Solar Energy: A Key to the Decarbonization and Development Conundrum

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Abstract: India has planned to achieve net-zero energy by 2070, and decarbonizing the power sector is a critical goal. Currently, India is dependent on power from coal and other fossil fuels. However, India also has ambitious development goals and is parallelly fighting other challenges like poverty, unemployment, and economic growth. Among others, solar energy is available in abundance in India and rapid solarization has been identified as the best way to achieve India's renewable energy targets at a mass scale. However, this also goes hand in hand with India's development goals. India is attempting to build local capacity to manufacture solar energy products and incentivizing local manufacturers to expand their production. At a tariff level, solar energy is cheaper than energy from fossil fuels, enabling access to renewable energy to the lower strata of society. Offgrid solar has been used as a solution to address local problems like power cuts at households with solar torchlights and safety at night with solar streetlights. Furthermore, India is an active player in the trade of solar Photovoltaics (PV) panels, with growing exports not only improving its trade bills but also creating economic opportunities for local manufacturers. Solar energy could be India's holy grail to achieve decarbonization as well as economic growth. This paper is a review of how India's decarbonization ef-forts through solar energy is also contributing to economic growth.

Keywords: Solar energy, decarbonization, energy security

1. Introduction

India is among the fastest growing economies in the world, with a steadily increasing GDP growth of 6.5–7% every year (See Table 1). With increasing population, at par with China, India's primary energy consumption is ever-growing. India is a fossil-fuel based economy with three-fourth of its energy demand met by coal and oil.

At COP27 in Glasgow, Prime Minister Narendra Modi committed to becoming net-zero by 2070. India's 5 main targets for climate action are:

1. Reach 500 GW non-fossil energy capacity by 2030.
2. 50 per cent of its energy requirements from renewable energy by 2030.
3. Reduction of total projected carbon emissions by one billion tonnes from now to 2030.
4. Reduction of the carbon intensity of the economy by 45% by 2030, over 2005 levels.
5. Achieving the target of net zero emissions by 2070.

Despite fast economic growth, advancements in industry and technology and urbanization of about 1.5% annually, 25% still live below the poverty line. India's HDI has been falling since 2019 (from 0.645 to 0.633 in 2021), in line with the global fall in HDI the past 2 years owing to multiple global crises (See Table 1).

Table 1. Socio-economic and energy indicators of India

Socio-economic indicators, 2022 (UN, WB)	**Value**
Population	1.42 billion
% Urban	36%
Human Development Index (2021)	0.633
GDP (current US$) US$	3.39 trillion
Average GDP growth rate (2014–2022)	5.7%
Agriculture, forestry, and fishing, value added (% of GDP)	17%
Manufacturing, value added (% of GDP)	13%
Services (% of GDP)	49%
Energy indicators, 2021 (BP, IEA)	**Value**
Primary Energy Consumption (Exajoules)	35.43
Primary Energy Consumption per capita (Gigajoules)	25.4
Oil Consumption (Exajoules)	9.41
Gas Consumption (Exajoules)	2.24
Coal Consumption (Exajoules)	20.09
Electricity generation (TWh)	1714.8
Final Energy Consumption (ktoe) (2020)	5,96,486
Generation % by Renewables (Including Hydroelectric)	40%
CO2 Emissions (million tonnes)	2279

With both developmental and decarbonization goals battling for priority, energy seems to be the common factor. The United Nations Sustainable Development Goals establishes a strong connection between sustainable human development and access to reliable and clean energy under Sustainable Development Goals (SDG) 7 [1]. Access to reliable and clean energy for power and cooking remains a challenge in India and is one of the primary roadblocks to poverty eradication, education, safety, health, and wellbeing in India. But to achieve these goals in parallel, India needs a solution that is immediate, economically viable and implemented at scale. Solar energy has the potential to catalyse development in both areas, decarbonization and development. For a developing country like India, this provides a valuable opportunity for ground-up, low carbon and sustainable development. In the past decade, the government has implemented several laws and policies on solar energy integration to aid India's net-zero and low-carbon transition goals. The national focus for the next few years is to boost local manufacturing, invite foreign investments and ramp up exports.

This paper discusses some of India's current solar energy policies and programs promoting renewable energy integration, and how they have and will concurrently benefit development in other areas. The objective is to provide insight to other developing countries that are still building up, on how decarbonization and economic and social development can go together. The actual impacts of the policies and programs are not covered in this paper as it is beyond the scope of the analysis.

2. Solar Energy in India

India receives a Global Horizontal Irradiance of 1600–2200 kWh/m^2 annually [2]. Western to southeastern India, beginning from Rajasthan and Gujarat, and ending at Karnataka, Andhra Pradesh, and Tamil Nadu in South India, mainly sandwiched between the Western and Eastern Ghats, experience the highest irradiation between 1942–2159 kWh/m^2. Naturally, these are the parts that have been frontrunners in establishing solar energy policies and projects in the country.

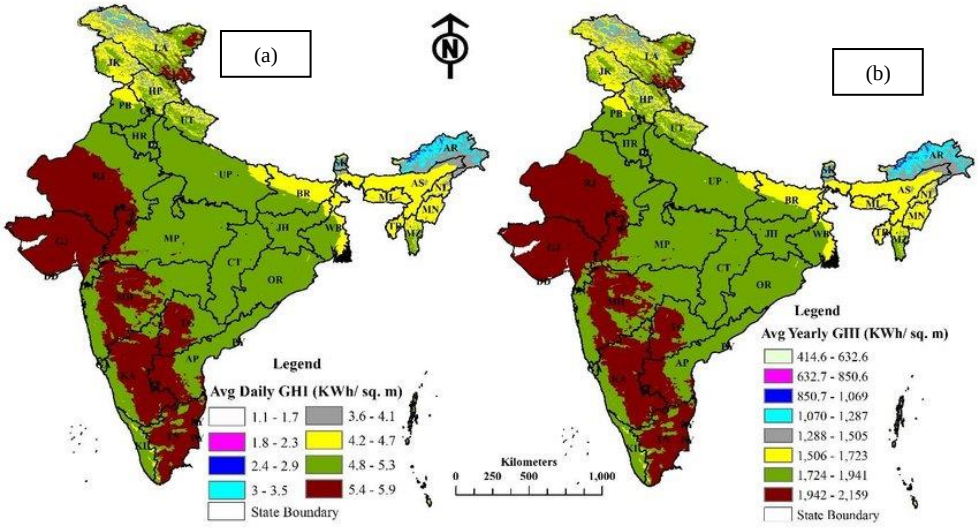

Fig. 1. Global Horizontal Irradiation: (a) Average daily, (b) Average annual [3].

A large part of India as seen in Fig. 1(a) and (b), in North and Eastern India also experience significant irradiation between 1,724–1,941 kWh/m2. While other renewable energy sources like wind and hydro are limited to coastal areas, solar energy is abundantly available in India with over 58% of the land mass 1.89 million km^2 receiving at least 5 kWh/sq.m. per day of annual average Global Insolation [4]. Considering that India enjoys an average of 300 days of sun, 20% of India's renewable energy target is planned to be achieved through solar energy. India's estimated solar potential is 748 GW, while the National Solar Mission (NSM) set a target of achieving 100 GW of solar capacity by 2022. The NSM under the National Action Plan on Climate Change (NAPCC) kickstarted India's solar growth. When the NAPCC was announced during the Manmohan Singh regime in 2010, the NSM's target was 20 GW by 2022. In 2014, PM Modi amped up the target to 100 GW by 2022 with 40 GW of rooftop solar and the remaining 60 GW of large and medium scale grid connected solar. However, as of November 2022 India's solar capacity was 61.97 GW, missing the target [5].

3. Decarbonization through Solar

As of May 2023, India's power sector is fossil fuel intensive at 57%, dominated by coal at 51% followed by gas and diesel [6]. Non-fossil fuel energy including solar, wind, nuclear and hydro accounts for 43% of the energy mix. Solar alone accounted for 16% of the energy mix. India committed to meeting 50% of its energy requirements through renewable energy and achieving an installed non-fossil capacity of 500GW by 2030.

The main reasons for the success of solar in India is the ambitious goal set by the NSM and the policies that followed, enabling a conducive environment for large scale implementation. The Solar Energy Corporation of India Ltd. (SECI) is the public sector unit in charge of achieving the targets of the NSM. Majorly through rooftop solar and large-scale solar parks, and incentivization of production and adoption of solar technologies, it has been ramping up solar capacity.

3.1. Large-scale solar implementation

One of the key drivers for the rapid solar integration in the power sector is the Renewable Energy Purchase Obligation (RPO). Indian households as well as commercial and industrial sectors rely on public and private utilities or Distribution Companies (DISCOMs), as it is known, for constant, reliable power. The National Tariff Policy 2016 targets this crucial link in the power supply chain and mandates a minimum RPO for all DISCOMs, i.e., mandatory purchase of renewable energy. Out of the total RPO, 10.5% should be

from solar energy. The policy allows the purchase and sale of Renewable Energy Certificates (RECs) by DISCOMs to meet the RPO targets, and non-compliance will incur penalties. State Electricity Regulatory Commissions (SERCs) may choose to provide higher RECs to distribution licensees that promote emerging renewable energy technologies and lower RECs to vintage plants.

While this initiative is crucial to achieving a bulk of India's solar energy goals at a mass scale, only a handful of states have managed to meet targets over the years. Several challenges such as lack of funding among DISCOMs, lack of transparency and economic challenges due to transmission losses need to be addressed to reap the benefits of this programme [7]. The success of RPOs in India are highly debated, but the initiative, specifically having included solar-based RPOs are lauded for pushing DISCOMs to set local targets and ramp up their solar energy integration. Despite shortfalls in meeting RPO targets, the programme has increased access to clean, green energy across the country.

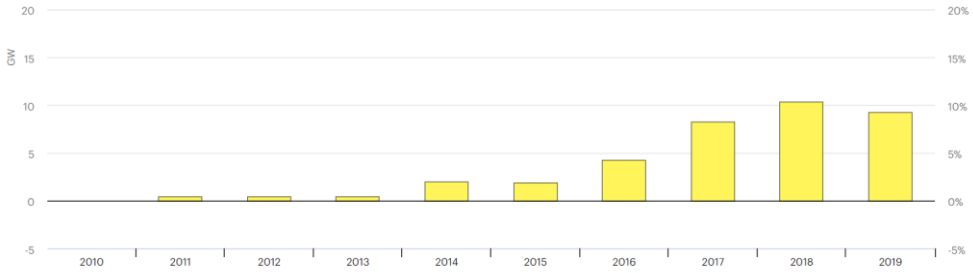

Fig. 2. Annual solar capacity additions in India from 2010–2019 [8].

Fig 2. indicates India's increasing solar capacity in the past decade. While "Ultra Mega Solar Parks" are being set up across the country, there is significant effort towards promoting Rooftop Solar (RTS) in residential, commercial, and educational buildings, and establishing rooftop solar farms. Amidst land acquisition challenges, transmission losses and grid instabilities, RTS de-risks investment in the PV industry [9]. With a target to achieve 40 GW of RTS capacity by 2026, India's efforts towards strengthening its RTS infrastructure with both on-grid and off-grid solar has instilled greater energy independence and security at a household and building level. The Electricity (Rights of Consumer) Rules, 2020 under the Electricity Act, termed buildings that have Rooftop Solar (RTS) as 'prosumers' whereby they produce their own energy and interact with the grid. The Rules mandate the SERCs to facilitate the setting up of RTS in the building sector and enable net/gross metering system with distribution companies for grid integration. A simplified online process encourages consumers to apply for rooftop solar with the Central Financial Assistance subsidies and free maintenance for several years [10]. Solar panels are no longer restricted to affluent households and Tier-1 cities in India. However, despite efforts, the RTS programme was not as successful in most states. Despite subsidies and quick payback, building owners are conservative about upfront investments. Roof rights in a primarily rental economy occupying high rise buildings with minimum roof area is also a challenge to the uptake of RTS. Gujarat on the other hand, is a leader in RTS deployment in India.

Gujarat is culturally different from other Indian states, wherein the people are more receptive of government policies that could lead to monetary benefit. The people are known to be open to business prospects and taking risks that can result in profits. Due to this reason, solar energy was introduced in Gujarat much earlier than other states and took off rapidly. This seems to be an important reason why Gujarat became a pioneer in solar compared to other states with similar topography and resources, like Rajasthan and Tamil Nadu.

Table 2. Top performing states in residential rooftop solar (Phase II) [11]

States	Installed Capacity (Up to July 30, 2023)
Gujarat	1,710 MW
Kerala	133 MW
Rajasthan	44 MW
Haryana	34 MW
Telangana	33 MW

The Surya Urja Rooftop Yojana (SURYA) scheme in Gujarat provides a subsidy of 40% for residential solar installations of up to 3 kW and 20% for installations beyond 3 kW and up to 10 kW. It allows net-metering and capitalization of excess power produced [12]. Table 2 shows the top performing states in RTS and Gujarat is a clear leader. As of 2023, Gujarat's RTS capacity stood 1.7 GW. Gujarat also took the initiative to solarize the entire Modhera village, India's first solar powered village that operates on ground-mounted solar and RTS during the day and Battery Energy Storage System (BESS) during nights. This not only saves on electricity bills for over 6,500 residents of the village, but excess energy is transported back to the grid and earns them a passive income [13].

One of the main challenges with renewable energy is variability. To tackle this, India introduced the National Wind-Solar Hybrid Policy in 2018 to promote grid-integrated wind-solar hybrid projects, wherein the rated capacity of one resource should be at least one-third of the total [14]. The aim is to achieve more stable electricity generation through renewables, and to use land more efficiently. Energy storage is also promoted as part of this program. Tariffs are determined based on competitive bidding or agreed fixed tariffs, based on factors such as minimum firm output per day, or output during defined hours, rate of variability etc. To ensure stable supply, Power Purchase Agreements are set up between the SECI and the hybrid generators for a minimum of 25 years.

3.2. Affordable solar energy

To promote renewable energy, an important strategy that India is focusing on is lower tariffs. In the past few years, India has seen a steep decline in renewable energy tariffs, especially solar tariffs, encouraging more and more investments in solar energy (See Fig. 3). The Electricity Act provides that electricity tariffs can be determined by the respective SERCs. In practice, both Feed-in-Tariffs (FiTs) and auction-based tariffs are common, based on the policies and guidelines adopted by the SERCs.

The National Tariff Plan laid down the policy of competitive bidding to determine tariffs so that renewable energy is available at affordable prices. In 2020, a 1070 MW solar project in Rajasthan was awarded to the lowest ever bid of $0.03/kWh. Bidders sign PPAs for 25 years, giving them a stable market in the long-term. This has attracted greater foreign investment in the Indian renewable energy market. Renewable energy generation at such low tariffs encourages more DISCOMs to procure renewable power beyond the RPOs as the price is lower than that of coal-based power ($0.13/kWh in 2021). Some states continue to follow Feed-in-Tariffs (FiTs) where the SERCs fix the tariffs. Gujarat is among the states with the largest installed solar capacities, primarily due to its early low FiT model with long-term PPAs that led to greater demand and supply of solar energy.

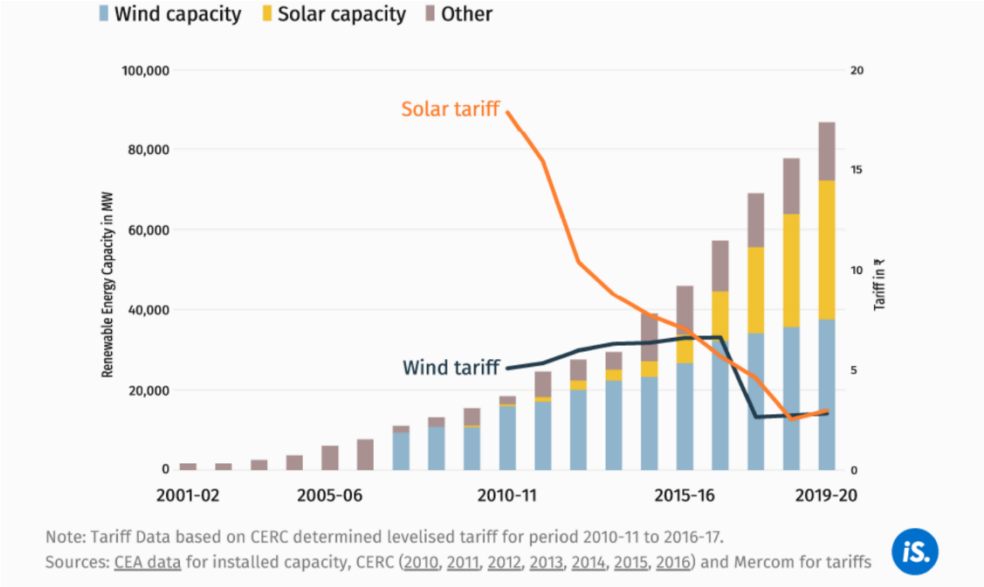

Fig. 3. Solar and Wind Energy Tariffs trends from 2001–2020 [15].

Studies show that the lower cost of Photovoltaics (PV) modules and subsidies to lower financing costs and maintenance are key drivers of the lower Levelized Cost of Energy (LCOE) of solar. According to a 2019 Wood Mackenzie report, the LCOE of solar in India fell below that of conventional coal power [16]. With frequent blackouts in India due to coal shortages and demand management, solar could be an economically viable option to flatten loads during peak hours and enable critical functions without disruptions. In 2023, The Electricity (Rights of Consumer) Rules was amended to include Time of Day (ToD) tariffs wherein electricity tariffs are 20% lower during 8 solar hours as defined by the SERCs, and higher during peak and non-peak hours when solar energy is not available. This is applicable to domestic, commercial, and industrial consumers, and puts the onus on the consumers to manage their demand and maximize the use of energy solar energy. This policy essentially encourages greater renewable energy integration into the grid and DISCOMs getting an opportunity to meet their RPOs, while consumers also benefit from lower electricity bills for clean energy.

4. Energy Security, Economic and Social Development

4.1. Rural electrification

With clean energy targets looming in the background, India is yet to achieve energy security. Universal electrification is yet to be achieved on ground. While in 2018 the Prime Minister announced that every village in India now has access to electricity, only 97% of all households in India are electrified [17]. A survey among 15,000 household in India showed that 76% percent had interruptions in supply [18]. However, India has achieved immense success in electrification from 56% in 2000 to 96% in 2020. The 2014 Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) scheme was launched with the aim to achieve rural electrification in areas where grid-powered electricity is not viable. Since the launch of the programme, standalone solar power packs comprising 200-Watt peak and 1000-Watt hour lithium phosphate battery storage, supporting LED lights, DC fans and power plugs were provided to hard-to-reach rural households [19]. Through off-grid and local mini-grids, India has been making strides in electrification through renewable energy, especially solar. Table 3 shows the number of villages that have benefitted from off-grid solar electrification.

It is important to note the on-ground realities of these policies, as several accounts show the failure of the

off-grid systems due to the poor quality of equipment and lack of maintenance support [20]. These are realities of several policies and regulations in India where well-thought-out schemes do not attain fruition on-ground as planned. However, it seems intuitive to exploit India's abundant solar potential to address the typical challenges of rural electrification. In addition to providing low-carbon electricity, off-grid, and mini-grid solar could transform the lives of people living in remote locations, with respect to their health, education, and overall quality of life.

The Off-grid and Decentralized Solar PV Applications Programme under the NSM is one such initiative. It promotes technologies such as solar street lighting, solar water pumps for irrigation, solar home lighting systems such as lamps and lanterns in households, and off-grid solar power plants at public service institutions such as schools and police stations. The aim is to achieve 2GWp through off-grid solar technologies. State governments are also actively promoting on and off-grid solar trees, that take up minimum space but can light up public spaces.

Table 3. Number of villages electrified through off-grid solar under DDUGY [21]

State/Union Territories	Number of villages
Arunachal Pradesh	555
Assam	394
Bihar	207
Chhattisgarh	473
Jammu and Kashmir	54
Karnataka	27
Madhya Pradesh	33
Maharashtra	43
Manipur	99
Meghalaya	82
Odisha	399
Rajasthan	93
Uttar Pradesh	31
Uttarakhand	24
Total	**2,762**

These are critical resources and infrastructure, especially in rural and remote areas in India where homes, school and offices do not have reliable electricity thereby affecting critical everyday activities. In a survey among 120 people from a village in Assam where solar LED streetlamps were installed, 90% of the respondents said that mobility at night felt safer, as opposed to earlier when they feared theft, physical abuse, and attack from wild animals [22]. Women felt safer to walk alone at night, and they also allowed their children to go outside and play during evenings. During power cuts, they sat together with their neighbours around the streetlamps, which fostered a sense of community.

While there have been efforts towards off-grid solar integration, on-grid solar would result in large scale solar integration in India (See Fig. 4). India is investing in Green Energy Corridors (GEC) to increase renewable energy in the power grid by addressing the current lack of stable transmission systems for renewable energy. As of 2020, the GEC has commissioned 3,200 ckm of dedicated transmission lines and 17,000 MVA substations for renewable energy within states like Tamil Nadu, Gujarat, Rajasthan, Madhya Pradesh, Karnataka, Maharashtra, and Andhra Pradesh [23].

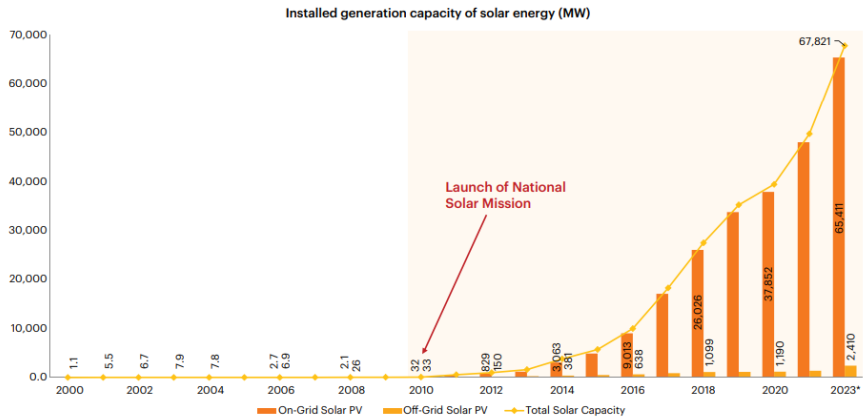

Fig. 4. Installed generation capacity of on-grid and off-grid solar [24].

With some parts of India being renewable energy rich and others having a deficit, the GEC intends to connect with the national power infrastructure using interstate transmission lines of 9,700 ckm of and substations of 22,600 MVA, integrating 20 GW of renewable energy into the national grid by 2026. The intra-state lines are already installed with Renewable Energy Management Centers, and the under-construction interstate transmission lines will also be modernized with real time monitoring and energy storage systems to reduce the variability of renewable energy and push in more non-fossil energy into the national grid.

4.2. Global leadership in solar

One main challenge to achieving the 2022 solar energy target was the import duty regulations that were announced in 2021 [25]. From April 2022, India announced that import of solar cells and solar modules will incur a 'Basic Custom Duty' of 25% and 40% respectively. India is heavily dependent on China for solar energy infrastructure, and the BCD was introduced to promote self-sufficiency. Previously, there was a "safeguard duty" of 15% on import of solar cells and modules from China and Malaysia. The introduction of import duties has been lauded by the industry and policy makers as a move to reduce import dependence and developing local capacity as a step towards greater energy security and resilience in India. Technology dependence on other countries would put India in a vulnerable position in the face of global crisis such as COVID-19 or wars when global trade sanctions maybe in action. When greater domestic manufacturing capacity, Indian manufacturers will be able to compete with the prices offered by the importers. Further, India can participate in the global supply chain and trade of solar. However, the biggest drawback of BCDs is that domestic manufactures need to ramp up their capacity at a rapid pace to meet the demand. This could become counterproductive, resulting in higher production costs of solar PV due to the demand-supply gap. Imposition of the BCD also triggered an artificial increase in prices of domestic PV modules. Additionally, due to domestic manufacturing shortages India is considering a pause on the BCD, but the duty is currently still in place.

To increase local material sourcing and production of PV modules, the Ministry of New and Renewable Energy (MNRE) introduced the National Programme on High Efficiency Solar PV Modules, to provide 'Production Linked Incentives' for setting up manufacturing units and the sale of high efficiency solar photovoltaics [26]. The manufacturers are also required to set up systems for recovery and recycling of PV waste. Additionally, subsidies for the grid connected rooftop program also mandate the use of solar PV from domestic manufacturers. Overall, the intent is to strengthen domestic manufacturing capacity of solar, promote a circular economy and reduce the carbon footprint of solar PV. Increasing manufacturing capacity by leveraging import duty can benefit India's long-term decarbonization by diversifying its energy mix and

increasing use of renewable energy. Currently, India's solar PV manufacturing capacity is 28 GW, and is planned to be increased to about 100 GW by 2026. This could make solar energy even more accessible and affordable locally, and lead to greater investment and revenue from exports. From 2002 to 2022 India has received over $13 billion in Foreign Direct Investment for non-conventional energy, almost all of it through solar [27].

An IRENA report on renewable energy and employment pointed out that this increase in India's solar manufacturing capacity has led to increased employment opportunities in the renewable energy sector. According to the report, there are about 2,17,000 jobs in solar, with 1,37,000 in on-grid solar and about 80,000 in off-grid, and 21% of those employed are women [28]. India continues to build employment capacity among the people through training programs like the Suryamitra Skill Development Programme by the National Institute of Solar Energy, where over 53,000 people have been trained between 2015–2023.

5. Conclusion

At COP26 in Glasgow, India committed to net-zero by 2070, keeping in mind the developmental needs of the country. At COP28 in Dubai, India again emphasized that developing countries are paying the price for damage done by wealthy nations. Yet, India is the fifth largest country to deploy solar energy in the world with an installed capacity of 68 GW, right behind developed nations like the United States and Japan. Policies and programmes over the last 2 decades have accelerated solar deployment in the country so much so that it is not a new technology anymore, even in rural areas. India approached the effort in 2 ways: On-grid solar for large scale renewable energy deployment and off-grid solar to fill the gaps. Off-grid solar took many forms like home lighting and street lighting that illuminated spaces and provided safety as well as the possibility of self-development beyond daytime. Off-grid solar also enabled affordable irrigation for agriculture.

Through large scale solar deployment, India is not only working towards SDG7 i.e. Affordable and Clean Energy, but other SGDs directly such as No Poverty (SDG 1), Decent Work and Economic Growth (SDG 8), Industry, Innovation, and Infrastructure (SDG 9), Sustainable Cities and Communities (SDG 11), Responsible Consumption and Production (SDG 12), and Climate Action (SDG 13). While India is yet to achieve many of its developmental goals, its abundant solar potential offers an opportunity to invest in more sustainable, and cleaner development in the country. However, the main roadblock for India is that well-meaning policies and programs do not often get translated on-ground or are not maintained over the longer term. Routine audits and checks need to be established to ensure quality of services as well as accountability of local implementers.

Funding for solar has been increasing through private investments, green bonds and debts from banks and financing institutions. While building up capacity and participating in the global trade, India is also aiding other countries to achieve their decarbonization goals. Along with France, India conceived the International Solar Alliance (ISA) among solar rich countries along the Tropic of Cancer to mobilize funds and accelerate demand for solar energy. India is planning on investing $25 million to set up the Global Solar Facility that is set to attract private investments for off-grid solar technologies for underserved nations in Africa, Asia, the Middle East, and Latin America [29].

With greater on-ground implementation and quality of services, India could be a pioneer and an example for countries in the global south towards achieving a low-carbon transition that benefits every single person.

Conflict of Interest

The author declares no conflict of interest.

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