EEJOURNALS OPEN ACCESS

EURASIAN EXPERIMENT JOURNAL OF ENGINEERING

(EEJE) ISSN: 2992-409X

@EEJE PUBLICATIONS Volume 5 Issue 1 2025

Renewable Energy Policy: Comparative Analysis of Global Approaches

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ABSTRACT

This study presents a comprehensive comparative analysis of renewable energy policies across global regions, highlighting the frameworks, instruments, and implementation strategies employed to facilitate the energy transition. It examines the evolution of renewable energy governance through regulatory, market-based, and fiscal policy mechanisms, focusing on their adaptability to technological innovation and regional diversity. By evaluating case studies from the United States, Germany, and China, the research identifies patterns in policy success, institutional challenges, and investment behavior. The study further investigates the environmental and economic implications of renewable energy deployment, assessing how policy incentives support technological scalability and investor confidence while mitigating emissions and promoting sustainable development. The findings underscore the need for cohesive, flexible, and innovation-driven policy instruments to ensure equitable and efficient renewable energy integration globally.

Keywords: Renewable energy policy, feed-in tariffs, market-based instruments, regulatory frameworks, technological innovation, energy transition, environmental sustainability, comparative policy analysis.

INTRODUCTION

Renewable energy policies represent an evolving landscape characterized by multiple perspectives and parallel developments. Core approaches encompass end goals, market impacts, and implementation mechanisms, each offering distinct insights into overall evolution. The trajectory advanced along concurrent tracks: early policies such as PURPA emphasized programmatic efficacy, whereas later instruments like renewable energy certificates (RECs) permit utilities to fulfill portfolio standards by procuring credits in lieu of constructing facilities. An international policy appraisal concludes that current frameworks inadequately support the deployment of technically feasible renewable-energy technologies at scale. Multiple governance challenges emerge from the complexity of sufficiently addressing these issues and managing the ongoing energy transition at the global level. When considered as an average mandate, the total portfolio-standard requirement is circa 12% by 2020. Policies accelerate since the late 1990s, with 28 in place and 19 pending, exhibiting a balanced mix of quantitative targets, incentives, and advocacy documents. Classes of policy instruments constitute three broad categories: (1) regulatory instruments, (2) market-based instruments, and (3) others they characteristically include taxes and subsidies. More than half of these policies intend to benefit from technology innovations; a figure that provides an important benchmark for comparison and lessons learned on forms of renewable energy policy and future directions. A comparative evaluation thus rests on technological innovation and regional diversity. The analysis presents an overview of global trends and a set of specific policies at the national level, which jointly sketch the broad articulation of renewable-energy support worldwide. It proceeds by examining technological innovations completed by a snapshot of recent regional frameworks. Concepts and insights from these two domains allow a close look at the emerging structure, success, and prospects of current renewable-energy policy at distinct geographic scales [1, 2].

Global Overview of Renewable Energy

Governments worldwide have pursued policies and regulations incentivizing the generation and use of renewable energy, bringing about a shift from traditional centralized energy systems to decentralized, low-emission, and low-

risk operations. Renewable energy systems encompass sources such as wind, photovoltaic, geothermal, ocean, biofuels, hydropower, solar thermal and stationary fuel cell power. Within the broad category of renewable energies lie sub-sectors including biomass, solar, geothermal, hydropower, tidal, and wind energies, each subjected to distinct policies and regulations that influence various communities and stakeholders differently. This diversity complicates policymaking, as measures aiming to support one type of renewable energy can inadvertently place others at a disadvantage. For instance, in Florida, wind energy remains economically unfeasible due to modest wind speeds, whereas solar energy corresponds closely with peak energy demands, rendering onshore wind unsuitable as a renewable partner [3, 4].

Policy Frameworks

Renewable energy policy is a dynamic field marked by complexity and diverse approaches centered around market deployment and development mechanisms. These approaches offer unique perspectives on development, prioritizing economic and environmental benefits, which drive legislative support and industry strategies. The primary aim is to enhance effectiveness and equity while expanding market opportunities through ESS systems. While objectives remain stable, they shift based on political, technological, and geographical factors, emphasizing variations in outcomes. Each nation's trajectory reflects its historical context and employs methods like buyouts, feed-in tariffs, taxes, and regulatory reforms to foster growth. Common program types and instruments showcase a converging evolution in policy development. The adaptability of policy approaches is critical for success, transitioning from supporting specific technologies to broader goals of cost reduction and diversification. Models focusing on quality of life, equity, justice, and economic development help contextualize future trajectories. Renewable energy promotion relies on targeted support instruments such as subsidies and feed-in tariffs and frameworks for electricity markets, which act as indirect promotion tools. Installed capacity serves as a more relevant indicator of market deployment than actual electricity production. Research supports feed-in tariffs as effective in promoting efficiency and extending similar approval to tender schemes, but highlights that some policies fail to generate a renewable market. While foundational, investment programs require additional measures to cultivate growth. Mercantilist interventions may lack large-scale deployment mechanisms, whereas feed-in tariffs and tenders support genuine markets. Quotas adjust investment volumes, with carbon pricing and capacity mechanisms generally correlating with lower deployment values due to their push-effect nature. Target mechanisms indicate growth potential when allied with functional markets, while certificates and tenders denote success only at set targets, becoming inflexible when these targets are unmet. Evidence points to the prominence of established support mechanisms in actual policy, raising concerns about the efficacy of other financial incentives when lacking market support. Since conditions vary by investor perspectives and market factors, the differing outcomes of single policies across nations and technologies do not contradict the presence of typical patterns associated with specific instruments [5, 6].

Regulatory Approaches

Differentiated policy frameworks promote diverse categories of renewable energy at different stages of technological maturity and in different locations. Support for emerging renewable energy technology comes primarily from public funds for research, development and demonstration. Early-phase renewable energy technologies are supported by public funds for research, development, demonstration (RD&D) and education. Many policies support renewables in their demonstrated form. Technology-push policies are demand-pull instruments meant to create a market for renewable energy technologies. Demand-pull policies create a market for already demonstrated renewable energy technologies and can be categorized in several ways. Regulatory approaches aim to establish social norms for the accelerated adoption of renewables. Regulations may either accelerate the adoption of renewables or the quality of electricity delivery. Several nations have adopted renewable portfolio standards, which stipulate a minimum level of production or capacity by renewable energy technologies. In principle, portfolio standards establish a demand-pull effect regardless of the subsidy level implied by prices. Standards and quotas can also be explicit, such as an obligation imposing the purchase of a minimum share of electricity produced by renewables or an obligation for distributors to allocate a minimum percentage of revenues or profits for this purpose. Financial support generally aims to increase the profitability of renewable energy sources and can be differentiated into price-related and investment-related incentives. Price-related support includes feed-in tariffs, price subsidies and net metering. Investment-related support includes capital subsidies (or fiscal incentives) and concessional loans [7, 8].

Market-Based Instruments

Market-based mechanisms leverage supply and demand to channel private investments into renewable energy. Key examples include feed-in tariffs, quota systems, and tendering schemes. These instruments provide insights into renewable energy design and performance. Feed-in tariffs offer guaranteed contracts with premium prices, ensuring long-term price certainty for producers. They thrive in favorable energy planning conditions, particularly in emerging economies like China and India, and are relatively simple and cost-effective to administer.

By mitigating the risks linked to regulatory incentives, feed-in tariffs enhance investment appeal by assuring significant returns; their market penetration correlates strongly with tariff levels and duration. Many developers, including small-scale operators, are drawn to these schemes, although project financing remains a challenge in developing countries. Quota mechanisms, such as renewable energy certificates, mandate that producers derive a set percentage of market sales from renewables. These certificates are traded in markets governed by fixed exchange rates, with price fluctuations influencing investment risk and appeal. Quotas generally attract larger developers with easier access to capital, but their success largely hinges on policy design. Complementary processes like permitting and land-use planning are essential for successful large-scale deployment. Tendering schemes utilize competitive auctions to regulate new project entries under specified conditions, allowing governments to manage project numbers and comply with deployment targets. However, such systems expose developers to risks regarding licenses, permits, and government contract fulfillments, making them more suitable for countries with credible governments and planning stability [9, 10].

Subsidies and Incentives

Governments use a range of subsidies and incentives in support of renewable energy. Many subsidies overlap; for example, producers receiving feed-in tariffs might also qualify for tax reductions or reductions on royalty payments. These financial incentives serve either to promote the use of renewables or to encourage conservation. Developing countries such as China focus on renewable energy as a cost-saving mechanism to support development, while developed countries including the United States often treat it as an environmental issue. China remains committed to expanding its renewable-energy capabilities, implementing a package of policy measures that includes tax reductions, feed-in tariffs for grid-connected renewable electricity, research incentives, and subsidies for energy-conservation technologies. The government provides significant assistance to domestic renewable-energy industries. Government support employs multiple forms, which differ by industry and by the degree and type of government intervention [11, 12].

Regional Case Studies

The United States considered establishing a national renewable portfolio system (RPS) to synchronize program design across states; however, the initiative failed to pass. Credit trading markets associated with RPS programs could potentially be more effective if implemented nationally, as they alleviate the financial burdens associated with renewable energy development. Countries that ratified the Kyoto Protocol employed trading in compliance certificates to meet emission reduction targets. Wind energy projects require substantial front-end investment and entail long payback periods. Supply-side initiatives consequently reduce initial barriers to diffusion and were preferred by both regional states and the Central Government. California and Germany have emerged as leaders in the adoption of environmental policies, exerting influence at the federal and European Union levels, respectively. Both regions operate within larger federal systems and have actively formulated policies to promote renewable energy. Despite California's pioneering stance, the United States has exhibited some ambivalence toward its policies. Germany leverages its membership in the European Union to advance and legitimize national policy objectives, though it also confronts tensions related to national sovereignty. Comparative analysis of these models offers policymakers a valuable benchmark for understanding the complex interplay between interests and institutional frameworks that shape renewable energy development [13, 14].

Technological Innovations

Amongst the many roles of a policy maker, encouraging the rapid uptake of novel technology remains an enduring challenge. Nowhere is this more apparent than the widespread desire for carbon-neutral energy generation. The widespread desire for carbon neutral energy is evident. Although their overall effectiveness is yet to be fully elucidated, very few would dispute the utility of policies that favour the research, development and deployment of carbon-neutral or renewable energy technologies. Policy choices for governments wishing to encourage investment in renewable energy technologies span subsidies, pricing structures and long-term purchase arrangements alike. Justified largely on the desire to meet carbon reduction targets, low-carbon technology programmes are now widespread, with communities worldwide deploying wind, solar, biomass, tidal, wave and geothermal solutions both through governments and municipalities. Renewable energy technologies represent one option that may be instrumental in simultaneously addressing global climate change, energy security and energy poverty. There are concerns, however, that these technologies will necessarily remain niche solutions unless their deployment is supported through sustained efforts to address issues of scale and competitiveness [15, 16].

Economic Impacts

Empirical analysis shows that renewable energy policies enhance investor appeal, which, in turn, benefits respective economies. Nonetheless, the shrinking technologies by capacity have affected employment factors such as quantity and quality, which are crucial to economic growth. Additional insights reveal that post-implementation shifts continue to influence economic rates, suggesting the need for historical policy flexibility and cognizance of evolving aspects. The primary economic stimulus of concern encompasses the economic boost facilitated by

renewable energy investment, which exhibits strong positive correlations with economic growth and the Global Competitiveness Index, potentially contributing to the employment effect. The policies considered herein enhance investor confidence and demonstrate efficiency by applying cost-effective solutions for fulfilling renewable energy obligations. Embedded in policy prioritisation and implementation mechanisms, this principle requires a vibrant economy. Concurrently, renewables tend to lower electricity costs by dampening spikes, thereby improving economic metrics. By contrast, the congruence of economic support with effective policy implementation remains an essential yet unfinished endeavour [17, 18].

Environmental Considerations

Unlike most electricity sources, some renewable energy technologies provide access to clean energy services essential for development. They can be deployed swiftly and cost-effectively to meet household and local demands before the widespread availability of grid electricity at the national level. Several other environmental benefits associated with renewable energy sources exist. Because most renewable energy technologies have an energy payback time (the time required to generate as much energy as is used during their production) of less than two years, they contribute very little to global warming over their operational life. Large-scale hydropower, however, is not considered renewable energy due to watershed destruction and greenhouse gas emissions from flooded vegetation. Geothermal drill rigs have been observed to emit high levels of noxious gases such as ammonia, hydrogen sulphide and mercury. However, modern drill rigs clean these emissions before release so that in most cases the emissions are reduced to safe levels 60well below those that would be produced from fossil fuels. Biofuels such as biodiesel significantly reduce the rate of nitrates entering water supplies, a phenomenon commonly encountered in diesel fuel spills. Large-scale use of biomass can, however, lead to land use conflicts and diminish sustainability [19, 20].

Social Dimensions

Beyond supporting higher levels of clean energy investment, the social dimensions of policy form an increasingly important component of clean energy governance. The energy transition is not simply a technical process but an inherently political effort involving numerous venues and challenges over how to balance competing interests. Equity occupies a prominent place in these considerations. The resulting focus on efficacy and efficiency has led to other policy considerations, such as equity, to go largely overlooked. Clean energy policies create winners and losers among competing technologies, ratepayers, taxpayers, and stakeholders. Advocates of more equitable transitions thus emphasize a fair distribution of goods and burdens, a meaningful voice in decision-making, broader ownership and opportunities, access to affordable and reliable energy, and a sustainable environment [21, 22].

Policy Challenges and Barriers

Despite a wide array of policy mechanisms, addressing climate change through renewable energy expansion remains challenging for both policymakers and investors. Most industrialized nations have adopted mechanisms such as feed-in tariffs, tender regimes, tax incentives, and renewable portfolio standards. Recent empirical assessment of these policies in thirty-five countries offers a global overview of their impact on power sector deployment. Policy design and implementation markedly influence their effectiveness and efficiency in fostering renewable energy. Feed-in tariffs emerge as the most effective, as they align closely with investor interests. Many other incentive programs exhibit significant variation in structure and success, while the investment climate often suffers from incoherence and lacks incentives for ongoing service and maintenance of generation facilities. This volatility increases investment risk, prompting investors to demand higher returns and discouraging financing for innovative technologies. From a policy viewpoint, several persistent barriers impede expansion. Firstly, incumbent interests can strongly influence the form and content of renewable energy policies. In some countries, these vested interests have transferred market risk to investors by structuring initiatives that allow compliance through purchasable financial instruments rather than mandatory facility development. Secondly, many incentive mechanisms remain fixed at rates tied to artificial baselines that neither reflect actual costs nor project future trends. Thirdly, despite the reported existence of thousands of global instruments, regional discrepancies and poor coordination at the international level continue to pose significant obstacles to renewables growth [23, 24].

Future Trends in Renewable Energy Policy

Renewable energy policy is undergoing notable transformations as jurisdictions adapt to evolving economic and technological landscapes. Policies are becoming more market-oriented; examples include a growing emphasis on rooftop solar and a shift from feed-in tariffs to feed-in premiums. Rapid change characterized by increasing hybridity, as policymakers adopt diverse approaches to support renewable energy expansion, is evident in both the United States and Europe. These developments reflect broader trends toward aligning policy instruments with maturing markets and declining technology costs. Establishing robust market frameworks and fostering partnerships with key stakeholders are critical to advancing renewable energy development. In industrialized countries such as China, Germany, and India, research identifies mechanisms for overcoming barriers to

innovation and diffusion of cleaner technologies, highlighting the importance of sustainable innovation policy regimes and effective intermediation. Financing models, including the Clean Development Mechanism, and adaptive instruments like tradable renewable energy certificates illustrate approaches to manage market uncertainties and risk perceptions. Additional insights into sector transformation, energy-efficiency programs, and project-specific case studies provide guidance for formulating policies that stimulate clean energy investment and deployment [25, 26].

CONCLUSION

The comparative analysis of global renewable energy policies reveals a multifaceted and evolving landscape shaped by diverse national priorities, institutional capacities, and technological contexts. While regulatory and market-based instruments like feed-in tariffs, quota systems, and subsidies have achieved varying degrees of success, their effectiveness largely depends on local governance, financial viability, and complementary frameworks. Regional case studies demonstrate that countries with stable institutions and proactive policy environments such as Germany and parts of the United States are better positioned to scale renewable technologies and achieve environmental goals. Technological innovation, supported by consistent policy incentives, remains a critical lever for long-term transformation. However, to achieve global energy targets, future policies must prioritize flexibility, equity, and integrative planning that aligns climate commitments with economic and social development objectives. Only through coordinated and adaptive strategies can renewable energy fulfill its potential as a cornerstone of a sustainable global energy future.

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CITE AS: Kibibi Wairimu H. (2025). Renewable Energy Policy: Comparative Analysis of Global Approaches. EURASIAN EXPERIMENT JOURNAL OF ENGINEERING, 5(1):54-59.