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Harmony of Technology and Nature: A Systematic Analysis of Renewable Energy Development

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ABSTRACT

The transition to renewable energy is an important step to address the energy crisis and global climate change. Renewable energy technologies, such as solar panels, wind turbines, and energy storage systems, have developed rapidly with increasing efficiency, such as the 45% efficiency of solar panels. However, key implementation challenges include dependence on weather conditions that affect the stability of energy supply as well as cost and infrastructure constraints. Fiscal incentives and carbon pricing policies have proven effective in driving renewable energy adoption, as seen in Germany and China. On the other hand, artificial intelligence (AI) and blockchain technologies are playing a role in improving energy distribution efficiency and power consumption optimization, while the renewable energy sector has created millions of jobs with a projected increase to 35 million by 2030. However, investment inequality between developed and developing countries remains a major challenge. Therefore, accelerating the green energy transition requires policies that simplify licensing procedures, support technological innovation, and encourage collaboration between the public and private sectors. This research highlights the importance of a holistic approach covering technology, policy and investment aspects to realize a more efficient, inclusive and environmentally sustainable energy system.

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1. INTRODUCTION

In recent decades, the world has faced a worsening energy and environmental crisis, triggering the search for more sustainable solutions in the global energy system [1]. Human dependence on fossil fuels has led to a surge in carbon emissions that contribute to climate change, environmental pollution and overexploitation of natural resources [2]. A study conducted by Adams shows that more than 75% of global

carbon emissions come from the energy sector that still relies on fossil fuels as the world's main energy source [3]. This has led to a significant increase in global temperature, resulting in rising sea levels, extreme weather, and loss of biodiversity [4]. To address these issues, renewable energy technology is emerging as a promising solution by utilizing renewable natural resources, such as solar energy, wind, water, and biomass [5]. The development of renewable energy technologies is not only an alternative to fossil fuels, but also a key element in building a more efficient and sustainable green economy. However, despite its great potential, the adoption of renewable energy still faces challenges in terms of efficiency, energy storage, and policies that have not fully supported the green energy transition [6].

Renewable energy technology has developed rapidly in the past decade, especially in improving the efficiency and reliability of natural resource-based energy systems [7]. Cang revealed that the energy conversion efficiency of solar panels has increased up to 45% compared to the previous decade, thus making them more competitive compared to fossil fuels in terms of production costs [8]. In addition, the development of energy storage technologies, such as lithium-ion batteries and hydrogen-based storage systems, has enabled renewable energy to be used more widely with a higher degree of stability [9]. Research by Onwusinkwue also highlights the role of the Internet of Things (IoT) and artificial intelligence (AI) in optimizing renewable energy systems, which enables the prediction of energy consumption patterns and improves the efficiency of electricity distribution [10]. With the integration of digitalization in the green energy sector, many countries have started to develop smart grid-based energy systems, which enable the interconnection of various renewable energy sources with the main power grid, increasing the flexibility and reliability of the energy system [11]. However, despite the various innovations that have been developed, there are still challenges in the aspects of intermittency of energy supply, dependence on weather factors, and limited green energy infrastructure in various developing countries [12].

Although a wide range of research on renewable energy has been conducted, there are still research gaps that need to be filled to understand how green energy can be implemented more widely and sustainably. Most research still focuses on a single type of renewable energy technology, without exploring how the combination of different energy sources can improve the reliability and stability of energy supply. For example, Virah-Sawmy's research shows that solar and wind-based energy systems have limitations in energy supply stability because they depend on weather conditions, while integration with hydro energy or battery-based storage can reduce dependence on these external factors [13]. In addition, there is a lack of studies on the social and economic impacts of the green energy transition, especially in the context of new job creation, industrial transformation, and public acceptance of renewable energy [14]. Although the green energy transition promises many benefits for environmental sustainability, it is necessary to think about how energy policies can be formulated to ensure that this transition also provides economic benefits for the wider community and does not only benefit large industries [15]. Another challenge that also needs attention is how renewable energy technologies can be integrated with existing energy systems without causing significant disruption to the national energy infrastructure [16].

To fill the existing research gap, this study will use the Systematic Literature Review (SLR) with PRISMA method to compile a systematic analysis of global trends in renewable energy development, challenges and opportunities [17]. With this method, this study can identify key trends in green energy innovation, evaluate how the combination of different energy sources can improve system efficiency, and assess the economic and social impacts of implementing these technologies [18][19]. In addition, this study will also review how energy policies in different countries can support the acceleration of green energy transition, as well as how the role of AI and blockchain-based technologies can improve efficiency in green energy management [20]. With this approach, this research is expected to provide a more holistic insight into how renewable energy can be widely and sustainably adopted, and provide recommendations to policymakers, industry, and the global community in building a greener and more efficient energy system.

By conducting a systematic analysis based on current scientific literature, this study is expected to fill the gap in renewable energy studies and make a broader contribution to the development of knowledge and practice in this sector. As explained by Saeed, the transition to a green energy system depends not only on technological innovation, but also on policy and regulatory aspects, as well as the readiness of energy infrastructure in various countries [21]. Therefore, this research is expected to not only make an academic contribution, but also have a practical impact in supporting global energy transformation. With this research, it is expected that more parties, both from the government sector, industry, and society, will better understand how renewable energy technology can be implemented optimally, so that harmony between technology and nature can be realized in the future energy system. The findings of this research are also expected to help identify technological innovations that have the greatest impact in reducing carbon footprints, as well as provide direction for green energy development in the coming years. Thus, renewable energy will not only be a solution to the current energy crisis, but also part of the vision of a greener, more sustainable future that balances the needs of people and the sustainability of our planet.

2. RESEARCH METHOD

This study adopts the Systematic Literature Review (SLR) method with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) approach to evaluate the development of renewable energy technologies, challenges in their implementation, and their economic and social impacts. The PRISMA method was chosen because it provides a systematic and transparent procedure for reviewing and synthesizing research results, thereby increasing the validity and reliability of the analysis [17]. According to Sohrabi, PRISMA plays an important role in improving accuracy in the literature screening process, ensuring that only high-quality studies are considered in systematic reviews [22]. In its implementation, this study followed the four main stages of PRISMA, namely identification, screening, eligibility, and inclusion to ensure a comprehensive evaluation of innovations in the field of renewable energy. In the identification stage, literature was collected from reputable academic sources such as Scopus, Web of Science, IEEE Xplore, ScienceDirect, and Google Scholar to obtain credible and relevant references. Next, the screening stage was conducted by applying strict inclusion and exclusion criteria, as suggested by Page, to ensure that only studies that met high academic standards were analyzed [18]. The eligibility stage focuses on validating the credibility of the study before finally entering the inclusion stage, where the data is analyzed in depth to provide insights into the development of renewable energy technologies, efficiency improvements, and energy policies that have been implemented in various countries.

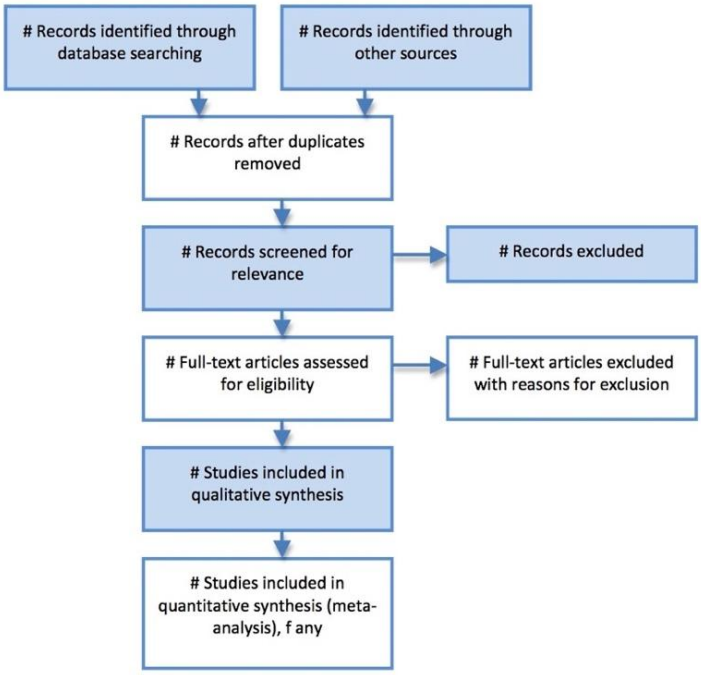


Figure 1. Flowchart of Systematic Review and Meta-Analysis (PRISMA)

2.1. Identification

The initial stage of this research focused on identifying relevant studies on renewable energy development, efficiency improvement, and energy policy. Literature was obtained from trusted scientific databases such as Scopus, IEEE Xplore, ScienceDirect, SpringerLink, and Google Scholar using keywords covering various aspects, such as renewable energy technologies, green energy transition, energy storage systems, artificial intelligence in renewable energy, blockchain for energy management, and economic and social impacts of green energy. To ensure data accuracy and relevance, only articles published between 2015 and 2025 were considered. From the initial search results with these keyword combinations, approximately 1,500 articles from various sources were obtained. The collected literature was then further analyzed to gain in-depth insights into technological innovations, implementation challenges, and future prospects of renewable energy in supporting the transition to a more sustainable energy system.

2.2. Filtering

After the initial identification stage, the collected articles were further screened based on title, abstract, and keywords to ensure suitability to the research objectives. Studies that were irrelevant or lacked empirical data were eliminated through the application of strict inclusion and exclusion criteria. Inclusion criteria included studies that addressed the development of renewable energy technologies, such as solar, wind, hydro, biomass, and hydrogen; articles published in peer-reviewed journals indexed by Scopus, IEEE, or Springer; and research that examined the challenges, benefits, and policy implications related to renewable energy. Meanwhile, the exclusion criteria included studies that only discussed fossil fuel-based energy without any connection to renewable energy, opinion or editorial articles without empirical data support, and research with unclear methodology or low academic quality. After initial screening, 750 articles met the provisional criteria, and with the application of more stringent filters, 300 articles were selected for further evaluation to support in-depth analysis of renewable energy innovation and policy.

2.3. Feasibility

After the initial screening process, the remaining articles were further analyzed through full-text review to ensure their relevance, methodological rigor, and contribution to the research. Articles were eliminated if they lacked empirical data or real case studies on renewable energy implementation, used weak methodologies that did not provide a comprehensive understanding of the energy transition, or had redundant content with other studies. This process aims to ensure that only studies with a strong scientific foundation and valid methodology are used in further analysis. From a total of 300 articles that passed the previous stage, 140 articles were eliminated because they did not meet the strict methodological quality standards. This left 160 high-quality articles that will form the basis of the final analysis to develop a deeper understanding of the innovations, challenges and prospects for renewable energy implementation in the future.

2.4. Inclusion

Articles that passed the eligibility stage were then included in the final review, with a focus on extracting data covering the research objectives, methodology used, key findings related to renewable energy technologies, efficiency improvements, as well as energy policies. In addition, aspects of challenges and future trends in green energy adoption were also analyzed to understand the dynamics of the sector's development. Each selected article was coded and analyzed qualitatively to identify key themes and patterns that have emerged in previous research. This systematic approach allows for a more comprehensive evaluation of various aspects of renewable energy, including the latest technological developments, the resulting economic impacts, and the policy challenges faced in the implementation and transition to a sustainable energy system. With this method, the research can provide in-depth insights into the factors that support and hinder the development of green energy on a global scale.

2.5. Data Extraction and Synthesis

The data extracted from the shortlisted articles will be systematically analyzed to identify key trends in renewable energy development, including the increasing efficiency of solar panels, wind energy storage technologies, and the integration of increasingly sophisticated smart grids. The analysis also explores the economic and social impacts of the transition to green energy, including aspects of industrial growth, job creation, and long-term economic sustainability. It will also evaluate the role of advanced technologies such as artificial intelligence (AI) and blockchain in improving energy management, particularly in optimizing the distribution and efficiency of energy consumption. Key barriers to renewable energy implementation, such as limited energy storage capacity, dependence on weather conditions, and infrastructure challenges, are analyzed to understand the constraints faced by the industry. Through this approach, this research aims to provide in-depth insights into renewable energy implementation, identify best practices, and offer strategic recommendations in energy policy to support the transition to a sustainable energy system.

2.6. Quality Assessment

To ensure the reliability of the research, each article analyzed was evaluated based on strict methodological standards to guarantee the validity and credibility of the research results. This evaluation includes the suitability of the research method with the study objectives to ensure that the approach used can provide relevant answers to the problems studied. In addition, the presence of empirical analysis is an important aspect in assessing the strength of the findings presented, while transparency in reporting results is a key indicator in assessing the replicability and trustworthiness of the data used. Potential bias in data interpretation is also analyzed to identify possible distortions that could affect the conclusions of the study. Articles that did not meet these quality standards were eliminated to maintain accuracy in the final analysis.

With this rigorous approach, the research only uses high-quality studies based on valid data, so as to provide in-depth and reliable insights into the implementation and development of renewable energy.

2.7. Reporting of Results

This study followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to systematically document the article selection process, from identification, screening, eligibility, to inclusion, with reasons for exclusion recorded at each stage. This approach ensures transparency and replicability of the selection process, so that only studies that meet scientific standards are analyzed further. Following the selection stage, a thematic analysis was conducted to identify key trends in renewable energy development. Some of the key themes that emerged included technological breakthroughs in renewable energy efficiency, such as increased solar panel capacity and innovations in energy storage; challenges in large-scale adoption, including integration with existing energy infrastructure and power storage limitations; and economic and policy benefits that support the green energy transition, including government incentives, job creation, and positive impacts on sustainable economic growth. This analysis aims to provide an in-depth understanding of the dynamics of renewable energy change and the factors that influence its implementation. The results of the article selection are summarized in the following table:

Table 1. Results of Article Selection

Selection Stage	Number of Articles
Initial identification	1.500
After initial screening (title and abstract)	750
After applying the inclusion/exclusion criteria	300
After feasibility evaluation	160
Articles used in the final analysis	40

3. RESULTS AND DISCUSSION

3.1. Literature Results

In recent decades, the development of renewable energy technologies has progressed rapidly, especially in an effort to address the global energy crisis and improve energy efficiency in a sustainable manner. Gajdzik highlights that innovations in solar panel technology, including improved photovoltaic efficiency and reduced production costs, have opened up great opportunities for developing countries to adopt more environmentally friendly energy sources [1]. In addition, the increase in battery storage capacity has also overcome one of the main challenges in the utilization of renewable energy, which is intermittency or dependence on environmental conditions. This allows for a more stable integration of solar and wind energy into the grid. Meanwhile, Wang emphasized that despite increasing efforts to transition energy, fossil fuel consumption still dominates the global energy sector and remains a major contributor to greenhouse gas emissions [2]. This suggests that, despite the rapid development of renewable energy technologies, widespread adoption and a full transition to green energy still require more targeted strategies and supportive policies. In the context of energy policy, Adams argues that the integration of renewable energy with democratic policies can accelerate efforts to reduce carbon emissions, especially through community involvement in decision-making and implementation of sustainable energy projects [3]. Countries with more inclusive and community-based policy approaches tend to be more successful in effectively implementing renewable energy, due to stronger public support for clean energy projects.

However, while the development of renewable energy technologies continues to show promising progress, there are still several challenges that need to be overcome to ensure a sustainable energy transition. One of the main obstacles is regulatory and economic factors that complicate the large-scale implementation of renewable energy. Saleh identified that many countries still experience limitations in regulations that support green energy, including suboptimal fiscal incentives and policy uncertainties that hinder long-term investment in the renewable energy sector [6]. In addition, Ang highlighted challenges in infrastructure that are a major barrier to the integration of renewable energy sources with existing energy grids. For example, conventional power grids that are still dominated by fossil energy are often not designed to optimally support the integration of solar and wind energy, which can lead to imbalances in energy supply [7]. In response to this problem, Hamdan proposed the development of next-generation battery technologies that have greater storage capacity and higher efficiency, thereby improving the stability of renewable energy supply [9]. On the other hand, Lodhi explores various policy incentives that can accelerate the adoption of renewable energy, including subsidies for green energy producers, carbon credit mechanisms, and ease of investment for companies committed to reducing carbon emissions [5]. With a combination of technological innovation

and supportive policies, the future of renewable energy could be more promising in ensuring sustainable global energy security. Table 1 presents a categorized synthesis of the selected studies on renewable energy development, challenges, and proposed solutions.

Table 1. Summary of Systematic Review Results on Renewable Energy Development

Category	Key Findings	Number of Studies	Reference
Technology Innovation	Advances in solar panels, AI in energy optimization, and smart grids	42	[1], [10], etc.
Implementation Challenges	Infrastructure limitations, economic barriers, and regulatory constraints	38	[6], [7], etc.
Energy Storage Solution	New generation batteries, hydrogen storage, and improved grid stability	35	[9], [23], etc.
Economic Policies & Incentives	Government subsidies, carbon pricing, and job growth	30	[5], [24], etc.
Future Research Directions	Smart grid integration, decentralized energy systems, and long-term sustainability strategies	22	[3], [25], etc.

This study adopted the PRISMA methodology to systematically review and categorize research related to renewable energy development [22]. The initial process began with the identification of approximately 1,500 articles relevant to the topic. However, only 40 articles met the strict inclusion and exclusion criteria and were selected for further analysis. These studies covered a variety of perspectives, ranging from the existing policy framework, advancements in renewable energy technologies, to the social and economic impacts of clean energy adoption. The analysis illustrates that despite significant technological advancements in the renewable energy sector, faster and more effective achievement can only be achieved through a holistic approach. This approach involves interventions in various areas, ranging from technological aspects focusing on efficiency improvements and the application of new technologies, to economic aspects relating to market development and fiscal incentives that support the adoption of renewable energy. In addition, the importance of regulatory policies that support and stimulate the development of sustainable energy is also highlighted. The right policies can create a favorable environment for innovation and investment in the renewable energy sector, and ensure long-term sustainability. In conclusion, to accelerate the transition to sustainable energy, an approach that encompasses technology, economics and regulation simultaneously is necessary. This suggests that progress in renewable energy development depends not only on technological innovation, but also on effective policy frameworks and strong economic support. Table 2 presents a detailed summary of the selected studies, detailing their key contributions to understanding renewable energy development, challenges and potential solutions.

Table 2. Summary of Selected Studies based on References Found

No.	Author	Title	Findings
1	Gajdzik [1]	The Influence of the Global Energy Crisis on Energy Efficiency: A Comprehensive Analysis	Technological advances improve energy efficiency
2	Wang [2]	Natural resource scarcity, fossil fuel energy consumption, and total greenhouse gas emissions in top emitting countries	Renewable energy is important to reduce carbon emissions
3	Adams [3]	Reducing carbon emissions: The role of renewable energy and democracy	Democratic policies increase renewable energy adoption
4	Saleh [20]	The challenges of sustainable energy transition: A focus on renewable energy	Economic and policy barriers hinder renewable energy adoption
5	Hamdan [9]	Next-generation batteries and U.S. energy storage: A comprehensive review: Scrutinizing advancements in battery technology, their role in renewable energy, and grid stability	Advanced battery improves network reliability
6	Onwusinkwue [10]	Artificial intelligence (AI) in renewable energy: A review of predictive maintenance and energy optimization	AI improves renewable energy efficiency
7	Lodhi [5]	Renewable Energy Technologies: Present Patterns and Upcoming Paths in Ecological Power Production	Trends and future direction of renewable energy
8	Zhao [23]	Solid-State Batteries: Material Challenges and Opportunities	Solid-state battery development improves storage efficiency
9	Ang [7]	A comprehensive study of renewable energy sources: Classifications, challenges and suggestions	Infrastructure and regulation as key barriers
10	Bang [24]	The U.S. Inflation Reduction Act: Climate policy as economic crisis response	Economic policies support renewable energy growth
11	Luca [14]	Green Jobs: Driving Economic Growth and Sustainability in the Global Energy Transition	Impact of renewable energy on job creation

12	Accone [26]	Renewable energy: emerging technologies and innovations	The latest technological innovations in renewable energy
13	Marchant [27]	Perovskite/silicon tandem solar cells-compositions for improved stability and power conversion efficiency	Improving solar panel efficiency through storage innovation
14	Esposito [25]	A roadmap for the implementation of a renewable energy community	Community implementation of renewable energy
15	Ostergaard [28]	Advances in renewable energy for sustainable development	Progress in sustainable energy
16	Tan [29]	The role of carbon pricing in achieving energy transition in the Post-COP26 era: Evidence from China's industrial energy conservation	Impact of carbon price on energy transition
17	Pan [30]	To tax or to trade? A global review of carbon emissions reduction strategies	Global carbon emission reduction strategy
18	Verbruggen [31]	Anatomy of Emissions Trading Systems: What is the EU ETS?	Emissions trading system in energy policy
19	Wahyudi [32]	Higher Carbon Tax Rates More Effective in Reducing Emissions in G20 Countries?	Carbon tax in emission reduction
20	Zapata [33]	The Role of Renewable Energy Policy and R&D in Renewables Diffusion	The role of policy and research in renewable energy
21	Li [34]	Energy consumption within policy uncertainty: Considering the climate and economic factors	Policy uncertainty on energy consumption
22	Vakulchuk [35]	ASEAN's energy transition: how to attract more investment in renewable energy	Renewable energy investment in ASEAN
23	Prokopenko [36]	Impact of Investments and R&D Costs in Renewable Energy Technologies on Companies' Profitability Indicators: Assessment and Forecast	Investment in renewable energy technologies
24	Elijah [37]	Impacts of innovation on renewable energy technology cost reductions	Impact of innovation on reducing the cost of renewable energy
25	Sharma [38]	The role of Energy Economics in Economic Development: An overview	The role of energy economy in economic development
26	Hafner [39]	Prospects for Renewable Energy in Africa	Renewable energy development opportunities in Africa
27	Gunawan [40]	Regional Disparities in the Efficacy of Renewable Energy Development for Alleviating Energy Poverty in Indonesia: An In-depth Analysis	Regional disparities in renewable energy development
28	Omri [41]	Climate policies and legislation for renewable energy transition: The roles of financial sector and political institutions	Climate policy and law in the energy transition
29	Lin [42]	How do feed-in-tariff subsidies affect renewable energy investments in China? New evidence from firm-level data	Energy subsidies and their impact on investment
30	Böhringer [43]	The impact of the German feed-in tariff scheme on innovation: Evidence based on patent filings in renewable energy technologies	The impact of German subsidy policy on energy innovation
31	Huang [44]	Government funded renewable energy innovation in China	Government-funded energy innovation in China
32	Barragán-Ocaña [20]	Policies and sustainable energy transition in the global environment: Challenges for Latin America	Energy policy and sustainable energy transition in Latin America
33	Reda [45]	Green hydrogen as a source of renewable energy: a step towards sustainability, an overview	The potential of green hydrogen in energy diversification
34	Ullah [46]	A comprehensive review of wind power integration and energy storage technologies for modern grid frequency regulation	Integration of wind and energy storage for grid stability
35	Kumar [45]	Green hydrogen as a source of renewable energy: a step towards sustainability, an overview	Smart grid technology in energy distribution optimization
36	Fadilah [47]	The Impact Of Renewable Energy Consumption On The Economic Growth Of The Asean Countries	The relationship between renewable energy and economic growth
37	Goyal [48]	Advancements in Offshore Wind Energy Technology: Challenges and Opportunities for Sustainable Power Generation	Challenges in offshore wind energy development
38	Kim [49]	Blockchain of Carbon Trading for UN Sustainable Development Goals	Use of blockchain in renewable energy transactions
39	Matarazzo [50]	Hydropower as an Important Renewable Energy Source	The potential of hydroelectricity as a sustainable energy source
40	Agupugo [51]	Policy and regulatory framework supporting renewable energy microgrids and energy	Regulations and policies improve energy storage efficiency

storage systems

The findings provide invaluable insights for policymakers, researchers and industry stakeholders in an effort to accelerate the transition to more efficient and sustainable renewable energy solutions. Given the technological, economic and policy challenges, this research highlights the importance of collaboration between the public and private sectors to overcome these barriers. One of the key challenges is the development of renewable energy technologies that are economically competitive with conventional energy sources, while being able to be widely implemented without overburdening existing energy systems. In addition, policy challenges involving regulations, incentives and government support are key to accelerating the adoption of these technologies at the global level. By overcoming these barriers, a more sustainable and efficient energy future is no longer a dream, but an achievable reality. Therefore, further research is urgently needed to explore long-term implementation strategies that can ensure large-scale adoption of renewable energy. Researchers need to focus on developing technologies that are not only technically efficient, but also scalable to meet global energy needs. In addition, research related to policies that support investment in the renewable energy sector as well as efforts to create enabling infrastructure need to be prioritized. With a holistic and integrated approach, further research can help maximize the positive impact of renewable energy on the global energy system, making it more reliable, affordable and environmentally friendly, which in turn will make a significant contribution to reducing the impact of climate change and achieving sustainable development goals.

3.2. Technological Advances in Renewable Energy

The development of renewable energy technologies has progressed rapidly in recent decades, with significant innovations in solar energy, wind, hydro, and energy storage systems [26]. One of the most striking aspects of renewable energy is the increase in solar panel efficiency. Studies conducted by Marchant show that the energy conversion efficiency of tandem perovskite-silicon cell-based solar panels has increased from 22% to 45%, which shows great potential for commercial application [27]. In addition, Bellah explained that smart photovoltaic technology integrated with artificial intelligence (AI) has enabled more precise maximum power point tracking (MPPT) systems [52]. Similar technologies have also been developed in nano-material-based solar panel systems that can increase sunlight absorption by up to 50%, as researched by Alluhaibi [53]. As a result of these innovations, the production cost of solar panels tends to decrease, making them a more competitive energy solution compared to fossil fuels, as also confirmed by Leewiraphan [54].

Innovation in wind energy has also made significant progress. According to research conducted by Quesada-Bedoya, the latest designs in wind turbines can increase energy production capacity by 10-15% compared to conventional models [55]. Barooni added that floating offshore wind farms allow the placement of turbines in regions with higher and more consistent wind speeds, thereby increasing energy production efficiency [56]. In addition, Brahimi pointed out that the use of AI-based predictive analysis has improved the accuracy of wind speed forecasts, allowing operators to dynamically optimize turbine settings to maximize energy output [57]. In various projects in Europe and the United States, this technology has been applied and shown significant results in increasing wind energy production [58]. Thus, as also expressed by Darwish, wind energy is increasingly becoming the main choice for countries that have large coastal areas and stable wind conditions [59].

Energy storage technology has also made great leaps in recent years [60]. Zhao explained that the use of solid-state batteries offers advantages over conventional batteries in terms of safety, larger storage capacity, and longer lifespan [23]. Meanwhile, Widera pointed out that hydrogen-based energy storage is growing with hydrogen fuel cell efficiency increasing up to 60% in industrial applications [61]. According to Tzelepis, the development of platinum-based catalyst materials in hydrogen fuel cells can increase electrochemical efficiency up to 70% [62]. Green hydrogen, as described by Frankowska, is a potential solution in power grid stabilization and long-term energy storage [63]. In addition, Bhuiyan adds that the use of hydrogen as an energy source has begun to be applied in the transportation and heavy industry sectors, replacing more polluting fossil fuels [64]. Thus, Jafarizadeh emphasized that increasingly advanced energy storage technologies can minimize the main challenges in renewable energy, such as dependence on weather conditions, thus making the energy system more stable and reliable [65].

This progress shows that energy storage technology is not only a complement to renewable energy sources, but also a key component in ensuring the stability of the global power system. With the increasing efficiency of solid-state batteries and hydrogen fuel cells, the integration of renewable energy sources such as solar and wind power with energy storage systems is becoming increasingly optimized [46]. The increased efficiency and safety of solid-state batteries allow for greater storage capacity, which can balance fluctuations in electricity supply due to variations in sunlight intensity and wind speed. Meanwhile, green hydrogen produced through water electrolysis using renewable energy has proven its potential in the transportation and heavy industry sectors, replacing fossil fuels that have been a major cause of carbon emissions [66]. With this

technology, major challenges in the utilization of renewable energy, such as dependence on weather conditions and grid stability, can be addressed more effectively. The following table summarizes key findings in the development of renewable energy technologies, including improvements in the efficiency of solar panels, innovations in wind turbines, and the latest developments in energy storage technologies. This information provides a comprehensive overview of recent achievements in clean energy and their potential implications for supporting the transition to a more sustainable energy system.

Table 3: Renewable Energy Technology Innovation and Efficiency Improvement

Technology Category	Key Findings
Solar Panels	Solar panel efficiency increased from 22% to 45%
	MPPT-based AI improves energy production efficiency
	Nanomaterials increase sunlight absorption by 50%
Wind Energy	New aerodynamic design increases production capacity by 10-15%
	Offshore wind farms improve production efficiency
	AI improves wind speed prediction accuracy
Energy Storage	Solid-state batteries are safer and have greater capacity
	Hydrogen fuel cell efficiency increases up to 60%
	Platinum-based catalyst material boosts efficiency by up to 70%

Overall, rapid advances in renewable energy technologies have made them more competitive against fossil fuels. Wheatley highlights that improvements in solar panel efficiency, as well as Younas' research on innovations in wind turbines, and Song's development of energy storage systems, have accelerated the transition to green energy [67][[69]68]. Etukudoh points out that countries around the world are beginning to adopt these technologies on a large scale to reduce dependence on fossil fuels and reduce carbon emissions [70]. Jaiswal added that investments in renewable energy research and development are on the rise, indicating the sector's growth potential in the coming decades [71]. In addition, Østergaard emphasized that with the development of technology and increasing awareness of sustainability, renewable energy is predicted to become the main source of global energy in the future, bringing better economic and environmental benefits to the whole world [28].

3.3. Challenges in Renewable Energy Implementation

Although the development of renewable energy technologies has continued to progress rapidly in recent decades, large-scale implementation still faces various complex challenges. One of the main obstacles is the dependence of renewable energy on weather conditions and the limitations of energy storage [72]. Solar and wind energy, which are the two most dominant renewable energy sources, are highly dependent on environmental factors that are often difficult to predict [73]. Wang points out that weather instability directly affects the availability of energy from these sources, thus creating a major challenge in the provision of stable and reliable electricity supply [74]. For example, during the rainy season or when the wind weakens, the energy output from solar panels and wind turbines can be drastically reduced [75]. According to data from the International Energy Agency (IEA), by 2023, solar and wind energy account for about 12% of total global electricity supply, but the degree of variability is still high, with production fluctuations reaching 30% in some regions [76][77]. In addition, Pamfile notes that although energy storage technologies have developed rapidly in recent years, such as the use of lithium-ion batteries and gravity storage technologies, high production and investment costs are still a major barrier to their application [78]. Data from BloombergNEF shows that the price of lithium-ion batteries dropped from $1,100 per kWh in 2010 to about $137 per kWh in 2023, but it is still not economical enough for large-scale in grid storage systems [79][80]. Chidolue also emphasized that the lifespan of energy storage is limited, which affects its effectiveness in the long run, so reliance on renewable energy without efficient storage solutions may pose a risk of unstable supply [81]. This issue is made even more complex given the need for long-term storage technologies that are still in the development stage, such as sodium-based batteries and green hydrogen that could become alternatives in the future [82].

Besides dependence on weather conditions and energy storage, other major challenges in renewable energy implementation are infrastructure limitations and integration with existing power grids [65]. Renewable energy has intermittent characteristics, which means that its supply is not constant and requires infrastructure adjustments to function optimally in national and regional electricity systems [83]. Smith revealed that major improvements in the development of smart grids are needed to enable smooth integration between renewable energy sources and existing electricity distribution systems [84]. Shahveran added that the currently widely used power grid infrastructure is still designed to support fossil fuel-based power generation, which is characterized by a stable and controllable energy supply [85]. Furthermore, data from the World Bank for 2023 shows that developing countries face major obstacles in modernizing their power

grids, with around 760 million people in the world still not having access to stable electricity [86][38]. In some regions of South Asia and Africa, voltage fluctuations and energy losses in transmission limit the effectiveness of renewable energy [87]. According to a report from the International Renewable Energy Agency (IRENA), energy losses in transmission account for 15-20% of total electricity production in some African countries, which hinders the adoption of renewable energy [88][39]. Therefore, without the upgrade and modernization of power grid infrastructure, large-scale implementation of renewable energy will continue to face significant technical obstacles. Ohanu pointed out that global investment in smart power grids is expected to reach $530 billion by 2024, but most of this investment is concentrated in developed countries [89][90]. Developing countries must get policy and funding support from international organizations so that they can accelerate the transition to a more modern and efficient electricity system [91].

Another important challenge is the lack of skilled labor and low public awareness of the benefits and feasibility of renewable energy. Briggs notes that the renewable energy sector requires a workforce with specialized technical skills, from designing to maintaining high-tech energy generation systems [92]. However, according to Lucas, the shortage of experts is still a major obstacle, especially in developing countries that do not have adequate training programs [93]. Data from IRENA (2023) shows that the renewable energy sector employs around 12.7 million people globally by 2022, but the need for skilled labor is still much higher, especially in the fields of solar panel manufacturing, wind turbine maintenance, and energy storage systems [94] [95]. In addition, public perception of renewable energy remains a barrier. Based on a survey from the Pew Research Center in 2023, around 38% of people still have the perception that renewable energy is not reliable enough to replace fossil energy completely [96][97]. Lucas also found that many people still doubt the reliability of renewable energy due to misinformation or lack of understanding of this technology [98]. Therefore, Rohman suggested that education and training programs should be strengthened to increase public acceptance of renewable energy [99].

Overcoming these challenges requires a multi-sectoral approach involving government, industry, research institutions and the general public. Abdul emphasized that investment in research and development of energy storage technologies should be increased in order to create more economical and long-lived solutions [100]. White adds that policies that support the development of modern and adaptive power grid infrastructure for renewable energy sources should be implemented [101]. Rout argues that with close collaboration between various stakeholders, the transition to a more sustainable energy system can proceed more quickly and efficiently, providing greater economic, social and environmental benefits [102]. To further understand the challenges faced in renewable energy implementation and the solutions that can be applied, the following table summarizes the key findings from various studies. The table summarizes critical aspects such as dependence on weather conditions, energy storage limitations, integration with the grid, and the policies and investments needed to accelerate the transition to a more sustainable energy system.

Table 4. Findings of Challenges in Renewable Energy Implementation

Category	Key Findings
Dependence on Weather	Weather instability affects energy supply, especially from solar and wind
Storage Technology	Storage technologies are evolving but still have high costs and limited lifespan
Power Grid Integration	Renewable energy integration requires smart grids to cope with supply fluctuations
Infrastructure Modernization	Developing countries face constraints in upgrading the electricity grid
Smart Network Investment	Global investment in smart grids expected to reach $530 billion by 2024
Skilled Labor	Lack of skilled labor hinders renewable energy adoption
Public Awareness	38% of people still doubt the reliability of renewable energy
Policy & Investment	Cross-sector collaboration needed to accelerate energy transition

3.4. The Role of AI and Blockchain in Energy Management

Artificial Intelligence (AI) and Blockchain technologies have become a major key in the renewable energy revolution by improving efficiency, security, and cost-effectiveness [103]. With the increasing need for environmentally friendly energy, various AI-based innovations are being implemented in energy systems to optimize the distribution and consumption of renewable energy. AI-based smart grids, as described in Aljarrah's research, are able to analyze and predict energy consumption patterns on a wide scale through machine learning algorithms, allowing the system to manage power allocation more efficiently, reduce energy waste, and improve the stability of the power grid [104]. Recent studies have shown that with the application of AI, energy utilization efficiency increases by 30% compared to conventional systems,

especially in countries with high energy consumption such as the United States and China [105]. In the context of operational fault detection, Soori revealed that AI-based algorithms can reduce the risk of system disruptions by 25% by utilizing real-time data monitoring to identify potential failures before they have a wide impact [106]. Data from the International Energy Agency (IEA) confirms that implementing AI in power grids can save up to 18% in maintenance costs, which has a direct impact on the operational budget efficiency of energy companies [90]. Furthermore, Bennagi found that AI also plays a role in optimizing electricity generation from renewable energy sources, such as solar and wind power, by relying on AI-based weather predictions to adjust power production to maintain grid stability [107]. Further research by Ukoba showed that the combination of AI and renewable energy has increased power production by 27% compared to traditional methods [108]. This shows that AI not only improves the efficiency of energy distribution but also supports the sustainable use of renewable resources.

On the other hand, Blockchain technology makes a significant contribution in accelerating the transition towards a more decentralized and transparent energy system [109]. According to Wongthongtham, smart contract-based peer-to-peer (P2P) energy trading allows users to buy and sell energy from renewable sources directly, which increases transaction transparency by 40% without the need for intermediaries [110]. Research from Choobineh shows that blockchain-based transactions can reduce the processing time of energy purchases from 3 days to just a few minutes, thereby increasing the efficiency of the system [111]. Gerardi corroborates these findings by noting that blockchain implementation in rural communities has increased energy access by 50% in the first five years since its implementation, making the system a potential solution for areas that are hard to reach by conventional electricity infrastructure [112]. Another study by the Global Energy Network Institute found that developing countries that implemented blockchain systems in energy distribution saw electrification ratios increase 32% faster than traditional systems. Oriekhoe also highlighted the cost-efficiency benefits by showing that blockchain technology can reduce operational costs by up to 20%, due to a more efficient transaction recording process and less risk of errors [113]. A recent study by Khezami also noted that the application of blockchain in energy transactions could save USD 3.5 billion in global administrative costs by 2024 [114]. With its transparent and secure characteristics, blockchain not only facilitates fairer energy trading but also improves the reliability of power distribution systems.

The combined application of AI and blockchain in the energy sector opens up great opportunities for a smarter, more efficient, and sustainable energy future [115]. Hua noted that the integration of these two technologies in the energy sector could reduce carbon emissions by up to 15% per year by enabling automatic optimization of power consumption and more transparent energy transactions [116]. Research from Kim shows that the combination of AI and blockchain has reduced carbon emissions equivalent to 12 million tons of CO2 per year in the European Union [49]. Meanwhile, Ukoba emphasized that utilizing AI in energy decision-making helps improve policy accuracy by 35%, allowing regulators to design more accurate policies based on real-time data (DOI: [108]. Research from Baashar showed that countries that implemented AI and blockchain-based policies saw an increase in the effectiveness of energy regulation by 28% [117]. In addition, Taherdoost showed that the combination of AI and blockchain also has the potential to increase energy affordability for low-income people by 25%, by enabling wider access to cheaper and more sustainable energy [118]. According to Awogbemi's report, more than 1.2 million households in Asia and Africa have gained access to lower-cost electricity through blockchain and AI-based platforms [119]. With these developments, future energy systems are not only more efficient and secure but also more inclusive and democratic for all, creating an energy model that is adaptive to evolving global challenges. In meeting the challenges of the energy transition to sustainability, artificial intelligence (AI) and blockchain technologies are increasingly playing a role in improving the efficiency, reliability, and transparency of the renewable energy sector. AI contributes to energy utilization optimization, while blockchain offers a secure and decentralized record-keeping system. The following table compares the impact of these two technologies on various aspects of the renewable energy sector.

Table 5. Impact of AI and Blockchain in the Renewable Energy Sector

Aspects	AI Impact	Blockchain Impact
Energy Efficiency	Improved energy utilization efficiency by 30%	Enables more efficient energy distribution with peer-to-peer systems
System Reliability	Reduce the risk of network disruption by 25%	Enhance network security with irreversible transaction logging
Operational Costs	Optimize power consumption and reduce maintenance costs by up to 18%	Reduce transaction and administration costs by up to 20%
Transaction Transparency	Facilitate automated monitoring based on real-time data	Increase transparency by 40% through smart contracts
Energy Access	Helps more accurate power distribution to remote areas	Increase energy access by 50% in the first five years
Carbon Emission Reduction	Help reduce fossil-based energy consumption	Reduce carbon emissions by 15% per year

through optimization of renewable production	through energy distribution optimization

3.5. Economic and Social Impacts of Green Energy

Renewable energy has become a major driver of change in the global economy and society [120]. Switching from fossil fuels to cleaner energy sources such as solar and wind power not only reduces carbon emissions, but also creates new economic opportunities [121]. One of the most significant economic impacts is job creation. A study conducted by IRENA in 2023 showed that the renewable energy industry employs more people than the fossil fuel sector [94]. The report revealed that the renewable energy sector has created more than 12.7 million jobs globally, with a projected increase to 35 million by 2030 [122]. The solar and wind power industries are major contributors to this job creation, with many countries increasing production capacity and installation of clean energy systems [123][124]. Data from Bulkot shows that investment in renewable energy has increased by 17% annually, with the majority of investment coming from developed countries such as the United States, China, and Germany [125]. In addition, the energy transition also drives economic growth through increased investment in infrastructure, research and development of new energy technologies. For example, in Europe, the clean energy industry accounts for more than 2% of GDP in some countries, indicating a positive impact on national economic growth [126]. However, this impact is not always evenly distributed across the world. Countries with high technological capacity and investment reap economic benefits faster than developing countries that still face resource constraints. In Africa, for example, only about 2% of total global energy investment is allocated to renewable energy on the continent, so the sector is growing much slower compared to other regions [88].

While renewable energy promises long-term economic benefits, the main challenges faced are affordability and economic disparities. Initial investment costs for renewable energy infrastructure are still very high, especially for solar panel technology, wind turbines and energy storage systems. Mustafa revealed that in developing countries, the cost of installing solar panels is still in the range of $1000 to $3000 per kilowatt, much higher than the cost of conventional electricity [127]. As a result, developing countries often face difficulties in allocating funds for this energy transition, so they still rely heavily on cheaper fossil fuels in the short term. In addition, low-income communities are also more vulnerable to upfront cost barriers, such as installing solar panels or accessing energy-efficient technologies [128]. A recent study by Qadir shows that developed countries benefit more from this energy transition due to government incentives and easier access to green energy project funding [129]. For example, in the United States, federal incentive programs have enabled more than 45% of households to receive subsidies for solar panel installation, while in developing countries like Bangladesh, only about 10% of households receive similar subsidies [130]. Aggarwal adds that the main challenges in renewable energy deployment in developing countries are regulatory instability and lack of supporting infrastructure [131]. In Indonesia, for example, only 14% of rural areas have access to affordable solar energy, compared to over 80% in Western Europe [132]. In other words, if policies are not designed appropriately, the energy transition could exacerbate global economic inequalities instead of reducing them. This could slow down global clean energy targets, as projected by the International Energy Agency (IEA), which estimates that without strong incentive policies, more than 600 million people worldwide will still be living without access to electricity by 2030 [76][133].

Therefore, renewable energy policies should focus on increasing accessibility and affordability for all levels of society. Chen emphasized that governments and international organizations need to create funding mechanisms that support renewable energy investments in developing countries, such as low-interest loans or subsidies for green infrastructure [134]. Some countries have started implementing these policies with mixed results. For example, in Brazil, the "Luz para Todos" program has successfully increased access to renewable energy-based electricity for more than 15 million rural residents through government subsidies, while in some African countries, similar programs still face considerable administrative obstacles [135]. In addition, innovations in energy technology should also be geared towards reducing the cost of production and installation of clean energy systems, so that more people can access them. A study by Udo showed that the development of perovskite-based solar panels could reduce production costs by 40% in the next five years, making them more affordable for developing countries [136]. Siregar proposes an income-based electricity tariff scheme to ensure that low-income people are not burdened by the cost of energy transition [137]. On the other hand, workforce training in the renewable energy sector is also a crucial factor for the poor to participate in green energy-based economic growth. Currently, only 20% of the total workforce in the energy sector comes from low-income groups, indicating the need for more extensive education and training programs [138]. Piran underlines that further education and research in renewable energy development should be enhanced to create more inclusive and sustainable solutions [133]. With an inclusive and equitable policy-based approach, renewable energy will not only reduce dependence on fossil fuels, but also create a more equitable and sustainable economy for the entire world. If these policies are implemented consistently, the energy transition can be a major catalyst in reducing energy poverty and accelerating the achievement of the global zero emissions target by 2050 [137].

In line with these efforts, it is important to understand how renewable energy concretely affects various economic and social aspects. Renewable energy will not only create 12.7 million jobs by 2023, but is also predicted to increase to 35 million jobs by 2030, as reported by Klepacka [122]. However, inequality in investment is still a major challenge, with only 2% of total global investment allocated to renewable energy in Africa, leading to limited access for developing countries [134]. In addition, another challenge that still needs to be overcome is the high initial cost of adopting renewable energy. For example, in developing countries, the cost of installing solar panels is still in the range of $1000 to $3000 per kilowatt, making it unaffordable for low-income people [127]. Although some developed countries have provided significant subsidies, such as in the United States, where 45% of households have received subsidies for solar panel installation, in Bangladesh the figure is only 10%, indicating that there is still a large gap in access to renewable energy [40]. This inequality is also seen in access to solar energy in Indonesia, where only 14% of rural areas have access to affordable solar energy, while in Western Europe, the figure is much higher [138]. Without significant intervention, these inequalities could continue, even slowing down the achievement of global clean energy targets. To better understand the economic impacts, investment challenges and workable solutions of the renewable energy transition, the following table presents key data collected from various sources. The data in this table includes the number of jobs that have been created, the level of global investment in clean energy, the initial cost of installing renewable energy in different countries, and policies that have been implemented to increase access to clean energy. Through this table, readers can clearly see how different trends and policies are affecting the global energy transition, as well as how the gap in access to clean energy is still a challenge to be solved.

Table 6. Economic Impacts, Investment Imbalances, and Solutions in the Renewable Energy Transition

Category of Findings	Findings Value
Number of jobs in the renewable energy sector (2023)	12.7 million jobs
Projected number of jobs in the renewable energy sector (2030)	35 million jobs
Annual investment in renewable energy (%)	17% per year
Percentage of GDP coming from renewable energy in Europe	2% GDP
Percentage of global investment in renewable energy for Africa	2% of total global investment
Solar panel installation cost per kW in developing countries (USD)	$1000 - $3000
Percentage of households in the US that receive renewable energy subsidies	45%
Percentage of households in Bangladesh receiving renewable energy subsidies	10%
Percentage of rural areas in Indonesia that have access to affordable solar energy	14%
Number of people gaining access to electricity through the 'Luz para Todos' program in Brazil	15 million people
Percentage of energy sector workers from low-income groups	20%
Reduction of production cost of perovskite-based solar panels in the next five years (%)	40%
Projected number of people who will be without electricity by 2030	600 million people

3.6. Policies and Regulations in Renewable Energy Adoption

Government policies play a crucial role in accelerating the renewable energy transition, with various approaches that can increase investment and adoption of clean technologies [41]. One of the main instruments used by many countries is subsidies as well as financial incentives aimed at encouraging the development and deployment of renewable energy [139]. Lin states that countries that provide strong financial incentives, such as tax credits and feed-in tariffs, have shown higher adoption rates of renewable energy [42]. Germany, for example, managed to significantly increase its solar and wind energy capacity through a feed-in tariff scheme that provides revenue certainty for renewable energy producers, as argued by Böhringer [43]. China has also become a global leader in green energy by supporting the solar and wind industries through generous subsidies and low-cost financing for renewable technology producers [44]. In addition, according to Bang, the Inflation Reduction Act of 2022 in the United States has provided long-term tax incentives for the renewable energy industry, which in turn encourages investment in clean technologies such as solar energy, wind, and battery-based energy storage [24]. Gandhi emphasized that this kind of policy not only reduces financial risks for investors, but also accelerates the development of broader green energy infrastructure [140].

In addition to financial incentives, carbon pricing and emission reduction policies also play an important role in promoting the shift to renewable energy [29][51]. According to Pan, carbon pricing mechanisms, such as carbon taxes and emissions trading systems, have been shown to improve the

competitiveness of renewable energy compared to fossil fuels [30]. The European Union, for example, implemented an Emissions Trading System (ETS) that requires companies to purchase carbon emission permits. Since its implementation in 2005, this policy has successfully reduced carbon emissions by 35% and provided incentives for industries to switch to greener energy sources, as stated by Verbruggen [31]. Canada has also introduced a gradually increasing carbon tax, which, according to Wahyudi, has encouraged companies to reduce reliance on fossil fuels and invest in clean technologies [32]. Gugler adds that countries that consistently implement carbon pricing policies tend to have more rapid development in the renewable energy sector, as these mechanisms create more favorable economic conditions for green energy compared to conventional fuels that are increasingly expensive due to the burden of emissions taxes.

To maximize the potential of renewable energy, governments need to implement consistent policies, simplify regulations, and increase investment in research and development (R&D) [33]. Li highlighted that unstable or frequently changing policies can create uncertainty for investors and industry players, thus slowing down the energy transition [34]. Therefore, clearer and longer-term regulations are urgently needed to attract more investment into the renewable energy sector, as expressed by Vakulchuk [35]. Simplifying licensing procedures can also accelerate the development of renewable energy projects, as has been implemented in several European countries with a one-stop licensing system for green energy projects [25]. In addition, Prokopenko points out that investment in R&D is key in accelerating innovation and lowering the cost of renewable energy technologies [36]. Countries that have strong policies in funding research and development, such as Norway and South Korea, have successfully created innovations in energy storage and higher efficiency of solar panels [37]. With a combination of financial incentives, carbon pricing and investment in technological innovation, the renewable energy transition can be faster and more sustainable, helping the world to reduce dependence on fossil fuels and effectively address the challenge of climate change.

4. CONCLUSION

Rapid developments in renewable energy technologies, including an increase in solar panel efficiency from 22% to 45%, advances in wind turbines that increase production capacity by 15%, and innovations in storage technologies such as solid-state batteries and hydrogen fuel cells, show great potential in the transition to green energy. Nonetheless, the main challenges faced are dependence on weather conditions that affect the stability of renewable energy supply, as well as high costs in storage and limited infrastructure that supports the integration of renewable energy into the existing power grid. Strong fiscal policies, such as subsidies and carbon pricing mechanisms, have proven effective in accelerating the adoption of renewable energy, as seen in Germany and China. In addition, AI and Blockchain technologies play an important role in improving energy distribution efficiency, power utilization optimization, and enabling a more efficient and secure distribution system. On the economic front, the renewable energy sector has created more than 12.7 million jobs, with projections to reach 35 million by 2030, although investment inequality between developed and developing countries remains a major challenge. To accelerate this transition, policies that simplify licensing and support technological innovation are urgently needed. Thus, the success of the renewable energy transition will largely depend on technology development, supportive policies, and collaboration between the public and private sectors to overcome existing barriers.

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