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Grid Interactive Renewable Power in India—a Review

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Abstract In February 2015, India announced 175 gigawatts (GW) of capacity additions in renewable power by 2022. Private sector dominates the Grid Interactive Renewable Power (GIRP) but at the same time is dependent on government policies substantially. The scenario of high investment costs is changing, especially in the case of wind and solar power, yet the challenges like high debt cost, variability output, inadequate grid infrastructure, and competition with conventional power prevail. A state-wise analysis reveals that the installed capacities in case of wind and biomass respond strongly to the power tariff for industries while the relationship with the benchmark tariffs is weak though positive. Solar

Highlights

- Grid interactive renewable power (GIRP) is an option for providing cleaner, affordable, and reliable power to both the rural and growing urban population.
- Recently, India announced 175 gigawatts (GW) of capacity additions in renewable power by 2022.
- GIRP installations are primarily dominated by the private sector while the sale and returns are mostly governed by the policies and government and not the market.
- The increased installed capacities of GIRP among the leading states are due to wind energy; other resources are still to be largely harnessed.
- Wind- and solar-based GIRP power plants are now able to provide electricity at cost comparable to conventional electricity.
- Usage of wind potential has stronger and positive relationship with the power tariff for industries than the wind power tariff.
- Solar energy is still largely untapped for grid interactive renewable power but weakly responds to the solar as well as an industrial tariff.
- The installed biomass-based grid interactive power responds strongly to industrial tariff though the states with high biomass potential encourage biomass power by determining high biomass tariff.
- Scenario is to be created wherein the potential utilization of renewable power responds to the benchmark tariffs for renewable power as well as power tariff for industries to continue interest of private sector in renewable power to achieve the announced targets.

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potential is still largely untapped but gaining momentum. With time, it is important to create a scenario wherein GIRP responds strongly to the benchmark tariff identified by the states as presently it responds to power tariff for industries for augmented interest of private sector as one of the means of achieving the ambitious renewable energy targets.

Keywords Renewable energy · Grid interactive renewable power · India · Tariff · Power tariff for industries · Wind · Solar · Biomass

Introduction

India is the second largest country in the world; in terms of population hosting, about 18 % (1.3 billion) of the world's population [1] and 76.6 million households in India still depend on kerosene as the main source of lighting [2]. Out of 1000, only 742 households report consumption of electricity [3]. About 10,958 villages were still un-electrified[1] [4]. Achieving high levels of electrification status still needs massive financial interventions. Renewable energy sources (RES) being clean, eco-friendly, and endless are recommended as one of the sustainable means for achieving the objective of universal access to electricity [5–9]. Renewable energy projects are taken up at two levels:

(a) Feeding into the grid, and revenue model is through signing of power purchase agreements (PPA)
(b) Off grid model, wherein, in most cases, the capital costs are borne through government schemes, and the operating costs are recovered through tariffs, and other income generation options, including cross subsidy across consumer categories

The role of grid interactive renewable power (GIRP) gains prominence over stand-alone renewable systems with more and more areas falling under the purview of the grid network. However, the decentralized renewable energy systems still hold prominence and prospects in locations where grid network is technically and/or financially not viable. Recently, the government of India announced capacity addition target to take the total renewable capacity to almost 175 gigawatts (GW) by the end of 2022. Through the lens of available literature and existing databases, the present paper reviews the barriers, opportunities in GIRP in a context of India along with its relationship with determining factor for sustainability, the tariff.

The paper contributes to the literature by providing (1) the barriers and opportunities associated especially with GIRP whereas majority of the literature focus on decentralized renewable-based generations while discussing access to electricity and (2) an analysis of actual installed capacity [2] of renewable potential relating it to tariff fixed by the states for renewable-based generation and industrial tariffs. The paper is organized as follows: the next section gives a snapshot of development of GIRP in India along with existing potential and usage of renewable power. Sections 3 and 4 discuss the existing barriers and changing scenario in renewable-based power generation. A state-wise analysis of relationship between tariff (tariff for renewable power as per state regulations and industrial tariff both) and the resource wise usage proportion of renewable power as well as installed capacities and potential is taken up in section 5.

Development of GIRP in India

The Indian experience in RE in over three decades has resulted in total installed GIRP capacity of 43086.82 MW (as in April 2016), accounting for 14 % of the total installed power generation capacity [10, 11]. India started the quest for development of RE in the early 1980s, beginning with demonstration projects, followed by initiatives to move towards commercializing the various RE technologies [9].

Renewable Energy Sources[3] (RES) in the total installed generation was reported first time in the year 1990 (end of seventh five-year plan period); since then, the share of RES in total generation has been rising steadily. Table 1 clearly indicates that, initially, the annual capacity addition of RES was very slow during the initial years, but from 2008 onwards, the share of RES increased considerably. Figure 1 presents the scenario of GIRP in India. Out of the total installed generation capacity of renewable power as on 31-03-2016, wind power accounted for about 64.62 %, followed by solar power (12.57 %) and biomass power (11.46 %) [14].

As part of its Union Budget 2015–2016, India aims to install 60 GW of wind power capacity and 100 GW of solar power capacity by 2022, which is more than six times the current installed capacities of 22 and 3 GW, respectively [21]. India needs as much as USD 200 billion to meet its target to install 100 GW of solar power and 60,000 MW of wind power by 2022 [22]. The finance ministry gave a boost to renewable power targets in its budget in February 2015, announcing that a national investment fund will be created to support infrastructure companies. Doubling the coal production tax is also expected to generate new funds for clean-energy projects [23].

The total potential for renewable power generation in the country as on 31.03.15 is estimated at 896,603 MW which includes wind power potential of 102,772 MW (11.46 %), SHP (small hydropower) potential of 19,749 MW (2.20 %),

[1] A village in India is considered as electrified if 10 % of the households are electrified.

[2] Installed grid interactive renewable power capacity divided by potential

[3] The generation stations with installed capacity less than or equal to 25 MW are indicated under (RES). Renewable Energy Sources (RES) include small hydropower (SHP), biomass gasifier, biomass power, urban and industrial waste power, and wind energy.

biomass power potential of 17,538 MW (1.96 %), 5000 MW (0.56 %) from bagasse-based cogeneration in sugar mills, and solar power potential of 748,990 MW (83.54 %) [14]. State-wise potential and RE installed capacities are provided at Appendix (Table 6). On an average, 3 % of the total renewable potential is translated into grid interactive renewable power by the states. The progress of renewable energy in paving the way in electrification is slow not only in the country but also in other developing countries. The subsequent section discusses about the barriers in growth of renewable power and the changing scenario in renewable-based generations leading to opportunities.

Barriers

The barriers and opportunities are identified through search of available literatures published in peer-reviewed journals and by the organizations engaged with renewable energy projects. Barriers in general are classified into technical barriers, financial barriers, and market barriers.

Compared to conventional technologies, RE technologies are unique in many ways as compared to generation from conventional sources. The technologies deliver less energy when compared to conventional technologies. For, e.g., solar PV modules deliver power with utilization of 15–20 %, wind turbines operate with load factors of 15–20 %, and small hydromachines deliver at load factors of 20–40 % in very good water surplus environments. To compound matters, the electricity produced must be consumed near the point of production and cannot be stored (except for chemical energy). As against this, large hydropower plants operate at load factors of 60 % or higher and thermal- and gas-based power plants have load factors of over 85 % and higher in some instances. India's renewable resources are abundant, but the output of wind and solar photovoltaic is variable, and in the case of wind in particular, subject to uncertainty. In addition, unlike conventional (fossil fuel-fired power stations), renewable power plants only generate under appropriate weather conditions and this variability of output has caused concern to system operators throughout the world [24].

In general, one of the barriers identified in case of renewable energy development is the higher capital cost than conventional power generation technologies, the main reason being the lack of economies of scale.[4] In addition to the initial costs, the generation costs are also high due to their low utilization factors. RE technologies, unlike fossil-based energy technologies, have high capital costs but very low operating costs spread over 25–30 years and the cost of finance (currently ranging from 12 to 14 % in India) forms a significant component of the power tariff from these sources [24]. However, the cost competitiveness of renewable technologies is improving from the past few years.

In India's case, renewable project revenues currently depend more on policy support rather than on the prices of fossil fuels such as both the accelerated depreciation (AD) and the generation-based incentive (GBI), which comprised 10 % of wind energy incentives (GBI, expired in March 2012 and was reintroduced in 2013), affected the sector significantly [25]. The size of sustainable electricity market is not big enough, and private investment is discouraged due to lack of sufficient market base [26]. Absence of supply chain for renewable energy technologies (RET) and high implementation risks for RETs discourages private sector participation in RE [27]. Market failures (due to market distortions owing to subsidies or imperfection) in general are identified as one of the restricting factors in the diffusion of renewable energy technologies [28, 29]. Haanyika while reviewing power sector reforms across developing countries indicates that market reforms are not designed to specifically deal with the problems of RE confronting many developing countries [30].

Shrimali et al. (2015) conclude that higher financing costs increase the Indian renewable energy cost by 22–28 % and identify the high cost of debt as the biggest issue facing renewables in India (contributing to 24–32 % of the finance cost). Financial institutions consider solar energy technologies to have unusually high risks while assessing their creditworthiness because solar energy projects have a shorter history, lengthy payback periods, and small revenue stream and thus implying higher financial charges (e.g., interest rates) to solar energy projects [31]. In India, the high base rate of debt overwhelms other policies [32]. However, government policies in particular feed in tariff/preferential tariff, accelerated depreciation, and generation-based incentive had supported the renewable energy development in India.

Present investment flows into Indian renewable energy, like those of conventional power and transmission investment, are insufficient to meet India's deployment targets [24]. State owned transmission and distribution companies are by far the largest purchaser of electricity, including that from renewable energy sources (RES). However, these transmission and distribution companies due to financial and resources constraints may increase the risk of curtailment[5] to the private owned renewable generation companies [24]. Other barriers identified for India are delays in obtaining clearance for projects awarded through the competitive bidding resulting in a levy of penalty on the developer, financially weak developers, non-availability of evacuation infrastructure, and grid integration in case of remote sites [27].

[4] RE technologies are generally available in the kW range (up to 100 kW) and also in the megawatt range (up to 5 MW). As against this, conventional power size plant sizes are in the range of 250/500/800 MW thus getting enormous advantage from economies of scale.

[5] Curtailment occurs due to congestion in the grid, i.e., the grid is congested and cannot carry any more electricity, or if there is no buyer for the electricity.

India's grid is unable to handle the intermittent energy produced by renewable sources like solar and wind and needs a radical upgrading in order to make sure power generated in solar parks reaches end users [24]. The government is working towards constructing a "Green Energy Corridor" to facilitate transmission of renewable energy, but this is a long and expensive process [23].

Changing Scenario and Opportunities

Cost reduction in renewable energy technologies is observed since the year 2010 [33]. The recent report on renewable power generation cost [34] concludes that the renewable are slowly becoming the low cost option for grid supply. In India, average installed costs for biomass for power, hydropower, and onshore wind average between USD 1.240 and USD 1.390/kW. The average installed costs for large-scale solar photovoltaic (PV) have fallen dramatically in India, to around USD 1.670/kW in 2013 and 2014 (from USD 2.646/kW in the year 2013). The report finds that the Levelized Cost of Energy[6] (LCOE) of onshore wind is now within the same cost range, or even lower, than for fossil fuels and the best wind projects around the world are consistently delivering electricity for USD 0.05/kWh without financial support. In fact, in India today, new wind projects at the point of generation are cheaper than the comparable costs of power from new imported coal-based projects and the solar photovoltaic generation costs are cheaper than the cost of natural gas-based generation [24].

The high capital cost of renewable energy projects is compensated through the regulations and policies such as Generation-Based Incentives (GBI), accelerated depreciation, tax holidays, concessional customs and excise duty exemptions, sales tax exemption, and loan availability through Indian Renewable Energy Development agency (IREDA). Such as a GBI scheme applicable for the entire 12th plan period with a target of 15,000 MW provides GBI to wind electricity producers @ USD 0.0075 per unit of electricity fed into the grid for a period not less than 4 years and a maximum period of 10 years with a cap of USD 149,913 per MW [35]. Accelerated depreciation to reduce tax and strengthen cash flows is applicable in case of wind, solar, and biomass power. Renewable Energy Certificate (REC) market is still in a nascent stage, and the demand is overpowered by huge supply of REC's resulting in flooring of prices.

In India, there were two green bond issuances by banks in 2015—Yes Bank (USD 1500 million) and Export Import Bank (USD 500 million); and the country's first corporate green bond was recently issued by CLP Wind Farms (USD 900 million) [36]. India's Bharti Enterprises (in banking sector) in June 2015 announced venture set at USD 20 billion with target to build 20 GW of solar energy in India [36]. IREDA (India's leading non-banking financial institution in the renewable energy sector) recently launched tax-free bonds worth USD 307 million to raise funds, which would be used to finance renewable energy projects.

Consistent with the growing maturity of the sector, the perceived risk of investing in renewables has fallen in recent years. Non-OECD (Organization for Economic Development and Cooperation) countries account for more than 70 % of the growth in renewables seen since 2009, and renewable power investment in 2014 was around 90 % higher than the net investment in fossil fuel power [36].

The tariff for end users ranges for 2 kW connected load for grid connected power ranges between USD 0.025 to 0.098 per kWh [37]. The prices paid by state utilities to buy renewable power vary from state to state which in general ranges between USD 0.045 and 0.225 per unit while the tariff for coal-based power where the tariff starts from USD 0.057 (with no blended share of imported coal) to USD 0.088 (with 90 % share of blended coal) [38]. The lower tariffs fixed for end users may discourage the state utilities to opt for RE power. However, the tariff for wind power in Tamil Nadu at present is comparable to the tariff for coal-based generation. The recent rates quoted by SunEdisons in Andhra Pradesh for solar electricity are lower than the power generated from 90 % blend of imported coal. However, the instances of comparative tariff from renewable-based power are few.

The Ministry of New and Renewable Energy in India has prepared a draft Renewable Energy Act 20XX for India, which broadly proposes provisions for institutional structure, supportive ecosystem, economic and financial framework, constitution and operation of national and state level funds to support renewable energy applications including distributed and grid connected renewable electricity [39]. This is presently under discussions with various stakeholders. In addition, the states have their own set policies and regulations for renewable energy. The state level policies and regulations hold prominence as the states are majorly responsible for electricity generation and grid interactive renewable power. The State Electricity Regulatory Commission (SERC) deals with the matters concerning generation, transmission, distribution, and trading of electricity within the states.

Based on the discussions in paper so far, Table 2 compiles the strengths, weaknesses, opportunities, and threats (SWOT) of GIRP in context of India.

An Analysis Through the Lens of Tariff

The grid interactive renewable power plants in India are majorly owned by the private sector. The returns are primarily dependent on tariff of the electricity sold and other policies/regulations such

[6] LCOE is the total cost to build and operate a new power plant over its life divided to equal annual payments and amortized over expected annual electricity generation. It reflects all the costs including initial capital, return on investment, continuous operation, fuel, and maintenance, as well as the time required to build a plant and its expected lifetime.

as wheeling charges, energy banking, tax exemptions, other incentives like generation-based incentives (GBI), and so on. The states are primarily responsible for generation and distribution of grid interactive renewable power as well as for the linked policies and regulations. The policies, in general, are investor friendly in all the states and show little variability except for tariff and RPO. In view of the tariff playing a key role in the investments from private sector, an analysis of the role of tariff was carried out. This section attempts to identify the relationship between the tariff (both tariff identified by the states for sale of power solar, wind- and biomass-based power, and the industrial tariff) with the status of GIRP. SHPs are not considered as the resource is highly localized and water is a state subject.

Wind-Based GIRP

The states, which are leading in grid interactive renewable power, are primarily because of wind power. The rapid growth in installed capacity for wind power came through policies that allowed industrial consumers to set off their own consumption from electricity generated through wind assets anywhere in the state. Table 3 presents the correlation values for the selected indicators related to wind-based GIRP for all the 28 states in India. The table clearly indicates that there is strong and positive correlation between the power tariff for industries[7] and usage proportion of wind potential (and installed capacities).

The Fig. 2a depicts the scatter plot with usage proportion of wind energy as dependent variable with tariff decided by the states to be paid for purchase of wind energy. Only the states with defined tariff in regulation are presented in the scatter plot. It is likely that the higher tariff will lead to higher proportion of utilization of potential. Tamil Nadu is the only state where the usage proportion is about 51 % whereas the tariff is lower than the average tariff. There are four states, Andhra Pradesh, Haryana, Odisha, and West Bengal, where the tariff is high but the usage proportion of wind potential is low. Among these four states, the wind potential of Haryana, Odisha, and West Bengal are very poor. Andhra Pradesh has low electricity tariff rates for industries but high tariff rates for wind power for the sale to state electricity distribution and transmission companies. Scatter plot at Fig. 2b indicates that the states with high usage proportion of wind power (Tamil Nadu, Maharashtra, and Rajasthan) also have high electricity tariff rates for industries. The industries in the states with high electricity tariff for industries are more inclined to purchase wind-based power which in general is lower than the industrial tariff.

As of today, Tamil Nadu is the largest producer of wind power in India. The peak period for capacity additions in wind were during the years 2004 to 2012, the capacity addition dropped drastically from the year 2013 onwards. As per the tariff orders 2009 in Tamil Nadu, the tariff works out to USD 0.049 per unit for the period up to 31-3-2009 and USD 0.051 per unit after 1-4-2009 [42]. Wind tariff in Tamil Nadu has not changed much so far. During the period (200–2013), Tamil Nadu became a favorable destination for wind power because of attractive wheeling and banking facilities on charges of 5 % each, favorable terrain in potential locations with easy accessibility, Higher Plant Load factor (PLF) of 30 % and therefore higher power generation per MW, and reasonable power tariff and regular payment by TNEB and adequate infrastructure for power evacuation including permission for investors to put up their own substations [40].

Solar-Based GIRP

Solar tariff as well as industrial tariff for electricity has almost negligible but positive correlation with the usage proportion of solar potential for grid interactive renewable power (Table 4). Tariff in general case of solar is decided through bidding process. Recently, United States-based SunEdison has won a bid to sell solar power in India at a record low tariff, USD 0.0706 per kilowatt-hour for a 500 MW project in Andhra Pradesh, which could boost the appeal of the renewable source. The sale of power, however, is through bundling with conventional power by National Thermal Power Corporation Ltd (NTPC) at an average rate of USD 0.053 a unit [43].

Figure 3a, b indicates that solar power is responsive to both solar tariff and industrial tariff in a positive way. However, the relationship with any of the tariff is not very strong. The reason may be attributed that the solar is still nascent compared to wind and biomass in grid interactive power. Presently, majority of the solar power plants sell the generated electricity to state transmission facilities and not the industries. Learning from the example of Tamil Nadu in case of wind power, it is important to retain the minimum level of tariff to provide sufficient profit levels to the private sector so that the investments in solar power continues in the future to achieve the targets announced for renewable energy by 2022.

As per Central Electricity Regulatory Commission (CERC), solar tariff is exclusive of taxes and pass through allowed on actual basis. Various fiscal and regulatory instruments have been used to encourage solar energy such as tax incentives, preferential interest rates, direct incentives, loan programs, construction mandates, renewable portfolio standards, net metering, interconnection standards, and demonstration projects, but the level of incentives does not seem to be adequate to substantially increase the penetration of solar energy in the global energy supply mix [31].

Biomass-Based GIRP

Biomass power generation is becoming an emerging industry in India over the last decade (44). The leading state for biomass power projects is Chhattisgarh, Uttar Pradesh,

[7] Industrial tariff for the year 2014 is considered.

Maharashtra, Andhra Pradesh, and Tamil Nadu, and the states which have taken position of leadership of bagasse cogeneration[8] projects are Andhra Pradesh, Karnataka, Maharashtra, Tamil Nadu, and Uttar Pradesh [44].

Table 6 indicates that the tariff for biomass has strong and positive correlation with the potential of biomass while the industrial tariff has strong and positive correlation with the installed capacities of biomass-based grid interactive power. A review of ownership of biomass power in the Infraline database indicates that the biomass-based power plants in general are owned by the private developers. The correlation table (Table 5) is indicative that industrial tariff influences the installed capacities of grid interactive biomass power but at the same time the potential of biomass for industrial use is not adequately tapped. A clear relationship between the electricity tariff for industries and installed capacities of grid interactive power is provided in Fig. 4a. Majority of the biomass power is generated for captive use in industries [45]. The states with biomass potential are also promoting the grid interactive biomass power by determining high tariff rates for biomass power (Fig. 4b). In case of commercial production of electricity through biomass, continuous availability and supply of biomass is a major barrier. A large potential of biomass is untapped for renewable power in spite of the Government of India being relatively ambitious on policy making, regulation, institutional creation, and mobilization of industry interest into biomass; e.g., by liberal tax regime, easy land acquisition, and compulsory power purchasing from biomass-based power producers [45] (Table 6).

Conclusion

Grid interactive renewable power is one of the key drivers for enhancing access to electricity among the energy-deprived rural as well as increasing urban population. India has huge potential of renewable power, in particular of solar and wind. Presently, the high installed capacities of GIRP at state level are mainly due to wind power with solar power coming into its own increasing share in recent years. The other renewable resources are still to be adequately utilized considering their immense potential. India is emerging as one of the leaders in renewable power by declaring the target of capacity addition of 175 GW of renewable power in its grid by 2022.

Presently, the private sector has supported the government in moving towards achieving the targets, indicating positive response to the policies at the national and state levels. However, the response has been different in different states, which are linked to the policies announced by the states in addition to national policies. The returns on GIRP capacities are linked to a considerable extent on government policies (such as GBI and benchmark tariffs decided by the states) while market has little influence on renewable-based power. Market is still in a nascent stage to be able to overcome the barriers linked to renewable-based grid interactive projects, and government support is still needed to internalize some of the associated risks and costs [46].

There exist two options for the GIRP investor. First option is to set up the GIRP with the intention of consuming the electricity generated through GIRP for their own consumption at their industrial facilities. The second option is to sell the electricity to the distribution utilities or to a third party (within or outside the state) based on medium or long term power purchase agreements. Thus, power tariff for industries becomes one of the driving forces in utilizing wind power as well as biomass power, primarily to offset high expenses on electricity expenditure. However, the level of usage of wind potential is substantially higher than the biomass potential. Biomass still faces constraints of regular supply of biomass with attractive prices. Solar is still in the emerging phase, and presently, the solar power in general is purchased by the state owned transmission and distribution companies.

The analysis has shown that states with high benchmark RE tariffs are not necessarily those with high RE utilization of potential. There are some states with lower tariffs that have been able to attract private investments primarily through non-tariff policies such as wheeling, banking, and availability of infrastructure for setting up and evacuating GIRP. However, the investments in such states are declining for the particular RE resource.

Strong economic justifications in terms of tariff as well as market creation for the produced renewable-based electricity in the state level policies are needed for private sector to promote enhancement of share of renewable energy in grid electrification. The states are coming up with innovative policies such as RE parks, RE zones which have certain incentives for a limited period. With time, more emphasis is to be paid to build a scenario wherein the renewable-based power responds to the benchmark tariff (decided by the states to feed in grid); almost in the similar patterns, it is presently responding to the electricity tariff for industries so that the ambitious renewable energy targets are met as well as renewable power also influences the electricity access scenario of the country. The states have to listen to the voices of the practitioners to make the GIRPs economically viable and sustainable in long run.

Compliance with Ethical Standards

Conflict of Interest Manjushree Banerjee and Gautam Dutta declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

[8] In bagasse cogeneration waste of sugar mills known as bagasse (The dry pulpy residue left after the extraction of juice from sugar cane) is used as fuel for electrical energy generators by gasification technology.

Appendix

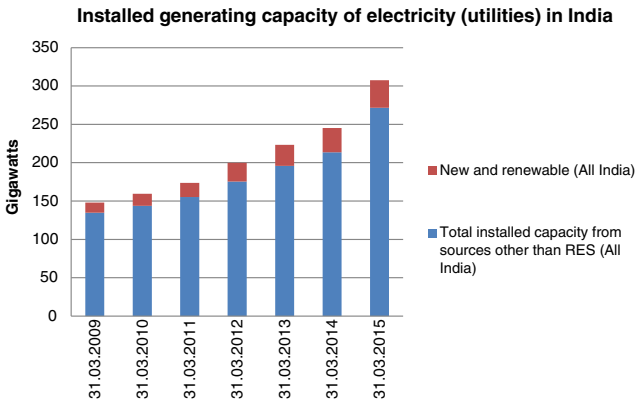
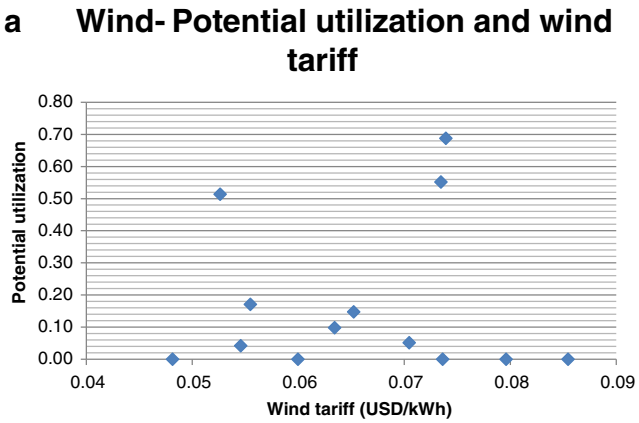


Fig. 1 Installed generating capacity of electricity (utilities) in India. Source [14–20]



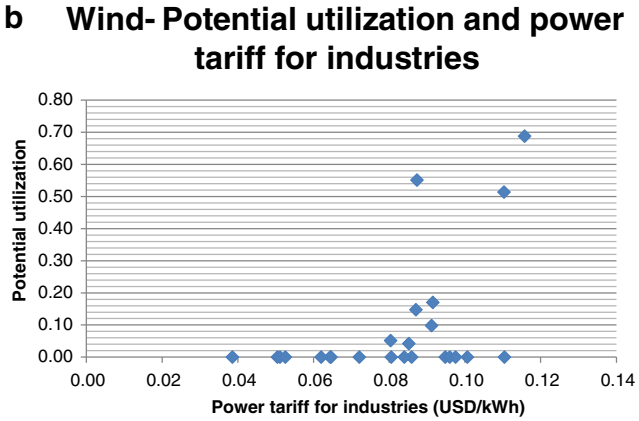
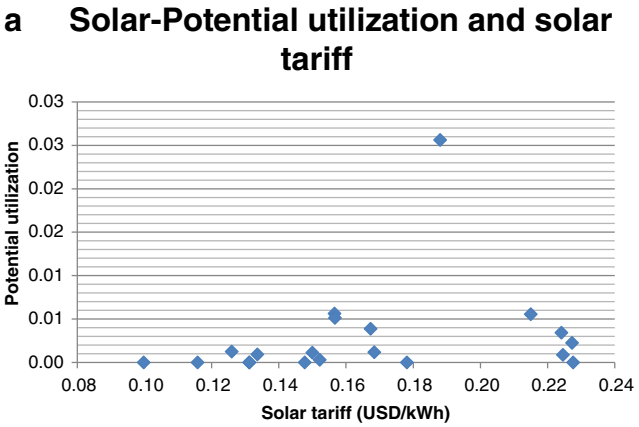


Fig. 2 **a** Relationship between wind tariff and usage proportion of wind potential (1.00 INR = 0.0149913 USD, 1.00 USD = 66.7052 INR). Source: Websites of state nodal agencies in renewable energy [14, 40, 41]. **b** Relationship between the industrial tariff and the usage of wind potential. Source: Websites of state nodal agencies in renewable energy [14, 40, 41]



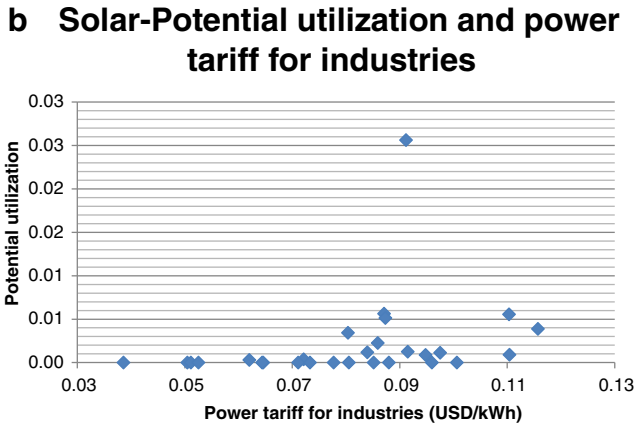


Fig. 3 **a** Relationship between solar tariff and usage proportion of solar potential. Source: Websites of state nodal agencies in renewable energy [14, 40, 41]. **b** Relationship between industrial tariff and usage proportion of solar potential. Source: Websites of state nodal agencies in renewable energy [14, 40, 41]

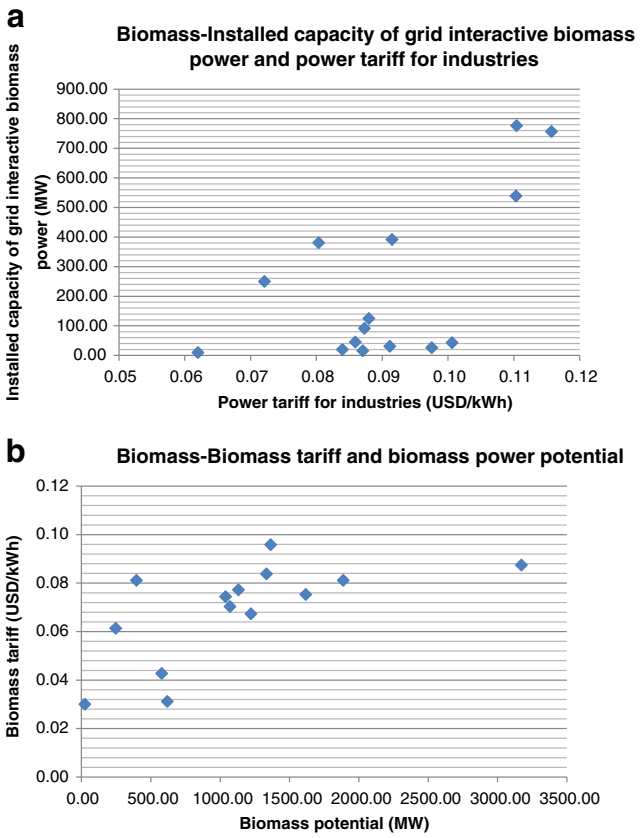


Fig. 4 **a** Relationship between industrial tariff and installed capacity of grid interactive biomass power. Source: Websites of state nodal agencies in renewable energy [14, 40, 41]. **b** Relationship between biomass potential and tariff. Source: Websites of state nodal agencies in renewable energy [40, 41]

Table 1 Growth of installed capacity, share of RES in total installed generating capacity

Year	Total installed generating capacity (MW)	Total installed RES generating capacity (MW)	% of total capacity
End of 6th plan (1985)	42,585	0	0
End of 7th Plan (1990)	63,636	18	0.03
End of 8th Plan (1997)	85,795	902	1.05
End of 9th Plan (2002)	105,046	1658	1.58
End of 10th Plan (2007)	132,329	7761	5.86
End of 11th Plan (2012)	199,877	24,503	12.26
Mid of 12th Plan (2015)	276,089	35,777	12.96

Source: [12, 13]

Table 2 GIRP in India—strengths, weaknesses, opportunities, and threats

Strengths	**Weaknesses**
• Supportive policies such as GBI, accelerated depreciation, tax holidays, and exemptions	• High capital cost
• Reducing cost of wind- and solar-based power	• Variable output
	• Inadequate grid infrastructure
	• Nascent market
	• High debt cost
	• RPO targets are not mandatory
Opportunities	**Threats**
• Ambitious targets for renewable energy particularly for wind and solar	• States are the major buyers
• Huge untapped renewable potential	• Operational risks
• Scope for more private players	• Dependent on policies for incentives and returns to an extent
• Limited state-based generation units	• Uncompetitive tariff compared to coal-based generation
• Regulatory Purchase Obligations (RPO)	

Table 3 Correlation matrix for wind

	Potential	Installed GIRP capacities	Potential utilization[a]	Wind tariff	Power tariff for industries
Potential	1.0000				
Installed GIRP capacities	0.3451	1.0000			
Potential utilization	−0.2480	0.6844	1.0000		
Wind tariff	−0.1033	−0.1734	0.3638	1.0000	
Power tariff for Industries	0.0068	0.8062	0.7832	−0.0332	1.0000

[a] (Installed GIRP capacities)/potential

Table 4 Correlation matrix for solar

	Potential	Installed GIRP capacities	Potential utilization[a]	Solar tariff	Power tariff for industries
Potential	1.0000				
Installed GIRP capacities	0.6834	1.0000			
Potential utilization	0.1990	0.8386	1.0000		
Solar tariff	−0.2824	−0.0951	0.0780	1.0000	
Power tariff for industries	0.0427	0.0212	0.0792	−0.0770	1.0000

[a] (Installed GIRP capacities)/potential

Table 5 Correlation matrix for biomass power

	Potential	Installed GIRP Capacities	Potential utilization[a]	Biomass tariff	Power tariff for industries
Potential	1.0000				
Installed GIRP capacities	0.3182	1.0000			
Potential utilization	−0.1551	0.7398	1.0000		
Biomass tariff	0.6324	0.1542	−0.3533	1.0000	
Power tariff for industries	0.3732	0.6878	0.1419	0.3732	1.0000

[a] (Installed GIRP capacities)/potential

Table 6 Potential of renewable power and installed capacity of grid interactive renewable power in India (MW)

States/UTs	Wind		Small hydropower		Biomass power		Waste to energy		Solar		Total	
	Potential	Installed capacity	Potential	Installed capacity	Potential	Installed capacity	Potential	Installed capacity	Potential	Installed capacity	Potential	Installed capacity
Andhra Pradesh	14,497	1155	978	232	578	390	123	58	38,440	357	54,916	2192
Arunachal Pradesh	236		1341	104	8				8650	0	10,236	104
Assam	112		239	34	212		8		13,760		14,330	34
Bihar	144		223	71	619	43	73		11,200		12,559	114
Chhattisgarh	314		1107	52	236	265	24		18,270	73	19,951	390
Goa			7	0	26				880		912	0
Gujarat	35,071	3876	202	16	1221	56	112		35,770	1024	72,726	4973
Haryana	93		110	74	1333	52	24		4560	12.8	6470	138
Himachal Pradesh	64		2398	754	142		2		33,840		36,446	755
Jammu and Kashmir	5685		1431	156	43				111,050		118,208	156
Jharkhand	91		209	4	90		10		18,180	16	18,580	20
Karnataka	13,593	2871	4141	1177	1131	664		1	24,700	104	44,015	4818
Kerala	837	35	704	198	1044		36		6110	12	8732	246
Madhya Pradesh	2931	1126	820	86	1364	36	78	4	61,660	678	66,853	1930
Maharashtra	5961	4638	794	336	1887	1033	287	13	64,320	378	74,500	6400
Manipur	56		109	5	13		2		10,630		10,811	5
Meghalaya	82		230	31	11		2		5860		6185	31
Mizoram			169	36	1		2		9090		9261	36
Nagaland	16		197	30	10				7290		7513	30
Orissa	1384		295	64	246	20	22		25,780	67	27,728	151
Punjab			441	156	3172	140	45	10	2810	200	6768	508
Rajasthan	5050	3866	57	24	1039	11	62		142,310	1264	148,518	5265
Sikkim	98		267	52	2				4940		5307	52
Tamil Nadu	14,152	7514	660	123	1070	662	151	8	17,670	419	34,152	8727
Tilangana									20,410	91	20,410	91
Tripura			47	16	3		2		2080	5	2131	21
Uttar Pradesh	1260		461	25	1617	889	176	5	22,830	140	27,593	1059
Uttarakhand	534		1708	209	24	30	5		16,800	5	19,071	244
West Bengal	22		396	98	396	26	148		6260	7	7222	131

Source: (12)

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