



HARNESSING RENEWABLE ENERGY FOR A SUSTAINABLE FUTURE

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ABSTRACT: This manuscript provides a comprehensive analysis of the current state and future prospects of four major renewable energy technologies: wind, hydropower, solar thermal, and ocean energy, with a particular emphasis on tidal energy. The global energy landscape is undergoing a dramatic transformation, driven by increasing energy demand, intensifying environmental concerns, and the urgent need to mitigate climate change. Renewable energy sources are uniquely positioned to lead this transition, offering viable solutions to meet growing energy needs while minimizing environmental impacts and promoting sustainable economic development.

KEYWORDS: *Renewable Energy; Sustainable Development; Energy Transition; Smart Grids; Environmental Impact.*

1. WIND ENERGY: A Mature and Widely Deployed Technology

Wind energy, a mature and widely deployed renewable energy technology, is experiencing exponential growth due to remarkable technological advancements. Modern wind turbines, characterized by larger rotor diameters and taller towers, have significantly increased efficiency, enabling energy capture even at lower wind speeds. The use of advanced materials, sophisticated control systems, and optimized blade designs has substantially decreased the levelized cost of electricity (LCOE), making wind power a highly competitive and cost-effective energy source. Ongoing research focuses on enhancing efficiency further through blade design improvements, exploring the potential of offshore wind farms, and mitigating environmental impacts like effects on wildlife. The integration of wind energy into smart grids, facilitated by advanced communication technologies and data analytics, is improving grid stability and energy management. Countries with high wind energy potential, such as the United States, China, India, and Germany, are actively investing in this technology to meet growing energy demands and achieve their sustainable development goals (SDGs). The sector is also driving significant job creation and economic development.

2. HYDROPOWER: A Tried and Tested Technology with a Focus on Sustainability

Hydropower, one of the oldest and most established renewable energy sources, has played a crucial role in meeting global energy demands for centuries. The 20th century witnessed a



dramatic expansion of hydropower capacity through the construction of large dams, but environmental concerns related to habitat disruption and community displacement have led to a re-evaluation of traditional hydropower practices. Recent research is focused on developing smaller-scale, more environmentally friendly technologies, such as run-of-river systems, which minimize ecological disruption while maximizing energy capture. Innovations in turbine design, combined with environmental impact assessments (EIAs) and adaptive management strategies, are reducing the negative environmental impacts associated with hydropower. The modernization of existing facilities, along with the integration of hydropower with other renewable energy sources, is enhancing the efficiency and reliability of hydropower systems and contributing to grid stability. Countries with significant hydropower resources, like China, Brazil, the United States, Canada, and India, continue to invest in this technology to support economic growth and mitigate climate change.

3. SOLAR THERMAL POWER: A Growing Competitor with Technological Advancements

Solar thermal power, particularly Concentrated Solar Power (CSP) systems, experienced significant growth during the energy crises of the 1970s. CSP systems use mirrors or lenses to focus sunlight onto a receiver, generating thermal energy to drive turbines and produce electricity. The innovation in CSP technology continues, with enhancements in heat storage systems, improved mirror efficiency, and optimized system design leading to increased efficiency and cost-competitiveness. Molten salt thermal storage allows for continuous electricity generation even during periods of low sunlight, addressing the intermittency challenge. The integration of CSP with other renewable energy technologies, such as photovoltaic systems, is maximizing efficiency and energy output. Countries with abundant solar resources, including the United States, China, Spain, and several countries in the Middle East, are aggressively investing in CSP technology, driven by supportive government policies, declining costs, and growing market demand.

4. OCEAN ENERGY: Unlocking the Potential of Tidal Power

Ocean energy, particularly tidal energy, represents a promising but still developing renewable energy source. While the concept of harnessing tidal energy has historical roots, significant technological advancements have predominantly occurred in the 20th and 21st centuries. The Rance Tidal Power Station in France, commissioned in 1966, serves as a landmark example demonstrating the feasibility of commercial-scale tidal energy generation. Current research focuses on enhancing efficiency, durability, and environmental sustainability through improvements in turbine design. Tidal barrage systems, while capable of generating significant power, often pose ecological challenges. Tidal stream turbines, which utilize underwater turbines, are a more environmentally friendly option. The use of advanced monitoring technologies, including underwater drones and acoustic sensors, is essential for assessing environmental impacts and implementing mitigation strategies. Further research is needed to address the challenges associated with cost and environmental impacts to fully unlock the potential of this technology.



5. PRESENT TRENDS: Integration, Innovation, and Sustainability

Current research across all four technologies highlights a strong emphasis on integration with smart grids, innovation in designs and materials, and environmental impact studies. The integration of renewable energy sources into smart grids is improving grid stability and efficiency through better management of electricity supply and demand. Continuous innovation in designs and materials is reducing costs and enhancing performance. Environmental impact assessments are ensuring responsible development and mitigating any negative effects on ecosystems and wildlife.

6. ALIGNMENT WITH SUSTAINABLE DEVELOPMENT GOALS (SDGs)

All four technologies demonstrably contribute to the achievement of several Sustainable Development Goals (SDGs). Renewable energy technologies significantly contribute to SDG 7 (Affordable and Clean Energy), SDG 13 (Climate Action), and SDG 8 (Decent Work and Economic Growth). They further contribute to SDG 9 (Industry, Innovation, and Infrastructure) through technological advancements and investments in renewable energy infrastructure. Specific examples include reduced greenhouse gas emissions, job creation, and sustainable economic development.

7. CONCLUSIONS: A Sustainable and Secure Energy Future

The transition toward a sustainable energy future requires a concerted global effort. The continued development and deployment of renewable energy technologies, coupled with supportive government policies and a commitment to environmental sustainability, are essential for ensuring a secure and reliable energy supply. By investing in these technologies and adopting sustainable energy practices, nations can mitigate climate change, enhance energy security, and foster economic development. International collaboration and knowledge sharing will be crucial in accelerating the pace of this transition, leading to a more sustainable and equitable energy future for all.