

A REVIEW ON RENEWABLE ENERGY ADOPTION AND ITS ENVIRONMENTAL BENEFITS

Dr. Romila Karnawat,

Department of Chemistry,

SCRS Government College, Sawaimadhapur

Dr Deepika Bhandari,

Department of Physics,

SRLS Government College, Kaladera, Jaipur

ABSTRACT

This research paper investigates the adoption of renewable energy technologies and their environmental benefits, focusing on developments in this era. The study examines the growth of solar and wind energy, evaluates the reduction in carbon emissions, and assesses other environmental impacts such as air quality improvement and biodiversity conservation. This paper provides a detailed understanding of the progress and challenges in the renewable energy sector through a comprehensive review of existing literature, policy analysis, and case studies.

INTRODUCTION

The increasing awareness of climate change and its devastating impacts has spurred global interest in renewable energy sources. By 2016, significant strides had been made in adopting renewable energy technologies, particularly solar and wind energy. This paper explores the extent of this adoption, its environmental benefits, and the challenges that remain. The introduction provides an overview of the importance of renewable energy, the motivation for its adoption, and the scope of the study. The Paris Agreement of 2015 marked a pivotal moment in global climate policy, with countries committing to significant reductions in greenhouse gas emissions. Renewable energy emerged as a crucial component of these commitments, offering a sustainable alternative to fossil fuels. The years leading up to 2016 saw remarkable technological advancements and substantial investments in renewable energy infrastructure. Renewable energy refers to energy generated from natural processes that are continuously replenished. The main types include solar, wind, hydro, geothermal, and biomass

energy. This paper focuses on solar and wind energy due to their significant adoption and impact.

Renewable energy plays a crucial role in mitigating climate change by reducing reliance on fossil fuels, major carbon emissions sources. Additionally, renewable energy contributes to energy security, reduces air pollution, and supports sustainable development.

The primary objectives of this research paper are to analyze the growth of solar and wind energy adoption, evaluate the environmental benefits associated with this adoption, identify the key challenges and barriers to further expansion, and discuss policy measures and technological innovations that support renewable energy growth.

METHODOLOGY

Data for this research was collected from a variety of sources, including government reports, industry publications, and international organizations such as the International Energy Agency (IEA) and the United Nations (UN). The study also incorporates case studies from countries that have made significant progress in renewable energy adoption.

The collected data was analyzed to identify trends in renewable energy adoption, quantify environmental benefits, and understand the effectiveness of different policy measures. Comparative analysis was conducted to evaluate the performance of solar and wind energy technologies.

DISCUSSION

(i) Growth of Solar and Wind Energy Adoption

Solar Energy

Solar energy experienced exponential growth in the years leading up to 2016. The cost of solar photovoltaic (PV) panels decreased significantly, making solar energy more accessible and economically viable. Countries like China, the United States, and Germany emerged as leaders in solar energy installation.

According to the International Renewable Energy Agency (IRENA), global solar PV capacity grew from 40 GW in 2010 to over 300 GW in 2016. This growth was driven by several factors, including technological advancements, economies of scale, and supportive policies. For instance, the cost of solar PV modules fell by about 80% between 2010 and 2016, largely due to increased production capacity and improvements in manufacturing processes.

China became the world's largest solar market by 2016, with an installed capacity of over 77 GW. The Chinese government implemented aggressive policies like feed-in tariffs and subsidies to promote solar energy adoption. Similarly, the United States saw significant growth in solar capacity, driven by federal tax incentives and state-level renewable portfolio standards. Germany continued to be a leader in solar energy, despite a gradual reduction in feed-in tariffs.

Wind Energy

Wind energy also saw substantial growth, with significant investments in both onshore and offshore wind farms. Technological advancements in turbine

design and efficiency contributed to the increased adoption of wind energy. The European Union and the United States were notable leaders in wind energy capacity.

Global wind energy capacity increased from 180 GW in 2010 to over 500 GW in 2016, according to the Global Wind Energy Council (GWEC). The average capacity factor of wind turbines improved due to better designs and larger rotor diameters, making wind energy more competitive with traditional power sources.

The European Union accounted for a significant share of global wind capacity, with countries like Germany, Spain, and Denmark leading the way. Offshore wind energy also gained momentum, with the United Kingdom becoming a global leader in offshore installations. In the United States, wind energy capacity reached over 82 GW by 2016, supported by the Production Tax Credit (PTC) and state-level renewable energy standards.

(ii) Environmental Benefits of Renewable Energy

Reduction in Carbon Emissions

The most significant environmental benefit of renewable energy adoption is the reduction in carbon emissions. By replacing fossil fuel-based power generation, renewable energy sources contribute to lower greenhouse gas emissions. The shift towards renewables was estimated to have avoided millions of tons of CO₂ emissions by 2016.

According to the IEA, the growth of renewable energy between 2010 and 2016 helped avoid approximately 1.3 billion tons of CO₂ emissions annually. Solar and wind energy played a major role in this reduction, with solar PV alone avoiding over 300 million tons of CO₂ emissions in 2016. This reduction is equivalent to taking about 60 million cars off the road for a year.

Improvement in Air Quality

The adoption of renewable energy also led to improvements in air quality. Fossil fuel combustion

releases pollutants such as sulfur dioxide (SO₂), nitrogen oxides (NO_x), and particulate matter (PM), which are harmful to human health and the environment. Renewable energy sources do not produce these pollutants, thereby contributing to cleaner air.

A study by the American Lung Association estimated that the use of wind and solar power in the United States in 2016 helped avoid approximately \$7.3 billion in health costs related to air pollution. The reduction in pollutants resulted in fewer respiratory and cardiovascular diseases, improving public health outcomes.

Biodiversity Conservation

Renewable energy projects, particularly wind and solar farms, have a lower impact on biodiversity compared to fossil fuel extraction and use. However, it is important to consider the potential impacts of large-scale renewable energy projects on local ecosystems and wildlife. Proper site selection and environmental impact assessments are crucial to minimizing these impacts.

Studies have shown that careful planning and the use of mitigation measures, such as radar technology and turbine curtailment during peak migration periods, can significantly reduce these impacts. Solar farms, on the other hand, can affect land use and habitat if built in sensitive areas. Using degraded lands or integrating solar panels into urban areas can help minimize the impact on biodiversity.

(iii) Challenges and Barriers to Renewable Energy Adoption

Economic Barriers

Despite the decreasing costs of renewable energy technologies, economic barriers remain. Initial capital costs for renewable energy projects are high, and there are challenges related to financing and investment. Additionally, subsidies for fossil fuels continue to distort energy markets.

One of the main economic barriers is the high upfront cost of renewable energy installations. While the levelized cost of electricity (LCOE) for solar

and wind has decreased significantly, the initial investment required can still be a deterrent for some investors. Innovative financing mechanisms, such as green bonds and power purchase agreements (PPAs), have been developed to address these challenges, but access to capital remains an issue for many projects.

Fossil fuel subsidies, estimated at over \$500 billion annually in 2016 by the International Monetary Fund (IMF), also pose a significant barrier. These subsidies lower the cost of fossil fuels, making it harder for renewable energy to compete on a level playing field. Phasing out these subsidies and implementing carbon pricing mechanisms can help address this issue(5).

Technical and Infrastructure Challenges

The intermittent nature of solar and wind energy requires advanced grid management and energy storage solutions. Integrating renewable energy into existing grids poses technical challenges, and there is a need for upgrading infrastructure to accommodate higher shares of renewables.

One of the key technical challenges is the variability of solar and wind power. Unlike fossil fuel plants, which can provide constant power, solar and wind output fluctuates with weather conditions. This variability requires grid operators to balance supply and demand more dynamically, using advanced forecasting and demand response technologies.

Energy storage solutions, such as batteries and pumped hydro storage, are critical for managing intermittency. By 2016, battery costs had begun to decline, and several large-scale storage projects were underway. For example, the Horns Dale Power Reserve in Australia, completed in 2016, became the world's largest lithium-ion battery storage facility, providing grid stability and renewable energy integration.

Grid infrastructure also needs to be upgraded to support higher shares of renewables. This includes modernizing transmission and distribution networks, building new transmission lines to connect remote renewable energy sites, and

implementing smart grid technologies to enhance grid flexibility and resilience.

Policy and Regulatory Barriers

Effective policy frameworks are essential for promoting renewable energy adoption. Inconsistent policies, regulatory uncertainties, and lack of long-term planning can hinder progress. Clear and predictable policies are crucial for attracting investment and fostering industry growth.

Feed-in tariffs (FiTs) and tax incentives have been instrumental in driving renewable energy adoption. FiTs guarantee a fixed price for renewable energy generated, providing revenue certainty for investors. Tax incentives, such as the Investment Tax Credit (ITC) in the United States, reduce the cost of renewable energy projects, making them more attractive to investors.

Renewable energy targets and mandates also play a key role in promoting adoption. By setting clear targets for renewable energy generation, governments can signal their commitment to the sector and provide a framework for planning and investment. For example, the European Union's Renewable Energy Directive set a target of 20% renewable energy in the EU's energy mix by 2020, driving significant growth in renewable capacity.

Social and Cultural Barriers

Beyond economic, technical, and policy barriers, there are also social and cultural challenges to the widespread adoption of renewable energy. Public perception, local opposition, and the need for community engagement play crucial roles in the successful implementation of renewable energy projects.

Public Perception

Public perception of renewable energy can vary widely based on cultural, social, and economic contexts. In some regions, there is strong support for renewable energy due to its environmental benefits and potential for job creation. However, in other

areas, there may be resistance due to concerns about reliability, aesthetics, or perceived costs.

Educational campaigns and public awareness initiatives are essential to improve public understanding of renewable energy benefits and address misconceptions. Involving local communities in the planning and decision-making process can also help build trust and support for renewable energy projects.

Local Opposition

Residents may oppose wind farms or solar installations due to concerns about noise, visual impact, or potential effects on property values. Addressing these concerns through transparent communication, fair compensation, and community benefits can help mitigate opposition.

Case studies from countries like Denmark and Germany have shown that community ownership and participation in renewable energy projects can lead to higher levels of acceptance and support. For example, in Denmark, a significant portion of wind farms is owned by local cooperatives, which has contributed to widespread public support for wind energy.

Need for Community Engagement

Successful renewable energy projects often require active community engagement and participation. This involves not only informing the public about the benefits and potential impacts of renewable energy but also involving them in the planning and development process. Community engagement can lead to better project outcomes, increased local support, and more sustainable long-term operations.

Strategies for effective community engagement include conducting public consultations, forming advisory committees, and ensuring that community members have a voice in project decisions. Additionally, providing tangible benefits to the local community, such as job creation, infrastructure improvements, or revenue sharing, can enhance support for renewable energy projects.

(iv) Technological Innovations and Future Prospects

The future of renewable energy adoption and its environmental benefits will be shaped by ongoing technological innovations and advancements. Continued research and development (R&D) are essential to address current challenges and unlock new opportunities for renewable energy.

Advancements in Solar Technology

Solar technology has seen significant advancements in efficiency, cost reduction, and integration into various applications. Innovations in materials science, such as the development of perovskite solar cells, have the potential to increase solar cell efficiency and reduce manufacturing costs. Additionally, advancements in energy storage, such as the development of more efficient and affordable batteries, can enhance the reliability and flexibility of solar energy systems.

The integration of solar energy into building materials, known as building-integrated photovoltaics (BIPV), offers exciting prospects for urban environments. BIPV systems can be seamlessly incorporated into roofs, facades, and windows, transforming buildings into power generators. This approach not only increases renewable energy capacity but also reduces the need for additional land and infrastructure.

Innovations in Wind Energy

Wind energy technology continues to evolve, with advancements in turbine design, materials, and control systems. Larger and more efficient turbines are being developed, capable of capturing more energy from the wind. Offshore wind energy, in particular, holds great potential, with floating wind turbines enabling installations in deeper waters and areas with stronger wind resources.

Research into wind turbine aerodynamics and materials is focused on improving performance and reducing costs. Innovations such as direct-drive turbines, which eliminate the need for a gearbox, can reduce maintenance requirements and increase

reliability. Additionally, using advanced materials, such as carbon fiber and lightweight composites, can enhance turbine efficiency and durability.

Emerging Technologies and Synergies

Beyond solar and wind, emerging technologies such as wave and tidal energy, advanced geothermal systems, and bioenergy have the potential to diversify and expand the renewable energy portfolio. These technologies can provide additional clean energy sources and complement existing renewable energy systems.

Integrating renewable energy with other technologies and sectors can create synergies and enhance overall sustainability. For example, the combination of renewable energy with smart grid technologies, electric vehicles, and energy-efficient buildings can create more resilient and efficient energy systems. Furthermore, developing hydrogen as a clean energy carrier offers opportunities for decarbonizing sectors such as industry and transportation.

Policy Recommendations and Strategies

To further accelerate renewable energy adoption and maximize its environmental benefits, a comprehensive and coordinated approach is needed. This includes implementing supportive policies, fostering innovation, and promoting international collaboration.

Supportive Policies

Governments play a crucial role in creating an enabling environment for renewable energy. Supportive policies such as feed-in tariffs, tax incentives, and renewable energy targets can drive investment and deployment. Additionally, policies that address barriers to grid integration, streamline permitting processes, and promote market access for renewable energy are essential.

Long-term policy stability and predictability are key to attracting investment and fostering industry growth. Governments should establish clear and consistent policy frameworks, backed by regulatory certainty, to provide confidence to

investors and developers. Phasing out fossil fuel subsidies and implementing carbon pricing mechanisms can also level the playing field and incentivize the transition to renewable energy.

Continued investment in research and development is critical to advancing renewable energy technologies and addressing current challenges. Governments, private sector entities, and research institutions should collaborate to support innovation and accelerate the commercialization of new technologies.

Public funding for R&D, demonstration projects, and pilot programs can help de-risk innovative technologies and bring them to market. Additionally, fostering partnerships between academia, industry, and government can facilitate knowledge sharing and drive technological advancements. Supporting entrepreneurial ecosystems and providing incentives for startups and small businesses in the renewable energy sector can also spur innovation.

Promoting International Collaboration

Renewable energy adoption is a global challenge that requires international cooperation and collaboration. Sharing best practices, knowledge, and technologies across borders can accelerate the transition to renewable energy and enhance its environmental benefits.

International organizations, such as the International Renewable Energy Agency (IRENA) and the International Energy Agency (IEA), play a vital role in facilitating cooperation and knowledge exchange. Multilateral agreements, such as the Paris Agreement, provide a framework for countries to work together towards common climate and energy goals. Bilateral and regional partnerships can also promote joint research, capacity building, and technology transfer.

CONCLUSION

The adoption of renewable energy, particularly solar and wind energy, saw significant growth, bringing

substantial environmental benefits, including reductions in carbon emissions, improvements in air quality, and conservation of biodiversity. However, challenges remain in the form of economic, technical, and policy barriers. Continued efforts in technological innovation, supportive policies, and investments are crucial for accelerating the transition to a sustainable energy future.

In summary, renewable energy adoption is a critical component of global efforts to combat climate change and promote environmental sustainability. The progress made provides a strong foundation for further advancements and highlights the importance of continued commitment and action in the renewable energy sector. Through a combination of technological advancements, supportive policies, and international cooperation, the world can achieve a cleaner, more sustainable energy future.

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