

Green Energy in India

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Abstract- Green energy plays a vital role in achieving sustainable development by providing clean, renewable, and environmentally friendly alternatives to fossil fuels. This paper examines the concept, types, importance, applications, and future prospects of green energy, with special emphasis on India's renewable energy sector. Major sources such as solar, wind, hydroelectric, geothermal, biomass, and green hydrogen are discussed along with their environmental, economic, and social benefits. The study highlights India's remarkable progress in renewable energy through government initiatives, policy support, advancements, and ambitious targets for expanding clean energy capacity. It also explores challenges related to grid integration, financing, land acquisition, and workforce development. The paper concludes that green energy is essential for reducing carbon emissions, enhancing energy security, creating employment opportunities, and supporting India's transition towards a sustainable and low-carbon economy.

I. INTRODUCTION

Green Energy refers to the energy derived from natural renewable sources that have a minimal impact on the environment. This form of energy is essential for sustainable development. As it helps reduce greenhouse gas emissions and combat climate change. Key sources of Green energy include solar energy, which harnesses sunlight through solar panels, wind power, which utilizes wind turbines to convert wind energy into electricity, and hydrogen power which generates energy from flowing or falling water, biomass energy, derived from organic materials such as plants and waste, geothermal energy which taps in to the earth's internal heat are also significant contributors to the green Energy landscape.

Green Energy is characterized by its sustainability, as these resources are naturally replenished and do not deplete over time. Unlike fossil fuels, which release harmful pollutants and contribute to global warming, green energy sources provide a cleaner alternative that promotes environmental health. By investing in and transitioning to green energies solutions. Societies can move towards a more sustainable future. Reduce their carbon footprints, and foster energy independence. This shift addresses environmental concerns and creates economic opportunities in the growing green

technology sector. As awareness of these benefits increases, green energies become crucial in global energy policies.

The Power of Green Energy for a Sustainable Future: Today climate change and environment issues have become more pressing than ever. Rising carbon emission, air pollution and ecosystem degradation for the increase the need for clean and sustainable energy sources in the face of the environmental damage caused by fossil fuels and transitioning for renewable energy is no longer a choice but a necessity.

Green energy is a renewable energy source derived from nature that does not harm the environment. These renewable resources generate electricity and heat without causing any damage to nature.

Meaning of Green Energy: Green energy is derived from sustainable and renewable resources aiming to minimise environmental harm compared to conventional energy sources. Natural energy sources such as solar, wind, hydroelectric, geothermal, biomass and green hydrogen fall into this category. As environmental challenges and climate change intensify, transitioning to clean Energy is crucial for both protecting ecosystems and ensuring energy independence.

Types of Green Energy: green energy is derived from sustainable and renewable sources, aiming to minimise environmental harm compared to conventional energy sources. Natural energy sources such as solar, wind, hydroelectric, geothermal biomass and green hydrogen fall into this category. As environmental challenges and climate change intensify, transitioning to clean Energy is crucial for both protecting ecosystems and ensuring energy independence.

*Solar energy: converts sunlight into electricity through photovoltaic panels.

*Wind energy: wind energy harnesses the kinetic energy of air currents using wind turbines to generate electricity.

* Hydroelectric energy: hydroelectric energy utilises the power of flowing water, providing a continuous and clean energy source.

*Geothermal energy: geothermal energy generates power by harnessing hot water and steam from deep within the earth's crust.

*Biomass energy: biomass energy is generated by converting organic waste into energy through biological processes.

*Green hydrogen: green hydrogen is an environmentally friendly form of hydrogen produced via water electrolysis using renewable energy sources without carbon emissions.

Each of these sources leverages nature's renewable potential to minimise the environmental damage caused by fossil fuels.

The Importance of Green Energy: Green Energy not only protects the environment but also offers significant economic and social benefits.

Environmental Benefits of Green Energy: why fossil fuel consumption increases carbon emissions leading to global warming and environment pollution, renewable energy sources eliminate these negative effects. Energy sources like solar wind and hydroelectric help reduce air and water pollution, preserve natural habitats, and create a healthier environment.

Economic Advantages of Green Energy: Green energy presents significant economic opportunities in the long run. As renewable energy technology advances, these systems become more accessible and cost-effective. Additionally, the green energy sector drives job creation and generates new employment opportunities.

Social Benefits of Green Energy: The use of clean Energy directly impacts human health. With reduced air pollution respiratory diseases decrease and overall quality of life improves. Creating a cleaner world is not just about protecting humanity today but about securing a sustainable future for future generations.

Types And Applications of Green Energy: Green energy is derived from various renewable sources and has a wide range of applications. These systems provide an opportunity to generate energy without harming nature, reducing dependency on fossil fuels while contributing to a sustainable future. Here are the most common types of green energy and their applications.

SOLAR ENERGY: Solar energy is one of the cleanest and most abundant renewable energy sources, harnessed directly from sunlight. Photovoltaic (PV) panels convert sunlight into electricity, which is used across various sectors from residential buildings to industrial facilities. Roof top systems, solar farms and largest scale solar power plants are the most common solar energy applications.

Additionally solar thermal systems provide an efficient solution for heating and hot water needs in residential and commercial areas. As technology advances solar panel costs continue to decrease while efficiency rates improve making solar energy more accessible than ever.

Wind Energy: Wind energy is a renewable power source that generates electricity by harnessing the kinetic energy of air currents. This energy is captured through wind turbines and utilised in large- scale power plants in coastal areas, high- altitude regions, and offshore locations.

Due to their low operating cost and high efficiency wind turbines offer an economically viable energy solution. Energy efficiency is exceptionally high particularly in regions with strong and consistent winds. Wind energy helps reduce fossil fuel consumption and minimises Carbon emissions while playing a key role in preserving natural resources.

Hydroelectric Energy: hydroelectric energy is one of the oldest renewable energy sources generating electricity from the flow of water. Hydro power plants can operate using large scale dams or smaller river-based systems.

Wild large hydroelectric plants have high energy production capacities; they must be carefully planned due to their impact on ecosystems. On the other hand small-scale hydro power systems offer a more environmentally friendly option, making them an ideal solution for meeting energy needs in rural areas. Since hydroelectric energy provides continuous and stable power generation it plays a crucial role in ensuring energy security.

Geothermal Energy: Geothermal energy is produced by harnessing hot water and steam from deep within the Earth's crust. It is widely used for both electricity generation and direct heating applications. Geothermal Energy is particularly effective for volcanic regions providing a low carbon and highly efficient energy solution.

Geothermal power plants generate electricity by using steam and hot water extracted from underground reservoirs to drive turbines. In addition geothermal resources are utilized to heat buildings and cities, regulate greenhouse climate and support thermal tourism. As a sustainable and locally sourced energy option geothermal energy significantly contributes to energy independency.

Biomass Energy: Biomass energy is a renewable power source generated from organic waste materials. Agriculture waste, animal manure, forest products, and organic household waste are used in biomass energy production, offering an effective waste management solution.

Biomass energy is a versatile alternative to fossil fuels with byproducts such as biogas and biodiesel serving as environmentally friendly substitutes. Biogas plants convert organic waste into gas for sustainable energy production. Compared to fossil fuels like coal biomass energy produces lower carbon emissions and causes less environmental harm during energy generation.

Green Energy sources hold great potential for sustainable and environmentally friendly energy production. Expanding the use of these renewable energy sources is critical to meeting the growing Global energy demand while reducing fossil fuel consumption. With the right investments and technology advancements, green energy will continue to be the most critical power source of the future.

II. GREEN ENERGY IN INDIA

India's Renewable Energy Revolution

India is experiencing a remarkable transformation in its energy sector, driven by ambitious renewable energy targets, supportive government policies, and rapidly declining technology costs. As the world's third largest energy consumer and one of the fastest growing major economies, India's approach to Green energy is crucial for both national development and global climate goals. The country has set an ambitious target of achieving 500 GW of renewable energy capacity by 2030, representing one of the most aggressive renewable energy expansion programs, globally. This commitment demonstrates India's leadership in the transition to clean energy and its

recognition that renewable energy is essential for sustainable economic growth. 118GW current capacity of Indian green energy.

Solar Energy Leadership : India has emerged as a global solar energy leader, with solar capacity growing from just 2.6 GW in 2014 to over 60GW today. The National Solar Mission, part of the National Action Plan on climate change, has been instrumental in driving this growth through supportive policies, financial incentives, and infrastructure development.

The Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) scheme is revolutionising agricultural energy used by promoting solar pumps and grid connected solar projects on farm lands. This initiative addresses multiple challenges: reducing agriculture electricity subsidies providing additional income to farmers and expanding renewable energy capacity.

III. MAJOR SOLAR INITIATIVES

Rooftop Solar Program: Target of 40 GW by 2022 with subsidies for residential installation.

Solar Parks: Large- Scale developments like the 2,245 MW Bhadla Solar Park in Rajasthan.

Floating Solar: Innovative installations on reservoirs and water bodies.

Canal Top Solar: dual benefits of energy generation and water conservation.

Manufacturing Push: Production Linked Incentive(PLI) Kim per solar equipment manufacturing. The declining cost of solar technology combined with India's excellent solar resource (most regions receive 4-7kWh/m²/day), makes solar energy increasingly attractive for both utility scale and distributed applications. Solar tariffs in India have reached among the lowest globally demonstrating the technology's competitiveness.

State Level Solar Leadership: Several Indian states have emerged as solar energy leaders. Rajasthan leads in installed capacity, leveraging its abundant sunshine and large land availability. Gujarat pioneered early solar policies and continues to be a major contributor. Karnataka has successfully integrated rooftop solar programs, why Tamilnadu has developed significant solar capacity alongside its wind energy leadership.

The integration of solar energy into India's grid required significant infrastructure upgrades and smart grid technologies. The development of the green energy corridor facilitates the transmission of renewable energy from resource rich States to demand centres, ensuring efficient utilisation of clean energy resources.

Wind Energy Expansion

India is the fourth-largest wind energy market globally, with installed capacity exceeding 65 GW. The country's wind energy sector has matured significantly, with modern high capacity turbines replacing older, smaller installations and new Offshore wind development beginning to take shape. The Western and Southern coastal regions along with the states of Tamil Nadu, Gujarat, Maharashtra, and Rajasthan, offer excellent wind resources. The Western ghats and coastal areas experience strong, consistent winds that make wind energy highly viable and cost-effective.

Offshore Wind Potential: India's offshore wind potential is estimated at over 70GW with excellent resources along the Western coast (Gujarat and Maharashtra) and eastern coast (Tamilnadu and Orissa). The government has set a target of 30 GW offshore wind capacity by 2030, representing a significant new frontier for renewable energy development.

Offshore wind offers several advantages over also installations: higher and more consistent wind speeds, larger turbines and minimal land use conflicts. The development of India's offshore wind sector will require significant investment in Port infrastructure, specialised vessels and skilled workforce development.

Technology And Innovation: the Indian wind energy sector has embraced technological advancement, with modern wind farms featuring turbines with capacities of 2-3 MW and hub heights exceeding 120 meters. Advanced wind forecasting systems and grid integration Technologies ensure optimal utilisation of wind resources and grid stability.

Recovering of older wind farms with modern efficient turbines is becoming increasingly common allowing developers to significantly increase energy generation from existing sites. This approach maximizes land use efficiency and improves the economics of wind energy projects.

Economic Impact and Job Creation: the wind energy sector has created substantial employment opportunities across manufacturing, installation, operation and maintenance. Indian companies like Suzion have become global players in wind turbine manufacturing, while international companies have established significant manufacturing and development operations in India.

Rural communities hosting wind farms benefit from land lease payments, local employment opportunities, and improved infrastructure. The development of wind energy projects often brings better roads, transmission lines and economic opportunities to remote areas.

IV. HYDROELECTRIC HERITAGE AND INNOVATION

Hydroelectric power has been a cornerstone of India's electricity generation for decades, currently contributing about 45 GW of capacity. India's diverse geography from the Himalayas to the Western ghats provides excellent opportunities for hydroelectric development across multiple scales.

The government has renewed focus on hydroelectric development, declaring large hydro projects as renewable energy and providing various incentives. The target is to achieve 70GW of

hydroelectric capacity by 2030, requiring significant investment in both large and small scale projects.

Small Hydro Revolution: small hydroelectric projects (under 25 MW) are particularly attractive in India due to the lower environmental impact and ability to share remote communities. States like Himachal Pradesh, Uttarakhand and Arunachal Pradesh have significantly small hydro potential that can provide decentralized clean Energy to hill Communities.

Ran-off- river small hydro projects minimise environmental disruption while providing clean Energy and local economic benefits. These projects often require less investment and have shorter development timelines compared to large Dam projects.

Pumped storage development: India is developing significant pumped storage capacity to support grid stability as renewable energy penetration increases. Projects like the 2400MW Tehri Stage II in Uttarakhand demonstrate the potential for large scale energy storage using India's mountainous terrain.

Pampered storage facilities provide crucial grid balancing servicing, storing excess renewable energy during peak generation periods and releasing it during high demand. This technology is essential for achieving high levels of renewable energy integration.

Environmental And Social Considerations: Modern hydroelectric development in India increasingly emphasizes environmental sustainability and social responsibility. Environmental flow requirements, fish ladders, and comprehensive impact assessments are standard components of new projects.

Community engagement and benefit sharing mechanisms ensure that local populations receive tangible benefits from hydroelectric projects. This includes priority in employment infrastructure development and revenue sharing arrangements.

Policy Framework And Government Initiatives:

India's Renewable energy success is built on a comprehensive policy framework that provides long-term clarity, financial support, and regulatory stability. The government has implemented numerous schemes and initiatives that address different aspects of the renewable energy values chain.

National Solar Mission: Launched in 2010, the National Solar Mission set ambitious targets for solar deployment and established a framework for policy support. The mission has revolved to include grid- connected solar, off-grid solar applications, and solar manufacturing incentives. The success of this mission has made India one of the world's largest solar markets.

Renewable Purchase Obligations (RPO): State electricity regulatory commission have mandated that distribution companies purchase a minimum percentage of their electricity from renewable

sources. This policy create a guaranteed market for renewable energy and derives demand for clean Energy projects.

The RTO framework includes separate targets for solar, Non-solar renewable energy, and hydroelectric power, ensuring balanced development across different renewable Technologies. Renewable Energy Certificates (RECs) provide flexibility for States to meet their obligations through market mechanisms.

Financial Mechanism and Incentives:

- Generation Based Incentives (GBI): performance-support for wind energy projects.
- Accelerated Depreciation: Tax benefits allowing rapid depreciation of renewable energy assets.
- Concessional Finance: Low-cost funding through institutions like IREDA and PFC.
- Viability Gap Funding: Support for commercially viable projects required initial assistance.
- Green Bonds: Dedicated financing instruments for renewable energy projects.

Manufacturing and Technology Development:

The Production Linked Incentive(PLI) Kim Pramod domestic manufacturing of solar panels, wind turbines and energy storage systems. This initiative aims to reduce import dependence, create jobs, and build a competitive domestic renewable energy manufacturing sector.

Recharge and development Initiatives support Technology innovation including the establishment of renewable energy research institutes and funding for demonstration projects. The focus includes next- generation Technologies like perovskite solar cells, advanced wind turbines designs, and energy storage innovations.

Grid Integration and Infrastructure:

The Green Energy Corridors project involves significant investment in transmission infrastructure to evacuate renewable energy from resource- rich regions to demand centres. This includes High voltage transmission lines substations and grid balancing equipment.

Smart grid initiatives enable better integration of variable renewable energy sources through advanced forecasting, demand response, and storage integration. These Technologies are essential for maintaining grid stability with high levels of renewable energy penetration.

V. CHALLENGES AND SOLUTIONS

While India's renewable energy sector has achieved remarkable growth, several challenges remain that require innovative solutions and continued policy support. Addressing these challenges is crucial for achieving the ambitious renewable energy targets and ensuring sustainable energy development.

- **Grid Integration and Stability:** The variable nature of solar and wind energy presents grid Integration challenges, particularly as renewable energy penetration increases. Solutions include advanced forecasting systems, flexible generation resources, energy storage development, and demand response programs.

Grid flexibility improvements through smart grid technologies, improved transmission infrastructure, and market mechanisms for ancillary services are essential for accommodating high levels of renewable energy. The development of Regional Connectivity and Green Energy Corridors facilitates better renewable energy integration across states.

- **Land Acquisition and Environmental Clearances:** Large scale renewable energy projects require significant land areas, which can lead to acquisition challenges and environmental concerns. Solutions include innovative project models like solar Parks, floating solar installations, and canal-top solar projects that minimise land use conflicts.

Streamlined environmental clearance processes for renewable energy projects while maintaining environmental safeguards, help accelerate project development. The use of wasteland and degraded land for renewable energy projects provides dual benefits of clean Energy generation and land restoration.

- **Financial and Investment Challenges:** despite declining technology costs renewable energy projects still require significant upfront capital investment. Solutions include innovative financing mechanisms, green bonds, international climate Finance, and risk mitigation instruments that make projects more attractive to investors.

This financial health of State electricity boards affects variability to honor renewable energy contracts. Payment security mechanisms including payment guarantee funds and letter of credit requirements help mitigate this risk and attract investment.

- **Technical Workforce Development:** The rapid growth of renewable energy requires skilled technicians, engineers and managers across the value chain. Solutions include specialised training programs, industry academia partnerships, and certification teams that ensure quality and safety standards.

Skill development initiatives focus on manufacturing, installation, operation, and maintenance of renewable energy systems. These programs often target rural youth providing employment opportunities in the growing clean Energy sector.

Future Outlook And Opportunities

India's renewable energy future is bright with multiple growth drivers and emerging opportunities that position the country as a global clean Energy leader. The convergence of supportive policies, declining costs, Technology Innovation, and growing environmental awareness create a favourable environment for continued expansion.

Emerging Technologies and Applications: Green hydrogen production using renewable energy represents a significant new opportunity for India. The National Hydrogen Mission aims to make India a global hub for green hydrogen production and export, potentially creating a multi- billion industry while supporting decarbonization of hard- to- abate sectors like steel, cement and chemicals.

Electric vehicle integration with renewable energy creates synergies between transport electrification and clean Energy development. Smart charging systems can use renewable energy to power electric vehicles while providing grid balancing services through vehicle -to-grid Technologies.

Agrivoltaics combining Solar energy generation with agriculture, offers dual land use benefits and additional income for farmers. This approach is particularly relevant in India where land available for projects is limited.

Energy Storage and Grid Modernisation: Large -scale development of battery energy storage systems will enable higher levels of renewable energy integration while providing grid stability services. The declining cost of batteries combined with supportive policies, is driving rapid growth in energy storage deployment.

Distributed energy resources, including rooftop solar, small wind systems, and community energy storage, are transforming the traditional centralised grid model. Prosumers- consumers who also produce energy- are becoming increasingly common, enabled by net metering policies and declining technology costs.

International Cooperation and Leadership: India's leadership in international initiatives like the international solar Alliance demonstrates its commitment to global renewable energy development. Technology transfer, capacity building, and South-south cooperation initiative position India as a leader in the Global energy transition.

Climate finance and Carbon markets provide additional revenue streams for renewable energy projects while supporting India's climate commitments. The development of domestic carbon trading mechanisms can enhance project economics.

Economic and Social Benefits: The transition to renewable energy will create millions of jobs across manufacturing, construction, operation, and maintenance. These jobs are often local and cannot be outsourced, providing economic benefits to communities across India.

Energy access improvements through distributed renewable energy systems will bring electricity to remote areas where grid extension is not economically viable. Solar Home systems, mini grids, and community energy projects can provide clean, reliable energy to underserved populations. Air quality improvements from reduced fossil fuel combustion will provide significant health benefits, particularly in urban areas. The economic value of avoided health costs and environmental damage strengthens the case for renewable energy deployment.

Achieving Net Zero Emissions: India's commitment to achieving net zero emissions by 2070 requires massive scaling of renewable energy deployment alongside energy efficiency improvements and carbon capture technologies. The renewable energy sector will play a central role in this transition, requiring continued innovation, investment, and policy support. Sectoral decarbonization through renewable energy includes electrification of transport, industrial processes, and heating/cooling systems. This creates a new market for renewable energy while reducing overall carbon emissions across the economy.

VI. CONCLUSION

Green energy has emerged as a cornerstone of sustainable development and environmental protection. Renewable energy sources such as solar, wind, hydroelectric, geothermal, biomass, and green hydrogen provide clean and reliable alternatives to conventional fossil fuels. Their widespread adoption helps reduce greenhouse gas emissions, improve public health, strengthen energy security, and promote economic growth through job creation and technological innovation. India has made significant progress in renewable energy development through strong policy support, investment, and infrastructure expansion. Despite challenges such as grid stability, financing requirements, and land constraints, continued technological advancements and government initiatives are creating new opportunities for growth. Emerging sectors such as green hydrogen, energy storage, and electric mobility further enhance the potential of renewable energy. The transition to green energy is not only necessary for combating climate change but also for ensuring long-term economic and social well-being. With sustained commitment and innovation, green energy will play a crucial role in helping India achieve its renewable energy goals and its vision of net-zero emissions, thereby securing a cleaner and more sustainable future for generations to come.

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