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Renewable Energy Sources: Comparative Analysis of Solar, Wind, Hydropower, Biomass, and Geothermal Energy in India

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Abstract: ***The increasing demand for energy and growing environmental concerns have accelerated the transition toward renewable energy sources. Renewable energy technologies offer sustainable alternatives to fossil fuels while reducing greenhouse gas emissions and environmental degradation. Among the various renewable energy sources, solar, wind, hydropower, biomass, and geothermal energy are the most widely utilized worldwide. This study provides a comparative analysis of these renewable energy technologies with a focus on their technological principles, advantages, challenges, and development in India. Recent data from 2023–2025 reports and research studies were analyzed to evaluate the growth of renewable energy capacity. The findings indicate that solar energy has experienced the fastest growth in India due to technological advancements and supportive government policies, while wind and hydropower remain major contributors to the renewable energy mix. Biomass and geothermal energy also present promising opportunities for decentralized and sustainable energy production. The study concludes that integrating multiple renewable energy sources is essential for achieving energy security and sustainable development.***
Keywords: Renewable energy, solar energy, wind energy, hydropower, biomass energy, geothermal energy, India.

I. INTRODUCTION

Energy plays a crucial role in economic growth, industrial development, and improvement of living standards. For decades, fossil fuels such as coal, oil, and natural gas have been the primary sources of global energy. However, excessive use of fossil fuels has resulted in serious environmental problems including air pollution, global warming, and depletion of natural resources. In response to these challenges, renewable energy sources have gained increasing attention worldwide. Renewable energy is derived from natural processes that are continuously replenished, such as sunlight, wind, water flow, organic matter, and geothermal heat. India has emerged as one of the fastest-growing renewable energy markets in the world. Government initiatives such as the National Solar Mission and renewable energy policies have accelerated the adoption of clean energy technologies. According to the Ministry of New and Renewable Energy, India's renewable energy capacity reached around 220 GW by 2025.

II. LITERATURE REVIEW

Recent research highlights the importance of renewable energy in achieving sustainable development goals. The International Renewable Energy Agency reported that renewable energy accounts for a significant portion of global electricity generation. Studies also show rapid growth in solar installations and wind farms worldwide. Researchers have emphasized that renewable energy expansion can significantly reduce greenhouse gas emissions and dependence on fossil fuels.

However, issues such as energy storage limitations, grid integration challenges, and high initial investment costs remain important barriers.

III. SOLAR ENERGY

Solar energy is one of the most abundant renewable resources. Solar power is generated by converting sunlight into electricity using photovoltaic cells or by capturing heat using solar thermal systems. Photovoltaic panels are widely used in rooftops, solar farms, and industrial installations.

Solar energy is environmentally friendly and widely available. India has rapidly expanded solar capacity and it has become the largest contributor to the renewable energy sector. However, solar power generation depends on sunlight availability, which requires energy storage technologies for continuous supply.

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IV. WIND ENERGY

Wind energy converts the kinetic energy of wind into electricity using turbines. Wind farms are commonly installed in areas with strong and consistent wind patterns such as coastal regions and open plains. Wind energy is clean and renewable and produces no direct emissions during operation. India is among the leading producers of wind power with major wind installations in states like Tamil Nadu and Gujarat.

V. HYDROPOWER

Hydropower is one of the oldest renewable energy technologies and uses the energy of flowing water to generate electricity. Hydropower plants often involve dams that store water in reservoirs and release it through turbines. These systems are reliable and capable of producing large amounts of electricity. However, large hydropower projects may cause environmental and social impacts if not managed carefully.

VI. BIOMASS ENERGY

Biomass energy is derived from organic materials such as agricultural residues, wood, and animal waste. Biomass can be burned to generate electricity or converted into biofuels such as ethanol and biodiesel. This energy source is particularly useful in rural areas and can help reduce agricultural waste while providing additional income to farmers.

VII. GEOTHERMAL ENERGY

Geothermal energy originates from heat stored beneath the Earth's surface. Geothermal plants use steam or hot water extracted from underground reservoirs to generate electricity. This energy source provides stable power and produces minimal emissions. However, geothermal resources are geographically limited and still under development in India.

Table: Renewable Energy Installed Capacity in India

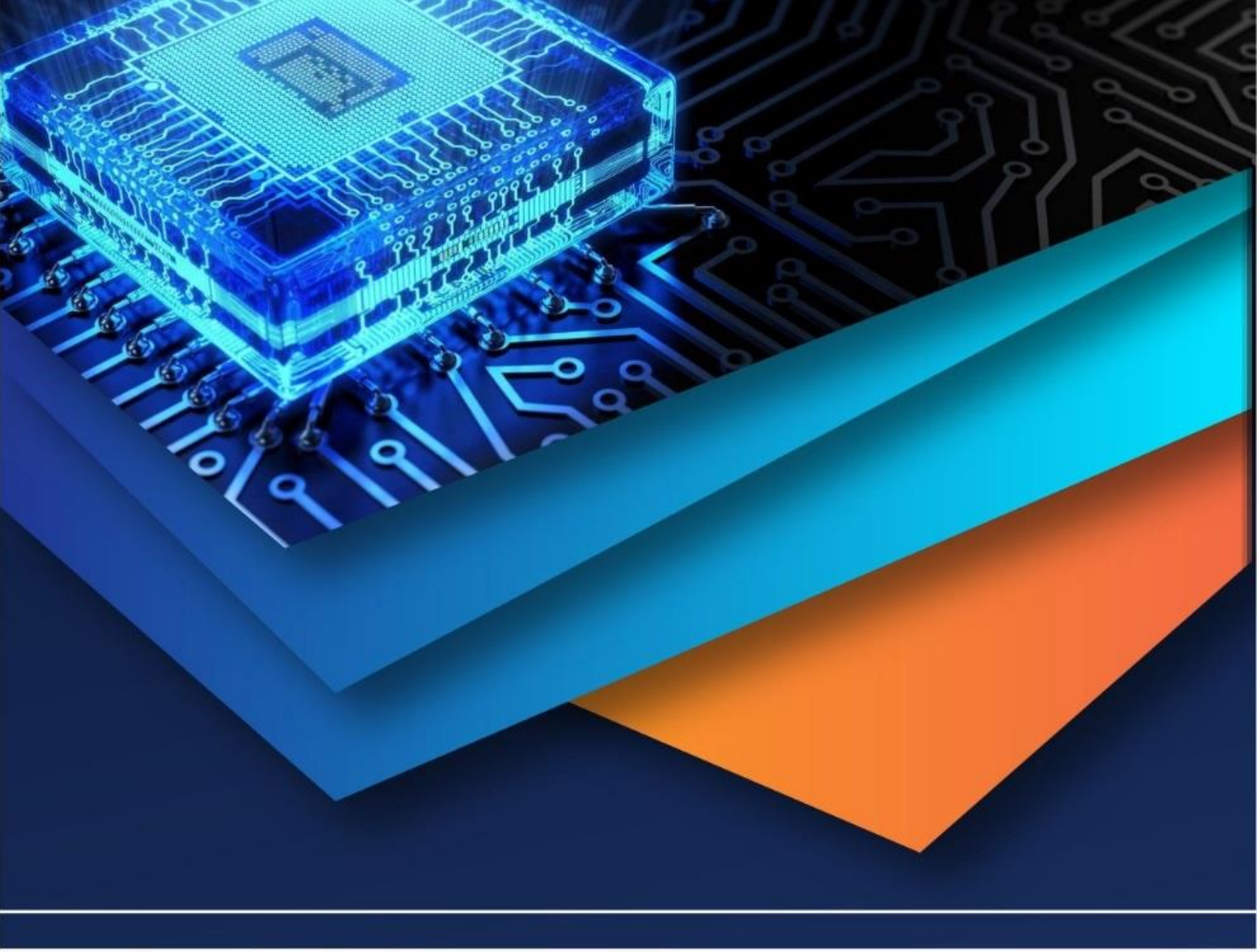
Energy Source	Installed Capacity (GW)
Solar Energy	105
Wind Energy	50
Hydropower	50
Biomass Energy	11.5
Small Hydro	5

VIII. CONCLUSION

Renewable energy technologies are essential for addressing global energy challenges and environmental concerns. India has made significant progress in expanding renewable energy capacity, especially in solar and wind power. Although challenges such as energy storage and grid integration remain, renewable energy will play a key role in achieving sustainable development and long term energy security.

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