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Article

Modeling of Renewable Energy Resources in Global Energy Management Systems

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Abstract: The International Renewable Energy Agency (IRENA) was established in 2009 and in 2024, its membership increased to 168 members plus the European Union countries. The purpose of IRENA is to promote the adoption of renewable energy across all industries in the world. Despite the utilization of renewable energy in sectors like power generation and construction, its application in other industries remains limited. Therefore, a literature review study was conducted to investigate the cost and other spatial constraints associated with renewable energy resources, including modeling and optimization techniques that could offer viable solutions to the future challenges faced by the renewable energy production systems. This paper has summarized the result of this study with a focus on the significance of modeling and optimization techniques in energy conservation to highlight the untapped potential for leveraging renewable energy resources in industrial applications. This paper also examined a few case studies from various regions of the world, demonstrating the promising opportunities for research in the modeling and optimization of renewable energy management systems.

Keywords: renewable energy resources; sustainable environment; optimization and modeling; energy management system

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1. Introduction

Renewable energy resources play an undeniable role in sustainable development of the communities in the world while minimizing the impact on climate change. Although renewable energy resources have been applied in power generation and building the infrastructure, they have a substantial potential to be applied in various industrial applications. By 2050, the use of renewable energy resources in the manufacturing industry will be multi-fold. Because of the destructive effects of carbon emissions on climate change, decision-makers need to consider renewable energy resources for as many industries as possible. Demand growth, advancements in technologies, cost reductions in renewable energy systems, environmental and energy security related issues will result in in the increased use of renewable energy resources attracting international government's attention. This resulted in the formation of an international agency in 2009 known as International Renewable Energy Agency (IRENA) by 149 governments (Moriarty & Honnery, 2019). Today, IRENA's membership is 168 plus the European Union. Using renewable energy resources is the goal of this agency which leads to energy access, economic developments, a sustainable environment, energy security, and policies and regulations.

The percentage of global and industrial energy use provided by renewable energy resources is 13% and 9%, respectively. The wood processing industry, pulp and paper industry, food and beverage industry, dairy industry, chemical and petrochemical industry, agricultural industry, iron and steel industry, mining industry, textile industry, and transportation industry are some of the industries that have the potential to use renewable energy resources. However, using renewable energy resource has some challenges. Cost of delivering heat produced by renewable energy resources and limited space to install the equipment needed for using renewable energies are couple of challenges (Taibi et al., 2012).

Figure 1 gives the percentage use of renewable energy for different industries (Taibi et al., 2012).

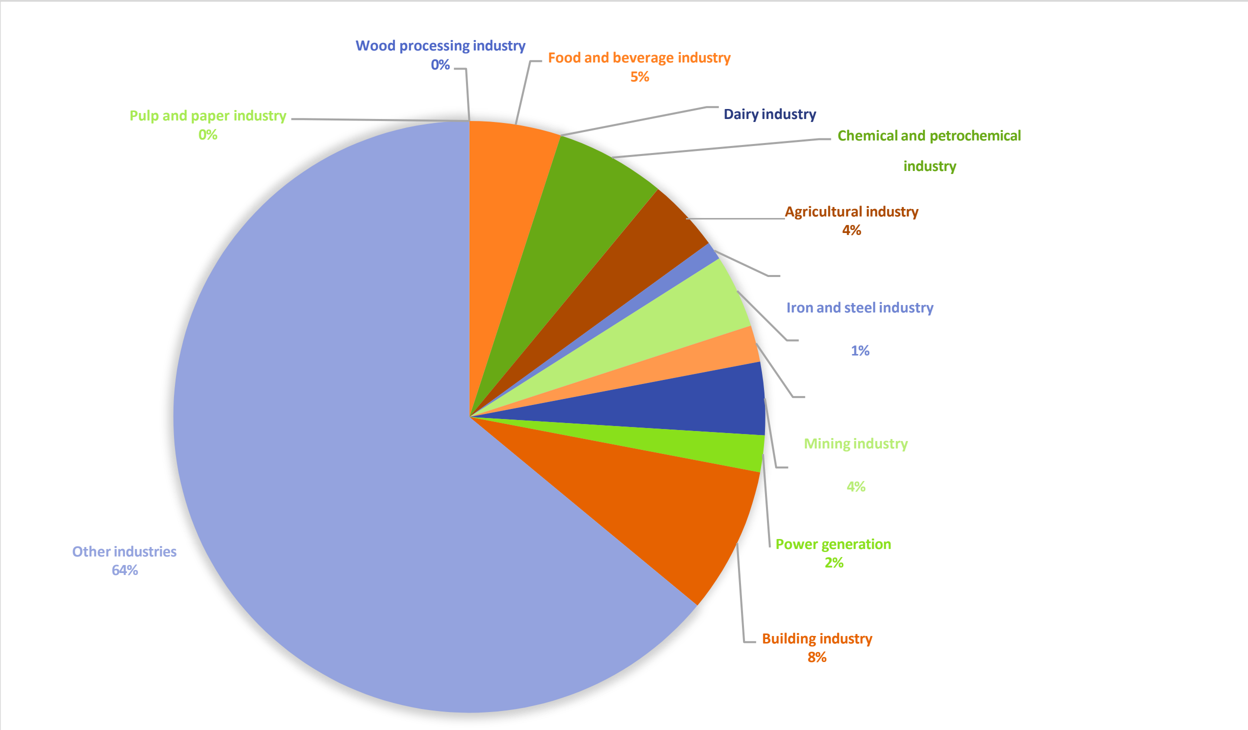

Figure 1. Share of different industries using renewable energy resource.

Renewable energy resources are variable and intermittent. The variants that can be predicted or unpredicted are a subset of intermittency and should be covered. Some special designs considering them can help face intermittency. One solution is to consider more than one renewable energy source. However, the system's total cost can be increased by considering special designs. Also, when we have more than one source, there is a flow between them that should be controlled. Selecting a suitable energy management strategy and modeling the problem to optimize the components' size is vital to minimize cost. So, optimization is an undeniable part of energy management systems to reduce costs. For energy management strategy, many approaches and techniques can be chosen according to the type of energy system and its components. All governments try to encourage industries to use renewable energy resources by regulating some policies. Mixing traditional and renewable energy resources increase reliability. Some other decisions that should be taken in energy management systems are sizing, storage options, control strategies, and optimization (Olatomiwa et al., 2016).

Variations in renewable energy resources, especially wind and solar photovoltaic (PV), would change these energy resources modeling. New optimization models should consider variability and uncertainty in renewable energy resources. Focusing on models with the flexible generation, interregional transmission, energy storage, and demand-side response constraints is a new trend in planning and optimizing renewable energy systems. New models are more complicated. In new models, the objective function is still the minimization of cost. These problems aim to make the renewable energy system economical and technical (Deng & Lv, 2020).

2. Governmental Policies

Governmental intervention in the market has a vital effect on the using renewable energy resources. Countries should have supporting programs for using renewable energy resources. Some factors facilitate governmental support of renewable energies in different countries. Enough financial support, growth of using renewable energy resources instead of traditional resources and attracting the support of public and private sectors can be charming to increase the renewable energy resource market.

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Several countries have implemented incentive-based policies to encourage environmentally friendly practices, by offering exemptions from vehicle registration taxes, reduced annual road taxes, and bus lanes, Norway has become a world leader in the adoption of electric vehicles (EVs), representing more than 60% of new car sales in 2022, the highest rate in the world (Anderson, 2002).

The German government provides low-interest loans and investment grants to support energy efficiency and renewable energy projects, resulting in renewable energy accounting for more than 46% of Germany's electricity generation (Wojtaszek et al., 2024). Tax credits for renewable energy production, rebates for energy-efficient home improvements, and the Renewable Fuel Standard mandate have all contributed to the growth of renewable energy and biofuels in the United States (Idoko et al., 2024). As a result of Sweden's carbon tax on fossil fuels, as well as its exemptions and reduced rates for energy-efficient industries, greenhouse gas emissions have been reduced while maintaining competitiveness (Andersson, 2019). Policies such as these demonstrate how incentives can be used to accelerate the adoption of sustainable technologies and practices across sectors, such as transportation, energy, and industry.

This paper concluded that some countries need lot of energy for their economic growth, like India, China, and Russia, there is a motivation to use these resources, but it can only be fulfilled by getting help from the government and businesses. Governments aim to reach economic growth and a sustainable environment called green growth, which can be obtained through environmental and economic development. Balancing traditional and renewable energy resources should be managed economically, which can be obtained by the regulatory balance between supply and demand in the energy market. Green technologies should be developed to generate energy optimally to maintain natural resources and reduce destructive CO2 emissions. As environmental issues increase by the demand growth of energy, cleaner technologies like renewable energy resources would be more needed. But this strategy may be in contradiction to removing poverty. So, countries should have some smart policies to reach these two goals concurrently, which can be obtained through the development of energy management systems (Smirnova et al., 2021).

India, with a potential of 1001 GW of renewable energy, has installed nearly 69 GW presently but aims to achieve 175 GW by 2022. However, barriers hinder renewable energy development. Also, India's vast solar energy potential provided a clean alternative to conventional, polluting energy sources. (Raina & Sinha, 2019) examined existing policies aimed at harnessing solar energy to position India as a global leader. It addressed barriers to solar electricity generation and provided an overview of the Indian PV market, highlighting key public and private sector players in solar photovoltaic development. This article identifies these barriers, provides recommendations to overcome them, and presents India's current energy scenario alongside its renewable energy potential and future targets.

In China, developing the renewable energy sector and upgrading the energy structure played crucial roles in combating climate change. Financial constraints were a significant challenge, linked to the country's financial development. (Ji & Zhang, 2019) conducted time series analysis using macro-level data, showing that financial development contributed 42.42% to the variance in renewable energy growth. The capital market emerged as the most influential factor, followed by foreign investment. A comparison with the EU and US cases suggested that China should closely examine the EU path for valuable insights for policymakers.

(Dai et al., 2016) evaluated the economic impacts and environmental benefits of large-scale renewable energy (RE) development in China by employing a dynamic computable general equilibrium (CGE) model. Achieving a 56% share of RE in total primary energy by 2050 could elevate non-fossil power sectors to a significant industry, contributing 3.4% to GDP. The RE max scenario projected output worth $1.18 trillion from RE-related upstream industries and the creation of 4.12 million jobs by 2050, alongside notable reductions in CO2 and air pollutant emissions.

In contrast to the global trend of decarbonizing electricity production, Russia's renewable energy policy prioritized economic benefits tied to green equipment manufacturing. The government's focus on industrial development was evident in its subsidies linked to strict local content requirements. Solar energy particularly benefited from this subsidy regime, favoring local manufacturers. (Boute &

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Zhikharev, 2019) analyzed Russian renewable energy regulation, highlighting the favorable treatment of solar generation. It attributed this treatment to the vested interests of influential industrial groups in the solar PV manufacturing sector, which facilitated the adoption of renewable energy technologies in Russia's oil and gas-dependent economy.

Table 1 summarizes the factors that attract government support for renewable energy resources in India, China, and Russia.

Table 1. Renewable energy resources attracting factors for governments in some countries.(Kar et al., 2024; Kilinc-Ata & Dolmatov; Wall et al., 2021).

Factors that attract government support for renewable energy resource
Private Consortiums and Public-Private Partnerships
Political support
Community support
Regulatory Frameworks and Emissions Reduction Targets
Transparent information
Energy Security and Reducing Import Dependence
Appropriate risk allocation between public and private partners
Cost Competitiveness of Renewable Technologies
Competitive procurement
Public Acceptance and Social Factors
Economic Development and Job Creation

3. Energy Savings

Using energy management systems for buildings, industries, and equipment can save energy. Saving energy percentages obtained by a study of 305 papers published from 1976 to 2014, including 105 building energy management systems, 103 industrial management systems, and 97 equipment energy management systems, is summarized in Table 2 (Lee & Cheng, 2016).

Table 2. Energy saving in different segments.

Segment	Energy Saving
Building energy management systems	Increased from 11.39% to 16.22%
Industrial management systems	Decreased from 18.89% to 10.35%
Equipment energy management systems:	
• Artificial lighting systems	• Up to 39.5% in average
• HVAC	• Around 14.07%
• other equipment	• Around 16.6%

The above values for energy savings were obtained by methods that did not consider optimizing under different constraints. So, the energy savings values may be underestimated or overestimated those values (Olatomiwa et al., 2016).

4. Optimization and Modeling

Optimization is the process of finding the best solution to a problem's objective function. This involves determining the most effective strategy or conditions to either maximize desired outcomes or minimize undesired ones. It typically involves mathematical relationships between objectives, constraints, and decision variables. Different types of optimization problems exist, categorized by factors like the number and types of objectives, variables, constraints, and problem structures. Real-world engineering problems often require optimization to handle numerous control variables within specified constraints.

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Different hybrid renewable energy resources' optimization methods have changed in recent years. These methods can be classified into classical methods, artificial intelligence (AI), hybrid algorithms, and software-based optimization tools, as seen in Figure 2.

Traditional optimization techniques rely on precise mathematical calculations to find the best possible solutions, providing definite answers. However, they face difficulties when dealing with numerous variables in complex scenarios. Early optimization methods often employ numerical, iterative, analytical, and probability analyses, utilizing differential calculus to efficiently compute energy models (Gonzalez et al., 2018). These techniques excel in finding optimal solutions in scenarios with continuous and differentiable functions. Yet, they struggle when faced with objective functions that lack these qualities, limiting their effectiveness in such situations. Table 3 summarizes the classification of classical optimization methods and their examples.

Table 3. Classification of Classical Optimization Methods.

Numerical	Graphical	Iterative	Probabilistic	Analytical
These methods involve employing mathematical tools or techniques to derive close approximations rather than precise solutions. For instance, they are utilized in designing off-grid solar/wind/diesel/battery systems and optimizing the configuration of hybrid wind/solar PV/hydrogen systems for desalination. Additionally, they help determine optimal solar PV power for residential micro-systems, considering factors like system cost and reliability. Various approaches, including deterministic and stochastic methods, are explored to address different challenges and enhance system performance. However, there are complexities, such as the high initial cost of batteries and the intricacy of optimizing systems with multiple variables and dimensions (Dong et al., 2024; El Alimi et al., 2014; Kaabeche &	Graphical approaches are straightforward for problems with two variables but may require approximations for more complex scenarios. While not suitable for high- dimensional problems, both graphical and mathematical methods remain valuable for practical applications when used appropriately. Examples include decomposing CO2 emissions in multi-product plants and analyzing PV system sizing based on solar radiation time series (Mahesh & Sandhu, 2019; Sinha & Chandel, 2015; Tsolas et al., 2018; Yap et al., 2020).	Iterative processes involve repetitive steps to approximate solutions to problems. While they are simple and straightforward to execute, they can be time-consuming due to multiple iterations needed to find optimal configurations. Examples include optimizing the capacity sizes of PV/wind components in Algeria and determining the best configurations of hybrid systems based on technical and economic models. Iterative procedures are also used to optimize the sizing of solar PV, wind, and battery components under various scenarios and operational conditions (Ayed	Probabilistic methods rely on probability theory and consider uncertainties to determine optimal solutions, although they do not guarantee them. They are particularly useful for dealing with multi-objective functions, nonlinear system responses, and long-term weather variables. Examples include using analytical approaches to estimate the long-term performance of hybrid solar-wind systems and developing hybrid programming models for effective analysis of system behavior under unpredictable conditions. Additionally, novel probabilistic approaches are introduced to optimize off-grid	These methods rely on mathematical and theoretical analysis to estimate component sizes based on economic viability and historical data. They are used to minimize system costs, extract parameters from manufacturer datasheets, and model system performance under uncertainties. While analytical methods offer simplicity and reliability, they may face challenges in estimating location-dependent equations and require additional computational effort. Researchers are turning to artificial intelligence techniques to

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Ibtiouen, 2014; Peng et al., 2024; Smaoui et al., 2015).	et al., 2024; Kaabeche et al., 2011; Nogueira et al., 2014) .	hybrid energy systems and evaluate system performance in specific geographical locations, such as the South China Sea. These methods provide insights into system reliability and performance under varying environmental circumstances (Das et al., 2024; Li et al., 2020; Telle et al., 2024; Tina & Gagliano, 2011).	address optimization challenges effectively (Khatod et al., 2010; Kolhe et al., 2003; Prakash et al., 2022).

For optimizing a system, the most useful strategies are classical techniques. However, limited space, firmness, difficulty in finding a global optimum, and disability to dynamic changes are their drawbacks. Although having some deficiencies, AI encompasses the development of intelligent machines and software capable of performing tasks similar to human cognition. Optimization, a core problem in AI, involves finding inputs to an objective function that yield maximum or minimum values while adhering to constraints. AI-based optimization algorithms, including those inspired by swarm intelligence, physics laws, human behavior, and evolution, have been developed to address complex optimization problems effectively. These algorithms offer advantages such as handling non-smooth and nonlinear problems, faster convergence, and flexibility. However, achieving a balance between diversification and intensification is crucial in AI optimization, ensuring exploration of the global search space while focusing on local areas. Researchers employ various AI optimization algorithms to determine the most efficient and cost-effective configurations for renewable energy systems, considering factors such as reliability, stability, and environmental impact. Additionally, AI techniques are integrated with renewable energy systems, such as membrane bioreactors, to enhance operational efficiency and reduce costs. The optimization of renewable energy systems involves evaluating different scenarios and algorithms to identify the most suitable solutions for specific applications and locations, ensuring reliable and sustainable energy generation. (Li et al., 2024) discusses how the drive for carbon neutrality is increasing the use of renewable energy (RE). However, integrating RE into power systems faces challenges due to its intermittent nature. Traditional methods struggle to balance supply and demand in real-time, leading to higher electricity prices. The article explores how artificial intelligence (AI) methods can help address these challenges by improving forecasts, power dispatch, system control, and market decisions related to RE. It also discusses emerging trends and approaches to tackle operational challenges in renewable power systems. (Al Smadi et al., 2024) discusses the importance of renewable energy, particularly photovoltaic (PV) systems, in addressing climate change. It highlights the role of static converters and energy storage batteries in improving energy quality. The study emphasizes the significance of artificial intelligence (AI) in optimizing PV system performance, introducing a novel approach using adaptive neuro-fuzzy inference systems (ANFIS). It underscores AI's role in ensuring continuous power supply and effective energy management through battery systems.

AI-based techniques offer the advantage of finding global solutions in a fraction of the time taken by classical methods. By leveraging hybrid algorithms, which combine multiple algorithms, we can

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achieve even faster, more reliable, and more effective optimization. Additionally, existing software solutions can be utilized to streamline the optimization process. Optimal operating and economic conditions and optimal performance are the goals of hybrid renewable energy systems' optimization. For example, finding the optimal size leads to the highest performance and economical investment. Many optimization techniques can be selected based on the number of objectives, the type of constraints, the type of variables, the type of equations, and the structure of the problem. Optimizing hybrid renewable energy systems is necessary to face climate change and reduce fossil fuel usage since it can reduce investment costs and increase reliability.

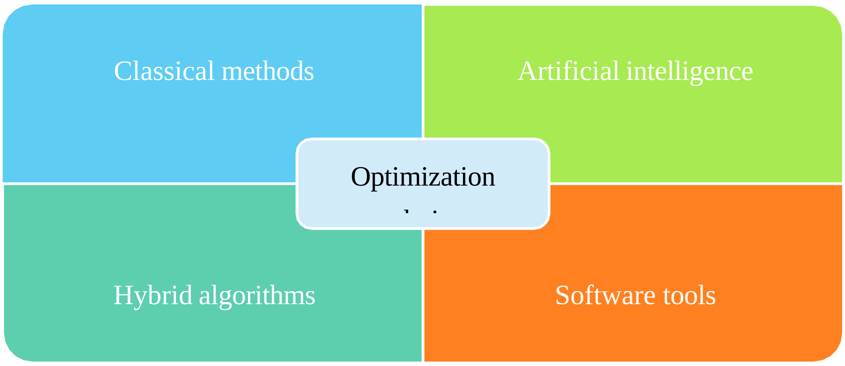

Figure 2. Four types of optimization methods.

Table 3 summarizes the location and application of the 305 papers on case studies studied by (Thirunavukkarasu et al., 2023).

Table 3. The location of case studies studied in the (Thirunavukkarasu et al., 2023).

Continent	Location	Number of published papers	Percentage%	Percentage%
	India	13	4.26%	
	Iran	18	5.90%	
	Vietnam	1	0.33%	
	Iraq	2	0.66%	
	China	2	0.66%	
Asia	Saudi Arabia	4	1.31%	15.70%
	Korea	1	0.33%	
	Malaysia	2	0.66%	
	Philippine	1	0.33%	
	Oman	2	0.66%	
	UAE	1	0.33%	
	Pakistan	1	0.33%	
	Ghana	1	0.33%	
	Kenya	1	0.33%	
	Tunisia	1	0.33%	
	Morocco	3	0.99%	
	Algeria	3	0.99%	
Africa	Egypt	12	3.93%	8.85%
	Nigeria	2	0.66%	
	South Africa	1	0.33%	
	Cameroon	1	0.33%	
	Ethiopia	1	0.33%	
	Benin	1	0.33%	
Europe	Italy	2	0.66%	2.62%
	Spain	1	0.33%	

	UK	2	0.66%	
	France	1	0.33%	
	Turkey	1	0.33%	
	Norway	1	0.33%	
America	USA	3	0.99%	1.64%
	Canada	2	0.66%	
Australia	Australia	1	0.33%	0.33%

As can be understood from Figure 3, among 305 studied papers, just 29.2% applied to a real case, among which 15.7% are in Asia, 8.85% in Africa, 2.62% in Europe, 1.64 in America, and just 0.33% in Australia. So, there is a huge potential for modeling and optimization cases that can be applied in different parts of the world. Even in Asia, where most case studies are located, just 15.7% of 305, i.e., 48 papers, consider modeling and optimizing renewable energy management systems. Also, few papers are applied to the industries discussed in section 1 except power generation. Although power generation case studies are noticeable compared to other industries, they still need more. It leads us to the fact that modeling and optimizing renewable energy management considering real case studies have great potential to be studied.

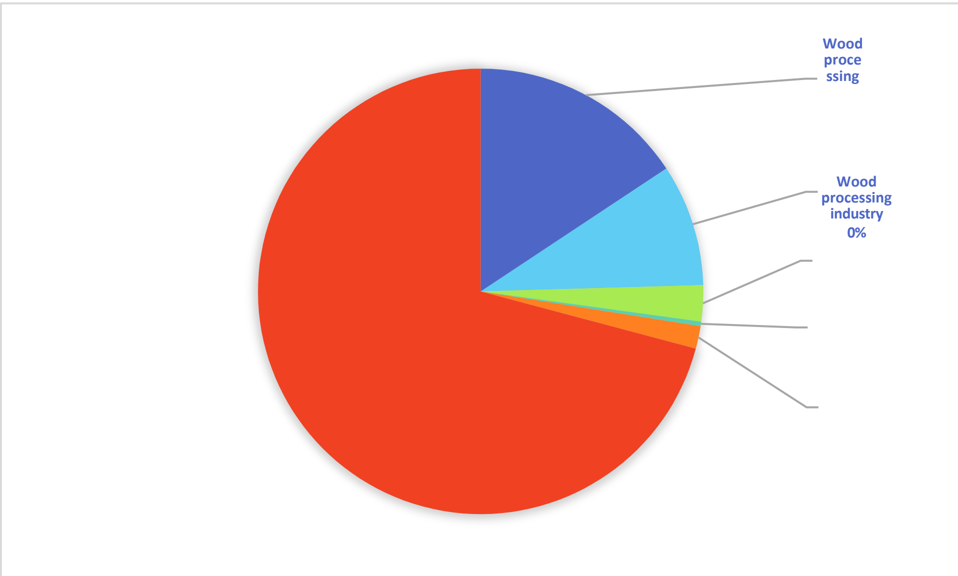

Figure 3. Share of case studies.

5. Economic Growth

This section explores how renewable energy impacts economic growth across various countries and regions. From Brazil's wind power investments to the European Union's sustainability goals, each study highlights the intertwined relationship between renewable energy adoption, economic development, and environmental sustainability. Insights from Turkey, Poland, Bangladesh, and others reveal unique challenges and opportunities in leveraging renewable resources for economic advancement. Through empirical research and modeling, these studies provide valuable perspectives on the transformative role of renewable energy in driving sustainable economic growth globally.

5.1. Brazil

Renewable energy investments, particularly in wind power in Brazil, are set to increase capacity by 450% by 2016, creating 90,000 jobs from 2012 to 2016. Over 74% of these jobs will be in construction and operation stages, offering significant local economic and social benefits (Simas & Pacca, 2013).

the relationships between economic activities, including energy production, trade, and economic growth, were examined using cointegration regression methods in (Hdom & Fuinhas, 2020) study. Electricity generation, GDP, and trade liberalization were found to have both positive and negative impacts on Brazil's economy, while a bi-directional causality was observed between trade openness and energy production. (Magazzino et al., 2021) explored the link between renewable energy consumption and economic growth in Brazil during the Covid-19 pandemic. Using Artificial Neural Networks (ANNs), it investigated whether increased use of renewables could positively influence GDP acceleration, potentially offsetting pandemic impacts. Results suggested that higher renewable energy consumption could sustain economic growth, as it accelerated GDP compared to other energy variables examined.

5.2. Russia

(Lisin et al., 2016) examined the economic prospects and development of power engineering enterprises in the Russian Federation. Forecasted costs for mastering advanced generation equipment production by Russian enterprises could enhance price competitiveness, highlighting the potential for the Russian power industry to dominate domestic and global power generation technology markets with additional resources for development. (Tishkov et al., 2020) reviewed Russian and foreign studies on renewable energy, reflecting the global trend of shifting towards renewable sources due to economic and environmental factors. The study aimed to determine the role of renewable energy in socio-economic security, identifying its potential and applications. Tasks included assessing socio-economic implications, studying foreign policies, and estimating the market growth potential, particularly in rural northern regions. The focus was on developing renewable energy sources in peripheral regions lacking electrical grids, to enhance socio- economic security with an environmental and economic focus.

5.3. EU member countries

EU member countries are actively pursuing climate change mitigation efforts to meet emission targets. (Alola et al., 2019) analyzed key drivers for achieving Sustainable Development Goals in reducing environmental pollution across 16 EU nations from 1997 to 2014, revealing the detrimental impact of non- renewable energy consumption on environmental quality and the positive role of renewable energy consumption in sustainability. It emphasizes the need for diversifying energy portfolios and calls for strengthened commitments toward emission targets for decarbonization and sustainable economic growth. (Melas et al., 2017) explored the relationship between energy security and economic development, highlighting challenges posed by energy source shortages and carbon depletion. It advocated for innovative solutions to ensure uninterrupted energy supply, such as integrating or coordinating energy systems. Using hydro energy storage as a case study, the paper demonstrated how renewable energy sources addressed shortcomings in traditional energy systems, potentially bolstering energy security globally and within European Union countries. (Chovancová & Vavrek, 2020) investigated the relationship between energy, economic growth, and environmental impact, highlighting the significance of renewable energy sources in EU countries. Through a cross-country comparison from 2008 to 2016, it found positive trends in decoupling energy consumption and greenhouse gas emissions from economic growth. Additionally, increased renewable energy production correlated positively with economic growth, suggesting potential for both economic and environmental improvements. The analysis revealed spatial variations within the EU and at the country level. (Radmehr et al., 2021) analyzed economic growth, carbon emissions, and renewable energy consumption in EU countries from 1995 to 2014 using spatial models. It found strong correlations with economic growth, bidirectional links between economic growth and carbon emissions, and unidirectional connections with renewable energy consumption. These findings offer insights for EU policymakers aiming for economic development and sustainability. (Azretbergenova et al., 2021) focusing on renewable energy production in 27 EU countries from 2006 to 2019, explored its impact on employment using panel ARDL tests. Results indicated a positive long-term effect of renewable energy generation on employment, suggesting its potential as a solution to high unemployment rates and emphasizing the need for broader adoption beyond policy recommendations. (Bernath et al., 2021) examined the importance of transitioning to renewable energy sources (RES) to meet EU climate targets. It emphasized the need for information on RES marketability and challenges posed by fluctuating generation. Sector coupling, integrating electricity with other sectors, was highlighted to enhance flexibility and stabilize market prices. The study assessed the impact of sector coupling on RES market values using the Enertile model.

(Shahbaz et al., 2017) investigated how electricity consumption, capital formation, and financial development affected economic growth in Portugal using quarterly data. It found that higher electricity consumption and capital formation increased economic growth, while greater financial development decreased it. The findings emphasize the importance of prioritizing economic growth to boost capital formation and leveraging renewable energy to reduce energy imports and external debt, particularly post- 2008 crisis. The Carpathian region in Ukraine was characterized by substantial renewable energy potential, particularly in small hydropower and geothermal sources, constituting 10.4% of Ukraine's total capacity. (Kravtsiv et al., 2017) aimed to identify opportunities for renewable energy development in the region, emphasizing the necessity for legislative and financial support as per the Ukraine-European Union Association Agreement. Strategies were proposed, including leveraging wind, solar, and geothermal energy, alongside private investment and public-private partnerships, to foster regional development.

In Ukraine, renewable energy accounted for only 4.4% of energy consumption, while vast agricultural and animal waste could potentially produce biofuels. (Pryshliak & Tokarchuk, 2020) highlighted the benefits of biofuel production from waste and identified factors influencing its development using the SWOT analysis method.

(Temiz Dinç & Akdoğan, 2019) examined the relationship between renewable energy production, energy consumption, and economic growth in Turkey from 1980 to 2016. It found bidirectional causality between renewable energy and economic growth, supporting the feedback hypothesis, and a causal link from energy consumption to economic growth. The study highlighted the importance of increasing renewable energy production and reducing energy consumption for Turkey's sustainable development. (Ertay et al., 2013) aimed to assess renewable energy alternatives to address Turkey's energy challenges, considering the country's substantial rise in energy consumption over the past three decades. The study utilized MACBETH and AHP-based multicriteria methods to evaluate renewable energy options, focusing on Solar, Wind, Hydropower, and Geothermal sources with 4 main attributes and 15 sub-attributes under fuzziness.

(Stadniczeńko, 2020) explored Poland's challenge in developing prosumer renewable energy sources amidst its heavy reliance on coal. Despite environmental concerns and EU pressure, Poland faces hurdles in transitioning to renewable energy. Analysis using World Development Indicators data showed a significant negative impact of prosumer renewable energy on Poland's environment, underscoring its economic value. The study also supported the Environmental Kuznets Curve hypothesis, suggesting initial benefits of economic growth followed by negative environmental effects. Adoption of prosumer renewable energy and eco-friendly technologies by the Polish government is vital for improving environmental standards throughout the production process.

5.4. America

(Faturay et al., 2020) examined the multi-regional economic impacts of wind energy farm installations in 10 US states using the US multi-region input-output (US-MRIO) model. The study found a total economic impact of $26 billion, with $3 billion associated with states without new wind energy capacity. Additionally, the installation led to a change in energy consumption, with an increase of about 6952 trillion of BTU in total economic throughput, notably affecting sectors like primary metal manufacturing and machinery manufacturing. (Zeeshan et al., 2021) investigated the relationship between FDI, energy consumption, natural resources, and economic growth in Latin America from 1990 to 2018 using Structural Equation Modeling. Results indicated significant and positive associations among FDI, energy consumption, natural resources, and economic growth. To sustain this growth, governments needed to prioritize reforming energy sectors, adopting renewable resources, and promoting green technologies while facilitating FDI inflows.

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5.5. Asia

(Borzuei et al., 2022) evaluated the impact of energy consumption and prices on renewable energy development in Iran across different economic growth phases using the threshold regression approach. Findings revealed a negative and significant relationship between energy prices and the adoption of renewable energy during periods of high economic growth, attributed to economic instability and mismanagement of resources, among other factors.

(Nosheen et al., 2021) examined CO2 emissions in Asian economies from 1995 to 2017, finding an inverted U-shaped relationship between GDP growth and carbon emissions, supporting the Environmental Kuznets Curve theory. Tourism, energy use, urbanization, trade openness, and financial development were identified as significant contributors to environmental degradation. To mitigate this, the study suggests Asian countries adopt renewable energy sources and eco-friendly technologies to sustainably support tourism while improving economic growth and environmental quality. (Arshad et al., 2020) investigated the impact of economic growth, energy consumption, and natural resources on carbon emissions across 11 countries from 1990 to 2014. Findings revealed that while both renewable and non-renewable energy consumption boosted economic development, natural resources had varied effects across regions. Non-renewable energy consumption and economic growth were linked to increased CO2 emissions, while renewable energy consumption reduced them. The study suggested prioritizing renewable energy sources to mitigate CO2 emissions and improving education and addressing corruption to stimulate economic growth in the studied areas.

(Huq, 2019) investigated the impact of Solar Home System (SHS) programs on the livelihoods of coastal communities in Bangladesh, where electricity access was limited. With 30 percent of the population lacking electricity, renewable energy technologies like solar power offered a solution to the energy crisis. Benefits included savings on kerosene, increased income-generating activities, improved access to education and safety, enhanced social status, and sustainable impacts due to the one-time investment nature of SHS. The findings highlighted the positive socio-economic impact of renewable energy initiatives in Bangladesh. (Sinaga et al., 2019) analyzed the relationship between hydropower energy consumption, economic growth, and carbon dioxide emissions in Malaysia from 1978 to 2016. Using advanced econometrics, it found a long-term relationship between these factors. Hydropower consumption and economic growth inversely impacted carbon dioxide emissions, with economic growth showing a positive effect. The findings suggest policymakers prioritize hydropower energy to mitigate environmental degradation.

(Wahyudi, 2019) focused on achieving the National Energy Policy's 2025 targets for new and renewable energy in Java Island, Indonesia. Using a computable general equilibrium model, energy planning aimed to balance supply and demand. Simulations in the green energy scenario projected a 12% increase in renewable energy by 2025, meeting the policy's 23% target.

(Wang et al., 2021) investigated the relationships among economic growth, financial development, and renewable energy consumption in China from 1997 to 2017. Using the ARDL-PMG model, it analyzed both long-run and short-run impacts at national and regional levels. Results showed that economic growth stimulated renewable energy consumption, while financial development had a negative impact, particularly in western China.

5.6. OECD countries

(Wang & Wang, 2020) investigated the impact of increasing renewable energy consumption on economic growth in OECD countries, focusing on the nonlinear relationship between them. Panel threshold regression models were developed, considering non-renewable energy intensity, urbanization level, and per capita income as threshold variables. Results indicate a positive effect of renewable energy consumption on economic growth, with the relationship being nonlinear.

5.7. Africa

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(Gyimah et al., 2022) examined the relationship between renewable energy consumption and economic growth in Ghana. It utilized Granger causality and mediation models using data from 1990 to 2015. Variables included renewable energy, GDP, foreign direct investment, gross capital formation, and trade. Results revealed a feedback effect between economic growth and renewable energy consumption. The study suggests promoting renewable energy to foster economic growth in Ghana.

5.8. Australia

(Sharma et al., 2020) examined challenges caused by high PV penetration, such as financial losses due to overvoltage-induced PV curtailment. It quantified impacts on reverse power flow, overvoltage, and undervoltage using a South Australian distribution feeder. Results showed reduced undervoltage but increased overvoltage, leading to inverter shutdowns. Financial losses from PV curtailment were estimated using different pricing perspectives. The study emphasized the need to consider these losses in network upgrade cost-benefit analyses amid evolving renewable energy frameworks.

Table 4. summarize these studies.

Table 4. Case studies on renewable energy systems focusing on economic growth in different countries.

Country/Region	Study	Focus
Brazil	Simas & Pacca (2013)	Renewable energy investments and job creation
	Hdom & Fuinhas (2020)	Relationship between economic activities, energy production, and trade
	Magazzino et al. (2021)	Link between renewable energy consumption and economic growth during Covid-19
Russia	Lisin et al. (2016)	Economic prospects of power engineering enterprises
	Tishkov et al. (2020)	Role of renewable energy in socio-economic security
European Union (EU)	Alola et al. (2019)	Drivers for achieving Sustainable Development Goals
	Melas et al. (2017)	Relationship between energy security and economic development
	Chovancová & Vavrek (2020)	Relationship between energy, economic growth, and environmental impact
	Radmehr et al. (2021)	Analysis of economic growth, carbon emissions, and renewable energy consumption
	Azretbergenova et al. (2021)	Impact of renewable energy production on employment
	Bernath et al. (2021)	Importance of transitioning to renewable energy sources
	Shahbaz et al. (2017)	Impact of electricity consumption and capital formation on economic growth
Ukraine	Kravtsiv et al. (2017)	Opportunities for renewable energy development in the Carpathian region
	Pryshliak & Tokarchuk (2020)	Benefits of biofuel production from waste

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Turkey	Temiz Dinç & Akdoğan (2019)	Relationship between renewable energy production, energy consumption, and economic growth
	Ertay et al. (2013)	Assessment of renewable energy alternatives
Poland	Stadniczeńko (2020)	Development of prosumer renewable energy sources
Latin America	Zeeshan et al. (2021)	Relationship between FDI, energy consumption, natural resources, and economic growth
Iran	Borzuei et al. (2022)	Impact of energy consumption and prices on renewable energy development
Asian Economies	Nosheen et al. (2021)	Analysis of CO2 emissions and economic growth
	Arshad et al. (2020)	Impact of economic growth, energy consumption, and natural resources on carbon emissions
Bangladesh	Huq (2019)	Impact of Solar Home System programs on coastal communities
Malaysia	Sinaga et al. (2019)	Relationship between hydropower energy consumption, economic growth, and carbon dioxide emissions
Indonesia	Wahyudi (2019)	Achieving National Energy Policy targets for renewable energy
OECD Countries	Wang & Wang (2020)	Impact of increasing renewable energy consumption on economic growth
China	Wang et al. (2021)	Relationships among economic growth, financial development, and renewable energy consumption
Ghana	Gyimah et al. (2022)	Relationship between renewable energy consumption and economic growth
Australia	Sharma et al. (2020)	Challenges of high PV penetration and financial losses
United States	Faturay et al. (2020)	Multi-regional economic impacts of wind energy farm installations

6. Conclusion

In conclusion, the benefits of using renewable energy resources, including significantly reduced carbon emissions, are contributing to energy in various industrial applications. Wood processing, pulp and paper, food and beverage, dairy, chemical and petrochemical, agricultural, iron and steel, mining, textile, and transportation are some of the industries in which renewable energy resources can be used. Optimizing energy management systems is essential to reduce costs and increase the reliability of renewable energy systems. This review study concluded that governments should support using renewable energy resources with smart policies for both environmental sustainability and economic growth concurrently. The studies presented in the section on economic growth highlight the critical role of renewable energy in fostering economic development while mitigating environmental degradation. The insights of this study also observed the lack of interest by some nations on the importance of continued research, policy innovations, and international collaborations to accelerate the global transition toward sustainable energy systems and resilient economies. Future studies should focus on assessing the long-term impacts of renewable energy resource integration,

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exploring innovative technologies for enhancing renewable energy generation and storage, and evaluating the socio-economic benefits of renewable energy adoption across diverse industrial sectors.

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