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## **Renewable Energy for a Sustainable Future: Technologies, Consumption Patterns, and Emerging Trends**

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### **Abstract**

Renewable energy sources have become an essential solution to meet the world's increasing energy demand while reducing environmental degradation and greenhouse gas emissions. Renewable sources like fossil fuels, solar, wind, hydro, geothermal, and biomass are naturally sustainable alternative for future energy production. But in present scenario these natural energy sources are influenced by factors such as climate change, environmental degradation, population growth, land-use changes, and excessive exploitation of natural resources. In this paper, we study the availability of major natural renewable energy sources and examine the challenges affecting their long-term sustainability. The study also highlights the importance of technological advancements, energy storage systems, and sustainable resource management in ensuring reliable renewable energy production. Discussed about the some government policies, public awareness, and investment in clean energy infrastructure to safeguard these valuable resources for future generations. Renewable energy will play a critical role in achieving global energy security and environmental sustainability.

**Keywords:** Wind Energy, Solar Photovoltaic, Solar Thermal Technologies, Geothermal Energy, Renewable Energy, Hydropower.

### **Introduction**

Modern societies require abundant and affordable supplies of energy for economic growth, urbanization, and improvement in the standard of living of its people. Because of these demands, the energy needs of the world continue to grow. Most of the world's present energy supplies come from fossil fuels which are eventually going to be depleted and cause environmental damage. Because of these conditions, the energy systems of the world are being altered to include greater use of various forms of renewable energy [1, 2, 3].

Examples of renewable energy sources include solar energy, wind, moving water, biomass, and geothermal energy. Even the ocean offers the potential for

renewable energy. Additionally, energy can be transported and stored using a carrier such as hydrogen which, if generated using renewable energy, can provide energy without emissions at the site of use [4, 5].

Reorganization of an energy system to rely more on renewable energy sources can create great opportunities for a nation to meet energy demands. The focus of this presentation is to illustrate the various opportunities and limitations of various renewable energy sources. Additionally, it illustrates India's recent growth in renewable energy sources and the impact of energy sources on India's goal to eliminate its reliance on coal [6, 7].

The cost of traditional fossil fuels is hard to predict. Meanwhile, renewable energy costs continue to drop. Over the last few decades, wind and solar power systems have gained in popularity and have become more affordable. Improved designs and greater experience have allowed the systems to become smaller and more efficient [8].

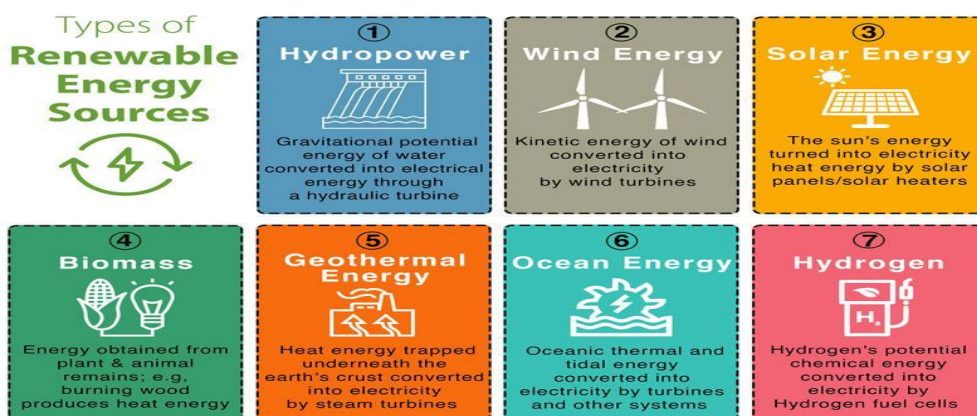
Burning fossil fuels like coal and oil produces greenhouse gases which contribute to global warming. Other pollutants are also produced which are harmful to humans and the environment. The burning of fossil fuels was determined to be the cause of the increase in several respiratory illnesses and other conditions. Many scientists agree that in the last hundred years the average temperature of the earth has increased. Other scientists predict that if nothing changes the polar ice caps will continue to melt, causing ocean levels to increase. Extreme weather conditions are expected to occur more frequently. Floods and droughts will become the new normal [9, 10]. Green chemistry offers many opportunities for the chemistry community and gives the field new vocabulary like "sustainable chemistry," "atom efficiency," and others. New concepts facilitate greater integration and intensification of chemical processes. Green chemistry enables new products with a greater emphasis on life cycle assessment and safety [11, 12]. Green chemistry is especially important to solve current and future problems caused by the growth of the chemical industry and to address climate change. The research shows that the use of oil and natural gas for energy has increased and the use of renewable energy sources has increased as well. These changes have caused a dramatic reduction in costs for renewable energy sources and new installations. The share of electricity generated from renewable sources in 2017 was over 25%. In 2017, the World Bank forecasted that the use of fossil fuels would rise for several more years. Between 2014 to 2016, annual CO<sub>2</sub> emissions remained unchanged, but rose by 1.4% in 2017 [13].

### **Concept of Green Energy**

The word 'renewable' means being able to be renewed. Renewable energy is the kind of energy that comes from sources which are naturally replenishing and never running out like solar energy, wind energy, hydro energy and so on. Green

energy is that which comes from; natural sources, such as the sun, wind, water, tides, geothermal heat or algae. Though there are some differences between green energy and renewable energy, in most cases, they are considered the same. In fact solar energy, wind energy, hydrothermal energy, geothermal energy, vibrational energy and biomass energy all are green as well as renewable. The concept of green energy is built on the principles of sustainable development, which aims to meet the needs of the present generation without compromising the ability of future generations to meet their own needs.

Green energy has become increasingly popular in recent years as more individuals, businesses and governments are realizing the importance of sustainability and environmental responsibility. Many countries have set ambitious goals for renewable energy adoption and have even committed to reaching net-zero emissions in the coming decades. Though there are still some challenges to overcome in the adoption of green energy, the benefits are clear. By switching to renewable energy sources, we can create a more sustainable and resilient energy system that will benefit both present and future generations [14, 15,16].



**Fig. 1: Different Types of Renewable Energy Sources**

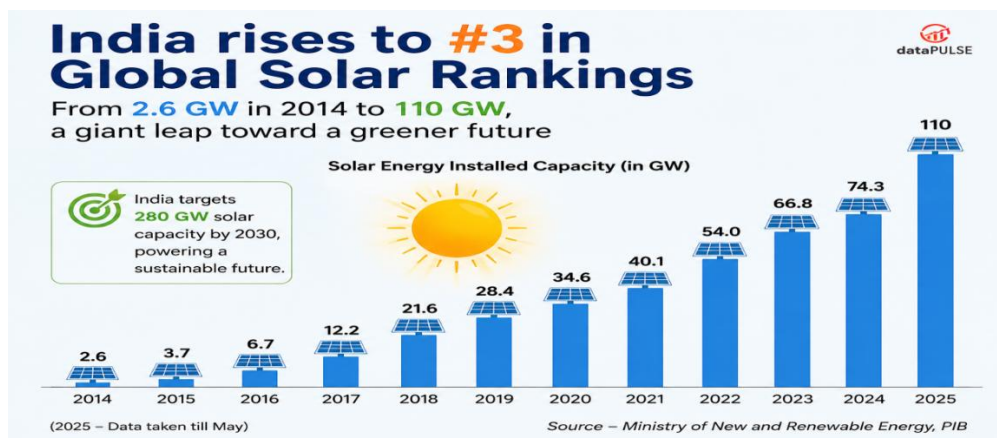
Renewable energy is energy that comes from natural resources that are replenished in nature constantly or periodically, making it a viable substitute for fossil fuels. Hydropower is the energy that is obtained from running water; wind power is the energy harnessed from the wind by windmills. Solar energy is the energy derived from the sun using solar panels and other devices. Biomass is energy in the form of plant and animal matter that can be burned for heat. The energy of the earth is called geothermal energy, while ocean energy is the energy obtained from tides, waves, and currents. Hydrogen is a clean energy source that can be used in fuel cells. These energy sources can be harnessed to create electricity while cutting down greenhouse-gas emissions [17, 18].

## Objectives of the Review

- To review the major renewable energy resources and their basic methods of energy conversion.
- To describe the present status and resource availability of renewable energy, with emphasis on India.
- To examine major technical, environmental and operational limitations associated with renewable technologies.
- To discuss the role of storage, grid integration, recycling and advanced technologies in future renewable-energy systems.
- To identify future prospects including advanced solar cells, improved wind systems, hybrid renewable systems, hydrogen and waste-to-energy pathways.

## Solar Energy

Solar energy refers to the energy derived from the sun's radiation and can be harnessed either as electricity by solar photovoltaic (PV) systems or as heat by solar-thermal technologies. In a solar PV system, sunlight interacts with solar cell semiconductor and generates direct-current electricity. The produced electricity is then converted to alternating current by power electronics for residential, industrial, and utility applications. Solar PV has seen a significant rise due to its ability to be developed at different scales from small residential installations to large utility-scale installations. The presentation predicts that solar will continue to be one of the leading clean energy technologies of the future. India's MNRE reported a solar capacity of 162.15 GW as of June 2026. Overall statistics indicating a rapid increase in the solar energy sector worldwide, with solar PV capacity reaching approximately 2.4 TW by the end of 2025 [19, 20].



**Fig. 2: Solar Energy Installed Capacity in India (2014-2025)**

The major limitations of solar energy are its dependence on sunlight, intermittency, land requirements for large installations, the need for storage or complementary generation, and end-of-life management of panels and associated batteries. Future development is expected to include higher-efficiency perovskite and tandem solar cells, which may offer lighter, flexible and potentially high-efficiency modules [21, 22].

- **Solar Energy Initiatives in India**

The presentation highlights several Indian initiatives intended to expand solar deployment at different scales. PM Surya Ghar encourages household rooftop solar, PM-KUSUM supports solar applications in agriculture, and Solar Parks facilitate large-scale solar generation. PM JANMAN is also identified as supporting off-grid solar for remote communities. Together, these approaches illustrate a combination of centralized generation, distributed generation and decentralized electricity access.

### **Wind Energy**

Wind energy is the kinetic energy of moving air that is converted to electricity by means of wind turbines. A wind resource, either onshore or offshore, can be used. Wind power has very low operational greenhouse-gas emissions, but electricity production varies with wind speed, resulting in requirements for grid flexibility, forecasting, storage and transmission. According to the presentation, India had approximately 57.44 GW of wind power capacity installed by June 2026. In addition to those key wind-resource states – Gujarat, Tamil Nadu, Karnataka, Maharashtra and Rajasthan – the presentation also revealed that India had by wind power ranking fourth in the world as of June 2026, according to GWEC 2026 and a statement by the Union Minister of State for MNRE [23, 24].

**Table 1: Last three year Wind Capacity Generated in India**

| <b>Year</b> | <b>Wind Capacity Addition (MW)</b> | <b>Wind Generation (billion units)</b> |
|-------------|------------------------------------|----------------------------------------|
| 2023–24     | 3,253                              | 83                                     |
| 2024–25     | 4,151                              | 89                                     |
| 2025–26     | 6,057                              | 106                                    |

Continuous variation can affect blades, gearboxes and towers, while voltage fluctuations, reactive-power management and frequency control can create additional grid-integration challenges.

**Table 2: Wind Energy Capacity Installed in Different States**

| <b>State</b> | <b>Wind installed capacity as on 30.06.2026 (in MW)</b> |
|--------------|---------------------------------------------------------|
| Gujarat      | 16086                                                   |
| Tamil Nadu   | 12273                                                   |
| Karnataka    | 8896                                                    |
| Maharashtra  | 6318                                                    |
| Rajasthan    | 5516                                                    |

|                |      |
|----------------|------|
| Andhra Pradesh | 4461 |
| Madhya Pradesh | 3686 |
| Telangana      | 128  |
| Kerala         | 71   |
| Others         | 4    |

### Hydropower

Hydropower is among the oldest large-scale renewable electricity technologies. It derives the gravitational potential and kinetic energy of water into electricity via turbines and generators. Reservoir-based projects can offer relatively consistent generation, peak-load management and, where applicable, energy storage. Hydropower is thus critical to both electricity production and grid balancing. Main concerns are ecological impacts, displacement, sedimentation and water availability. Large reservoirs can inundate forests and agricultural land and modify river ecosystems and aquatic biodiversity.

**Table 3: Hydropower Capacity in Different States**

| Project     | State/UT          | Capacity |
|-------------|-------------------|----------|
| Kishanganga | J&K               | 330 MW   |
| Kameng      | Arunachal Pradesh | 600 MW   |
| Rongnichu   | Sikkim            | 113 MW   |
| Vyasi HEP   | Uttarakhand       | 120 MW   |
| Parbati-II  | Himachal Pradesh  | 800 MW   |

Projects in mountainous and seismically active regions can face landslides, earthquakes and challenging geological conditions. The presentation notes that the 2013 Uttarakhand floods damaged several hydropower projects and related infrastructure. It also identifies the 2023 South Lhonak Lake glacial lake outburst flood in Sikkim as an event that caused severe infrastructure damage, including damage associated with the Teesta III hydropower project at Chungthang. These examples illustrate the importance of climate, geological and hydrological risk assessment in hydropower planning. The presentation states that Hydro Purchase Obligation (HPO) was introduced in 2021 by the Government of India to promote hydropower by obliging obligated entities to procure a specified share of electricity from hydropower sources [25, 26].

### Biomass Energy

Biomass energy is derived from organic matter including agricultural residues, plant matter, and animal wastes. The energy can be used in various forms such as electricity, heat, biogas, and liquid biofuels. India has a large biomass power potential due to the large amount of agricultural activity. Besides, it provides the additional benefit of converting agricultural and municipal wastes into useful forms of energy. Biomass is available seasonally and sparsely geographically. Furthermore,

collection and transportation can be costly, while storage can be problematic due to differences in moisture content and fuel quality. Competition with animal feed and other soil uses can also arise. Unsustainable biomass harvests have the potential to cause environmental degradation through natural forest loss. Therefore, efficient technologies for conversion and sustainable feedstock management are required. One promising direction is the integration of the biomass with a circular-economy approach. Agricultural residues and organic wastes can be converted into biogas, compressed biogas (CBG), heat, electricity, and various biofuels while reducing the burden of waste disposal [27, 28].

### **Emerging Renewable and Low-Carbon Pathways**

- **Geothermal Energy**

Geothermal energy utilizes heat from the Earth's core. It can generate heat, and, under the right conditions, electricity. The slides mention that India has a theoretical potential of 10 GW of geothermal power. They also stress that currently, it is a developing area, and it requires geological evaluation per-site.

- **Ocean Energy**

Ocean energy includes tidal, wave and ocean-current technologies. These derive electricity from the motion or temperature differential of water in the world's oceans. The slides describe ocean energy as a developing field and stress that the aforementioned technologies are dependent on further technological development and suitable resources.

- **Hydrogen Energy**

Hydrogen is an energy carrier rather than an energy source. It can store and produce electricity in fuel cells. They can provide energy independence if the right production methods are chosen. The environmental impact of hydrogen production depends on the energy used in the process. Transportation and storage are also crucial factors. If produced with renewable electricity, however, they can provide a means of storing and using renewable energy.

### **Present Status of Renewable Energy in India**

India has a lot of potential for renewable energy, but it is still mostly reliant on coal for electricity. They state that at the end of 2025, renewable sources, including large hydropower plants, provided 50.22% of India's electricity, as compared to 42.75% for coal. However, the numbers represent the total installed capacity, not the amount of electricity actually generated, and thus should not be compared to one another. India's electricity generation is thus still reliant on coal. However, growing renewable capacity can provide electricity to millions of people without emitting greenhouse gases into the atmosphere. However, the shift will require upgrades to the electric grid infrastructure and the development of electricity storage, variable generation, demand-side management, and regulation and market mechanisms for electricity [29].

## Major Limitations and Challenges

Renewable energy technologies have many benefits, but also present technical, environmental and material challenges that limit their ability to play a major role in the electricity sector. These factors are important considerations for long-term energy planning. Intermittency: The output of solar and wind turbines depends on weather conditions and requires forecasting, storage, flexible generation or grid connections. Energy storage: The need for grid-scale storage is growing as the share of variable renewable electricity grows, and battery technologies and end-of-life management create additional challenges. Battery waste: Different battery chemistries such as lead-acid, lithium-ion, LFP and NMC require different treatment, and damaged lithium-ion batteries can cause fires and thermal-runaway events. Hydropower impacts: Hydropower can impact forests, farmland, rivers and aquatic species, and the changing patterns of river flow and sedimentation can affect dam stability. Climate and disaster risk: Natural disasters such as floods, landslides, earthquakes and glacial lake outbursts can impact renewable-energy infrastructure, especially in hilly areas. Wind-turbine stresses: Wind-turbine structures can be stressed by varying wind loads and require careful management of power-quality and power-frequency issues. Biomass logistics: Seasonal variations in supply, the dispersed nature of biomass, costs of transporting and storing biomass and moisture content can reduce the viability of a given biomass resource. Land and resource requirements: Renewable electricity generation often requires large areas and significant infrastructure to connect to the grid, and the siting of these projects is often a challenge [30].

## Energy Storage and Advanced Technologies

Energy storage is a critical enabler for renewable energy systems. Batteries can provide short-term electrical storage, whereas, in suitable geographical locations, pumped-hydro storage can offer large-scale, long-duration storage. Long-term storage, as well as alternative means of energy storage outside the electrical system, may be provided by hydrogen. In the battery space, sodium-ion and solid-state batteries are two promising areas of research and development (R&D). They can offer improvements in terms of safety, cost, energy density, or abundance of key materials. At the same time, expanded collection and processing of spent batteries, as well as producer responsibility for end-of-life batteries, will become increasingly important. In photovoltaics (PV), perovskite and tandem cells offer a compelling R&D opportunity. Their mechanical and optical properties allow a variety of innovative designs and applications, but large-scale manufacturing will require advances in stability, manufacturing know-how, and material supply chains. The deployment of these new cells will also require considerations around their sustainability, reliability, and end-of-life recycling.

## **Future Prospects of Renewable Energy**

More efficient solar power: Perovskite and tandem solar cells can improve the conversion efficiency and allow lightweight or flexible modules. Advanced wind systems: Larger and more efficient turbines, including offshore systems, could expand the available wind resource. Better storage: Advanced batteries, pumped hydropower and hydrogen can help balance the supply from renewables with electricity demand. Waste-to-energy: Agricultural and organic waste can produce biogas, CBG and biofuel when the feedstocks are managed sustainably. Ocean energy: Tidal, wave and ocean-current technologies can become more viable as engineering and economic barriers are overcome. Distributed generation: Rooftop solar, solar pumps and village-level systems can improve access to electricity and reduce the reliance on a central supply. Hybrid renewable systems: Solar, wind and storage can be combined to provide more reliable electricity profiles. Recycling and sustainable materials: Improving recycling of solar modules and batteries can reduce material losses and environmental impact.

## **Conclusion**

India's evolving energy strategy is expected to place increasing emphasis on renewable energy as a key pillar of long-term energy security and sustainability. Renewable resources can contribute not only to electricity generation but also to a wide range of energy services across transportation, industry, agriculture, and households. Among these resources, hydropower can be developed at different scales, including micro, small, and large hydro systems, depending on geographical conditions and energy requirements. The reviewed literature indicates considerable scope for expanding solar and wind energy in India. However, their large-scale integration requires solutions for intermittency, energy storage, transmission, grid stability, and efficient resource management. Therefore, the future energy system should not depend on a single renewable source but should promote a coordinated combination of different technologies.

Further progress will require advances in battery storage, green hydrogen, pumped-hydro storage, electric and hybrid mobility, advanced materials, and smart-grid technologies. Sustainable management of biomass and efficient replacement or upgrading of existing energy infrastructure are also important. Improving the efficiency of currently installed renewable systems through modern materials, improved components, digital monitoring, and energy-management technologies can further increase their contribution. Thus, India's renewable-energy transition should be viewed as an integrated technological transformation in which generation, storage, transportation, materials, and energy efficiency develop together.

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