Renewable Energy in India: An overview and the path towards Sustainable Development

Abstract

The utilization of natural and energy resources began to manifest in the 19th century. Throughout the 20th century, energy usage escalated significantly. Currently, around 80% of global energy consumption is derived from the extraction of fossil fuels, including oil, coal, and gas. Renewable energy has grown increasingly vital as the world confronts the issue of alleviating the adverse effects of climate change and diminishing reliance on finite and polluting fossil fuels. Utilizing renewable energy sources is acknowledged as a crucial element in advancing sustainable development, which seeks to fulfill the requirements of the current generation without jeopardizing future generations. India, akin to other developing nations, is endeavouring to implement various strategies to guarantee a cheap and accessible energy supply for its socioeconomic and political sectors in pursuit of renewable energy advancement.India's Renewable Energy Goals stipulate an objective of attaining 500 GW of installed capacity by 2030. This study aim is to examine the several sources of renewable energy, including solar, wind, hydropower, geothermal, and biomass, to facilitate sustainable development in India. Strong policy support with stable and predictable regulations, effective grid integration strategies to manage variable renewables, dedicated funding for research and development, and strong public engagement are key findings to successfully implement the state-level renewable energy. Setting aggressive renewable energy capacity installation targets, easing grid integration through transmission infrastructure expansion, and offering financial incentives like subsidies and tax benefits are significant recommendations for India to promote renewable energy.

Keywords: Renewable Energy, Sustainable Development, environmental issues, Hydrogen production

Introduction

Addressing contemporary environmental issues necessitates long-term strategic efforts for sustainable development. In this context, renewable energy resources seem to be among the most efficient and effective alternatives. Consequently, there exists a profound relationship between renewable energy and sustainable development. Sustainable development pertains to the link between human society and the natural environment. Sustainable development has conventionally been conceptualized within the three-pillar framework of Economy, Ecology, and Society, facilitating a systematic classification of development objectives, wherein the three pillars are interrelated and mutually supportive (Omer, 2007). Sustainable development can be positioned on a continuum between the paradigms of weak sustainability and strong sustainability within an alternative conceptual framework. The two paradigms diverge in their assumptions regarding the sustainability of natural and anthropogenic capital (Rogers & Daly, 1996). Renewable energy can aid in achieving the development objectives of the three-pillar model and can be evaluated in relation to both weak and strong sustainability.

India's energy demand is projected to surpass that of any other nation in the forthcoming decades, attributable to its vast size and significant potential for growth and development. Consequently, the majority of this rising energy demand must be satisfied by low-carbon, renewable sources. India declared its objective to attain net zero carbon emissions by 2070 and to majority of its electricity requirements through renewable sources by 2030, signifying a pivotal moment in the global endeavour to address climate change.
According to (IBEF) Indian Brand Equity Foundation, as of 2023, India ranked 4th in wind power capacity, solar power capacity, and overall renewable energy installed capacity.

According to India’s Renewable Energy goals, following are the renewable energy targets:

- **Overall Capacity Goal** - 500 GW of Renewable Energy by 2030
- **Renewable Energy Share** - Target of reaching 40% of total electricity generation from renewable sources by 20230
- **Offshore wind potential** - Focus on developing 30 GW of offshore wind capacity by 2030

- **Green Hydrogen Production** – Target of producing 5 million tonnes of green hydrogen by 2030

Renewable Energy – Concept:

The phrase “Renewable Energy” encompasses a wide array of resources, all originating from self-renewing energy sources such as solar radiation, wind, hydropower, geothermal energy, and biomass, including energy crops, agricultural, industrial, and municipal waste. These resources can be utilized directly for heating and illuminating residences and other structures, generating electricity, solar cooling, and various commercial and human applications. Renewable energy sources are abundant and ubiquitous(Hosseini & Wahid, 2016). Conversely, fossil fuels (coal, gas, and oil) are non-renewable resources that require hundreds to millions of years for their formation. The combustion of fossil fuels for energy generation results in detrimental greenhouse gas emissions, including carbon dioxide. Producing renewable energy results in lower emissions compared to the combustion of fossil fuels. The conservation of energy and the utilization of renewable sources are the ultimate objective of energy management.

Sustainable Development – concept:

Sustainable development refers to progress that satisfies current need without jeopardizing the capacity of future generations to fulfill their own needs. Sustainable development originates from the 1987 study "Our Common Future" by the World Commission on Environment and Development, chaired by Brundtland.

A primary outcome of the Rio+20 conference was the consensus among member states to initiate a process for formulating a set of Sustainable Development Goals (SDGs) that will extend the Millennium Development Goals (MDGs). An inclusive and transparent inter-governmental mechanism would be established, accessible to all stakeholders, aimed at formulating global sustainable development goals for approval by the General Assembly. The Sustainable Development Goals (SDGs) are encompassed within Resolution 70/1 of the United Nations General Assembly, titled “Transforming our world: the 2030 Agenda for Sustainable Development.” Seventeen worldwide objectives were established in 2015 for the year 2030.

Renewable Energy Sources for Sustainable Development

In order to achieve sustainable development, renewable energy sources are derived from the natural and consistent flow of energy that occurs in the environment. Following is a list of some of the renewable energy sources that can be utilized for sustainable development:

- **Bioenergy**

Bioenergy, which is derived from biological sources, can be utilized to create electricity, heat, and cook food, as well as make biodiesel for transportation purposes. The use of bioenergy has a significant potential to reduce emissions of greenhouse gases and to guarantee a sufficient supply of fuel in the future.

- **Solar Energy**

All renewable energy sources for sustainable development that make use of direct sunlight are collectively referred to as solar energy. Solar energy is a phrase that is used to describe. Once solar energy is absorbed by the earth and changed into different forms, ocean thermal and wing energy are able to harness the results of this process. To generate power that can be used to meet the requirements for illumination, solar energy makes use of the irradiance that the sun emits. In addition to this, solar energy is utilized in the production of fuel, which can be utilized for transportation and other processes that are appropriate.

- **Hydropower**

In order to generate hydropower, which is one of the most important renewable energy sources for sustainable development, the elevation of water is manipulated from a higher level to a lower level. In order to generate electricity or to set turbines in motion, the energy is harnessed. Because it does not entail the manufacturing of any greenhouse gas, hydropower is considered to be a green form of energy because it is powered by technology that have been around for a long time.

- **Wind Energy**

From the moment that wind power was first developed. As a result of its becoming one of the most dependable renewable energy sources for sustainable development, it has emerged as the primary focus of attention. Wind energy is typically utilized for the purpose of moving big turbines and producing electricity. Its primary focus is on the utilization of the kinetic energy that is derived from the passage of air.

- **Geothermal Energy**

Geothermal energy is a dependable renewable energy source that may be utilized for the purpose of sustainable development. Geothermal energy is obtained from the interior region of our planet as a source of heat. The heat that is present in the crust of the planet is not evenly distributed, despite the fact that it is abundant. With the use of a well or some other form of extraction, the heat is extracted from reservoirs. After it has reached the surface, the heat can be utilized for the generation of electricity or for any other function that calls for the utilization of heat energy.

- **Tidal Energy**

The passage of wind is responsible for the formation of waves on the surface of the water. There is a considerable increase in the amount of energy that is created when the wind is sustained at a higher intensity for a longer period of time during which the intensity is maintained. The ocean covers 71% of the surface of the earth and has the ability to supply the world's population with the amount of power that they demand. The thermal contrasts that exist between shallow and deep saltwater, as well as wind, tides, and waves, will all contribute to the extraction of energy from the oceans.

Review of Literature

Lund (2006) Sustainable energy development methods often encompass three primary technological transformations: demand-side energy conservation, enhancements in energy

production efficiency, and the substitution of fossil fuels with diverse renewable energy sources. Therefore, extensive renewable energy deployment programs must incorporate methods for integrating renewable sources into cohesive energy systems, shaped by energy conservation and efficiency initiatives.

Moriarty &Honnery (2011) The global transition to renewable energy must be accompanied by a significant reduction in overall energy use for environmental sustainability. All energy sources produce undesirable environmental consequences, including local air, water, or soil contamination, greenhouse gas emissions, and loss of biodiversity. The environmental consequences associated with renewable energy sources might be ambiguous, mostly due to their current low output levels relative to the required demand. The establishment of new renewable energy projects has encountered local environmental resistance, which may intensify when renewable energy production is significantly increased. This analysis indicates that both overall energy reduction and renewable energy are necessary to mitigate the unavoidable unfavourable repercussions associated with any energy source. Consequently, it is probable that environmental and climate change limitations will further diminish the optimal gross output level from renewable energy sources, below what is suggested by an analysis of direct energy inputs alone.

Banos, Manzano-Agugliaro, Montoya, Gil, Alcade& Gomez (2011) This paper presents an overview of recent research advancements related to the application of optimization algorithms in design, planning, and control issues within the realm of renewable and sustainable energy. The research stated that the application of optimization approaches to address renewable energy issues has significantly escalated in recent years, particularly concerning wind and solar energy systems.

Hussain, Arif &Aslam (2017) The study performed an extensive examination of upcoming renewable technologies, including ocean energy, concentrated solar power, enhanced geothermal energy, cellulosic ethanol, and artificial photosynthesis. This technology analysis indicates that, as of June 2014, the total contribution of renewable energy sources is approximately 22%. This paper provides an overview of the evolution and potential of CO2 reduction for renewable, clean, and sustainable development. This research has elucidated the resources of the present status of the five foremost rising renewable and sustainable energy sources. The potential of each of the

five emerging renewable technologies is substantial, demonstrating the capability to meet humanity's energy requirements sustainably.

Harjanne&Karhonen (2019) Renewable energy has emerged as a significant concept in energy policy, with numerous national and international legal frameworks and regulations specifically structured to classify energy sources as renewable or non-renewable. This paper examines renewable energy as a socially created outcome of framing within energy policy. This research aims not to expound on the theoretical underpinning but to utilize principles from organizational science to analyze the role and influence of the shared notion of renewable energy.

Objective of the study

The fundamental objective of this research is to acquire a complete grasp of the idea of renewable energy and to investigate the role that renewable energy plays in the process of sustainable development in India. This article provides more information regarding the renewable sources that contribute to sustainable development as well as the steps that the government has taken to promote sustainable development through the utilization of renewable energy.

Methodology

The research predominantly utilizes secondary data and adopts a descriptive methodology. The data was sourced from multiple outlets, including magazines, journals, books, newspapers, and numerous official websites such as the Indian Brand Equity Foundation (IBEF), Press Information Bureau (PIB), and Central Electricity Authority (CEA).

Role of Renewable Energy for Sustainable Development

Sustainable Development includes environmental, social, and economic factors. Renewable energy is essential for attaining sustainability by tackling environmental issues, ensuring energy security, stimulating economic development, and improving social welfare.

a) **Environmental Benefits:**

- **Reduced Greenhouse Gas Emissions:**

Renewable energy sources, including solar, wind, hydro, and geothermal power, generate minimal to no greenhouse gas emissions throughout their operation. By substituting fossil fuels, they alleviate climate change and promote a cleaner, healthier environment. In comparison to coal-fired power plants, electricity generated from renewable energy sources emits 90 to 99% fewer greenhouse gases (GHGs) and creates 70 to 90% fewer pollutants.

- **Air and Water Pollution Reduction:** In contrast to traditional energy sources, renewable energy does not emit detrimental pollutants like sulfur dioxide, nitrogen oxides, or particulate matter. Thus, it enhances air quality, mitigates respiratory diseases, and safeguards ecosystems from acid precipitation. Furthermore, renewable energy initiatives typically exhibit reduced water consumption, hence alleviating pressure on regional water supplies.

- **Conservation of Natural Resources:** Renewable energy sources utilize the power of plentiful, naturally replenishable resources, including solar energy, wind, and hydropower. This diminishes dependence on finite resources such as fossil fuels, which are diminishing and contribute to environmental deterioration during extraction, transportation, and burning.

b) **Energy Security and Economic Benefits:**

- **Diversification of Energy Sources:**

Dependence on fossil fuels for energy renders economies susceptible to price volatility and geopolitical conflicts. Integrating renewable energy sources diversifies the energy portfolio, diminishes reliance on foreign fuels, and enhances energy security.

- **Job Creation and Economic Growth:**

The renewable energy sector has demonstrated significant potential for employment generation. Investments in renewable energy infrastructure, production, installation, and maintenance generate employment opportunities, stimulate economic growth, and benefit local communities. The renewable energy sector generates more employment per unit of energy produced than the fossil fuel business.

- **Cost Competitiveness and Price Stability:**

  Technological innovations and economies of scale have rendered renewable energy progressively cost-competitive. Solar and wind energy, specifically, have undergone substantial decreases in cost in recent years. This price consistency provides benefits compared to fossil fuels.

c) Social Benefits:

- **Improved Public Health:**

  The shift to renewable energy diminishes the release of harmful chemicals that adversely affect human health. Improved air and water quality leads to a reduction in respiratory disorders, cardiovascular conditions, and other health issues linked to pollution.

- **Access to Energy:**

  Renewable energy has the capacity to supply electricity to isolated and underprivileged regions. Off-grid renewable technologies, such solar panels and micro-hydro systems, can provide electricity to communities lacking traditional grid infrastructure, thereby enhancing chances for education, healthcare, and economic development.

- **Resilience and Disaster Mitigation:**

  Renewable energy systems, especially distributed generation from sources such as solar panels, can augment the resilience of energy infrastructure. Decentralized renewable energy systems can supply electricity during natural catastrophes and grid failures,

facilitating the operation of essential services and enhancing disaster response and recovery operations.

The Challenges India Faces in Scaling up Renewable Energy

The renewable energy sector is continually evolving, aiming to replace fossil fuels with sustainable alternatives such as solar, wind, and hydroelectric electricity. This transition contributes to mitigating greenhouse gas emissions and combating climate change. Furthermore, it aids to the reduction of carbon emissions and pollution levels, thereby fostering a better environment. The social adoption of renewable energy can improve health by reducing air and water pollution and providing healthier energy options. The principal challenges India faces are as follows:

1. **High Initial Investment**

   Renewable energy methods frequently require capital investment. The costs associated with the installation of panels, wind turbines, and other essential infrastructure may provide an obstacle. Acquiring money and financial incentives is crucial in surmounting these challenges.

2. **Integration into the Power Grid**

   Integrating energy sources into the current power grid architecture poses obstacles. Compatibility issues may emerge, complicating the effective management of grid stability and security. Enhancing the grid infrastructure to support the augmented input from sources is essential.

3. **Obstacles and Regulations**

   Acquiring permissions and licenses for energy projects can be intricate and protracted. Regulations governing grid connectivity may pose challenges that hinder project initiation.

4. **Environmental Effects**

   Notwithstanding its environmentally sustainable characteristics, renewable energy may nonetheless exert negative effects. The utilization of land for agriculture and wind turbines may interfere with wildlife habitats. The extraction of resources for technologies may also elicit concerns.

5. **Policy Inconsistencies**

   Volatile regulatory frameworks and erratic policies may discourage investment in renewable energy initiatives.

Government Initiatives for Sustainable Development through Renewable Energy

a) Net Zero Mission:

- The net-zero emission objectives require governments to achieve carbon neutrality by balancing carbon emissions with carbon sequestration and removal by 2050.
- Its carbon footprint ought to be zero.
- To mitigate climate change, lower temperature increases to 1.5 degrees Celsius above pre-industrial revolution levels.
- China has pledged to achieving net-zero emissions by 2060, while Europe, Japan, South Korea, and India have committed to doing so by 2050.
- After the USA and China, India is the third-largest emitter of greenhouse gases.

b) PM Modi revealed to the world the five Commitments / Amrit Tatva:

- Augment non-fossil power capacity to 500 GW by 2030, up from 175 GW in 2022, thereafter raised to 450 GW.
- By 2030, India will fulfill 50% of its energy requirements through renewable sources. Previously, it was 40%.
- India will remove one billion tons of carbon emissions between now and 2030.

- Reduce the carbon intensity of its economy to below 45% by 2030, previously set at 33% - 35%.
- On November 1, 2021, during the UN Climate Summit COP 26 in Glasgow, Prime Minister Narendra Modi said that India would attain the net-zero emission objective by 2070.

c) PM-KUSUM (Pradhan Mantri-KisanUrja Suraksha EvamUtthaanMahaabhiyan):

- The PM-KUSUM scheme has recently undergone evaluation by the Union Minister for Power and the Ministry of New and Renewable Energy (MNRE).
- It is a strategy for farmers that ensures a consistent electricity supply for irrigation while concurrently enhancing their income.
- Construct solar pumps and grid-connected solar and other renewable energy installations
- It received approval in February 2019.
- By 2022, the objective was to install 25,750 MW of solar and other renewable energy capacity.
- Grid-connected agricultural pumps can be solarized with a 30% subsidy from the central government, a 30% subsidy from the state, and a 40% contribution from the farmer.

d) OSOWOG (One Sun, One World, One Grid):

- OSOWOG = Green Grid
- The OSOWOG initiative was inaugurated by India and the UK at the Conference of Parties (COP 26).
- The objective is that "The Sun Never Sets."
- It has been incorporated into the World Bank's technical support program.

Data collection and Interpretation

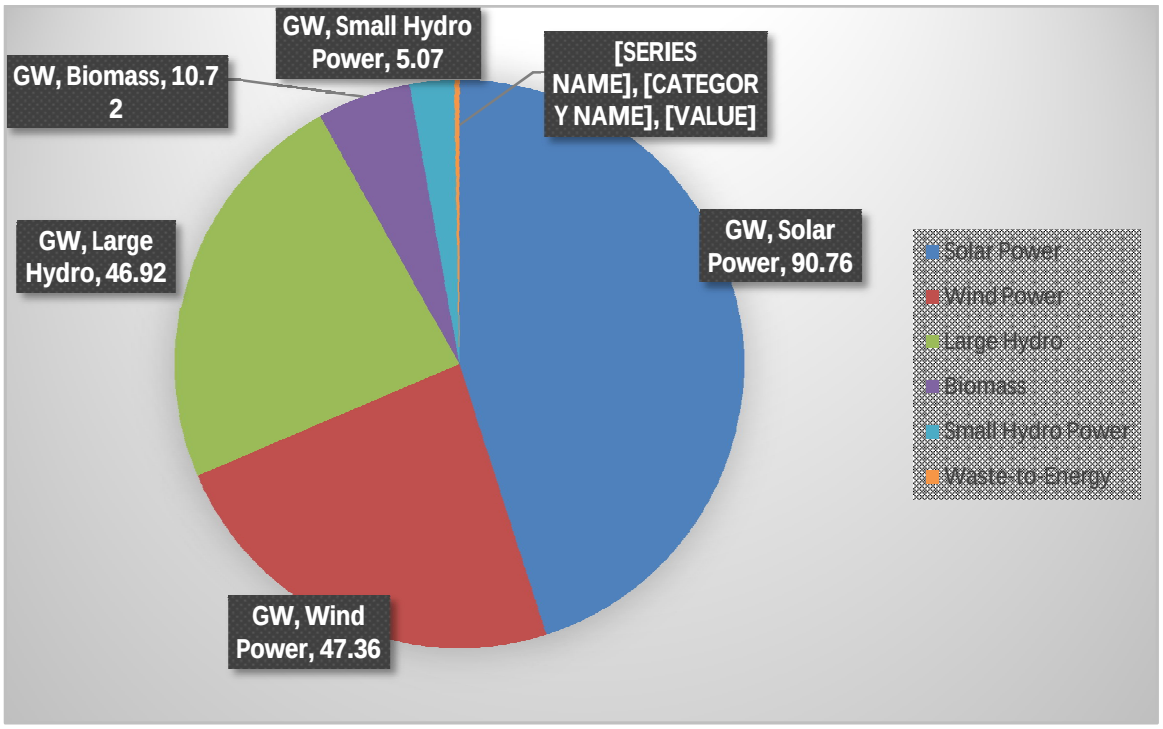
Table 1: Installed Generation Capacity(Fuel Wise) as on 30.06.2024

Category	Installed Generation Capacity (MW)	% of Share in Total
Fossil Fuel		
Coal	2,10,970	47.3%
Lignite	6,620	1.5%
Gas	24,818	5.6%
Diesel	589	0.1%
Total Fossil Fuel	**2,42,997**	**54.5%**
Non-Fossil Fuel		
RES(including Hydro)	**1,95,013**	**43.7%**
Hydro 46,928		10.5%
Wind, Solar and Other RE 1,48,085		33.2%
Wind 46,656		10.5%
Solar 85,474		19.2%
BM Power/ co-generation 10,355		2.3%
Waste to energy 593		0.1%
Small Hydro Power 5,005		1.1%
Nuclear	**8,180**	**1.8%**
Total Non-Fossil Fuel	**2,03,193**	**45.5%**
Total Installed Capacity (Fossil Fuel & Non-Fossil Fuel)	**4,46,190**	**100%**

[Source: Central Electricity Authority (CEA)]

Table 1 presents the installed generation capacity from fossil fuels and non-fossil fuels. Fossil fuels continue to constitute the greatest component, accounting for 54.5% of the total. In this context, environmental pollution is somewhat unavoidable. However, the government intends for primary energy sources to transition to new and renewable energies in the future.

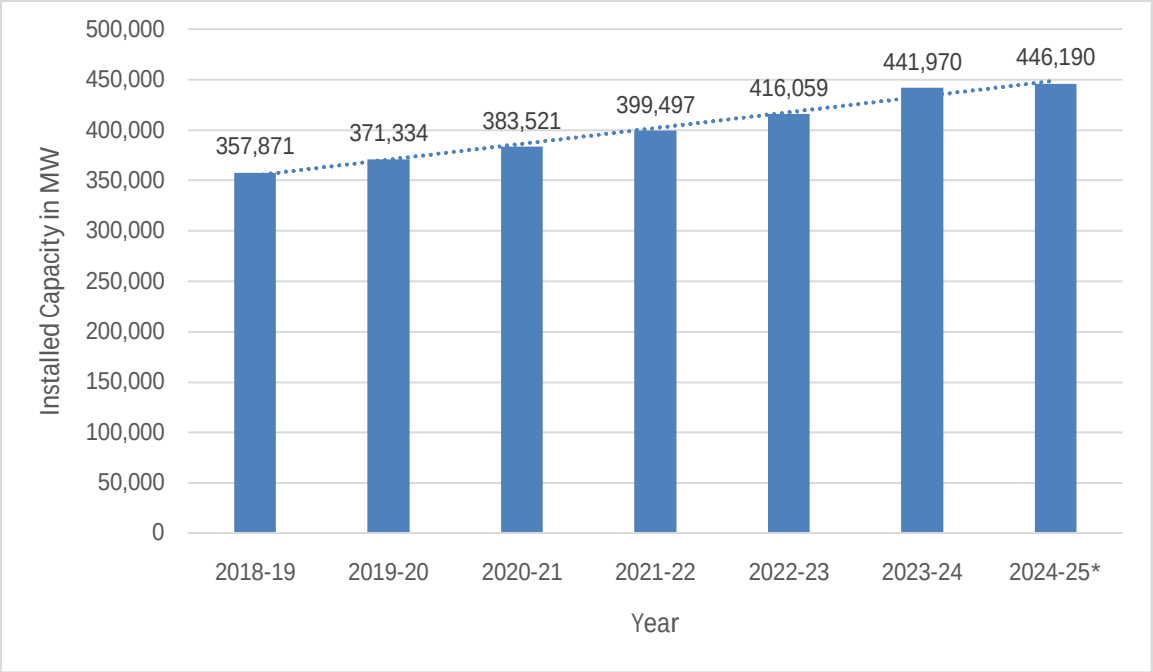
Figure 1: Installed Grid Renewable Power Capacity in India as of September 2024



Source: PIB (Press Information Bureau)

Figure 1 illustrates the installed renewable power capacity within India's system. As of September 2024, renewable energy sources, encompassing large hydropower, possess a total installed capacity of 201.43 GW. Solar power dominates with 90.76 GW, significantly contributing to India's initiatives to utilize its plentiful sunlight. Wind power ranks second with 47.36 GW, propelled by the tremendous potential of the coastal and inland wind corridors nationwide. Hydroelectric power significantly contributes to energy generation, with large hydro projects producing 46.92 GW and minor hydro power contributing an additional 5.07 GW, providing a dependable and sustainable energy source from India's rivers and water systems. Biomass contributes 10.72 GW, while Waste-to-energy adds 0.6 GW to the renewable energy portfolio.

Figure 2: Year Wise Total Power Generation Capacity from 2018-19 to 2024-25

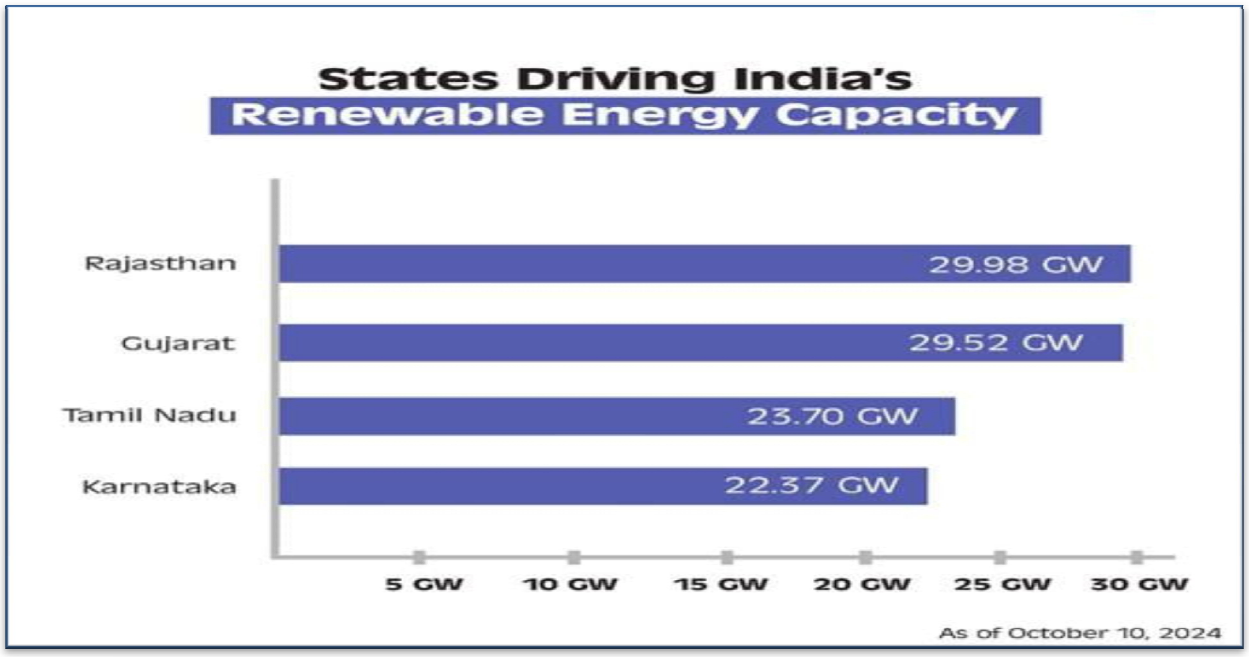


* upto June 2024

Source: PIB (Press Information Bureau)

The total power generation capacity is depicted in Figure 2 for the period going from 2018-19 to 2024-25. On the basis of the chart presented above, we are able to draw the conclusion that the overall power generation capacity is on an upward trend from one year to the next.

Figure 3: Leading States in Renewable Energy Capacity



Source: PIB (Press Information Bureau)

Figure 3 illustrates the foremost states in renewable energy capacity. Multiple states in India have established themselves as frontrunners in renewable energy capability, greatly advancing the nation's development. Rajasthan leads with a remarkable 29.98 GW of installed renewable energy capacity, capitalizing on its extensive terrain and plentiful sunlight. Gujarat follows closely with a capacity of 229.52 GW, propelled by its robust emphasis on solar and wind energy initiatives. Tamil Nadu has the third position with 23.70 GW, capitalizing on its advantageous wind patterns to produce significant electricity. Karnataka ranks fourth with a capacity of 22.37 GW, bolstered by a combination of solar and wind projects.

Result, Discussions and Suggestions

Result

1. **Current Status and Growth**
    - India is one of the largest expanding markets for renewable energy globally. It possesses a renewable energy capacity over 175GW, encompassing sun, wind, and additional sources like as hydropower and biomass.

- The administration has established ambitious objectives, including attaining 500GW of renewable energy capacity by 2030 and achieving net-zero emissions by 2070.

2. **Policy Framework**
    - Policies such as the National Solar Mission and the Wind-Solar Hybrid Policy are designed to expedite adoption.
    - Implementation of initiatives such as PM-KUSUM to enable farmers to install solar pumps and grid-connected renewable energy systems.
3. **Economic and Social Impacts**
    - Renewable energy initiatives generate employment, especially in rural regions.
    - Solar energy has significantly contributed to supplying electricity to isolated and underserved areas.
4. **Environmental Benefits**
    - Decreased carbon emissions and air pollution by substituting fossil fuels with renewable energy sources.
    - Conservation of natural ecosystems through less dependence on traditional power plants.

5. **Challenges**
    - Land acquisition challenges, grid stability concerns, and integration difficulties persist as substantial obstacles.
    - Reliance on imports for solar photovoltaic cells and absence of domestic production capability.
6. **Economic Development**
    - Renewable energy enhances energy security and diminishes reliance on fossil fuel imports.
    - Prospects for startups and investments in renewable energy technology such as battery storage and hydrogen fuel.

Discussion

1. **Rapid Adoption and Scalability**

Earlier literature viewed India’s renewable energy sector as slow-moving due to policy inefficiencies and lack of investment. Recent study highlight exponential growth, particularly in solar power, driven by falling technology costs and robust government support.

2. Focus on Sustainability

Earlier findings emphasised the economic costs of renewable energy adoption. Current research highlights a triple-bottom-line impact economic, social and Environmental benefits.

3. Technology Gaps

Prior research emphasized India's reliance on imported renewable energy technology. Although some of this remains accurate, the present study focus on domestic manufacturing indicates gradual progress.

4. Energy Access and Equity

Some research findings indicated a minimal effect on rural electricity. Current research demonstrates the essential significance of renewable energy in last-mile connectivity and in mitigating inequities.

Suggestions

1. Policy Recommendations

Enhance financial incentives for renewable energy initiatives, especially in impoverished areas. Augment Investigation and innovation in native production and energy retention technologies.

2. Awareness and Capacity Building

Inform local people about the advantages of renewable energy and offer training for clean energy employment opportunities.

3. **Grid modernization**

In order to control variations in renewable energy and assure stability, it is important to invest in smart grid.

4. **Decarbonization Beyond Power**

The focus should be expanded on renewable energy for industries, transportation, and programs involving green hydrogen.

5. **Public-Private Partnerships**

To entice commercial players and direct investments from outside, it is important to encourage collaborations in the field of renewable energy projects.

Conclusion

Renewable energy possesses significant potential to concurrently fulfill economic, social, and environmental goals as outlined in sustainable development initiatives. Renewable energy is a highly advantageous investment opportunity from a societal perspective. India's renewable energy trajectory has attained a key milestone, evidenced by the remarkable accomplishment of exceeding 200 GW of installed capacity. This achievement exemplifies the nation's dedication to a sustainable energy future, propelled by a variety of renewable sources, such as solar, wind, hydro, and bioenergy. The proactive measures, including OSOWOG (One Sun, One World, One Grid), the Net Zero Mission, PM-KUSUM, and other governmental plans, diminish dependence on fossil fuels. India, with an ambitious objective of achieving 500 GW from non-fossil sources by 2030, is poised to become a global leader in renewable energy, therefore enhancing environmental sustainability and energy security. These continuous initiatives demonstrate a comprehensive strategy for developing a sustainable economy, ensuring that India fulfills its energy requirements while also tackling urgent issues related to climate change and resource preservation.

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