European Economic Letters
ISSN 2323-5233
Vol 15, Issue 1 (2025)
http://eelet.org.uk

ELECTRICITY DEMAND DYNAMICS IN INDIA & POLICY RECOMMENDATIONS FOR SUSTAINABLE ELECTRICITY AVAILABILITY BASED ON SOLAR ENERGY

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ABSTRACT
India is the third-largest electricity producer globally but has a significantly lower per capita electricity consumption compared to the world average. High transmission and distribution losses at 19.27% further reduce electricity availability. This gap highlights immense potential for growth in electricity consumption, driven by India's rapidly growing economy and rising consumer aspirations. The Government, through its rural electrification policy initiatives viz. Deendayal Upadhyaya Gram Jyoti Yojana and Saubhagya, could achieve 'electricity access for all villages' by April 2018. However, the definition of 'village electrification' leaves room for improvement, as only basic infrastructure and 10% household coverage are required for a village to be considered electrified. Over the years, climate-related challenges & net zero objectives worldwide have helped to push the share of renewables' installed capacity in the energy mix, but challenges like lower efficiency of renewables, higher upfront cost of most renewables and over-reliance on fossil fuels remain. Solar energy, with its scalability and long-term sustainability, emerges as a promising solution to achieve energy & sustainability goals, especially through focused policy support and innovative financing models.

Introduction

India is the 3rd largest electricity producer in the world [1958 terawatt-hour (twh) in 2023, 6.5% of the world], behind China (9456 twh, 31.6% of the world) & USA (4494 twh, 15% of the world)[i]. However, on the basis of per capita electricity generation, India (1752 kwh/head/yr, 2023) ranks 71st in the world and scores much lower than the world average (4680 kwh/head/yr) (Energy Institute, 2024)[ii]. If we factor in the 'Transmission and Distribution' (T&D) losses, which is much higher in India at 19.27% (Central Electricity Authority, 2024)[iii] vs. 5% in USA (Energy Information Administration, 2023)[iv], the availability of electricity on a per capita basis for each Indian reduces from 1311 kwh/head/yr to 1058 kwh/head/yr.

This huge gap of electricity availability between India and the world points to only one direction: there is high scope for growth of electricity consumption in India. Such an assumption can be further accentuated by the fact that India is the fastest growing economy amongst the G20 Nations, with average Gross National Income growth of 7.0% during the eight-year period from 2014-15 to 2022-23 [excluding the corona pandemic year 2020-21, when the growth rate dipped to (-)7.0%] (Economic Survey, 2023)[v]. The positive ripple effect of a growing economy and its positive impact on the lifestyles and aspirations of the general populace is likely to lead to conspicuous consumption of products and services including lifestyle electrical gadgets/appliances, which will help in increased consumption of energy/ electricity.

Government Schemes for Better Power Infra and Availability

In order to reach electricity to the villages, the Indian Government launched the Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY) in December 2014, replacing the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), and allocated ₹42,553 crore towards various village electrification projects, which involved establishing new substations, separating feeders for agriculture and non-agriculture, and fortifying the entire electrical distribution system. The Pradhan Mantri Sahaj Bijli Har Ghar Yojana (SAUBHAGYA), which was introduced by the Indian government on 25th September 2017, aimed to electrify the remaining 11.87 lakh households, which remained un-electrified, for which the Central government planned to cover 60% of the project costs of the States. After about 7 months, on 28th April 2018, Govt. of India announced that "Every single village of India (about 5.97 lakh villages in total) now has 'access' to electricity".

Village Electrification in India

Whereas the availability of electricity (post T&D losses) for an average Indian, on a pan-India basis, is 1058 kwh/head/yr, the same would be much lower for the rural Indians. '100% electricity accesses' to all villages of India may be seen in

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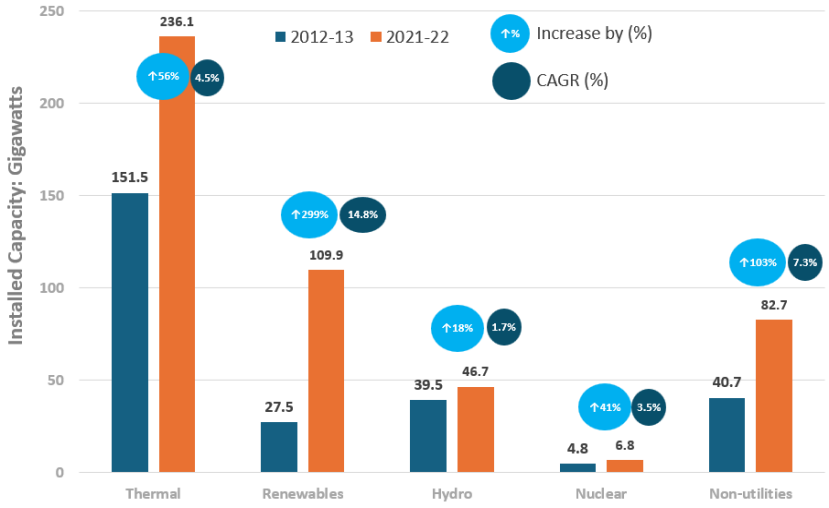
the backdrop of the definition of 'village electrification' (Economic Survey, 2023)[vi], as per which, 'a village would be declared electrified', if: a) Basic infrastructure such as distribution transformer and distribution lines are provided in the inhabited locality as well as the Dalit Basti hamlet where it exists; b) Electricity is provided to public places like Schools, Panchayat Office, Health Centres, Dispensaries, Community centres etc. and c) The number of households electrified should be at least 10% of the total number of households in the village'. Such definition of 'village electrification' provides significant scope for making electricity available at an affordable cost, so that the end users start consuming electricity when it is required most, i.e., during the evening peak hours.

More Electricity Generation Capacities with Focus on Renewables

Figure 1: Installed Electricity Generation Capacity (GW) 2012-13 and 2021-22

[Total capacity increased rom 264.1 GW in 2012-13 to 482.2 GW in 2021-22, increase by 83%, CAGR: 6.2%]

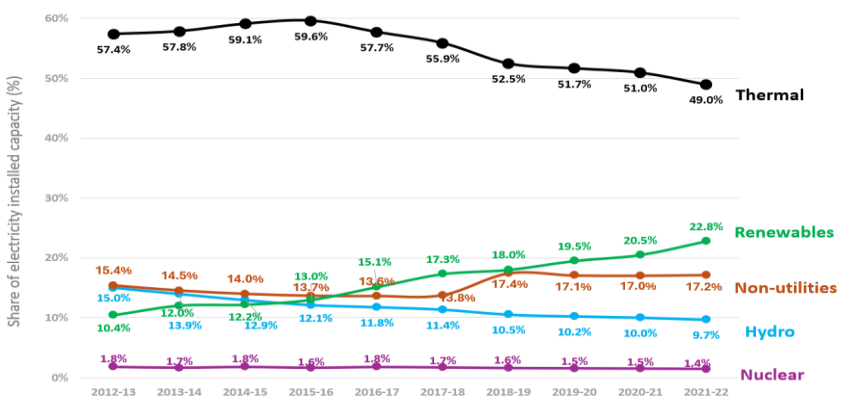


Analysis and Chart by the Author, based on data from Economic Survey 2022-23-Statistical Appendix (Govt. of India)

Govt. of India, through suitable policy formulations, structural interventions, and fund allocation, has been advancing the cause of increasing electricity production capacity and stronger distribution network. During the last 10 years, i.e., from 2012-13 to 2021-22, the total electricity generation installed capacity increased by 83%, from 264 giga-watt (GW) to 482 GW (CAGR of 6.2%) (Economic Survey, 2023)[vii]; The sharpest rise (up 4x) was seen in Renewables (from 27.5 GW to 109.9 GW, CAGR: 14.8%); Thermal capacity rose by 56% (from 151.5 GW to 236.1 GW, CAGR: 4.5%); Hydro capacity rose by 18% (from 39.5 GW to 46.7 GW, CAGR: 1.7%); Non-utilities capacity doubled from 40.7 GW to 82.7 GW (CAGR: 7.3%). [***Figure 1***].

Renewables – Only Electricity Source Whose Share Increased in Last Decade

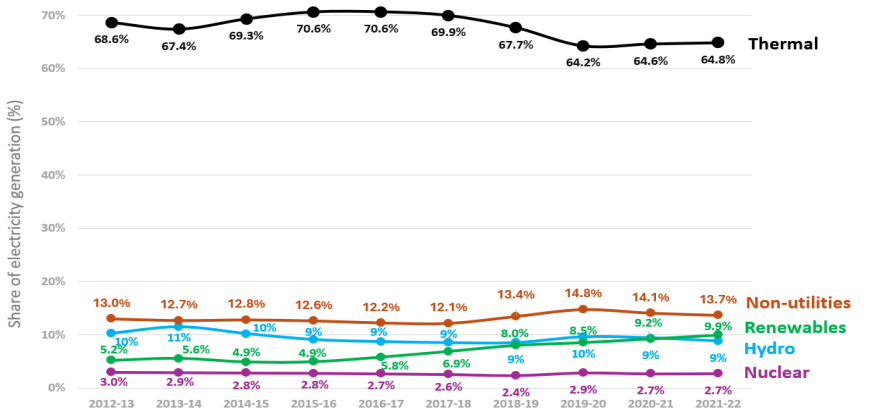
Figure 2: Share of Electricity Installed Capacity from various energy sources (Period: 2012-13 to 2021-22)



Analysis and Chart by the Author, based on data from Economic Survey 2022-23-Statistical Appendix (Govt. of India)

During the 10-year period from 2012-13 to 2021-22, amongst utilities, Renewables is the only electricity source, whose share of installed capacity increased from 10.4% to 22.8%. Share of each of the other utility sources, viz. Thermal, Hydro & Nuclear, decreased (Economic Survey, 2023)[viii]; combinedly, their share came down from 74.2% to 60.1% during last 10 years [***Figure 2***].

Figure 3: Share of Electricity Generation from various energy sources (Period: 2012-13 to 2021-22)



Analysis and Chart by the Author, based on data from Economic Survey 2022-23-Statistical Appendix (Govt. of India)

However, for the year 2022-23, though the Renewables' share of installed capacity was 22.8%, its share in electricity generation was only 9.9% (***Figure 3***), which is due to the lower efficiency or Capacity Utilization Factor (CUF) of Renewables (viz. Solar & Wind energy), as compared to Thermal energy.

Rise of Electricity Generation from Renewables Despite Lower CUF

During the 10-year period from 2012-13 to 2021-22, the overall CUF for electricity sector in India was 37% (Economic Survey, 2023)[ix]. During the same period, the overall CUF of various sources of energy, in decreasing order are, Nuclear (72%), Thermal (53%), Hydro (35%) and Renewables (18%)[ix]. During the same period, the overall electricity generation increased 1.6x, from 1109 Billion kwh (Bkwh) to 1719 Bkwh (4.5% CAGR). The share of electricity generated from Renewables almost doubled from 5.2% (58 Bkwh) to 9.9% (171 Bkwh), whereas the share of hydropower reduced from 10.3% (114 Bkwh) to 8.8% (152 Bkwh) and that of thermal power reduced from 68.6% (761 Bkwh) to 64.8% (1115 Bkwh)[x]

As on 31st December 2024, in India, non-fossil energy sources accounted for 47.1% (218 GW) of 462 GW installed capacity for electricity generation, out of which Wind and Solar sources accounted for 31.6% (142 GW) (Ministry of Power, Govt. of India, 2024)[xi]. However, the contribution of Wind and Solar to total energy output was far lower than its share in installation capacity, given that the Plant Load Factor (efficiency) of Wind and Solar is between 20 and 25 percent, whereas that of thermal power plants ranges between 60 and 65 percent. The comparatively steeper rise of 'electricity generation from Renewables', especially during the last 2 decades, can be attributed to factors viz., environmental (emission) concerns, emphasis on sustainability & sustainable development goals (SDG) of the United Nations (since 2015), technological advancements leading to cost competitiveness of the renewables, energy security concerns, policy support from the Government, etc.

Emission Reduction Efforts & Net Zero Targets

The Paris Climate Accord of 2015, where 195 nations agreed to limit global temperature rise to below 2°C, preferably below 1.5°C, has set the tone for enhanced global efforts towards combating climate change and achieving the Net Zero objectives. Achieving these goals require significant reductions in greenhouse gas emissions, primarily emanating from the fossil fuels. In this regard, various countries have set Net Zero targets: India aims for 2070, USA for 2050, and China for 2060. At COP29 (Baku, 2024), developed countries committed to mobilizing at least US$300 billion annually by 2035 to support developing countries in climate strategies, while also calling for a broader mobilization of private sector funds to reach a total of US$1.3 trillion per year by 2035. During the previous year, at COP28 (Dubai, 2023), the Nations across the world committed to a just and equitable transition from fossil fuels to reduce emissions. World & India's Net Zero target entails reducing reliance on fossil fuels and boosting the share of renewable energy sources in its energy mix, putting in place more energy-efficient policies, and promoting sustainable management practices.

The Inevitability: Solar Energy

Amongst the renewables, solar energy appears to provide the best possible solution for achieving the Net Zero objectives. The issues associated with other renewable energy options are multi-fold. E.g., Wind energy is site specific; Corporations and various other entities have already taken most of the favorable windy sites (with a viable wind speed of 4-6 meters/second) to set up wind power facilities. Offshore wind power facilities do provide an opportunity, but they are capex-heavy, and because the entire east coast of India (and sections of the west coast) is prone to cyclones, building them could be a risky gamble. Other renewable energy sources viz. geothermal energy and hydropower have site-specific issues viz. sensitivities of high tectonic activity zones, river basins, etc. Biofuels compete with food resources viz. land, water, ecology, etc. Moreover, these renewable energy sources not only entail higher upfront capital costs, but they also require large resources (including land) for scaling-up.

In contrast, Solar energy ticks many positive boxes for the world and for India. India is one of the finest places to set up solar power plants due to its tropical geographical position, and majority of its areas experience year-round high levels of solar radiation (Raina & Sinha, 2019)[xii]. Moreover, solar energy offers decentralized solutions (including off-grid / roof-top), minimal maintenance, suitability for rural electrification (micro-grid), reduced transmission losses, and is scalable. Scaling up of solar energy will also support manufacturing, job creation, and socio-economic development, making it pivotal for meeting India's sustainable energy goals and overall economic & social growth objectives.

Policy Recommendations for Large Scale Solar Adoption

A consumer survey of 401 participants conducted by the author concluded that consumers find solar energy socially and economically beneficial, trendy, and image-enhancing. In order to make solar energy more appealing to the consumers' psychological and economic aspirations, Government should formulate suitable policies to make solar technology more convenient to use and affordable. For urban areas, rooftop space availability is critical, especially in multi-story apartments, where solar power is often used for common areas. Policy measures should address both urban and rural needs, focusing on economic and administrative support to encourage widespread adoption of solar technologies.

Unified Tiered Subsidy Scheme:

Rural consumers often face unreliable power and prefer subsidized or free energy, making subsidies critical for encouraging solar adoption. The present low cost of solar energy applies only to large grid-connected projects, while rooftop/off-grid systems are more expensive and require subsidies, particularly for lower-income households. India currently operates three subsidy schemes: PM Surya Ghar, PM KUSUM, and PM JANMAN, with subsidies ranging from 30% to 80% of the upfront costs. However, such subsidies do not distinguish between the haves and have-nots. It would be worthwhile to adopt a tiered subsidy system based on consumer income and unify all existing subsidy schemes for better efficiency and better resource allocation. Subsidies should be seen as investments rather than expenses, which is expected to achieve long-term benefits like reduced fossil fuel dependence, lower emissions, forex savings, job creation, etc.

B2C Financing Structure & Scheme:

There is a need for a focused approach to finance B2C solar energy projects in India, particularly for rooftop and off-grid solarization. At present, 2 PSUs, viz. Indian Renewable Development Agency (IREDA) and Solar Energy Corporation of India (SECI) handle financing and implementation of renewable energy projects. However, these entities focus primarily on grid-connected (B2B) projects. There is no central agency, as on date, specifically dedicated to financing B2C solar energy initiatives. India aims to achieve 280 GW of solar energy by 2030, which includes 130 GW for rooftop and off-grid systems. As on 1st January 2025, only 20 GW rooftop and off-grid capacity has been installed. Installing balance capacity of 110 GW would require investment to the tune of ₹6.6 lakh crore (@ Rs 6000 crore per GW) over next five years. To manage this large funding need, it would be worthwhile to consider formation of a new PSU/entity under the Ministry of New and Renewable Energy, which would focus on financing B2C solar projects, offer low-interest loans, collaborate with rural/cooperative banks, and support the development of solar microgrids, which will lead to affordable financing and repair/maintenance systems and widespread solar adoption.

Solar Micro-Grids for Inaccessible Areas:

In remote areas, where traditional grid infrastructure is not available or uneconomical or impractical to extend, solar microgrids may be considered as an option to provide reliable electricity. While the initial investment for such projects is relatively high, microgrids are cost-effective in the long run and can improve local socio-economic conditions by supporting education, employment, and other commercial/livelihood activities. Moreover, such microgrids can integrate with other renewable energy options. However, challenges such as lack of awareness, financing, technical knowledge, and maintenance have hindered their success so far. The government, through the proposed B2C financing entity, may finance microgrids and involve local agencies/entities viz. NGOs, Self-Help Groups, Panchayats, etc. to ensure

community ownership and long-term sustainability. Establishing pilot microgrid projects with Government/CSR funding could be one of the best bets to de-risk, implement, learn, re-purpose & scale up micro-grids to larger no. of geographies.

Round-The-Year Consumer Awareness Development Plans:
The fact that many surveys have concluded about the 'trendiness' of solar energy amongst the consumers, bodes well for strategizing suitable consumer awareness initiatives (e.g., focusing on subsidies) to boost solar adoption. Localized approach may be adopted using cultural icons like folk singers to create relatable promotional content in regional languages. Nationwide campaigns may be launched to involve influencers viz. village leaders, teachers, folk musicians, self-help groups, etc. to encourage solar energy adoption. Regular year-round awareness campaigns, supported by dedicated energy budgets from the Central and the State agencies, may be launched, re-launched and followed up to ensure sustained consumer interest.

Net-Metering in The Long Run For Bettering Rural Income:
New technologies viz. 'net-metering' has the potential to accelerate solar energy adoption by enabling users to become producers as well as consumers, who not only generate electricity, they also sell surplus electricity to the grid. Such technology has significant socio-economic benefits and can be used as a unique selling proposition (USP) in communication campaigns for large scale solar adoption. Additionally, dynamic electricity pricing may be the policy of the future, where consumers can buy electricity from the grid during off-peak hours (@ lower price) and sell rooftop-generated electricity during peak hours (@ higher price), which can increase their income & further incentivize adoption. Policies should focus on incorporating these consumer benefits into awareness campaigns, which have to be launched and re-launched regularly by State and Central agencies for ensuring top-of-the mind recall.

Strong Repair & Maintenance Ecosystem:
In order to ensure sustainable adoption of solar energy, there is a need to establish & institutionalize a strong repair and maintenance ecosystem, especially in the rural areas, which will ensure that consumers realize the socio-economic benefits of solar energy. Government may formulate suitable policies to achieve 4 key objectives in this regard: a) create local solar technician jobs, b) introduce solar repair courses in industrial training institutes (ITIs) /skilling centers, c) incentivize manufacturers and NGOs to train youth, and d) promote use of CSR funds for conducting solar-skilling programs. Government may involve ITIs nationwide to offer job-worthy certification programs on 'solar technician training'. Such trained technicians could be employed by manufacturers, marketers, or NGOs as part of local repair and maintenance teams. This initiative would drive job creation, especially in rural and semi-urban areas, and support large-scale solar adoption by establishing robust sales and after-sales service systems.

Link Solar Projects to Livelihood Enhancement:
In order to promote solar adoption and ensure long-term sustainability of solar projects in rural areas, solar energy projects may be linked to livelihood enhancement. Examples include using solar-enabled systems for wheat/millet-flour-production, cold-press oil extraction, solar-powered embossing machines for making high-value leaf plates, all of which can enhance income. Initial capital costs for such projects can be sourced from corporate CSR budgets. The success of pilot projects in each block, to be implemented in association with local NGOs and funded through CSR, can serve as models for replication, fostering socio-economic benefits and widespread solar adoption in rural India.

Conclusion
The progress of solar energy adoption globally has been slow and in 2023 solar energy accounted for only 2.5% of total energy consumption and 5.5% of total electricity generation. The International Energy Agency (IEA) projects that solar electricity is likely to reach only about 25% of global electricity generation by 2050, citing challenges in scaling, particularly for off-grid solar systems. To overcome these challenges, effective policy measures by the Govt. must be supported by strong coordination with various stakeholder ministries, state-level agencies, and organizations like NGOs & the self-help groups (SHGs). A unified effort and direction in this regard is essential to create a sustainable solar-powered future for the next generation.

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