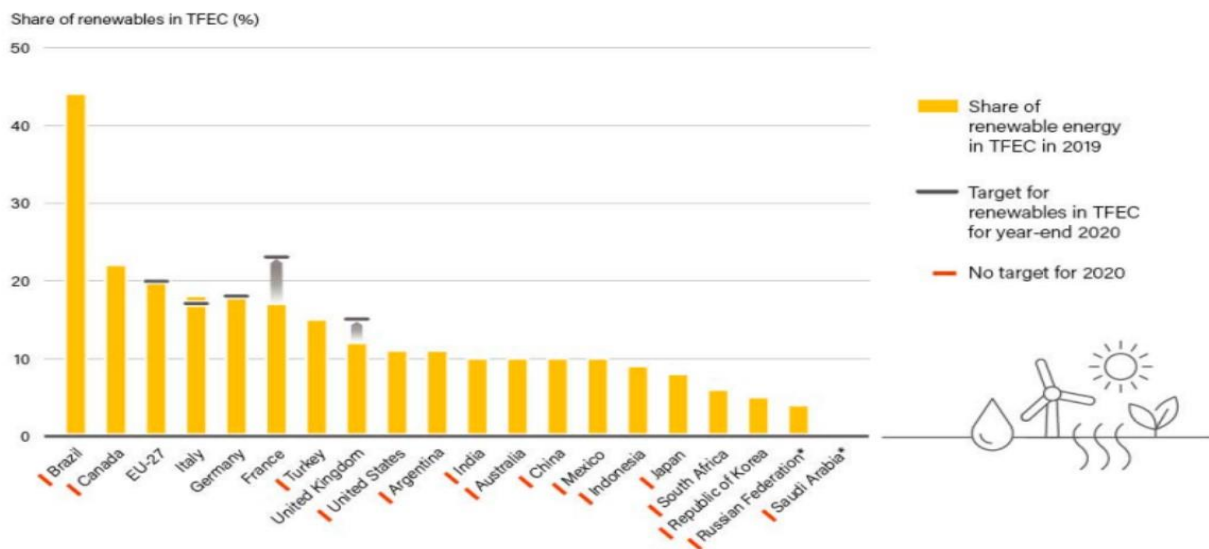


Figure 1. Share and Targets of Renewable Energy in G20 Countries, 2009–2019

2.3. Necessity of Renewable Energy Utilization

The alarm about the Earth's resource limitations was first sounded in 1970 by Pecchi, an Italian businessman, and Kingura A., director of the OECD and a member of the Club of Rome. In their report, "The Limits to Growth," they highlighted the energy constraints that would shake the world due to its dependence on fossil fuels, particularly oil, which has historically served as an indispensable resource for economic growth. The fluctuations in oil prices have

elicited significant international sensitivity and reactions (Foroughi, 1996).

Beyond the limitations of global energy resources, existing studies suggest that the necessity of utilizing renewable energy stems from multiple economic, environmental, and sustainability factors. Renewable energy sources are critical for mitigating climate change, reducing greenhouse gas emissions, and ensuring a sustainable energy future. These necessities can be summarized as follows:

A. Economic and Environmental Necessity:

Traditional energy sources, such as fossil fuels, have significant economic disadvantages, including price volatility and limited accessibility. In contrast, renewable energy sources offer more stable and potentially lower long-term costs, emphasizing their economic feasibility [14]. Moreover, the use of renewable energy reduces carbon emissions, greenhouse gases, and other pollutants, which are the primary drivers of climate change and environmental degradation [15]. The transition to renewable energy is essential for achieving global climate goals, such as the 1.5°C target set by international agreements. Renewable energy helps reduce carbon footprints and mitigate the adverse effects of climate change [16].

The rapid growth of investments in clean technologies over the past decade, coupled with projections for continued growth, highlights the increasing importance of renewable energy. This transition not only promises a more sustainable future and addresses climate change but also provides unique opportunities for economic growth and job creation at the global level [17].

B. Development and Sustainable Fuels:

Fossil fuels are finite and cannot be extracted indefinitely, posing significant challenges to long-term growth and sustainable development. Conversely, renewable energy sources such as solar, wind, and biomass are abundant and sustainable, making them vital for long-term energy security. Sustainable development refers to meeting current needs without compromising the ability of future generations to meet their own needs. Renewable energy plays a critical role in creating sustainable fuel sources. Achieving sustainable energy development requires the efficient use of economic, human, technological, and natural resources, both renewable and non-renewable. The gradual degradation of the natural environment and the inevitable depletion of fossil fuel reserves necessitate the search for alternatives [18].

C. Technological and Social Benefits:

Experts widely agree that the development of renewable energy technologies creates new job opportunities, contributing to economic growth. Additionally, these technologies foster innovation and the development of other technologies. Integrating renewable energy technologies, such as hybrid renewable energy systems (HRES), enhances energy efficiency and reliability. These systems can be optimized for various applications, maximizing economic and environmental benefits. The use of renewable energy improves air quality and human living conditions, which is particularly crucial in major cities facing air pollution

challenges, thereby fostering better social living conditions for urban populations [14].

D. Specific Applications:

Renewable energy can be particularly beneficial for specific economic sectors, such as agriculture. It provides sustainable power for irrigation, processing, and other farm operations, benefiting farmers by increasing agricultural productivity and reducing production costs. This reduces reliance on fossil fuels and promotes sustainable farming practices. Many industries can also utilize renewable energy to meet part of their energy needs. For instance, heavy industries can use geothermal energy for heat production. The transportation sector is another key area of application. Electric vehicles and other renewable energy-powered transportation options can significantly reduce air pollution in major cities [19].

E. Energy Storage:

As the share of renewable energy grows, efficient energy storage solutions become critical for managing supply and demand, ensuring a stable and reliable energy supply. Energy storage systems can manage the intermittency of renewable energy production, enhancing grid stability. By storing energy generated during off-peak hours, it can be utilized during peak demand periods, reducing electricity production costs and improving energy efficiency. Numerous studies have evaluated the energy and economic costs of producing, storing, and transporting various fuels derived from renewable electricity sources, confirming their feasibility [20].

3. Energy Consumption and the Share of Renewable Energy

In recent years, renewable energy sources, such as solar and wind energy, have been growing at an unprecedented rate, significantly increasing their share in global energy consumption. This trend reflects a global effort to reduce dependence on fossil fuels and transition toward more sustainable energy sources.

Despite progress, barriers that have hindered the growth of renewable energy in past years persisted in 2023. These obstacles include the absence of cross-sectoral and integrated strategies to guide the transition, insufficient political and executive support, continued subsidies for fossil fuels, the need for infrastructure development and increased financial capacity in certain markets, and the necessity for further innovation in specific sectors. Together, these factors have only led to a slow increase in the share of renewable energy in final energy demand. Simultaneously,

the world continues to burn fossil fuels at historically high rates.

Since 2009, the share of fossil fuels in final energy consumption has remained stable, while global energy demand has risen by approximately 20%. Renewable energy sources now account for just over 11% of global final energy

demand, representing a modest increase of about 9% over the past decade. Although renewable energy's share has grown annually by an average of 5% between 2009 and 2019, its growth rate has surpassed that of fossil fuels, which increased by 1.7% during the same period [13].

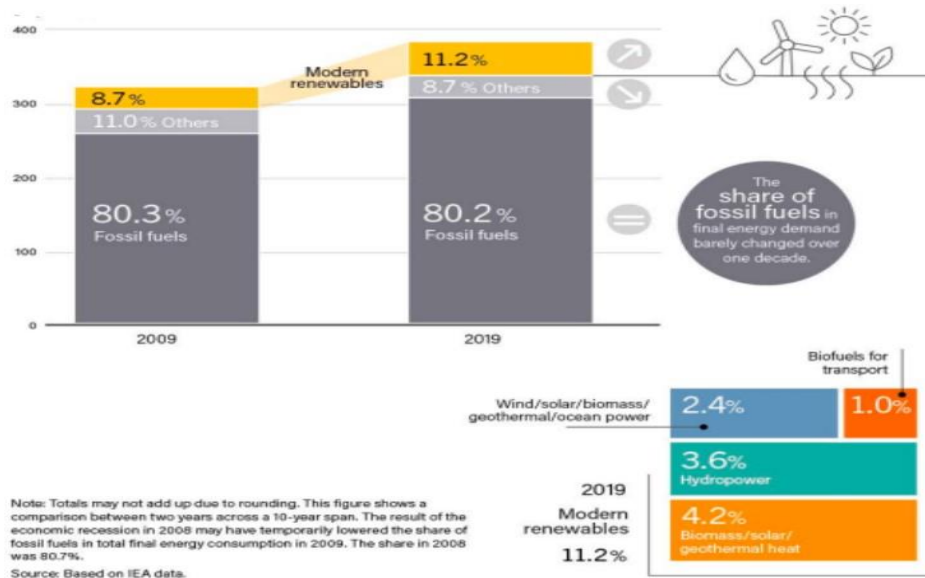


Figure 2. Approximate Share of Renewable Energy in Total Final Energy Consumption, 2009–2019

Recent studies show that in 2023, renewable energy accounted for 14.6% of global energy consumption, a growth driven by unprecedented expansion in solar and wind energy. In June 2024, the Energy Institute published a statistical report on the global energy landscape in 2023, providing a comprehensive overview of the supply and demand for major energy sources worldwide. This report indicates that renewable energy sources reached a new record in 2023, increasing their share of total primary energy consumption by 0.4% compared to the previous year. Solar and wind energy, in particular, continue to grow rapidly, playing a critical role in global energy supply and carbon reduction.

China leads this global movement, accounting for a significant portion of renewable energy development, while the United States, Europe, and Brazil have played key roles in advancing biofuels. However, overall energy demand continues to outpace the growth of renewable energy, underscoring the ongoing reliance on fossil fuels. This disparity highlights the urgent need for global efforts to increase the share of renewables in the global energy mix to meet carbon reduction targets and build a more sustainable future [21].

Recent reports also reveal that electricity generation from renewable sources, such as solar and wind energy, reached 4,748 terawatt-hours, representing a 13% increase over the previous year. This growth means that 74% of the net additional electricity generated globally came from these sources. Notably, solar energy added 346 gigawatts of new capacity, surpassing the 2022 record by 67%. China contributed a quarter of this growth, while Europe added 56 gigawatts of solar capacity, significantly boosting global capacity.

Wind energy also set a new record, with over 115 gigawatts of new capacity installed. Additionally, the share of biofuels in the global energy mix increased, with production rising by more than 17% compared to 2022. The United States and Brazil led this growth. In 2024, the production of bioethanol and biodiesel nearly equalized, with the United States, Brazil, and Europe consuming the majority of these renewable fuels [21].

China remains at the forefront, responsible for nearly 66% of the capacity increase. The total installed wind capacity in China now equals the combined wind capacity of North America and Europe. Offshore wind energy, one of the fastest-growing sectors in renewable energy, accounted

for 12% of Europe's capacity, while China added 37 gigawatts, rapidly advancing in this area.

4. Main Approaches to Renewable Energy Production and Distribution

Two distinct approaches to the production and distribution of energy are categorized as centralized and decentralized solutions, each with its own advantages and challenges. Renewable energy production generally involves multiple stages. Initially, electricity is generated through sources like wind or solar radiation (or other renewable sources). In the second stage, this electricity is either stored in batteries or converted into hydrogen via electrolysis.

The primary difference between batteries and hydrogen lies in their production and usage processes. Batteries are manufactured in factories before the second stage, whereas hydrogen undergoes an additional transfer process after production to fueling stations for hydrogen tank filling. Additionally, hydrogen fuel requires a fuel cell to convert it back into electricity, which results in lower efficiency and higher costs compared to batteries. While battery charging is faster, less expensive, and more efficient than hydrogen transfer, batteries have limited lifespans and higher costs, and battery waste is currently difficult to recycle. These two systems, despite competing with each other, share a larger battle against the globally established fossil fuel infrastructure, which has dominated for over 150 years and is now threatening global sustainability [22].



Figure 3. Simplified Stages of Renewable Energy Production

A. Centralized Renewable Energy Solutions

Centralized systems involve large-scale energy production facilities such as wind farms, solar power plants, and hydroelectric dams that generate electricity, which is then distributed through extensive transmission networks. These systems benefit from economies of scale and can efficiently meet the energy demands of large populations. Recent advancements in information and communication technologies, digitalization, Industry 4.0 paradigms, and the Internet of Things (IoT) have made this monumental transformation feasible. However, centralized systems often face significant transmission losses, require substantial infrastructure investment, and sometimes lack adequate connectivity to renewable energy networks [23].

Key Points:

- **Economies of Scale:** Centralized systems can produce large quantities of energy efficiently due to their size and capacity. This type of production is particularly effective in areas with high energy

demands, such as urban regions. Large infrastructure, like wind farms and solar power plants, aids in managing variable demand but requires extensive upfront investment [23].

- **Infrastructure Investment:** Significant investment in transmission infrastructure is necessary to distribute energy over long distances. Creating centralized energy distribution and transmission networks involves large-scale investments in transmission lines, transformers, and network management. Advanced technologies like battery storage and smart grids help mitigate this challenge by improving long-term cost efficiency [24].
- **Transmission Losses:** Energy loss during transmission is a major drawback that reduces overall efficiency. Energy losses in long-distance networks are particularly significant when the distance between production and consumption is

vast. Technologies such as ultra-high voltage (UHV) transmission lines and improved network management are being deployed to reduce these losses [23].

B. Decentralized Renewable Energy Solutions

On the other hand, decentralized systems consist of smaller, localized energy production units, such as rooftop solar panels, small wind turbines, and biomass generators. These systems are closer to the point of use, minimizing transmission losses and enhancing energy security. They also enable greater consumer participation, allowing individuals to produce and consume their own energy, effectively becoming "prosumers" [25, 26].

Key Points:

- **Reduced Transmission Losses:** In decentralized solutions, energy is generated closer to the point of use, minimizing losses. Installing rooftop solar panels or using local wind turbines reduces energy waste and decreases reliance on extensive transmission networks [25, 26].
- **Energy Security:** Decentralized systems enhance energy security by diversifying energy sources and reducing dependence on large-scale infrastructure. These systems allow users to produce and store energy locally, improving resilience against grid outages [12].
- **Investors:** Small businesses and individuals can generate energy and contribute to the grid, potentially earning revenue. This possibility accelerates return on investment while encouraging public participation in sustainable energy provision. Current models allow for decentralized energy production where actors like social groups, energy cooperatives, charities, and municipalities participate as energy owners and producers. End users can also engage in designing, developing, and delivering energy services [27].

4.1. Comparative Insights

- Flexibility and Scalability:

Decentralized systems offer greater flexibility for local demands and are easier to scale down compared to centralized systems. Conversely, centralized systems have limited scalability and rely heavily on large-scale initial investments [23, 27].

- Technological Integration:

Advancements in IoT, blockchain, and smart grids make decentralized systems more viable and efficient. However, centralized systems also leverage these technologies to optimize distribution [25].

- Investment and Maintenance Costs:

While centralized systems require substantial initial investment and significant costs, decentralized systems may incur higher maintenance expenses due to the larger number of smaller units, necessitating ongoing operational expenditures [25].

5. Legal and International Commitments Related to Renewable Energy

In light of the climate change crisis and the depletion of fossil fuel resources, renewable energy has long been recognized as one of the key solutions for achieving sustainable development. Consequently, the global community and international organizations have undertaken extensive efforts to encourage and mandate the use of clean energy resources by countries. This has included establishing numerous legal and regulatory frameworks at both international and domestic levels to facilitate actions in this domain. Below, we highlight some of the most significant legal and international commitments related to renewable energy.

A. International Commitments

- United Nations Framework Convention on Climate Change (UNFCCC):

Adopted in 1992, the primary goal of this convention is to stabilize greenhouse gas concentrations in the atmosphere at levels that prevent dangerous anthropogenic interference with the climate system. While the UNFCCC does not directly mandate the use of renewable energy, it encourages countries to adopt such sources as part of their efforts to reduce greenhouse gas emissions [28].

- Kyoto Protocol:

The Kyoto Protocol, as a supplement to the UNFCCC, established legally binding commitments for developed countries to reduce greenhouse gas emissions. Although the protocol does not explicitly address renewable energy, it promotes emission reductions through mechanisms such as joint projects involving renewable energy. The protocol was adopted on December 11, 1997, at the third Conference of the Parties (COP) to the UNFCCC in Kyoto, Japan, and entered into force on February 16, 2005, after Russia's

ratification. It required developed countries to reduce their greenhouse gas emissions by 5% below 1990 levels between 2008 and 2012, covering almost all major economic sectors. By November 2007, 174 countries had ratified the protocol, which remains one of the most comprehensive agreements on environmental protection and sustainable development [29].

- Paris Agreement:

Adopted in 2015, the Paris Agreement replaced the Kyoto Protocol and established more ambitious goals for reducing greenhouse gas emissions. Countries committed to limiting the increase in global temperatures to well below 2°C above pre-industrial levels, with efforts to limit the increase to 1.5°C. Achieving these goals requires countries to submit national plans for reducing emissions, which typically include targets for increasing the share of renewable energy. The agreement, legally binding and signed by 196 parties at COP21 in Paris, came into force on November 4, 2016. It stipulates that greenhouse gas emissions must peak by 2025 and decrease by 43% by 2030 [30].

- Glasgow Climate Pact (COP26):

In 2021, the Glasgow Climate Pact was adopted, aiming to make the 2020s a decade of climate action and support. The pact emphasizes the need for countries to enhance their commitments to curbing greenhouse gas emissions and building resilience against climate change. Key elements include reaffirming developed nations' pledge to provide \$100 billion annually to developing countries, agreeing to phase down coal power and eliminate inefficient fossil fuel subsidies, and addressing gaps between current emission reduction plans and those required to meet the Paris Agreement goals [28, 30].

- United Nations Sustainable Development Goals (SDGs):

Adopted in 2015, the SDGs include 17 goals for achieving sustainable development by 2030. Goal 7 specifically emphasizes affordable and clean energy, highlighting the importance of increasing the share of renewable energy in the global energy mix.

- Nationally Determined Contributions (NDCs):

Under the Paris Agreement, countries are required to submit climate action plans, known as NDCs, outlining their commitments to reducing emissions. Each subsequent NDC is expected to demonstrate greater ambition than its predecessor. The Glasgow Climate Pact underscored the importance of updating NDCs by the end of 2022 to align with the 1.5°C goal, reinforcing the need for ambitious national energy strategies and concrete climate actions [6].

- Financial Commitments and Support:

The implementation of the Paris Agreement and Glasgow Climate Pact also hinges on financial commitments, particularly the annual provision of \$100 billion by developed countries to developing nations. This financial assistance is critical for enabling low-carbon transitions and promoting the development of renewable energy technologies in emerging regions. Without comprehensive and coordinated efforts, including phasing out fossil fuel subsidies, achieving significant impacts through renewable energy policies will remain challenging [28, 31].

B. Domestic Legal Commitments

- National Laws and Regulations:

Many countries have enacted laws and regulations to promote the use of renewable energy. These may include incentives such as tax rebates, feed-in tariffs, and energy efficiency standards for buildings.

- National Energy Plans:

Countries often develop national energy plans that set long-term targets for increasing the share of renewable energy. These plans typically include specific measures, such as investments in research and development, the creation of carbon markets, and support for renewable energy projects.

6. Challenges of Renewable Energy

Numerous studies indicate that the current and future challenges of renewable energy broadly include financial limitations, technological constraints, regulatory and policy barriers, intermittent energy supply, integration with existing grids, and environmental impacts.

In a recent comprehensive study, Kristia and Rabbi (2023) investigated trends, challenges, and future prospects for integrating renewable energy within the context of business, management, and economic domains. By analyzing 294 research articles, the authors highlighted that despite extensive efforts over the past half-century to develop renewable energy technologies, challenges such as financial constraints, lack of adequate infrastructure, and production volatility have hindered this transition. Future research should therefore focus on financial incentive models, supportive government policies, and the development of innovative technologies, such as efficient waste-to-energy conversion and enhanced solar panel efficiency. The study also emphasizes the importance of

lifecycle management of technologies and the development of innovative business models to facilitate industrial collaborations [32].

7. Conclusion

This article examines the significant and growing transformation toward renewable energy, which is reshaping global energy systems. This transition is driven by urgent environmental concerns, particularly climate change, and the need to reduce dependence on fossil fuels. In light of the impacts of energy crises and the severe consequences of inaction, the adoption of renewable technologies such as solar, wind, hydro, biomass, and geothermal energy has accelerated, marking a critical moment in the search for sustainable energy solutions.

Significant advancements have positioned renewable energy as a crucial component of the global energy mix, with predictions suggesting that by 2030, renewables could account for nearly 50% of global electricity production. The importance of renewable energy is underscored by increasing investments in clean technologies, which reached unprecedented levels during the 2010s and are expected to grow further in the coming decades. This transition not only promises to address climate change but also presents opportunities for economic growth and job creation, as the sector currently employs millions globally.

However, disagreements over policies and the implications of regulatory changes, particularly investor-state disputes, highlight the complex interplay between government actions and market forces in the renewable energy landscape. Challenges persist, including energy storage, grid integration, and financing. The renewable energy sector faces significant obstacles such as the intermittent nature of renewable sources, technological limitations, and the need for supportive regulatory frameworks to facilitate integration into existing energy infrastructures.

Ultimately, the future of renewable energy research is defined by a commitment to innovation, equity, and sustainability, as countries strive to meet their energy demands while minimizing environmental impacts and strengthening economic resilience. Continued development of new technologies and collective international agreements will play a critical role in navigating this challenging yet promising energy transition, demanding significant focus and attention.

Authors' Contributions

Authors equally contributed to this article.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

All procedures performed in this study were under the ethical standards.

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