ROLE OF ELECTRICITY GENERATION TECHNOLOGY IN THE LONG-TERM ENERGY SUSTAINABILITY OF INDIA

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ABSTRACT

Electricity distribution has become one of the most essential components of our society since the beginning of human civilization, relying on an abundant, reliable, and affordable power supply. Fossil fuels dominate the production of electricity (89.57 %), emitting 68.7 % of greenhouse gases, polluting water and soil, and depleting fossil fuels. Future energy needs are faced with growing demand for coal (772 million tonnes by 2040) and fluctuating fuel prices. The Indian power sector withdraws over 20 billion m^3 of water, whereby coal power plants use around 35 % of freshwater. Among the seventeen sustainable development goals, Goal 7 emphasizes meeting the demand for electricity, the availability of clean fuels, and mitigating air pollution. In 2021, about 747 TWh of energy consumption was met by coal, oil (92 TWh), and solar energy (25 TWh). Renewable power would meet the world's growing energy needs, reduce greenhouse gas emissions, boost the economy, and strengthen the society. Therefore, renewable energy has gained global attention as a sustainable electricity source. For this, a thorough examination of the economic and social implications of electricity generation technologies must be carried out. This study discusses how fossil fuel-based electricity generation affects global health and the environment and helps achieve Goal 7 of the sustainable development goals. All sectors must work together to stop global warming and water war and make electricity available worldwide for integrated development.

***Keywords*:** *electricity generation, sustainability, emission, renewable energy, sustainable development*

INTRODUCTION

Sustainability is based on three pillars: environmental quality, equal opportunity for all, and economic viability. Goal 7 of the sustainable development goals (SDGs) emphasizes meeting the demand for electricity, the availability of clean fuels, and mitigating air pollution. Among all sectors, the energy sector contributes around 68.7 % of greenhouse gas emissions in India. Electricity contributes to environmental pollution, especially in developing countries [1]. The adoption of renewable energy technologies is the only solution to reduce energy pollution [2]. Non-renewable energy sources harm public health and pollute the environment, land, and water. Moreover, the depletion of

limited fossil energy resources is a major concern. This seriously affects their presence for coming generations and increases the dependence on imports from other countries. This circumstance requires a complete revision of the production, transmission, and use of electricity. Around the world, efforts have been made to prioritize renewable energy sources to address the supply gap while reducing environmental problems. These resources replace conventional sources in the energy sector, resulting in reduced emissions of carbon dioxide and other toxic effluents. The share of electricity production from renewable sources increased to 151,2 TW due to the availability of cost-efficient technologies for capturing and storing solar energy. The high availability of solar energy and wind energy reduces dependence on the import of oil and gas. The use of solar energy is expanding from solar roofs to solar parks; remote communities and rural areas have gained access to electricity thanks to renewable energy.

ENERGY AND ITS GROWING NEEDS IN INDIA

Electricity and the environment are linked because the effect of electricity generation technology on the environment cannot be ignored. India's population was 1.4 billion in 2021 and is expected to reach 1.6 billion by 2040, requiring a significant increase in energy production to meet energy demand. In 2020, about 91 % of the world's population had access to electricity [3]. In 2021, the country's energy demand was 1379812 million unit (MU), and the energy supply was 1374042 MU [4]. The country ranks second in terms of coal production, with 59 % of electricity production from coal [5]. The country focuses on the environmental aspects of energy consumption and emphasizes that energy must always be provided without interrupting the supply of electricity [6]. As we know, India is mainly dependent on oil (80 %), coal (10 - 20 %), and natural gas (55 %), which reflects the need for strategic alternative solutions for energy security, infrastructure development, research and development, and renewable energy sources. Therefore, the entire energy system should be sustainable in the long term. India is second largest coal consumer and fourth largest carbon dioxide emitter (a share of about 7 % in the global annual CO_2 emission) [7 - 9]. The country's energy intensity went down from 1.15 kilowatt hours (per 2011$ PPP (purchasing power parity)) in 2013 to 1.05 kilowatt hours (per 2011$(PPP)) in 2018 [10]. This decrease in intensity will positively impact the Paris Agreement target of 33 - 35 % reduction in emissions intensity, enabling India to meet 56 % of its target by 2030 [11].

ELECTRICITY SUPPLY IN INDIA

Electricity distribution has become a necessary aspect of our civilization. A stable, abundant, and affordable supply of electricity supports many human activities. The electricity in the energy grid is produced with fossil fuels (~ 60 %), which contributes to the generation of greenhouse gases [11]. Other environmental consequences produced by the power sector are loss of biodiversity, health hazards, and land degradation, which requires the decarbonization of the electricity sector. Electricity demand in India increased from 949 TWh to 2338 TWh between 2015 and 2030, making it the third largest electricity market in the world [12]. India's projected electricity demand increased by 6 % in 2021 and will grow at a rate of 5 % per year until 2040, nearly tripling global electricity demand as shown in Figure 1 [12]. In 2021, India's electricity generation capacity was 390791 MW, with 234024 MW from fossil fuels and 156347 MW from renewable energy sources. The country`s electricity supply is 817816 MU; there is still demand for 821705 MU of energy [13].

National Electricity Plan has prepared a ten-year action plan for the supply of electricity in the country in order to efficiently deliver electricity to citizens at an affordable price [14]. From 2017 to 2022, the plan predicts the shutdown of 22.7 GW of coal power plants

due to the insufficient area for Flu Gas Desulfurization (FGD) equipment [15]. The future power mix of India is a critical component in meeting the energy demand and emission reduction targets. India looks set to install 450 GW of renewable energy by 2030. However, due to the Covid-19 pandemic, the progress stalled in 2021. Several countries have changed their electricity policies due to the realization of global issues caused by global warming and the security of the energy supply.

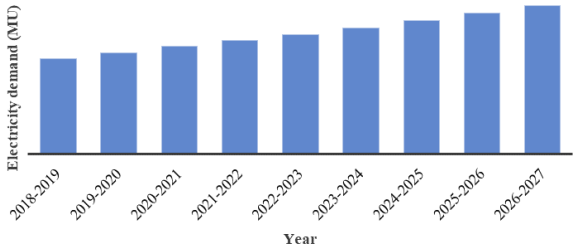

Figure 1. Electricity demand in India [12]

Sources of electricity generation

Coal energy

Coal-fired power plants are crucial in electricity generation since coal is relatively cheap, readily available, and well-established. Coal accounts for more than 57 % of India's total electricity generation. Despite significant resources, the quality of coal in the country is average, with 45 % ash and low calorific values. Even the imported high-quality coal contains 10 - 15 % ash [16]. Despite its negative consequences, the installed capacity of electricity generation from coal is still the largest among all sources (202665 MW), as shown in Table 1.

Natural gas and oil

Natural gas emits less CO_2 per joule supplied than coal or oil, emitting significantly fewer pollutants. India's natural gas reserves are estimated at 1241 billion m^3. In 2017, the crude oil reserves in the western offshore and Assam fields reached slightly more than 604 million tonnes, while gas reserves in the offshore fields are about 1290 billion m^3. The total installed capacity of oil- and gas-fired power plants in 2019 was 638 MW and 24937 MW, respectively [15]. However, the increased risk of leaks and spills can lead to disasters in gas exploration combined with oil drilling.

Table 1. Installed electricity generation capacity by source [11]

Technologies	Installed electricity generation capacity (MW)
Coal	202665
Lignite	6620
Gas	24900
Diesel	510
Renewable energy sources (RES incl. Hydro)	150544
Hydro	46512
Wind, Solar and other RE	104031
Biomass power/Cogen	10176
Waste to energy	434
Small hydro power	4831
Nuclear	6780

Solar energy

Solar photovoltaic (PV) is one of the fastest-growing renewable energy sources. Solar energy potential of India is about 748 GW, and the currently installed capacity is 53.99 GW [16]. PV systems vary in size from residential (10 kW) to utility-scale (1 - 10 MW). In recent years, the cost of solar panels has fallen dramatically, bringing the price of solar PV in some places on par with the price of coal.

Biomass

Biomass energy provided 149.2 million MWh of electricity in the Indian power sector in 2016. With a current installed capacity of 10.17 GW of biomass power plants, the country has exceeded its target of 10 GW of biomass energy in 2021 [17]. Unlike other

renewable energy technologies that depend on the weather, fuels for biomass power plants can be stored and transported easily. Besides the advantages, it also has a significant negative impact on the communities that surround it. Biomass power plants produce pollution and toxic ash that concern those who live near such plants.

Geothermal energy

The geothermal energy potential in India is more than 10000 MW. This energy produced from natural hot springs is converted into electricity in geothermal power plants. In cooperation with other countries, India has proposed to tap 10 GW, which could result in a production of 10 GW by 2030.

Nuclear energy

In 2021, about 1.12 % (43 TWh) of electricity in India was obtained from nuclear power plants [10]. India currently has 22 nuclear reactors with an installed capacity of about 6780 MW. The Kudankulam nuclear power plant, located in Tamil Nadu, is India's largest nuclear power plant. Nuclear power plants can produce constant electricity for a long time. The average operating life of a nuclear power plant is more than sixty years. It requires high capital costs and a long construction period. However, their production costs are low compared to the other options. In addition, the loss of capital invested, accidents, or damage may have irreversible effects on the environment and people.

Hydro energy

Hydropower is often recognized as a low-carbon energy source for electricity generation. In 2019, India installed 45.4 GW of hydropower capacity, while the installed capacity of small hydropower plants reached 4848.90 MW in 2021 [12]. Tehri Dam (largest dam) has an installed capacity of 1000 MW and is located in Uttarakhand (India). However, the decline in electricity production from hydropower plants is caused by alternative energy sources and a lack of effort. Large dams installed in India emit 33.5 MT of methane per year [18]. The displacement and destruction caused by large dams are serious threats.

Wind energy

Wind energy accounted for more than two-thirds of the total increase in renewable energy capacity in India between 2000 and 2008 [19]. Despite producing no emissions, wind energy projects have several adverse effects. Offshore wind power is also a viable solution in this case. The cost per MW for offshore turbines is higher because of the heavier constructions and foundations required in a marine environment; ideal tariffs can be attained due to the higher efficiency of these turbines following ecosystem development.

Emissions from the power sector

Power generation is a key component of economic and social progress. Power technologies affect the environment, resources, energy security, and social acceptance [20]. Although carbon capture technology in coal-fired power generation significantly reduces GHGs emissions, emissions are high and projected to increase until 2030, as shown in Table 2. Coal-fired power plants account for more than half of electricity generation capacity, making them one of the most polluting industries in the country. By 2022, India aims to reduce emissions from thermal power plants significantly. Electricity generation through solar photovoltaic power plants and coal produce ~ 40 g CO_2 eq/kWh and ~ 1000 g CO_2 eq/kWh, respectively (Table 3), which indicates the need to switch to renewable energy sources. The Ministry of Environment, Forests, and Climate Change has established standards for controlling GHG emissions, which are more rigorous for new power plants. The main categories of pollutants emitted by thermal power plants are: nitrogen oxide, sulphur oxide, greenhouse gases (GHGs), and particulate matter (PM).

The Government of India has taken various steps to reduce coal-fired power generation. Several councils and expert panels have recommended that no new coal-fired power plants be built. The total installed capacity of thermal power plants is about 234 GW; the country must stop increasing the capacity of thermal power plants to meet its promise to be net-zero by 2070 and to install approximately 500 GW of renewable energy by then.

Table 2. Estimated emissions from coal-fired power generation in 2030 [21]

	GW	PM2.5 (ktons)	SO_2 (ktons)	NO_x (ktons)	CO (ktons)	CO_2 (ktons)
India	457.9	1514	8447	8440	6547	4318

Table 3. Emission of carbon dioxide from electricity generation sources [22, 23]

Source	Total emission	Upstream	Operational processes	Downstream processes
Solar PV	~ 40 g CO_2 eq/kWh	~ 60 - 70 %	~ 21 - 26 %	~ 5 - 20 %
Coal	~ 1000 g CO_2 eq/kWh	< 1 %	> 98 %	< 1 %

ADVANTAGES OF RENEWABLES OVER CONVENTIONAL ENERGY SOURCES

The continuous supply of electricity has been a critical obstacle in the country's development. Renewable energy has recently received much attention as a sustainable source of electricity generation worldwide. India's favourable geographical location enables the country to have a secure, affordable, and sustainable future using available renewable energy technologies. Renewable energy plays an essential role in rapid and sustainable economic growth, alleviating electricity shortages, improving access to energy through diversification of fuel sources, and reducing dependence on conventional sources. Generation of electricity through renewables reduces the dependence on fossil fuels and their import, expands the availability of electricity, reduces fluctuation in electricity prices, increases employment opportunities, intensifies optimization of electricity needs and production, reduces the ecological and social effects of electricity production [24]. A study on the additional benefits of intensive emission reduction policies in the US confirmed that emissions reduction policies could prevent 36000 premature deaths per year from 2016 to 2030 [25]. Renewable energy technologies contribute to energy security by diversifying fuel mixtures and are actively involved in various measures to revive the economy [26]. Increased use of renewable energy sources reduces emissions and energy dependence on other countries by promoting domestic manufacturing industries, regional and engineering sectors, improving R&D technology, and creating more jobs [27]. Renewable energy sources are the most suitable solution for solving such problems [2]. Renewable energy sources offer critical electricity in village and coastal areas where the electricity system is underdeveloped [28].

A study by Bridge to India (2014) estimates that approximately 0.32 million jobs would be created in the next ten years through small rooftop installation, and about 71000 jobs would be created in the utility-scale system. The renewable sector employed approximately 0.39 million people in India and 9.8 million globally in 2016 [29]. Renewable technologies (solar, wind, hydropower) will help the country achieve sustainable development goals. In 2020, worldwide employment in renewable energy reached 12 million [30]. The government has also taken concrete actions for grid installations across the country and encouraged research and development.

CONCLUSION

Developed and developing countries face energy security and environmental concerns due to electricity generation. The demand for energy is growing, and available fossil fuels are limited and pollute the environment. Concern about resource depletion and pollution can be controlled by exploring

alternatives. Existing power generation systems are now being retrofitted with pollution-control technology, which requires additional space while increasing the costs of power generation. The government has issued several instructions for the use of advanced technologies to limit emissions, but conventional energy sources must be abandoned. Renewable energy technologies are the most acceptable options for generating electricity. Since no source is flawless, renewable technologies also have some issues. In addition, existing technologies will become obsolete if we rely only on modern technologies. Renewable technologies are expensive because they are in the development phase and intermittent, which requires storage for continuous use. For this purpose, research and innovations are being carried out, and the price of these technologies is also falling. Electricity generation using renewable sources would result in the reduction of mortality and morbidity, the creation of more jobs, and the reduction of GHG emissions, all of which would contribute to India's sustainable development.

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