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Solar Energy: A Convergence of Demand and Supply of Energy for Sustainable Development

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ABSTRACT

India's transition towards renewable energy is crucial for its sustainable development, and solar power is emerging as a central component in this transformation. This paper explores the multifaceted role of solar energy in meeting the country's increasing energy needs, while also addressing the pressing challenges posed by climate change. Given its geographical advantage and abundant sunshine, India has significant untapped solar potential that can be effectively utilized to power its future. The Jawaharlal Nehru National Solar Mission, launched in 2010, set ambitious goals to establish India as a global leader in solar energy. The mission initially aimed for 100 GW of installed solar capacity by 2022, with a long-term target of reaching 200 GW by 2030. This study examines the economic, environmental, and social dimensions of solar energy adoption, emphasizing its capacity to generate employment, enhance energy security, and significantly cut greenhouse gas emissions. In addition, the paper analyses the key policies and initiatives taken by Government of India to support solar energy development. Finally, this paper advocates a strong and sustained commitment to solar energy is essential not only for meeting India's energy goals but also for achieving broader environmental and economic sustainability. By embracing solar power, India can position itself as a leader in clean energy while fostering inclusive and irrepressible growth.

Key words: Solar Energy, Renewable Energy, Sustainable Development

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Introduction

In the new environment of economic growth and human development revitalization, renewal energy is expanding its sphere of influence in the global energy issues. Considering the Indian context, it is evident that, despite having the world's fastest-growing economy, the country is confronting an energy crisis as its demand for energy continues to rise. Growing population pressure for energy depleting the natural resource and endangered the concept of sustainable development. With dependence on fossil fuels contributing to greenhouse gas emissions, rising import bills, and air pollution, the urgency for clean and sustainable energy solutions has never been greater. Renewable energy, particularly solar power offers a viable solution to inclusive growth and sustainable development. The sustainable development is one of the longest continuously running arguments among the prominent economists, social thinkers, environment scientists, and policy makers in the sphere of economics, politics, and human development. Sustainable development is development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs. It contains the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given.

Solar energy development contributes to sustainable development by providing a renewable and low-emission source of electricity, reducing dependence on fossil fuels. It supports environmental sustainability by lowering greenhouse gas emissions and mitigating climate change impacts. Additionally, solar energy promotes economic and social sustainability through job creation and improved energy access in underserved regions. These advantages are alluring every country in the world to develop the infrastructure of solar energy, with India in the forefront.

India’s geographical advantage of abundant sunlight makes it uniquely positioned to harness solar energy on a large scale. Recognizing this, the Government of India launched the Jawaharlal Nehru National Solar Mission (JNNSM) in 2010 under the National Action Plan on Climate Change (NAPCC). Since then, solar energy has emerged as the cornerstone of India’s green energy transition. This paper examines the economic, environmental, and social implications of solar adoption while highlighting policy initiatives, challenges, and future prospects.

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Rationale of the Study:

1. To analyse the socio-economic and environmental implications of India's renewable energy policies on poverty alleviation and inclusive growth.
2. To what extent has the expansion of renewable energy capacity in India contributed to progress toward specific Sustainable Development Goals (SDGs)?
3. Analysing the policy measures that can optimize the synergy between renewable energy adoption and Sustainable Development Goals (SDGs).

Methodology:

This study is based on the secondary data which was collected from different sources. Data related to renewable energy capacity especially solar energy was collected from the Ministry of New and Renewable Energy (MNRE), Solar Energy Corporation of India (SECI) and the Indian Renewable Energy Development Agency (IREDA) and International Renewable Energy Agency (IRENA). Except to this, data was collected from various journals, reports of NITI Aayog, Press Information Bureau (PIB), UN reports. Socio-economic and demographic data from the National Sample Survey Office (NSSO) and Census of India. Assessing the policy documents and secondary literature to understand the enabling or constraining factors behind renewable energy adoption and its impact on sustainable growth.

The National Solar Mission: Ambitions and Achievements:

The Jawaharlal Nehru National Solar Mission (JNNSM), launched in January 2010, represents one of the most ambitious renewable energy programs in India's history. Introduced under the National Action Plan on Climate Change (NAPCC), the mission sought to mainstream solar power within India's energy mix and position the country as a global leader in renewable energy. The mission's vision was not only to reduce India's carbon footprint but also to foster energy security, industrial development, and inclusive growth. The initial target under the JNNSM was the installation of 20 GW of solar capacity by 2022. However, as solar technology costs declined and global climate commitments intensified, this target was scaled up to 100 GW by 2022 and a longer-term vision of 200 GW by 2030 was articulated. Institutional mechanisms such as the Solar Energy Corporation of India (SECI) and the Indian Renewable Energy Development Agency (IREDA) played crucial roles in financing, tendering, and implementation. Policy instruments such as capital subsidies, tax incentives, viability gap funding, and the

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Production Linked Incentive (PLI) scheme have supported the mission. The government also promoted net-metering, accelerated depreciation benefits, and concessional financing to accelerate adoption.

The National Solar Mission has been instrumental in propelling India into the league of leading solar nations. Its ambitious targets, phased implementation, and policy innovations have driven rapid solar expansion, tariff competitiveness, and global recognition. While challenges remain in areas such as rooftop solar, manufacturing dependence, and grid integration, the mission stands as a pivotal milestone in India's pursuit of a sustainable and green economy.

Solar Energy Potential in India

India's solar energy potential is estimated at over 750 GW, given that most parts of the country receive 4–7 kWh per square meter of solar radiation daily across 300 sunny days annually. States like Rajasthan, Gujarat, Madhya Pradesh, and Andhra Pradesh offer vast potential due to their arid and semi-arid lands. Beyond large-scale solar parks, decentralized solutions such as rooftop systems, mini-grids, and solar irrigation pumps are gaining prominence. These not only enhance rural electrification but also strengthen agricultural sustainability and inclusive growth.

Renewable Energy Policies of India: Poverty Alleviation and Inclusive Growth:

Renewable energy has emerged as a strong pillar of India's development strategy, addressing both environmental sustainability and socioeconomic challenges. In particular, national renewable energy policies are closely aligned with the goals of poverty alleviation (SDG-1) and inclusive growth. Given India's large rural population and growing energy demand, renewable energy provides opportunities not only for reducing carbon emissions but also for improving livelihoods and creating jobs. It is found that small-capacity solar installations in India generate approximately 24.5 job-years per MW (GOI, 2024). The following table describes the employment opportunities that are generated by only solar energy sector except the other renewal energy sectors like wind, sea waves, bio fuel etc.

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Agencies	Matric	Jobs
MNRE	Job-years per MW (small solar)	24.5 job-years/MW
IRENA	Solar PV jobs in India	318,600 jobs (2023)
IRENA *(global)*	Solar PV employment	7.1–7.2 million jobs (2023)
IRENA	Total RE jobs in India	1.02 million jobs (2023)

Source: GOI, 2024 & IRENA, 2024

Importantly, rural workforce participation, including women in installation and distribution activities has expanded. These opportunities are particularly relevant for marginalized communities, offering pathways for economic mobility. The renewable energy policies can be seen in access to affordable and clean energy, rural electrification and solar home systems. The declining cost of solar technologies has made solar energy increasingly competitive with conventional energy sources. This economic feasibility reduces dependence on imported fossil fuels, thereby strengthening national energy security. In emerging economies like India, domestic solar capacity contributes to reducing the trade deficit by lowering oil and coal imports. India imports nearly 85 percent of its crude oil and significant quantities of coal. Expanding solar energy reduces dependence on these imports, enhances energy security, and lowers vulnerability to global price shocks. Lower fossil fuel imports also help reduce India's current account deficit. These supportive policies and falling tariffs have made solar competitive with coal-based power. Transparent of bidding processes have attracted substantial domestic and foreign direct investment (FDI), making the sector a promising engine for future growth.

Some of the implications are reflected through the multiplier effects on local economies and environmental improvements. Reliable electricity access stimulates small-scale enterprises, enabling value addition in rural industries and supporting inclusive economic development thereby narrowing the energy access gap. Furthermore, reduced reliance on fossil fuels lowers pollution, which translates into better health outcomes and reduced healthcare costs, factors that contribute indirectly to poverty reduction. Renewable energy adoption also enhances climate resilience, reducing vulnerability to energy price shocks and mitigating risks associated with environmental degradation.

Environmental sustainability is intrinsically tied to poverty alleviation. Policies encouraging solar, wind, and biomass energy reduce greenhouse gas emissions, contributing to India's climate commitments under the Paris Agreement. Improved environmental quality,

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clean air, reduced deforestation, and sustainable land use, benefits the poor disproportionately, as they are most vulnerable to ecological degradation. By promoting decentralized and community-driven energy solutions, policies support social inclusion and empower local governance structures.

India's Renewable-Energy Expansion and Progress:

Affordable and Clean Energy:

India's renewable energy transition has significantly advanced the objectives of Sustainable Development Goal-7, towards the affordable and clean energy. According to the **Renewable Energy Statistics 2023–24** released jointly by the Ministry of New and Renewable Energy (MNRE) and the Central Electricity Authority (CEA): **Total installed power capacity (all sources)** reached **441.97 GW** as of 31 March 2024 (GOI, 2024). **Renewable energy capacity (including large hydro)** accounted for **190.57 GW**, constituting **43.12 percent** of total installed capacity. **Cumulative renewable capacity excluding large hydro** (i.e., solar, wind, bio-power, small hydro) was **143.64 GW**. Detailed breakdown of this **143.64 GW** (excluding large hydro) is as follows:

Renewal Energy Sources	Contribution	Percentage
Solar Power	81.81 GW	56.95
Wind Power	45.89 GW	31.95
Bio-Power	10.95 GW	7.62
Small Hydro Power	5.00 GW	3.48

Source: Authors compiling

As is shown in table that solar power share is largest in case of renewal energy and on the other side the contribution of small hydro power is minor only 3.48 percent. This shows the solar power sector has great potential to chase the demand of energy. In the fiscal year 2023–24 alone, **18.56 GW** of renewable capacity was added, compared to **7.35 GW** of non-renewable capacity, demonstrating a sustained momentum in renewable expansion This growth has supported the affordability of electricity through competitive solar and wind tariffs while expanding the share of clean energy in the national grid. Furthermore, universal household electrification was achieved under initiatives such as Saubhagya and DDUGJY, which provided

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over 28 million household connections, reinforcing equitable and reliable energy access. Large-scale deployment across states, growing manufacturing, and robust policy backing are all helping India quickly reach its 2030 non-fossil energy objective of 500 GW.

Decent Work and Economic Growth:

The expansion of renewable energy in India has emerged as a catalyst for Sustainable Development Goal-8 (SDG-8), Decent Work and Economic Growth, by creating substantial green employment opportunities, fostering industrial development through domestic manufacturing initiatives, and stimulating inclusive economic growth across value chains. Estimates suggest the sector already employs nearly a million workers, and with the target of 500 GW of non-fossil fuel capacity by 2030, it could generate an additional 3.4 million cumulative job-years, particularly in solar and wind. Government support through Production Linked Incentives (PLI) for solar manufacturing has also spurred domestic value chains, creating opportunities for MSMEs and fostering inclusive economic growth.

Climate Action:

India's accelerated adoption of renewable energy directly advances SDG 13, Climate Action by reducing reliance on fossil fuels, lowering greenhouse gas emissions, and aligning with the country's commitments under the Paris-Agreement and its long-term net-zero pathway. Renewable energy expansion is central to India's Nationally Determined Contribution (NDC), which aims to reduce emissions intensity of GDP by 45 percent by 2030 and achieve 50 percent non-fossil capacity in power generation. Solar and wind energy growth is directly displacing coal at the margin, contributing to mitigation efforts and aligning with India's long-term goal of net-zero by 2070. However, bottlenecks such as delayed project commissioning, grid integration challenges, and workforce skill gaps must be addressed to fully realize the climate benefits.

Policy Measures to Optimize the Synergy between Renewable Energy Adoption and Sustainable Development Goals in India

India's commitment to renewable energy expansion offers a unique opportunity to align with the United Nations Sustainable Development Goals (SDGs), to optimize this synergy, policy interventions must balance technological advancement, social inclusion, and environmental

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sustainability. Some of the policy measure and achievements in India's Renewable Energy Landscape are as follows.

PM-KUSUM: Policy Framework and Achievements:

The Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) was launched in 2019 by the Ministry of New and Renewable Energy (MNRE) with the dual objectives of enhancing farmers' energy security and promoting clean energy adoption in the agricultural sector. The scheme aims to add 34,800 MW of solar capacity by March 2026, supported by central financial assistance of about ₹34,422 crore (MNRE, 2019). PM-KUSUM is structured into three major components. Component A supports the setting up of decentralised renewable energy plants (500 KW–2 MW) on barren or fallow land, allowing farmers and rural entities to generate and sell power to distribution companies (DISCOMs) through a procurement-based incentive mechanism. Component B facilitates the installation of stand-alone solar pumps in off-grid areas, replacing diesel-based irrigation and reducing dependence on fossil fuels. Component C provides for the solarisation of existing grid-connected pumps and feeders, with the provision for farmers to sell surplus electricity to the grid. Together, these components aim to reduce agricultural reliance on subsidised electricity and diesel, while creating additional income streams for rural households (India.gov.in, 2023; IBEF, 2024).

By March 2024, the scheme had achieved significant progress, particularly in Components B and C. Component B saw the installation of about 4.4 lakh solar pumps in FY 2023–25 alone, marking a 4.2-fold year-on-year increase, while Component C witnessed the solarisation of nearly 2.6 lakh pumps, reflecting a 25-fold annual growth (PIB, 2024; IBEF, 2024). Cumulatively, the total number of solar pumps installed or solarised under the scheme surpassed 10 lakh units nationwide, and the financial outlay rose to ₹2,680 crore, a 268% increase compared to the previous year (Policy Circle, 2024). The scheme directly benefitted over 4.11 lakh farmers by early-2024, enhancing both irrigation reliability and household income opportunities through surplus energy sales (PIB, 2024).

Overall, the PM-KUSUM framework demonstrates how policy-driven renewable energy transitions in agriculture can simultaneously advance India's climate action (SDG 13), ensure affordable and clean energy access (SDG 7), and support rural livelihoods (SDG 8). Despite challenges of financing, DISCOM participation, and implementation delays, the scheme has established itself as a cornerstone of India's clean energy and rural development strategy.

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National Green Hydrogen Mission (NGHM):

The National Green Hydrogen Mission (NGHM), approved by India's Union Cabinet on January 4, 2023, is designed to position India as a global leader in the production, utilization, and export of green hydrogen and its derivatives. The mission targets a minimum production capacity of 5 million metric tonnes (MMT) per annum of green hydrogen by 2030, supported by an associated renewable energy expansion of 125 GW. The mission foresees mobilizing over ₹8 lakh crore in cumulative investments and generating in excess of 600,000 jobs, while also curbing fossil fuel imports by more than ₹1 lakh crore and reducing annual greenhouse gas emissions by approximately 50 MMT. To enable this transformation, NGHM introduces key interventions under the Strategic Interventions for Green Hydrogen Transition (SIGHT) programme allocating ₹17,490 crore specifically towards financial incentives for green hydrogen production and electrolyser manufacturing. Complementary initiatives include pilot projects in sectors such as low-carbon steel, mobility, and shipping (with combined budgets exceeding ₹2,300 crore), development of Green Hydrogen Hubs (₹400 crore), R&D under the Strategic Hydrogen Innovation Partnership (SHIP), as well as enabling infrastructure support, regulatory frameworks, and skill development programmes.

Suggestions and Conclusion:

The study reveals that India's renewable energy policies, particularly the Jawaharlal Nehru National Solar Mission (JNNSM), PM-KUSUM, and the National Green Hydrogen Mission (NGHM), have collectively transformed the country's energy transition landscape. To optimize the synergy between renewable energy adoption and sustainable development goals, several policy measures are essential. First, strengthening the domestic manufacturing ecosystem through targeted incentives, skill development, and technology transfer can reduce import dependence and enhance self-reliance. Second, expanding decentralized energy solutions—such as rooftop solar, mini-grids, and solar irrigation pumps—will empower rural communities, reduce regional disparities, and strengthen energy access for the marginalized. Third, policy frameworks should prioritize financing mechanisms, including concessional loans, blended finance models, and risk-mitigation instruments, to address liquidity constraints faced by developers and distribution companies (DISCOMs). Fourth, investments in grid modernization, storage technologies, and smart infrastructure are crucial for integrating intermittent renewables and ensuring system stability. Finally, closer alignment of renewable

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energy initiatives with social welfare policies can maximize poverty alleviation and enhance the distributive benefits of energy transitions.

India's renewable energy trajectory demonstrates how well-designed policies can simultaneously advance economic growth, social inclusion, and environmental sustainability. The JNNSM provided the foundation for scaling solar energy, while PM-KUSUM has integrated clean energy with agricultural transformation, directly benefiting rural households. The NGHM represents a forward-looking strategy, positioning India as a leader in emerging energy technologies and supporting long-term decarbonisation. Together, these policies highlight the country's capacity to align renewable energy adoption with global climate action and domestic development goals. Yet, realizing the full potential of this transition requires addressing structural barriers such as financing gaps, institutional coordination, and infrastructure bottlenecks. With continued policy innovation, investment, and community participation, renewable energy can serve as the cornerstone of India's sustainable development, advancing SDGs in an integrated manner.

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