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Chapter- 28

Present status and future outlooks of renewable energy in India for sustainable development

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Keywords: Energy Transition, Renewable Energy Policies, Sustainable development, Technological Advancements, Economic Viability.

Abstract:

The rapid industrialization and population growth in India have led to an unprecedented surge in energy demand, prompting a critical examination of sustainable energy sources. The present study delves into the current status and prospects of renewable energy in India, exploring its pivotal role in fostering sustainable development. The study encompasses an analysis of the current renewable energy landscape, government initiatives, challenges faced, and potential solutions. India has made significant strides in the deployment of renewable energy technologies, with a notable increase in solar and wind energy capacity. Government-led initiatives, such as the National Solar Mission and Wind Energy Mission, have played a pivotal role in promoting clean energy adoption. Despite these advancements, challenges like intermittency, grid integration issues, and financial barriers persist. The future perspectives of renewable energy in India are promising, driven by technological advancements, decreasing costs of renewable technologies, and a growing emphasis on sustainability. The adoption of energy storage solutions, smart grids, and digital technologies is poised to address the intermittency issues associated with renewables, enhancing their reliability and contribution to the energy mix. Moreover, this documentation explores the socio-economic benefits of renewable energy deployment, including job creation, improved air quality, and reduced greenhouse gas emissions. The transition to a cleaner energy paradigm aligns with India's commitment to global climate goals and contributes to the nation's resilience to climate change impacts. To summarize, the present status of renewable energy in India reflects commendable progress, with an optimistic trajectory for the future. Strategic policy frameworks, technological innovations, and international collaborations are essential components for overcoming existing challenges and unlocking the full potential of renewable energy for sustainable development in India. The current findings set the stage for a comprehensive exploration of the multifaceted aspects of India's renewable energy journey and its integral role in shaping a sustainable future.

Introduction:

In 1987, the term "sustainable development" was coined to describe progress that meets the demands of the present without compromising the ability of future generations to fulfill their own needs. It is an approach to advancing human well-being, considering social, ecological, and economic dynamics. Sustainable development encompasses the many tools and approaches that can be used to work towards the overarching aim of sustainability (Mensah, 2019; Mukherjee et al., 2022). After the nation experienced two oil shocks in the 1970s, 'self-

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sufficiency' in energy was found to be the primary motivator for renewable energy in the country. The Ministry of New and Renewable Energy (MNRE) is the Indian government's go-to ministry for all matters relating to new and renewable energy (Sangroya & Nayak, 2017; LeninBabu et al., 2023). To assist the country in meeting its energy demands, the Ministry's main objective is to develop and deploy new renewable energy sources. The Department of Science and Technology established the Commission for Alternate Means of Energy in March 1981 in response to the abrupt spike in oil prices, supply-side problems, and negative impacts on the monetary balance of payments (Difiglio, 2014).

Renewable energy and sustainable development:

Environmental responsibility is directly proportional to the adoption of renewable energy sources. Renewable resources refer to those resources that can be regenerated throughout time. They encompass the sun, wind, and geothermal heat, which are widely regarded as inexhaustible. The restoration of the supply of these resources occurs naturally over time (Figure 1). Hence, they possess the capacity to persist despite human-induced depletion. Their positive effects on productivity and human development can pave the way for progress in the following areas: climate change mitigation, access to pure energy, social and economic development, reduction of adverse health and environmental effects, and energy security (Strielkowski et al., 2021). Numerous academic institutions, economists, and—above all—stakeholders who stand to benefit from the global application of renewable energy technologies are interested in learning more about renewable power. Resource limitations, sustainable energy, biomass, and CO_2 emissions may all be used to support the idea that scientific interests are shifting from environmental sciences and energy sources to other fields. The role and position of renewable energy are becoming more widely recognized in the fields of computer science, mechanical engineering, science technology, and business economics (Kumar. J & Majid, 2020). Presently, the nation witnesses substantial strides in renewable energy adoption, notably in solar and wind sectors. The future outlook emphasizes the imperative of circular economy principles, promoting resource efficiency, and minimizing environmental impact (Saha, 2023). Harnessing renewable resources aligns with India's commitment to sustainable development goals, emphasizing a shift from linear to circular energy systems.

The perpetual utilization of energy sources derived from fossil fuels (coal, oil, and gas) posed significant challenges due to the exhaustion of fuel reserves, emissions of greenhouse gases and other environmental ills, geopolitical and military disputes, and the volatile nature of fuel costs (Figure 2). Unfavourable consequences will result from these concerns, which present an irreparable peril to human societies (Perera, 2017). On the contrary, renewable energy sources represent the most viable and exclusive solution to the escalating challenges. In 2023, the energy industry in the United States is expected to release 4,790 million metric tonnes of carbon dioxide (CO_2), a 3% reduction from 2022. The decrease in energy output from coal-fired power plants may be attributed mostly to the increased generation of electricity from

renewable sources like solar power. We predict that CO_2 emissions will drop by 1% from 2023 to 2024, continuing the current trend (Hodge & Nakolan, 2023).

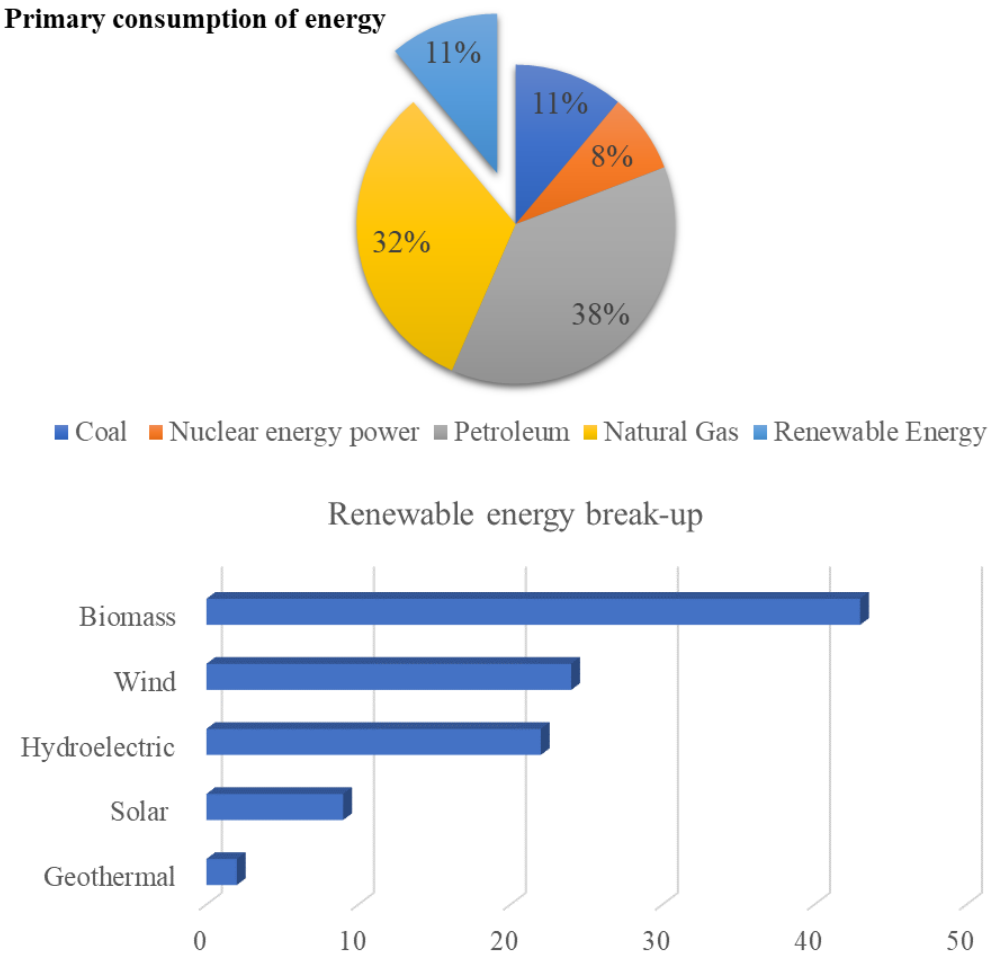

Figure 1. U.S. primary energy consumption by energy source, 2019. (Source and reproduced from EIA, US).

Sustainable in light of present and future economic and social requirements, renewable technologies are often regarded as eco-friendly options for generating electricity. The adoption of renewable energy technology presents a special opportunity to mitigate the consequences of climate change and the emission of greenhouse gases by substituting conventional sources of energy (those derived from fossil fuels) (Jaiswal et al., 2022). In contrast to the 5.5% rise of 2021, the main energy consumption grew by just 1.1% in 2022. With hydropower excluded, renewables made up approximately 7.5% of primary energy, up about 1% from 2021, while fossil fuels remained at 82% (Nasralla & Fletcher, 2023). Due to the high volatility of fossil fuel prices and the danger of supply interruptions, more energy customers globally are adopting on-site renewable energy systems and moving to electrified technologies across end-use industries. The global total final energy consumption (TFEC) increased by 16% between 2011

and 2021. In TFEC, the quantity of contemporary renewable energy grew from 30 exajoules (EJ) in 2011 to 50 EJ in 2021. The percentage of fossil fuels in TFEC decreased from 81.2% in 2011 to 78.9% in 2021 as the contribution from renewable energy sources rose; yet, throughout this time, the total amount of fossil fuels consumed increased by 35 EJ (REN21, 2023).

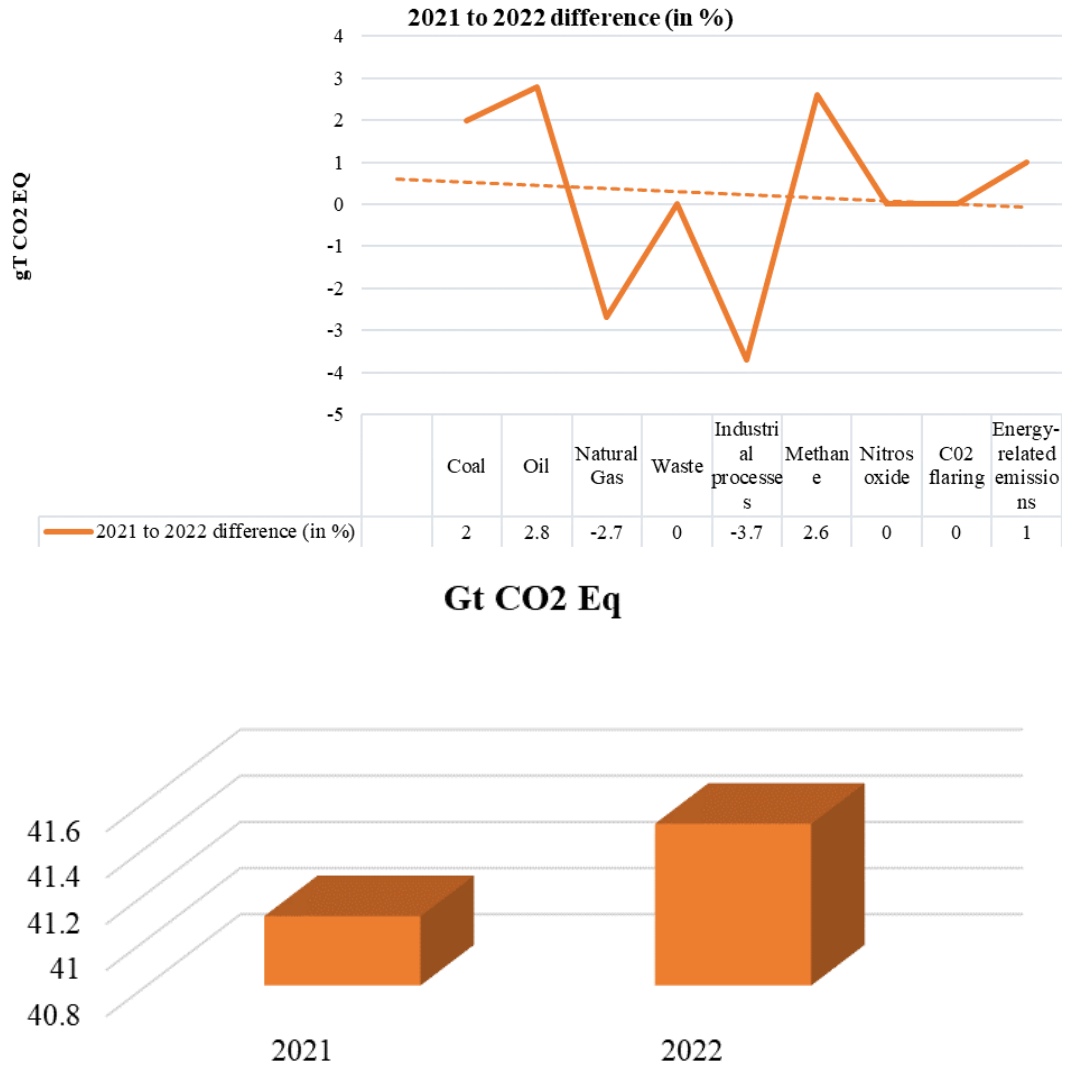

Figure 2. Carbon dioxide emission by source in the year 2021 and 2022. (Source and reproduced from: REN21).

Non-renewable resources are categorized as finite due to their extensive natural formation time. Once they are exhausted, they become inaccessible. Oil, natural gas, and coal are included in this category. One advantage of utilizing non-renewable resources to generate power as needed is the pre-existing availability of these resources in the market, along with the established infrastructure required for their utilization. Conversely, renewable resources exhibit

a lesser detrimental impact on the environment in comparison. The combustion of coal and oil results in the emission of carbon dioxide gas into the Earth's atmosphere. This gas acts as a greenhouse gas, contributing to the retention of heat and exacerbating the ongoing global warming phenomenon, thus further compromising the stability of the planet's climate system (Krautkraemer, 1998). As long as precipitation occurs, water can also be thought of as a renewable natural resource. The necessity of water conservation measures has been highlighted by shifting weather patterns. Natural energy is mostly met by coal, foreign oil, and petroleum right now, which is not only not renewable and therefore not a lasting answer to the energy problem but is also bad for the environment. Renewable energy technologies turn natural energy into energy that can be sold. India needs to make sure it has enough energy without hurting its economy, which means it needs to switch from non-renewable energy sources like coal and crude oil to renewable energy sources (Nordhaus et al., 1973; Rahman & Wahid, 2021).

The primary objective of sustainable development is to simultaneously attain human development objectives and ensure the continued provision of vital natural resources and ecosystem services by natural systems. The ultimate objective is to establish a societal framework wherein individuals' fundamental necessities can be fulfilled while also safeguarding the ecological equilibrium of the planet. The pursuit of sustainable development is predicated upon the imperative of striking a harmonious balance between the advancement of material prosperity, the protection of ecological integrity, and the promotion of social well-being (Bridger & Luloff, 2022). As per the Brundtland Report of 1987, sustainable development can be defined as the process of achieving development that fulfills the requirements of the current generation while ensuring that the capacity of future generations to fulfill their own needs remains intact. Contemporary deliberations on sustainable development notably encompass economic growth, social progress, and environmental preservation, with a collective focus on ensuring the well-being of future generations (Jarvie, 2016).

Under bilateral or cooperative methods, the following list of renewable energy activities will be taken into consideration for selling carbon credits under the Article 6.2 mechanism, as given by the National Designated Authority responsible for the adoption of the Paris Agreement (NDAIAPA) (Ministry of Environment, Forest and Climate Change, 2023):

i. Renewable energy with storage (only stored component)
ii. Solar thermal power
iii. Offshore wind
iv. Green Hydrogen & Ammonia
v. Tidal energy
vi. High Voltage Direct Current Transmission

Sustainability and renewable resources in India:

India is actively adopting and harnessing the potential of renewable energy sources. The organization has formally declared its objective of achieving carbon neutrality by the year 2070. Moreover, as stated by the Ministry of Power, it is anticipated that the nation will fulfill 62% of its energy demands by the year 2030 through the utilization of 500 GW of non-fossil fuel sources (Kumar, 2023). Nevertheless, to effectively accomplish its ambitious objective and facilitate the shift towards clean energy, the nation necessitates the assistance of advancements in renewable energy. The field of renewable energy has experienced rapid expansion. The ninth-largest economy is that of India. Due mostly to the nation's consistent economic expansion, energy demands are increasing at a rate of 2.8% annually. With around 1028 million people, India's population is expanding at a 1.58% yearly pace. It's possible that traditional energy sources could run out soon. Thus, energy from a source that is quickly replenished by a natural process and is not susceptible to depletion on a human time scale is actually what is meant to be understood as renewable energy. 37% of India's total energy consumed accounts for the renewable resource (Birol & Kant, 2022; Chilakapati & Manohar, 2023).

India has made significant progress in the pursuit of sustainable development by embracing renewable energy sources, with solar energy emerging as a prominent contender. Based on the data provided by the National Investment Promotion and Facilitation Agency, it is seen that as of May 2023, India's non-fossil fuel capacity reached a significant milestone of 178.79 gigawatts. This figure represents a substantial increase of 396% over the preceding 8.5 years (Singh, 2023). The REN21 Renewables 2022 Global Status Report says that India is ranked fourth in the world for installed renewable energy capacity, which includes large hydropower plants. It is also ranked fourth for wind power capacity and fourth for solar power capacity. In 2022, it achieved the most significant increase in renewable energy installations with a year-over-year growth rate of 9.83% (REN21, 2023). The operational solar energy potential has grown exponentially over the past 9 years, reaching 70.10 GW as of July 2023, which is a 30-fold increase. The installed capacity of renewable energy, including big hydro, has increased by around 128% since 2014. India's non-fossil fuel production has had a remarkable growth of 396% during the past 8.5 years, reaching a total of around 176.49 GW, which includes huge hydro and nuclear power. This accounts for over 43% of the country's overall capacity as of July 2023 (PTI, 2023).

The installed capacity of all of India, excluding captive capacity, as of March 31, 2022, was 399496.61 MW. This includes 46722.52 MW of hydropower, 236108.72 MW of thermal power, 6780 MW of nuclear power, and 109885.38 MW of renewable energy. It also takes into account the addition of new capacity, the up-rationing or de-rationing of existing capacity, and the retirement of outdated and inefficient units at the end of 2021–22. Except for major hydro, the generation from renewable energy sources (RES) increased at a compound annual growth rate (CAGR) of 12.80% between FY2011–12 and FY2021–22, from 51226.05 GWh to 170912.30 GWh (*General Review 2023*, 2023).

The objective of achieving economic growth using energy-intensive methods is a shared aspiration across all nations. Energy intensities are useful metrics for assessing the overall energy consumption throughout a manufacturing chain, as they provide a means to describe the total quantity of energy utilized. To have a comprehensive understanding of the total energy consumption of an economy, it is advantageous to amalgamate sector-specific energy intensities with the corresponding output requirements of these sectors. The variation in both the amount and structure of demand, along with the shifting energy intensities across different industries, leads to a corresponding change in energy consumption. The degree to which a product or sector is affected by changes in energy prices can be observed by the measurement of the energy required per unit of production, commonly referred to as energy intensity or specific energy consumption (Sorrell, 2015). A comprehensive comprehension of the impact of fluctuations in energy prices on aggregate energy consumption can be achieved by employing temporal analysis or conducting historical investigations on energy intensities. The paradox of energy lies in its indispensable role in sustaining human existence and advancement, juxtaposed with the adverse consequences arising from unregulated developmental endeavors heavily reliant on fossil fuel consumption, hence detrimentally affecting the environment. The energy demands of a nation are perpetually escalating as a consequence of population growth, industrialization, and various societal and economic determinants. The escalation of energy consumption presents two primary concerns. Firstly, the accompanying pollution has the potential to induce unforeseen alterations in the Earth's climate system, resulting in significant ramifications (Osobajo, 2020). Secondly, the utilization of non-renewable fossil fuels as the predominant energy source exacerbates the issue since their finite nature poses long-term sustainability challenges. Discussions about money and the imperative of economic growth occupy a prominent position, irrespective of individuals' concerns over the future of the planet. Researchers have undertaken investigations into nuclear power and other environmentally sustainable energy sources as a means to identify a viable replacement for fossil fuels and other non-renewable resources (Liddle & Huntington, 2021).

India's energy composition is characterized by coal accounting for around 60% of the total energy supply, followed by oil at 27%, natural gas at 7%, lignite at 4%, hydropower at 3%, and nuclear power at 0.22%. Utilizing renewable energy has a positive effect on business operations. Additionally, they are crucial to any country's efforts to improve economic growth and living standards. The use of fossil fuels and renewable energy sources may both benefit economic growth in G7 nations. There exist notable disparities in residential energy consumption patterns between rural and urban areas in India, as well as among various income categories within urban settings (Kumar. J & Majid, 2020). A significant proportion of rural Indian households, precisely 86.1%, continue to utilize fuelwood and dung cakes for cooking purposes. A total of 3.5% of households located in rural areas utilize liquid propane gas as their primary cooking fuel. Paraffin serves as the primary lighting source in 50.6% of rural households, whereas electricity is utilized by 48.4% of these residences. Approximately 270-

300 million metric tonnes (Mt) of fuelwood are annually utilized, whereas approximately 10.5 million metric tonnes (Mt) of kerosene are utilized, with 60% of this quantity originating from rural areas. The three main types of energy users are industry, residential, and agricultural. Together, they account for more than 85% of all electricity use, or 42.26%, 25.80%, and 17.35% of all non-utilities consumption (Figure 3) (*General Review 2023, 2023*).

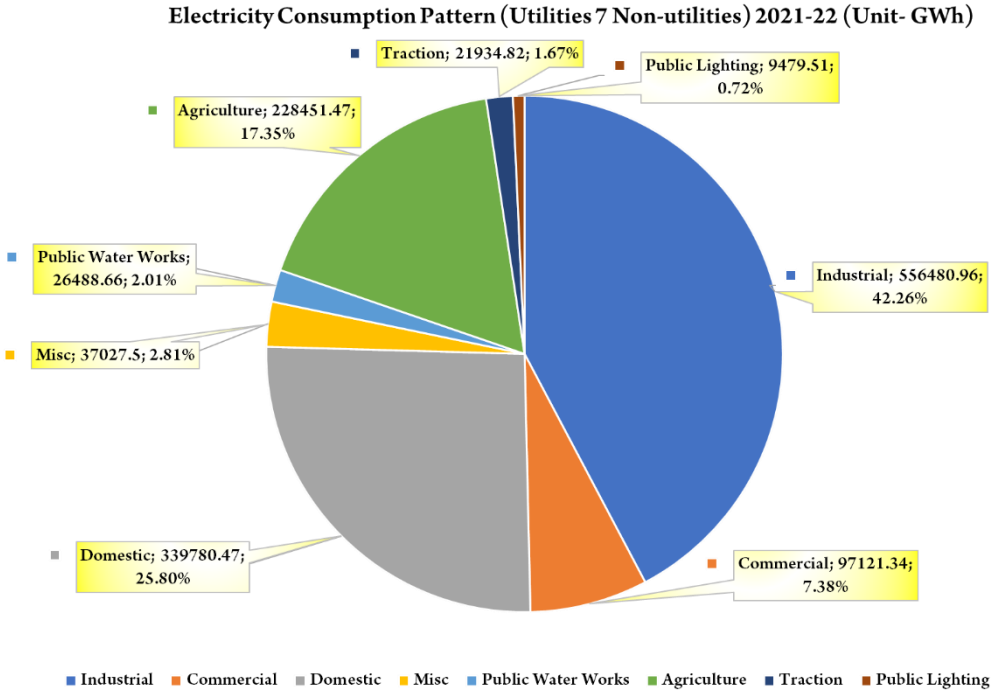

Figure 3. Electricity consumption patterns in 2021-2022 (*Data Source- General Review, 2023*).

The existing deficit in energy supply, the historical focus on conservation and fuel economy during the Industrial Revolution, and the shift from coal to oil in the energy sector collectively underscore the imperative for significant economic adjustments. There was a prior intention to augment the energy supply from several sources to promote its advancement and utilization. In recent times, there has been a notable movement in the emphasis of energy planning towards the establishment of sustainable energy systems. This shift is driven by the recognition of the evolving circumstances characterized by limited availability, high costs, and the unreliable nature of traditional energy sources. Consequently, energy planning now encompasses the exploration and development of alternative energy sources as well as the efficient use of energy resources (Holechek et al., 2022).

Solar energy:

Sunlight reaches Earth at a rate of 1.5 x 10^{18} kWh per year. In comparison to the world's present yearly energy usage, this is over 10,000 times greater. At its surface, the sun is about more than 5000°C hot. Continuous energy release from the sun is achieved through fusion reactions, which generate 3.94 x 10^{23} kW of power. The 93 million miles it takes for the sun's

radiation to reach Earth is approximately 91/3 minutes. At an average of 340 watts per square meter, or 1.73 x 10^{14} kilowatts, the amount of power that the sun emits is far more than what the Earth gets. Clouds, dust, and "greenhouse" gases like ozone, carbon dioxide, and water vapor absorb around 20% of the radiation, while the remaining 30% is reflected into space. India experiences yearly global radiation levels that are similar to those in tropical and subtropical countries, ranging from 1600 to 2200 kWh/m^2. Approximately 6,000,000,000 GWh of energy might be produced annually (Rhodes, 2010).

The amount of solar energy that India receives each year—more than 5,000 trillion kWh—far exceeds the country's total yearly energy usage. With an annual range of 2300–3200 sunshine hours, the average daily radiation across the world is about 5 kWh/m^2. The energy concreteness is depleted, and the availability is intermittent, but it can now be consistently converted to usable heat or directly generated into electricity, so it can be used for many things. About 20,000 MW of gross potential energy is located in Karnataka. Of the 18 projects approved by the government, one with a capacity of 4 MW out of a total of 116 MW has been put into operation (Harinarayana & Kashyap, 2014).

In recent years, solar power has made a noticeable difference in India's energy landscape. Decentralized and distributed applications powered by solar energy have helped millions of people in rural India with their energy needs, including cooking, lighting, and more, all while being kind to the environment. The monetary and social advantages encompass enhancing the standard of living and fostering economic prospects at the grassroots level, mitigating the hazards of respiratory and ocular diseases, generating employment opportunities within the village, and alleviating the burdensome tasks faced by female folks with the need to gather firewood from distant locations and prepare food in smoky kitchens (Yadav et al., 2019). Furthermore, the solar energy sector in India has emerged as a significant contributor to the nation's capacity for power generation via grid interconnections. In addition to addressing the increasing need for energy in the country and contributing to the government's goal of sustainable development, it also strengthens the government's efforts to ensure energy security (Obaideen et al., 2021).

Assuming that Solar PV modules occupy 3% of the wasteland area, the National Institute of Solar Energy (NISE) has estimated that India's solar potential is approximately 748 GW. With the National Solar Mission (NSM) being a crucial component, solar energy has assumed a pivotal role in India's National Action Plan on Climate Change. The debut of NSM took place on January 11, 2010. With the help of the states, the CGI launched the National Solar Mission (NSM) to combat energy insecurity and promote environmentally friendly development. As a bonus, it will be India's big contribution to the international fight against climate change. The Mission wants to make India a world leader in solar energy by quickly making sure that the laws are in place so that solar technology can be used all over the country. India has promised that by 2030, it will cut the amount of pollution caused by its GDP by 45 percent compared to 2005 levels and get about 50 percent of its electricity from sources other than fossil fuels. This

aligns with its Nationally Determined Contributions (NDCs) (Mitavachan & Srinivasan, 2012) (Figure 4).

Solar energy has been actively promoted throughout the country by the government. Among them are:

- Providing an automatic pathway for up to one hundred percent FDI,
- Projects that are scheduled to be operational by June 30, 2025, will not be charged for interstate sales of solar and wind power through the Inter-State Transmission System (ISTS).
- Certification of the Renewable Purchase Obligation's (RPO) trajectory to 2029–30,
- Standardization of solar photovoltaic system and device deployment notification,
- Creating a Project Development Cell to help bring in investment capital,
- To acquire power from grid-connected solar PV and wind projects, standard bidding guidelines are used.
- Power must be sent against a Letter of Credit (LC) or advance payment per government orders. This is to guarantee that distribution licensees will pay RE generators on schedule.
- The 2022 Green Energy Open Access Rules Notification: A Call to Action to Promote Renewable Energy.
- "The electricity (Late Payment Surcharge and related matters) Rules 2002" (LPS rules) became effective upon notification.
- The Green Term Ahead Market (GTAM) is going live to make it easier to trade renewable energy power, such as solar electricity.

According to the Renewable Capacity Statistics 2023 published by IRENA and the Global Status Report 2023 put out by REN21, India ranked fifth in solar PV installations globally at the end of 2022. Around 70.10 GW of solar power has been installed as of 30-06-2023. In recent years, India's solar power business has grown rapidly. In addition to addressing the increasing need for energy in the country and contributing to the government's goal of sustainable development, it also strengthens the government's efforts to ensure energy security (REN21, 2023).

India's government has set up several schemes to encourage the use of solar power in the country. Some of these are the Defence Scheme, the VGF Schemes, the Solar Park Scheme, the Bundling Scheme, the Grid Connected Solar Rooftop Scheme, and the Canal Bank and Canal Top Scheme. The above goals are what they want to achieve. There are also several legislative efforts aimed at improving solar power plants that are linked to the grid (Ministry of New and Renewable Energy, 2017).

In terms of solar power deployment, India is now ranked fifth globally. The country's solar plants have a total capacity of 70.10 GW dated 30-06-2023. The Ministry of New and Renewable Energy, Government of India (2023) reports that out of the total power production of 70.10 GW, ground-mounted solar projects will contribute 57.22 GW, rooftop solar operations will contribute 10.37 GW, and off-grid solar systems will contribute 2.51 GW (Solar overview, 2023).

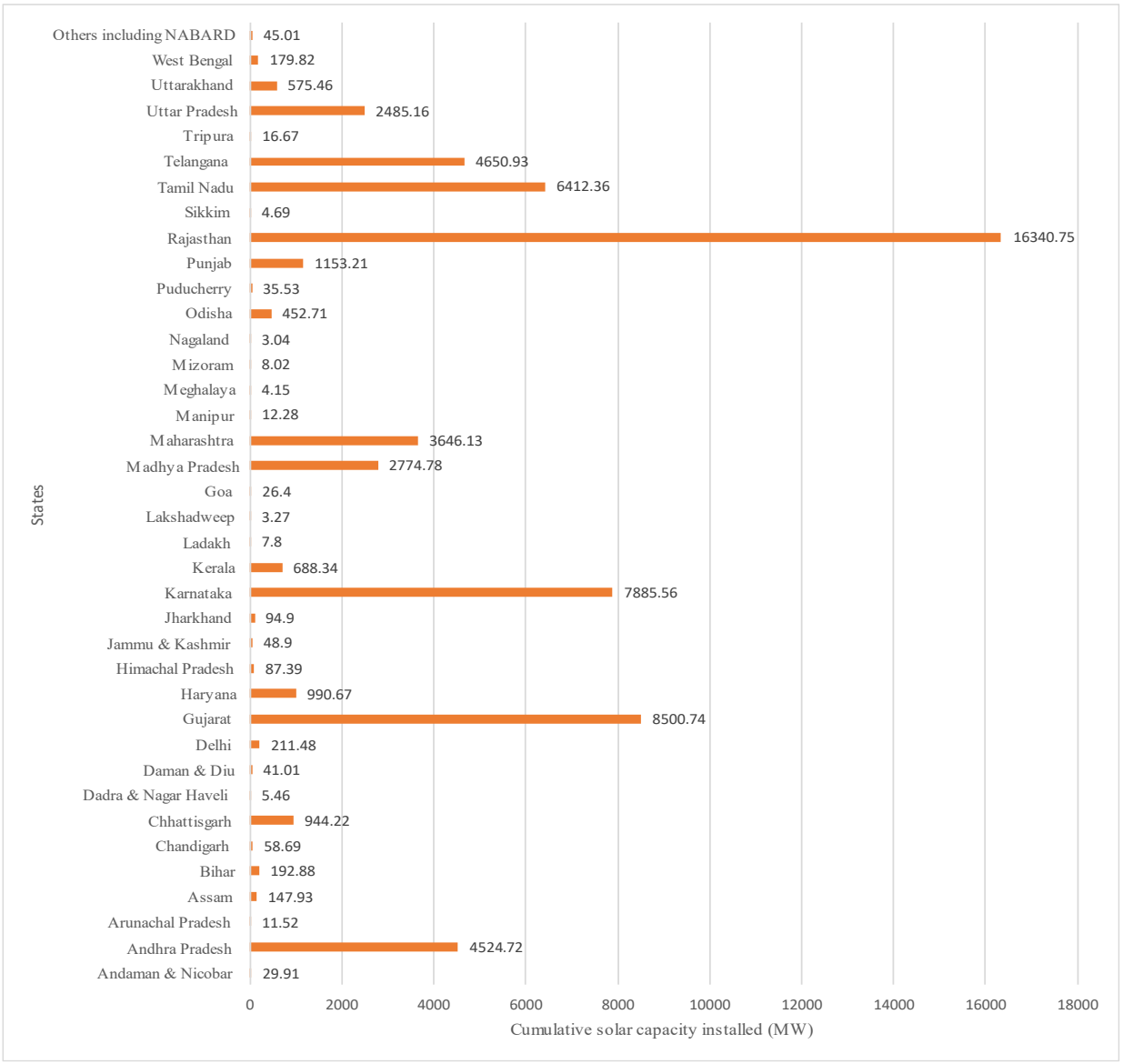

Figure 4. State-wise Cumulative Solar Installed Capacity in the country (as on 31-12-2022) (Source and reproduced from Annual Report, 2022-23, Ministry of new and renewable energy, Govt. of India).

Wind energy:

Wind power has grown at a faster rate than any other renewable energy source in India. Onshore and offshore wind power plants in India take advantage of the country's extensive coastline. The total installed power capacity of wind energy in India was 41.666 GW as of 30 September 2022. There is great promise for wind power to meet India's electricity demands and stimulate the economy. The Muppandal Wind Farm is India's biggest wind farm. A handful of Indian wind farms are among the world's ten biggest wind parks, demonstrating the country's

enormous wind energy potential. Wind farms in India are among the most advanced and efficient in the world, and the country's wind energy sector is highly developed (Bhatti, 2021).

In recent times, the Ministry of New and Renewable Energy has revealed significant findings regarding the wind energy capacity of India. This discovery highlights the country's commitment to sustainable energy practices and reveals which states have the most wind power potential. Also, the Ministry laid out new plans to make sure the wind power industry is more environmentally friendly and to increase its usage. As of April 2023, India's installed wind energy capacity was 42.8 GW (onshore wind), putting it fourth globally behind the US, Germany, and China. According to the National Institute of Wind Energy's wind resource assessment, the country's total wind power potential is 1,164 GW at 150 meters above ground level and 695.5 GW at 120 meters. As far as wind power potential (in GW) at 120 m above ground level is concerned, the top-performing Indian states are Gujarat (142.56), Rajasthan (127.75), Karnataka (124.15), Maharashtra (98.21), and Andhra Pradesh (74.90) (Figure 5) (Dey et al., 2022; Ministry of New and Renewable Energy, 2023).

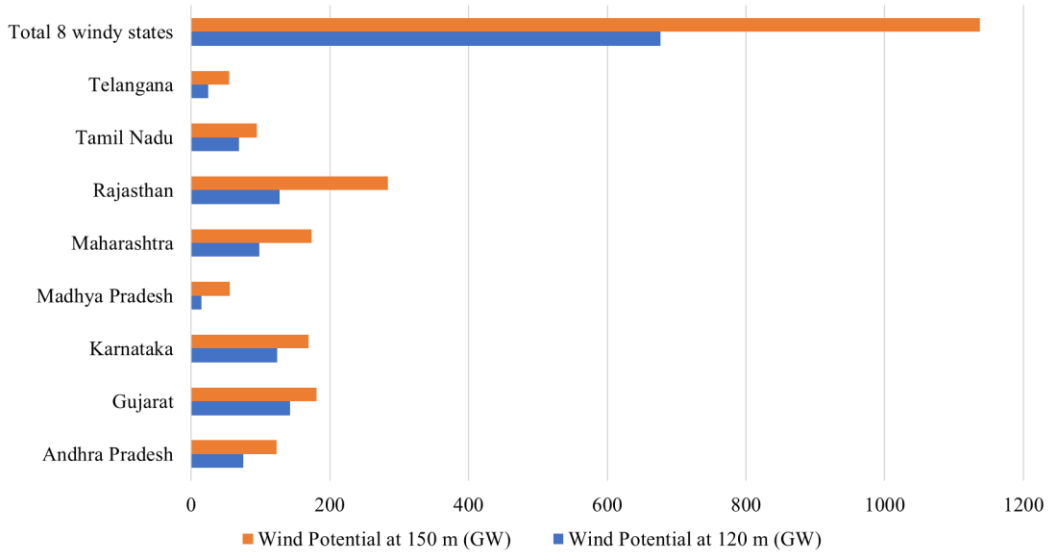

Figure 5. Potential of wind energy in different states of India (*Source: Ministry of New and Renewable Energy, 2023*).

Offshore wind farms are man-made structures set up at great distances from land. One major benefit of land-based installations is the stronger, more consistent wind experienced at lower elevations. Although located on land, nearshore wind farms are just a short distance from the water. The site's ability to harness both land and maritime breezes for energy generation is a major selling point. Using wind power has many advantages. Once set up, this renewable energy source requires very little maintenance because it is non-perishable. Petrol is superfluous (National Grid, 2022). Additional benefits might be found below:

– After commissioning, there is a short gestation period before power generation begins. As soon as generation starts, power is freely available.

– Power generation is more cost-effective due to the absence of input costs and almost nonexistent recurring charges.
– Environmentally speaking, wind power does not produce any harmful byproducts.
– The generation process is ongoing, unlike diesel power. Never put money into anything.

Reduced electricity generation and late payments to energy suppliers are examples of discom risks, and general challenges impacting distribution corporations. Meeting demand requires overcoming installation challenges and delivering electricity from wind farms to urban areas. Therefore, it might significantly lower the price of expanding the country's transmission network to link areas with abundant wind resources to big population centers. Local wildlife could be affected by wind farms. Research is still necessary to lessen the wind's influence on animals, even if wind energy projects are less harmful to wildlife than other energy ventures (Gandhi et al., 2022).

Launched in 2014, the National Wind Energy Mission aims to stimulate the growth of wind energy in India. In 2022, the mission aims to install 60 GW of wind power capacity. In 2015, the Indian government initiated the National Offshore Wind Energy Policy to promote the establishment of wind power facilities in rural and isolated regions. Wind-solar hybrid power plants: In 2018, the government introduced the Wind-Solar Hybrid Policy to promote the development of power facilities that integrate both wind and solar energy sources (Kandpal & Dhingra, 2021).

Hydro energy:

India has been utilizing hydropower for approximately 120 years. The history of hydropower in India commenced in 1897 with the commissioning of the first tiny 130 kW hydro project in the Darjeeling hills. The second project proposed in 1902 in the Mysore region of Karnataka was the 4500 kW Sivasamudram project, intended to provide electricity to the Kolar gold mines. Subsequently, other minor hydro projects were established throughout the nation's mountainous regions. The nation had a 1362 MW installed capacity before its independence (1947), including 508 MW of mostly small- and medium-sized hydropower dams. The MNRE estimates that small hydropower plants have a 20 GW potential nationwide (IREDA, 2023).

About 37% of all power generating capacity and more than 53% of electricity generation in 1947 came from hydropower. In India, hydropower began to lose ground to coal-based power generation in the late 1960s, and its proportion of capacity and generation dropped sharply. About 11% of electricity generation capacity in August 2023 came from hydropower, with a capacity of 46,865 MW (megawatts) (Figure 6). Hydropower accounted for 12.5% of India's energy generation in the year 2022-2023. By 2023, India possessed an operating pumped storage capacity of around 4745.6 MW. Furthermore, there were roughly 57,345 MW of pumped reservoir capacity in different stages of advancement in research and development (Sati et al., 2022).

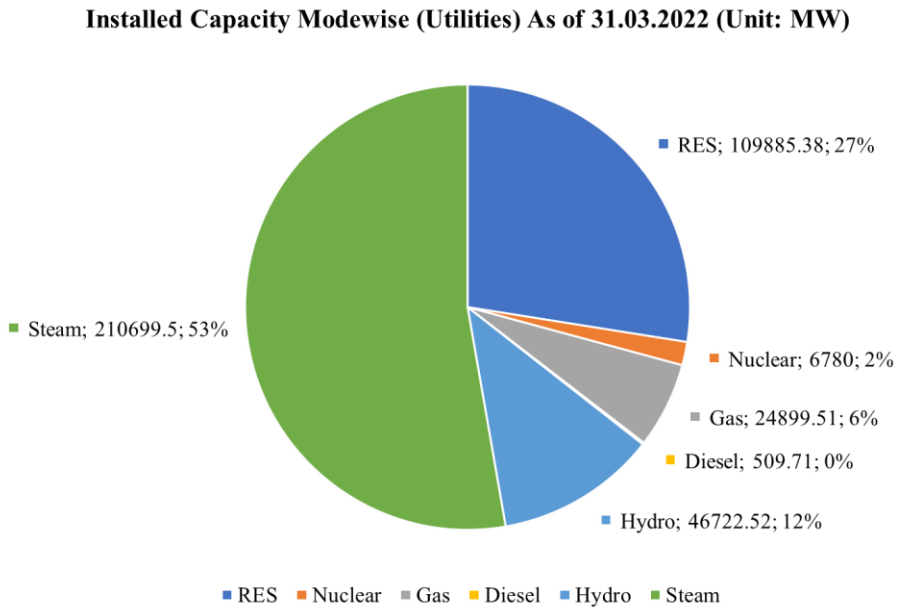

Figure 6. Electricity installed capacity in 2021-2022 (*Source- General Review, 2023*).

Small and large hydropower projects are the two general categories into which hydropower projects fall. Hydro projects in India that have a station storage of up to 25 MW are classified as Small Hydro Power (SHP) projects.

- Micro: up to 100 KW
- Mini: 101 KW to 2 MW
- Small: 2 MW to 25 MW
- Mega: Hydro projects with installed capacity ≥ 500 MW
- Thermal Projects with installed capacity ≥ 1500 MW

The Ministry of New and Renewable Energy has authority over small hydropower (up to 25 MW), while the Ministry of Power, Government of India, is in charge of larger hydro projects. With more than two-thirds of all renewable electricity produced worldwide, hydropower is currently the most popular renewable energy source. The installed hydropower capacity worldwide increased by 26 GW (gigawatts) in 2021 to 1360 GW. Hydropower produced 4,250 TWh (terawatt hours) of clean electricity globally, which is more than all renewable energy sources put together and 1.5 times the EU's total electricity usage (Nouni et al., 2006; Gupta et al., 2021).

However, the International Energy Agency (IEA) estimates that 45 GW of yearly capacity addition is needed to fulfill net-zero targets by 2050 and limit global temperature rises to 1.5°C. This is a significant shortfall. It would take 30 GW a year to limit temperature increases to 2°C. China accounted for around 80% of the newly constructed hydroelectric capacity in 2021. Three times as much hydropower was added to the grid in 2020—4.7 GW of pumped storage hydropower. The rate of increase in hydropower generation capacity worldwide in 2021 was a

little over 1.9 percent, which is not far from the 2 percent average yearly growth needed to reach the targets outlined in the Paris Agreement (Gielen et al., 2019).

Challenges of hydropower:

Large storage hydropower projects have significant negative social and environmental effects in addition to producing low-carbon electricity. They cause the uprooting of thousands of people, interfere with the ecology of rivers, lead to extensive deforestation, initiate the loss of aquatic and terrestrial biodiversity, and have a detrimental impact on agriculture, food systems, and water quality. Although dam construction is still ongoing in developing nations, it is progressing more slowly now that the finest locations have been chosen and alternative renewable energy sources like wind and solar are receiving more investment and policy attention. The majority of India's new hydropower projects are being developed in the vulnerable Himalayan mountains, where the risk of catastrophic floods and landslides has increased (De Faria et al., 2017).

Recent abrupt flooding in the Dhauliganga, Rishiganga, and Alaknanda rivers in Uttarakhand (Dist. Chamoli) in February 2021 resulted in numerous fatalities and significant damage to several hydropower projects. The Central Electricity Authority (CEA) reported that severe rains in July 2023 caused hydropower projects to be shut down and sustained damage, resulting in a total revenue loss of over INR 1.6 billion. There is a consensus that the extent of the loss was increased by the development of hydropower projects, highways, railway lines, and mining operations without proper appraisals and by the disregard for cumulative impact and disaster potential assessments, even though the exact cause of the 2021 flash floods—glacier crash, avalanche, and landslide—and by these actions (The Times of India, 2021).

Sikkim's Teesta-V hydropower facility was named a worldwide hydropower sustainability model in 2019. NHPC Limited owned and operated the 510 MW power station, which met or surpassed international good practice in all 20 performance categories. The Indian government and industry must promote openness by incorporating civil society, especially project-affected communities, to make hydropower planning sustainable. Large, 'smart' hydropower projects may address the economic, environmental, and social issues of local and downstream communities, as well as national economic advantages (IHA, 2019).

Green Hydrogen:

India has stated its goal of achieving energy independence by 2047 and net-zero status by 2070. It is anticipated that green hydrogen will play a significant role in meeting these objectives. The process of electrolysis, which involves splitting water into hydrogen and oxygen using electricity from renewable sources such as solar, wind, or hydropower, produces green hydrogen. This method yields a clean, emission-free fuel with the potential to replace fossil fuels and reduce carbon emissions. Green hydrogen can also be produced using biomass, which is gasified to generate hydrogen. The sustainability and purity of these two

manufacturing methods make green hydrogen an appealing alternative for the transition to a low-carbon future (Yadav & Shahi, 2023).

The demand for green hydrogen is rapidly increasing due to its potential to decarbonize various industries, including transportation, shipping, and steel. Green hydrogen can replace traditional fossil fuels in transportation, significantly reducing greenhouse gas emissions. It can also be used in industries to produce ammonia, methanol, and steel, which currently heavily rely on fossil fuels. As a backup energy source for renewable energy plants, green hydrogen offers a steady and reliable energy supply. Among its many applications, green hydrogen can be utilized in fuel cells for energy production and powering vehicles. It can also be used in the production of chemicals and fertilizers, heating systems, and other processes. Hydrogen fuel cells, known for their increased efficiency and energy density, are a preferred alternative to traditional combustion engines in vehicles. Additionally, microgrids, providing energy independence to remote areas, can benefit from green hydrogen (Kazi et al., 2021).

The significance of green hydrogen in India's journey towards energy independence cannot be overstated. Utilizing renewable energy sources like solar, wind, and hydropower to produce green hydrogen enhances energy security and reduces dependence on fossil fuels, ensuring a consistent and reliable energy source. Domestic production of green hydrogen eliminates the need for costly and hazardous imports. Moreover, creating green hydrogen from waste biomass provides additional revenue streams for farmers and neighbouring communities. Consequently, India has initiated the National Green Hydrogen Mission with a budget of Rs. 19,744 crores, aiming to produce 5 million metric tonnes of green hydrogen annually (Sheth, 2023).

In conclusion, green hydrogen holds great promise in reducing carbon emissions, decarbonizing various industries, and achieving energy independence. Its sustainable and environmentally friendly generation makes it a compelling option for the transition to a low-carbon future, utilizing renewable sources such as solar, wind, and hydropower. In industrial and transportation applications, green hydrogen provides a stable and predictable energy source, replacing traditional fossil fuels. Its capacity to reduce dependence on fossil fuels and provide a consistent and reliable energy source makes it essential for achieving energy independence (Marouani et al., 2023).

An estimated 5 million metric tonnes (MMT) of hydrogen are annually utilized in India for various industrial applications, including metal extraction and refinement, methanol production, ammonia generation for fertilizers, and petroleum refining. Most of this hydrogen, also known as "grey hydrogen," is currently produced through steam reforming of naphtha, natural gas, and other fossil fuels. Hydrogen gas is also produced as a byproduct of the chlor-alkali industry. Water electrolysis, utilizing grid energy, produces some hydrogen for specialized applications (The Economic Times, 2023).

Another crucial intervention would be to increase the production and usage of high-performance electrolyzers in sufficient quantities. Currently, only 2-4 GW of commercial electrolyzers are produced globally each year. Over the past three years, several business

organizations and national governments have announced intentions to deploy more than 200 GW of electrolyzer capacity by 2030. Consequently, the global capacity to create electrolyzers is expected to rise rapidly. To ensure supply chain stability and reduce dependency on imports, India must establish a robust local environment for electrolyzers' production. The Mission recommends domestic industry support to ensure significantly lower costs for India's electrolyzer production, enhancing the competitiveness of Made in India Green Hydrogen in international markets (Halder et al., 2024).

The use of green hydrogen and its derivatives has not yet replaced fossil fuels and their derived feedstock due to adverse cost economics, lack of uniform standards and regulations, supply issues, and the high infrastructure required for the transition. However, based on current trends and analyses, it is likely that Green Hydrogen will soon become cost-competitive for use in industry, mobility, and other sectors. This is attributed to technological advancements, decreased costs for renewable energy and electrolyzers, and aggressive national strategies by some major economies (*Green Hydrogen Cost Reduction*, 2020).

Government initiatives:

The Indian government is taking the following steps to strengthen the country's renewable energy industry:

- Green growth was identified as one of the seven priority nodes, known as SAPTARISHI, in the Budget for the fiscal year 2023-2024.
- Pumped storage projects received increased support in Budget 2023–2024, including the requirement to provide a complete framework for their development.
- The objective of the Union Budget 2023–24 is to construct resilient cities for the future. States and municipalities will be encouraged to adopt urban design modifications and efforts to transform their cities into "sustainable cities of the future."
- The Indian government has provided significant support to the industry and has spurred unprecedented growth by setting a target to reach net-zero emissions by 2070 and increasing its renewable energy goal to 500 GW by 2030 during the COP26 summit.
- A federal sector grant of US $1.02 billion (about Rs. 8,300 crore) has been allocated in the Budget 2023-24 for the development of ISTS infrastructure in Ladakh, which would facilitate the generation of 13 GW of renewable energy.
- On November 19, 2022, Prime Minister Mr. Narendra Modi inaugurated the 600 MW Kameng Hydro Power Station in Arunachal Pradesh. The project is located in the West Kameng District of Arunachal Pradesh and covers a distance of about 80 kilometers, with a budget of around Rs. 8,200 crores (US$ 1 billion).
- On November 9, 2022, Ms. Nirmala Sitharaman, the Minister of Finance and Corporate Affairs, approved India's ultimate Sovereign Green Bonds structure. This authorization will strengthen the objectives of the Nationally Determined Contributions (NDC)

outlined in the Paris Agreement and attract domestic and international finance for environmentally friendly projects.

- Solar Energy Corporation of India (SECI), which promotes the renewable energy industry, earned Rs. 1,000 crore (US$ 132 million) in the Union Budget 2022–2023. The government budgeted Rs. 19,500 crore (US$ 2.57 billion) for a Production Linked Incentive (PLI) to boost high-efficiency solar module production.
- India and Nepal have decided to create a Joint Hydro Development Committee in February 2022 to examine the viability of hydropower projects.
- At the Cop-26 Summit in Glasgow in November 2021, India's PM pledged to satisfy 50% of its energy demand from renewable sources by 2030 and develop 500 GW of renewable energy.
- The Ministry of Power introduced new regulations in October 2021 to alleviate the financial burden on stakeholders and ensure timely cost recovery in power generation.
- The Indian government passed further renewable energy laws in August 2021. The government's recent legislation aims to encourage large energy customers like businesses to utilize renewable energy.
- In July 2021, the Ministry of New and Renewable Energy will launch the second phase of the Rooftop Solar Programme to promote rooftop solar (RTS) systems in rural areas. The plan aims to build 4,000 MW of residential rooftop solar (RTS) electricity by 2022 with financial help. NTPC Renewable Energy Ltd., a fully-owned subsidiary of NTPC, received MNRE approval to establish a 4,750 MW renewable energy park in the Rann of Kutch in Khavada, Gujarat. Indian Railways, the nation's largest electricity generator, aims to cut emissions by 33% by 2030. Energy-efficient practices and the broad usage of clean fuels will achieve this.

The Indian government plans a $238 million National Mission on advanced ultra-supercritical technology for greener coal use. The government has allocated a total of US$ 4.63 billion for hydroelectric projects aimed at supplying power to communities in the Jammu and Kashmir region between 2018 and 2021.

Union Budget 2023: Priority 5: Green Growth:

The Prime Minister has articulated a vision for "LiFE," which stands for Lifestyle for Environment, aiming to catalyze a movement towards a lifestyle that is mindful of the environment. India is steadfastly progressing towards achieving the goals of 'panchamrit' and achieving net-zero carbon emissions by 2070, as a means to facilitate a transition towards a green industrialized and socioeconomic landscape. This Budget further emphasizes our commitment to promoting sustainable economic development through green growth:

- The National Green Hydrogen Mission, with a budget of Rs 19,700 crore, aims to enable the shift of the economy towards low carbon intensity. It will also help reduce reliance on imported fossil fuels and position the country as a leader in both technology

and the market in this emerging industry. The government aims to achieve an annual production of 5 million metric tonnes (MMT) by the year 2030.

- The Ministry of Petroleum & Natural Gas has allocated Rs 35,000 crore for priority capital investments in energy transition, net-zero targets, and energy security.
- Viability Gap Funding will be provided to assist Battery storage systems with a capacity of 4,000 MWH in Energy Storage Projects. A comprehensive structure for Pumped Storage Schemes will be developed.
- The construction of an inter-state transmission line will be undertaken to evacuate and integrate 13 GW of renewable energy from Ladakh. This project would require a capital expenditure of Rs 20,700 crore, with federal assistance of Rs 8,300 crore.
- A Green Credit Programme will be established by the Environment (Protection) Act. This will encourage environmentally conscious and adaptable behaviors by corporations, people, and local organizations and facilitate the mobilization of supplementary resources for these endeavors.
- The "PM-PRANAM" program, which stands for "Programme for Restoration, Awareness, Nourishment, and Amelioration of Mother Earth," would be initiated to encourage States and Union Territories to promote the use of alternative fertilizers and achieve a balanced use of chemical fertilizers.
- Under the GOBARdhan project, 500 new 'waste to wealth' factories will be set up to promote a circular economy by converting organic waste into valuable resources. The proposal entails the establishment of 200 compressed biogas (CBG) plants, with 75 plants located in metropolitan areas and 300 plants in community or cluster-based settings. The entire expenditure for this initiative amounts to Rs 10,000 crore. Eventually, a requirement will be implemented for all organizations that promote natural and bio-gas to have a 5% CBG mandate. Funding will be provided for the gathering of organic matter and the delivery of organic fertilizer.

Future of renewable energy in India:

India faces two main challenges: environmental and energy-related. India plans to increase the share of renewable energy sources in its future energy systems. Technologies for renewable energy evolve along with commercial and technical advancements. India, which has abundant renewable energy resources, is expected to develop and implement projects on a massive scale. India ranks sixth globally in terms of renewable energy production and fifth globally in terms of solar energy production. By 2025, the government wants to increase the capacity of renewable energy to 175 GW, which will be made up of 100 GW from solar, 60 GW from wind, 10 GW from biofuel, and 10 GW from hydropower. By achieving this goal, India would overtake several wealthy nations to rank among the world's top users of green energy. India's government has stated in its Proposed Nationally Determined Contribution to the United Nations Framework Convention on Climate Change that the nation aims to achieve 50% of its

total electrical capacity from non-fossil fuel-based energy sources by 2030 (Kumar et al., 2010). Every economy depends on the daily energy needs for things like computers, industrial equipment, lighting, heating, communications, and transportation. After the US and China, India is the third-largest consumer of energy globally. India uses 37% more energy per person than the world average. India's energy system is primarily based on the production of power from coal and the transportation and industrial use of oil. For the next generation to live in a cleaner, greener, and safer environment, a nation must prioritize energy security, economic growth, and environmental preservation. India has realized how important it is to acknowledge and value efforts aimed at advancing renewable energy sources and sustainable development. Ultimately, there are a lot of long-term benefits to renewable energy. India has a lot of potential for renewable energy to narrow the gap between supply and demand. Going into the future, vehicles powered by hydrogen and electricity will be the most practical options. The limitations of clean energy sources will be easily surmounted if this is done (Kumar. J & Majid, 2020; Strielkowski et al., 2021).

Fast Facts:

- The Paris Climate Accord, signed by over 180 nations, aims to restrict global temperature rise to less than 2°C (3.6°F) beyond pre-industrial levels by 2100. After the Trump administration withdrew from the Paris Agreement on Nov. 4, 2020, President Joe Biden signed an executive order to rejoin on Jan. 20, 2021.
- The 2020 COVID-19 pandemic encouraged a decrease in fossil fuel prices due to record-low usage. After the Ukraine-Russia war began in early 2022, oil prices surged and remained high.
- A 15-year-old tree produces 700 shopping bags.
- More than 2.5 million plastic bottles are used by Americans every 30 minutes. Despite being recyclable, most of these bottles are thrown away.
- Leaving your tap running while brushing your teeth uses around 4.68 liters of water. A 15-minute shower uses 25-50 litres.
- Overnight computer monitor use emits 9 million tonnes of CO2 annually. We must cut human carbon dioxide emissions by 45% from 2010 levels by 2030 and reach net zero by 2050 to prevent a climatic disaster.
- Denmark is the Earth's most eco-friendly nation, followed by Luxembourg, Switzerland, and the UK. Denmark has a centuries-old culture of sustainability, and world-class renewable energy is also available.
- Although China and India are major polluters, they plant more trees than any other country. With 80% of animals in forests and 20% of global emissions from deforestation, we must maintain forests.
- Approximately 71% of the Earth's surface is covered by water. The seas contain around 96.5% of the Earth's water, while the ice caps store around 2%. The residual water is

present in many water bodies such as wetlands, streams, ice caps, glaciers, and lakes, and as water vapor in the atmosphere, as well as in our taps. Just 1% of the Earth's water is potable for human consumption.

- The collective weight of the ants on Earth surpasses that of all human beings. The worldwide population exceeds 7 billion individuals, whereas the number of ants amounts to over 100 trillion.
- Recycling a single aluminum can conserves sufficient energy to power a television for three hours. Within the duration of reading this text, a total of 50,000 aluminum cans with a capacity of 12 ounces are manufactured.
- The Great Pacific Garbage Patch is a swirling and convoluted gyre comprised of refuse and detritus. Spanning an area twice the size of continental America, this region extends from the West Coast of North America to Japan along the Pacific Ocean. It is estimated to hold around 100 million tonnes of rubbish.

Conclusion:

In conclusion, the examination of the present status and future outlooks of renewable energy in India reveals a dynamic landscape shaped by technological advancements, policy interventions, and the pursuit of sustainable development goals. The country has made substantial progress in harnessing renewable sources, with notable achievements in the solar and wind energy sectors. However, challenges persist, including grid integration issues, financial barriers, and the need for enhanced storage solutions. Looking forward, the future outlook appears promising with the continued commitment to ambitious renewable energy targets and the adoption of innovative technologies. The intersection of sustainability and economic viability emerges as a focal point, emphasizing the importance of striking a balance between environmental conservation and economic growth. Renewable energy plays a crucial role in India's journey towards sustainability, aligning with global initiatives. The chapter underscores the significance of comprehensive policies, technological innovation, and international collaborations to propel India into a greener and more sustainable energy future. As the nation strives for energy security and environmental resilience, the evolving landscape of renewable energy in India remains a beacon of hope for a sustainable and equitable future.

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