User Guide for India’s 2047 Energy Calculator

Renewable Energy Sources (Solar, Wind and Small Hydro)

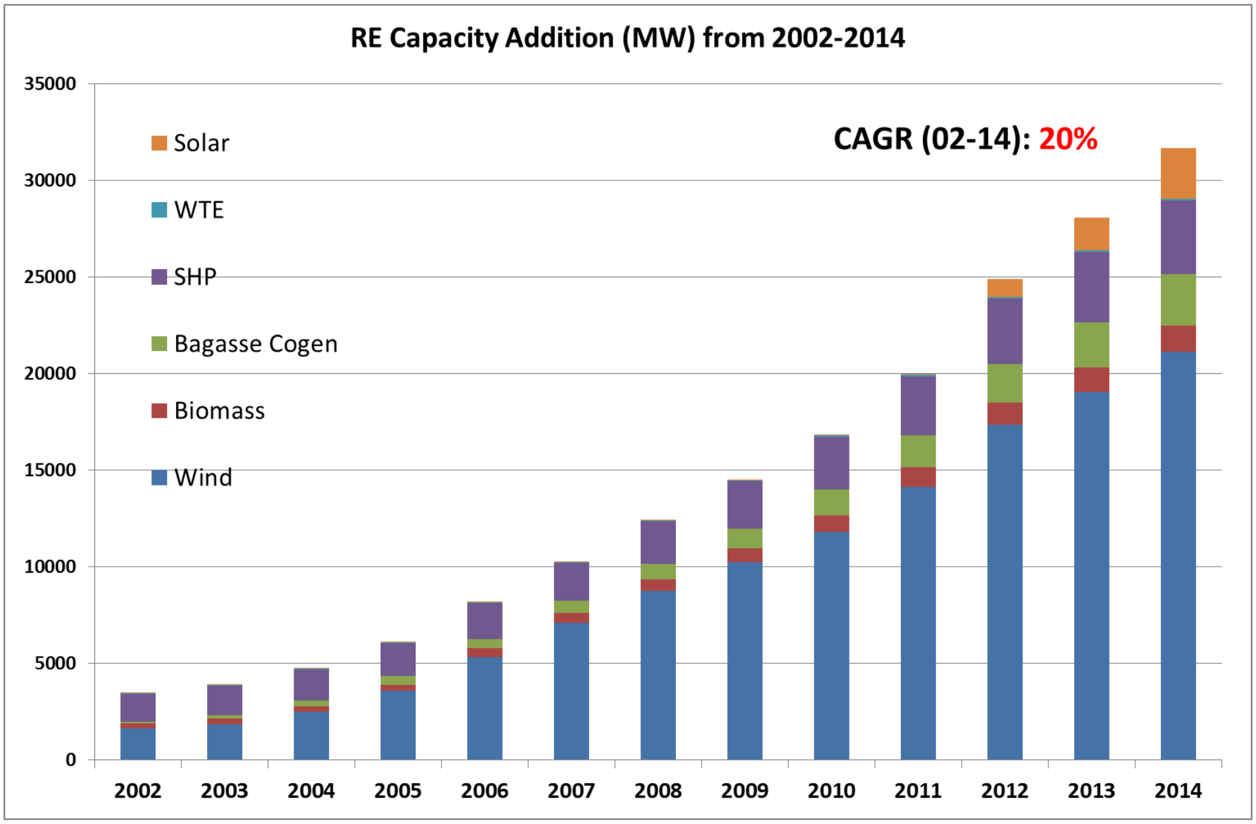
CONTENTS

1. INTRODUCTION

The Ministry of New and Renewable Energy (MNRE) is the nodal Ministry of the Government of India for all matters relating to new and renewable energy. The broad aim of the Ministry is to develop and deploy new and renewable energy for supplementing the energy requirements and enhancing the energy security of the country.

MNRE has designated state nodal agencies in each state which coordinate state level activities related to renewable energy and implement the programs of the Ministry. Apart from SNAs, the Ministry has several technology specific research organizations under its ambit. These include the National Institute of Solar Energy (NISE), the National Institute of Wind Energy (NIWE) formerly the Centre for Wind Energy technology (CWET), the Sardar Swaran Singh National Institute of Renewable Energy focusing on biomass energy and the Alternate Hydro Energy Centre (AHEC). Additionally the Indian Renewable Energy Development Agency (IREDA) is a Non-Banking Financial Institution under the administrative control of this Ministry for providing term loans for renewable energy. Finally for implementing the program on solar power, the Solar Energy Corporation of India (SECI), New Delhi was recently registered under Section 25 of Companies Act, 1956, as a company not for profit, under the administrative control of the Ministry of New & Renewable Energy (MNRE).

Recognizing the potential benefits of renewable energy (RE), Government of India (GoI) and various State Governments have taken several measures that have led to the increasing share of RE in the electricity mix of the country. These have resulted in nearly 35776 MW (as of May 2015) of grid-connected installed capacity which has roughly 13% of share in the total installed capacity and delivering close to 6.4% of the total electricity generation. The above data for renewables does not include the contribution of large hydro. The lion's share in this is taken by wind power at 23.4 GW (May, 2015). The adoption of a large target of 175 GW of RE capacity (excluding large hydro) by 2022 is a bold step towards a future RE denominated electricity system. Indeed, RE has come a long way in India and one can safely say that it is well on its way to becoming mainstreamed with an additional 30 GW capacity addition planned in the 12th five year plan (2012-17) being comparable to all existing RE capacity or ~60% of all conventional capacity (thermal+ nuclear+ large hydro) added in the 11th plan. The graph below captures the growth of the sector in the last 12 years. There has been an impressive growth with a CAGR of roughly 20% over this period.



EXISTING LEGAL AND ASSOCIATED POLICY-REGULATORY FRAMEWORK

Electricity as a subject lies in the concurrent list of the Indian Constitution and hence is dealt at by the Central and State Governments. It is governed by the Electricity Act of 2003 and the policies formulated under it. Some of the provisions related to renewable energy are reproduced below.

➢ ELECTRICITY ACT 2003

Section 86(1)(e): The State Commission shall 'promote cogeneration and generation of electricity from renewable sources of energy by providing suitable measures for connectivity with the grid and sale of electricity to any person, and also specify, for purchase of electricity from such sources, a percentage of the total consumption of electricity in the area of a distribution licensee.'

Section 61(h): The Appropriate Commission shall, subject to the provisions of the Act, specify the terms and conditions for the determination of tariff, and in doing so, shall be guided by the promotion of co-generation and generation of electricity from renewable sources of energy.

Apart from the EA 2003, there are several policies of the GoI which support and promote renewables. Some of the provisions related to renewable energy are reproduced below.

➢ NATIONAL TARIFF POLICY (2006, AMENDED IN 2011)

Section 6.4 Non-conventional and renewable sources of energy generation including co-generation:

(1) Pursuant to provisions of section 86(l)(e) of the Act, the Appropriate Commission shall fix a minimum percentage of the total consumption of electricity in the area of a distribution licensee for purchase of energy from such sources, taking into account availability of such resources in the region and its impact on retail tariffs. Such percentage for purchase of energy should be made applicable for the tariffs to be determined by the SERCs latest by April I, 2006.

(i) Within the percentage so made applicable, to start with, the SERCs shall also reserve a minimum percentage for purchase of solar energy from the date of notification in the Official Gazette which will go up to 0.25% by the end of 2012-2013 and further up to 3% by 2022.

(ii) It is desirable that purchase of energy from non-conventional sources of energy takes place more or less in the same proportion in different States. To achieve this objective in the current scenario of large availability of such resources only in certain parts of the country, an appropriate mechanism such as Renewable Energy Certificate (REC) would need to be evolved. Through such a mechanism, the renewable energy based generation companies can sell the electricity to local distribution licensee at the rates for conventional power and can recover the balance cost by selling certificates to other distribution companies and obligated entities enabling the latter to meet their renewable power purchase obligations. In view of the comparatively higher cost of electricity from solar energy currently, the REC mechanism should also have a solar specific REC.

(iii) It will take some time before non-conventional technologies can compete with conventional sources in terms of cost of electricity. Therefore, procurement by distribution companies shall be done at preferential tariffs determined by the Appropriate Commission.

(2) Such procurement by Distribution Licensees for future requirements shall be done, as far as possible, through competitive bidding process under Section 63 of the Act within suppliers offering energy from same type of non-conventional sources. In the long-term, these technologies would need to compete with other sources in terms of full costs.

(3) The Central Commission should lay down guidelines within three months for pricing non-firm power, especially from non-conventional sources, to be followed in cases where such procurement is not through competitive bidding."

➢ NATIONAL ELECTRICITY POLICY (2005)

Non-conventional sources of energy being the most environment friendly there is an urgent need to promote generation of electricity based on such sources of energy. For this purpose, efforts need to be made to reduce the capital cost of projects based on non-conventional and renewable sources of energy. Cost of energy can also be reduced by promoting competition within such projects. At the same time, adequate promotional measures would also have to be taken for development of technologies and a sustained growth of these sources.

The Electricity Act 2003 provides that co-generation and generation of electricity from non-conventional sources would be promoted by the SERCs by providing suitable measures for connectivity with grid and sale of electricity to any person and also by specifying, for purchase of electricity from such sources, a percentage of the total consumption of electricity in the area of distribution licensee. Such percentage for purchase of power from nonconventional sources should be made applicable for the tariffs to be determined by the SERCs at the earliest. Progressively the share of electricity from non-conventional sources would need to be increased as prescribed by State Electricity Regulatory Commissions. Such purchase by distribution companies shall be through competitive bidding process. Considering the fact that it will take some time before non-conventional technologies compete, in terms of cost, with conventional sources, the Commission may determine an appropriate differential in prices to promote these technologies.

Industries in which both process heat and electricity are needed are well suited for cogeneration of electricity. A significant potential for cogeneration exists in the country, particularly in the sugar industry. SERCs may promote arrangements between the co-generator and the concerned distribution licensee for purchase of surplus power from such plants. Cogeneration system also needs to be encouraged in the overall interest of energy efficiency and also grid stability.

➢ NATIONAL ACTION PLAN ON CLIMATE CHANGE (2008)

The NAPCC has suggested the following enhancements to the policy regulatory framework for RE.

A dynamic minimum renewable purchase standard (DMRPS) may be set, with escalation each year till a pre-defined level is reached, at which time the requirements may be revisited. It is suggested that starting 2009-10, the national renewables standard (excluding hydropower with storage capacity in excess of daily peaking capacity, or based on agriculture based renewable sources that are used for human food) may be set at 5% of total grids purchase, to increase by 1% each year for 10 years. SERCs may set higher percentages than this minimum at each point in time.

(ii) Central and state governments may set up a verification mechanism to ensure that the renewable based power is actually procured as per the applicable standard (DMRPS or SERC specified). Appropriate authorities may also issue certificates that procure renewable based power in excess of the national standard. Such certificates may be tradeable, to enable utilities falling short to meet their renewables standard obligations. In the event of some utilities still falling short, penalties as may be allowed under the Electricity Act 2003 and rules there under may be considered.

(iii) Procurement of renewables based power by the SEBs/other power utilities should, in so far as the applicable renewables standard (DMRPS or SERC specified) is concerned, be based on competitive bidding, without regard to scheduling, or the tariffs of conventional power (however determined). Further, renewables based power may, over and above the applicable renewables standard, be enabled to compete with conventional generation on equal basis (whether bid tariffs or cost-plus tariffs), without regard to scheduling (i.e. renewables based power supply above the renewables standard should be considered as displacing the marginal conventional peaking capacity). All else being equal, in such cases, the renewables based power should be preferred to the competing conventional power.

➢ JAWAHARLAL NEHRU NATIONAL SOLAR MISSION (2010)

The Jawaharlal Nehru National Solar Mission was launched on the 11th January, 2010. The Mission has set the ambitious target of deploying 20,000 MW of grid connected solar power by 2022. The mission aims at reducing the cost of solar power in the country and to achieve grid parity at soon as possible through among other things, long term policy and large scale deployment. The mission has been very successful in kick starting the solar revolution on a large scale in India. The present installed capacity of solar stands at roughly 3743 MW. Given the success of capturing the global cost reduction in solar PV through the instrument of reverse competitive bidding for cost discovery, there is now emphasis on possible revamping of the 2022 solar target upwards. PV tariffs have come down from Rs 17.91/kWh to around Rs. 6/kWh in a period of 4-5 years. This has resulted in the possibility of a five-fold increase in the national target from 20 GW to 100 GW[1].

➢ NATIONAL CLEAN ENERGY FUND (2010)

By levying a tax of Rs 50/ton on coal consumed within the country, the NCEF was created in 2010 mainly for developing and deployment of clean energy in the country. In 2014, this levy was raised to Rs 100/ton, and then in the 2015 budget, this levy has been further raised to Rs 200/ton which will result in an annual fund of ~ Rs 14,000 crore. This fund can go a long way in accelerating the growth of clean energy.

[1] http://www.pv-tech.org/news/india_to_boost_national_target_to_100gw_by_2022

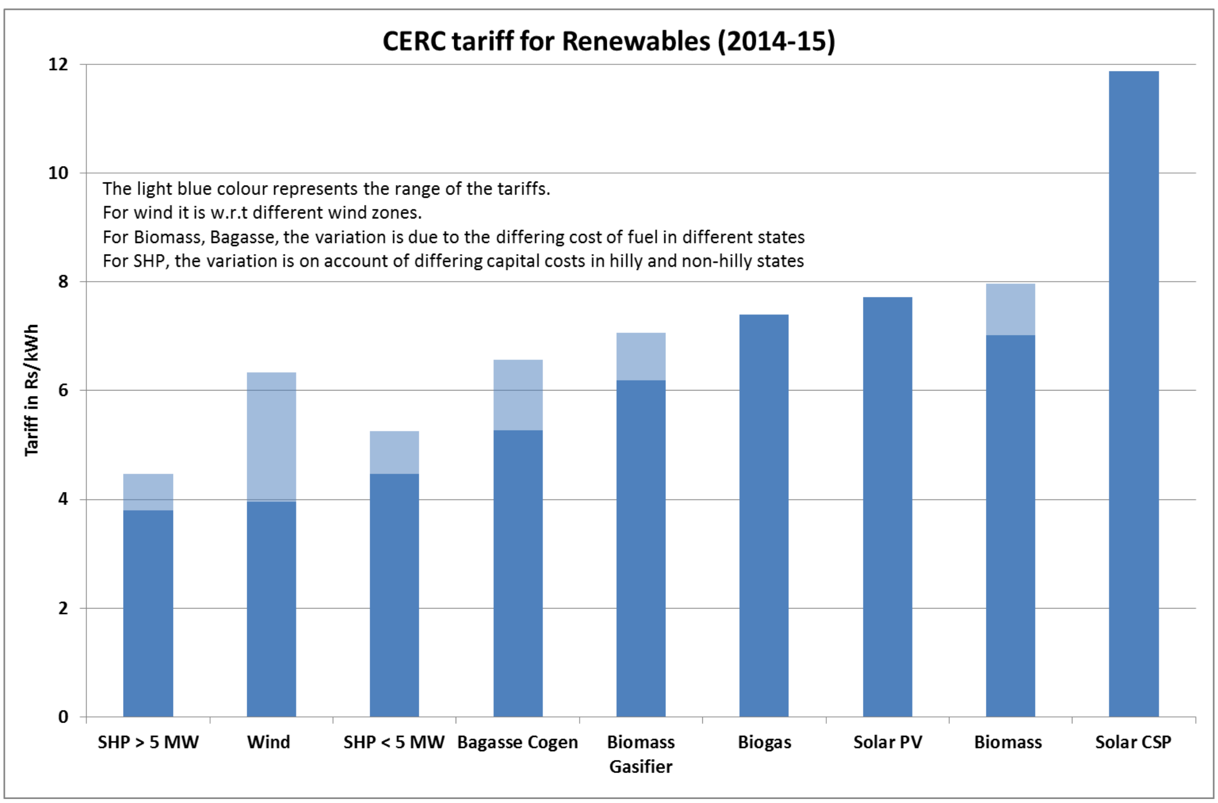
KEY REGULATORY INSTRUMENTS

Based on the above legal and policy provisions, three key regulatory instruments have played a major role in advancing renewables. These are

a. Preferential Feed in tariffs (FiT)
b. Renewable Purchase Obligation (RPO)
c. Renewable Energy Certificates (REC)

➢ PREFERENTIAL FEED IN TARIFFS (FIT)

Most ERCs have put in place technology specific FiTs for their states as is mandated by the E-Act. These tariffs are developed in a public consultative process after giving due consideration to views from all stakeholders. After considering all relevant fixed, operating & fuel costs and the normative generation from each resource, a levelized tariff is formulated with due consideration for return on equity, generally in the range of 16%. Such tariffs once decided hold over the length of the PPA (~ 20 yrs). Tariffs are revised each year for new upcoming projects. The table below provides a gist of the FiTs for various technologies for 2014-15 as announced by CERC.

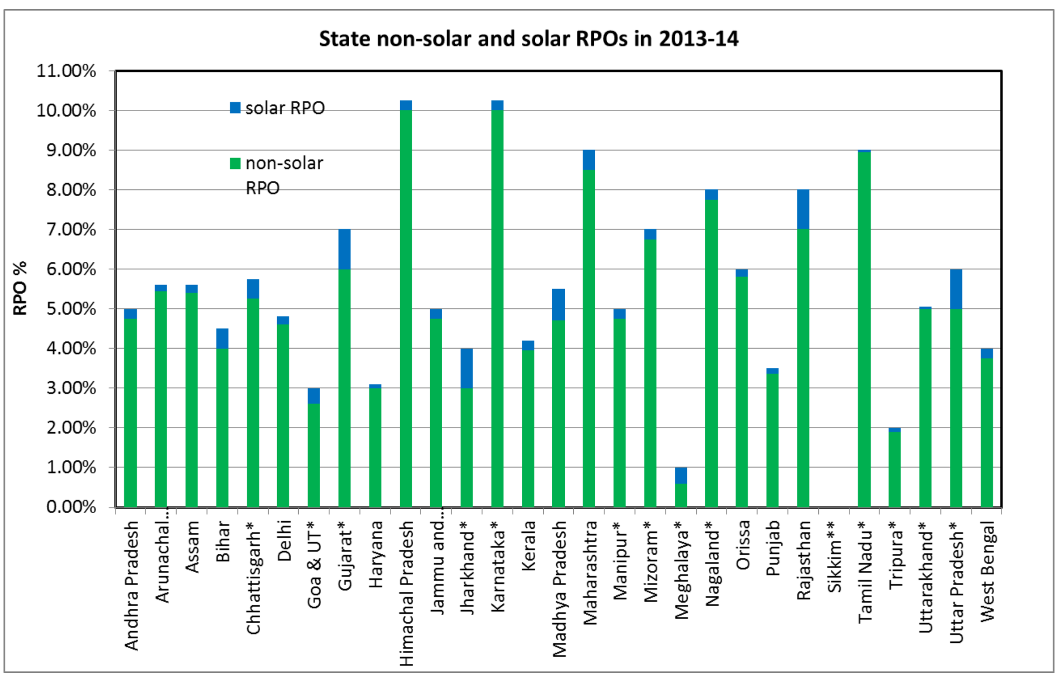


➢ RENEWABLE PURCHASE OBLIGATION (RPO)

The National Action Plan on Climate Change (NAPCC) has set an ambitious guiding target of 15% renewables by 2020. Such a move is largely in the right direction given the multitude of benefits (energy access, higher energy security, lower foreign exchange requirements, price stability, least impact on local and global environment etc) that RE offers in the country. To achieve such a national target, SERCs are required to set RE targets for obligated entities in their states through the instrument of RPOs as mandated by section 86 (1) (e) of Electricity Act 2003. The existing policy-legal framework lays down some guiding principles for ERCs while considering RPOs. Important among them are setting of a minimum RE target (including a separate one for solar) by taking into account the renewable resource potential within the State and the resulting retail tariff impact. Such RPO targets should be gradually increasing and be applicable not only to Utilities but also to Captive (CPP) and Open Access (OA) consumers.

Largely based on these principles, most states (28 out of 29 states in the country) have RPO regulations in place which vary widely from 1% to slightly over 10%. A closer look at the RPO regulations of six re-rich states (Gujarat, Rajasthan, Maharashtra, Tamil Nadu, Karnataka, Andhra Pradesh which account for more than 85% of the installed capacity) show that all of them have minimum RPO specified including a solar specific RPO, their RPO applies to OA/CPP consumers and allows for the REC as an instrument to comply RPO. All these states also have a RPO compliance and verification mechanism coupled with penal provisions in place.

The table and the graph below capture the solar and non-solar RPOs in each state.



➢ RENEWABLE ENERGY CERTIFICATE MECHANISM

The REC mechanism was instituted to overcome the geographical resource variation as a way towards RPO compliance. There are presently two types of RECs namely, non-solar and solar RECs. The renewable electricity generated under this mechanism is split into two parts: the grey electricity and the green environmental attribute (REC). The mechanism essentially involves issuance of RECs by a central agency (based on actual generation) to registered RE generators who can trade these certificates to obligated entities (utilities/CPP/OA) who need to fulfill their RPO. The grey electricity is treated as the same way as conventional power and the generator is assumed to be compensated at the pooled cost of power purchase (APPC)[2] of the buying utility. The RECs are to be compensated at a market determined price by trading these on the power exchanges within a price band (a floor and forbearance price) determined by the CERC which ensures sufficient compensation to the generator.

REC price band: The non-solar forbearance price is specified as the highest difference between the costs of generation (CERC RE Tariff) and the APPC considering all non-solar RE technologies for all states. In essence, Forbearance Price = Maximum (Preferential Tariff – APPC). For the solar forbearance price, a similar approach is used. The lower trading bound is called the floor price and is decided keeping in mind that RE generators should be able to at least recover their costs at this REC compensation. The difference (gap in Rs/kWh) between the project viability requirement (defined as the minimum price necessary to recover costs[3]) and APPC is arranged in ascending order as a supply curve for different RE technologies across all states. The expected generation (MUs) from each RE technology in a particular state is mapped with the respective difference (supply curve) between the project viability requirement and APPC. The floor price is thereafter discovered as the price (difference between feasibility requirement and APPC) at which a specified target RE generation[4] is realized on the generation curve. In essence, Floor Price = Market Equilibrium Price (Minimum requirement for Project Viability of RE technologies – APPC). However unlike the non-solar methodology which specified the market equilibrium price, the solar floor price is specified as the highest difference between the minimum requirement for project viability of Solar PV/Thermal and respective state APPC.

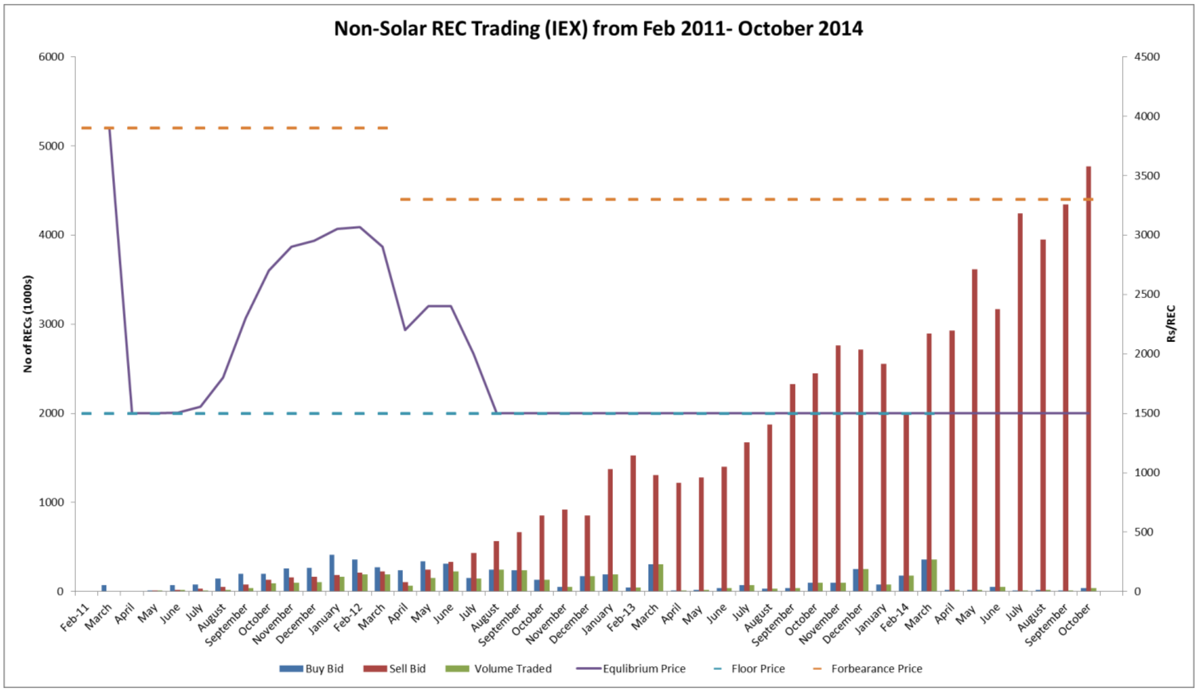
The figures below capture the essence of the non-solar and solar REC trade over the last three years. It shows traded volume, buy and sell bids and the market clearing price. We can also see that the REC price was revised once at the end of the first year and the new revised floor and forbearance were fixed for the next five years, from 2012-2017. While the demand for REC picked up through the FY 2011-12, resulting in higher discovered prices, the price has remained at the floor for just over two years due to

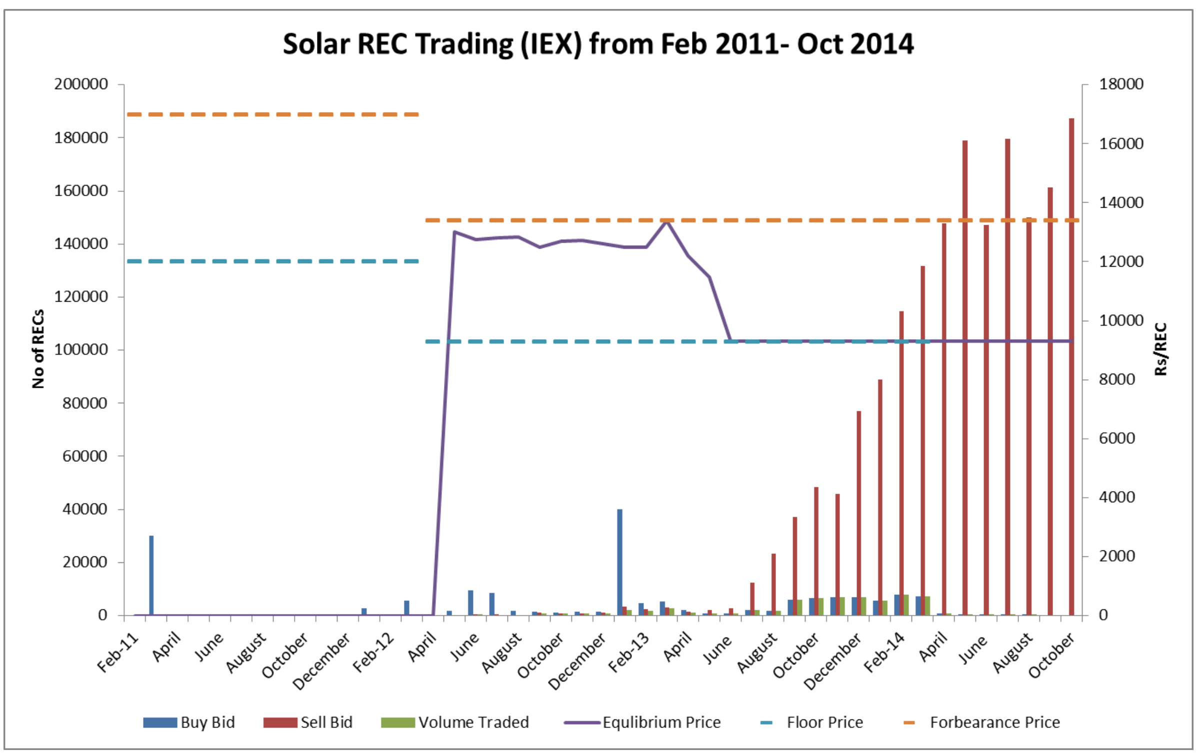
[2]"Pooled Cost of Purchase means the weighted average pooled price at which the distribution licensee has purchased the electricity including cost of self generation, if any, in the previous year from all the energy suppliers long-term and short-term, but excluding those based on renewable energy sources, as the case may be."

[3] Viability requirement shall cover loan repayment & interest charges, O&M expenses and fuel expenses in case of Biomass and Cogeneration.

[4] In this case it is assumed to be 70000 MUs (average of renewable energy target as per NAPCC and MNRE vision Report 2010 for non-solar)

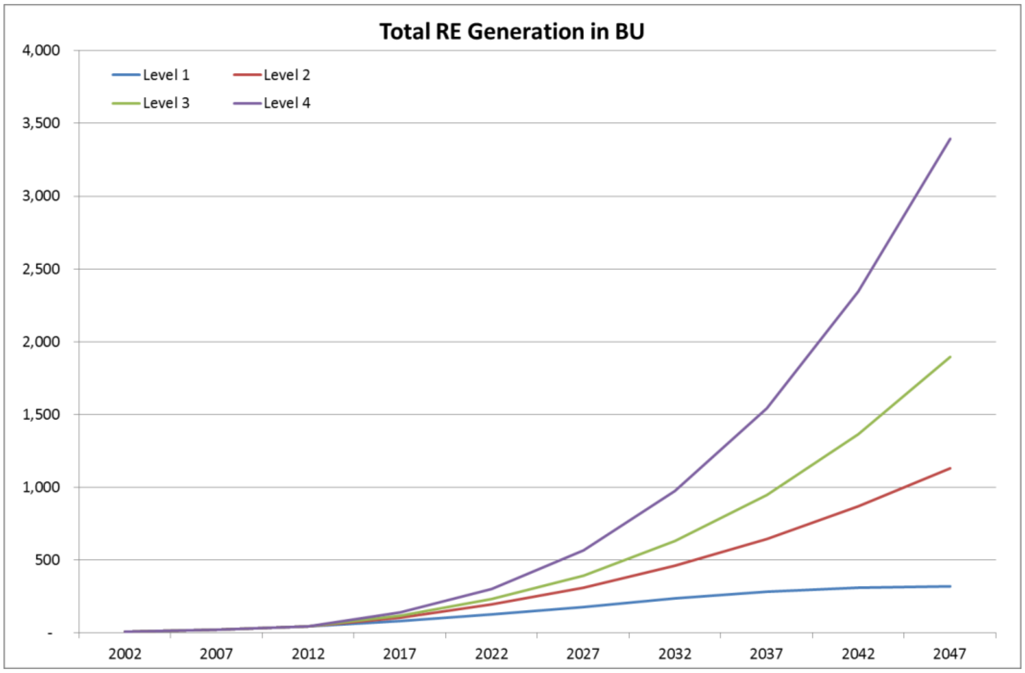
poor demand for RECs resulting from a variety of reasons. The REC mechanism presently (as of Nov 2014) has 1021 projects with a total capacity of 4588 MW registered under it.

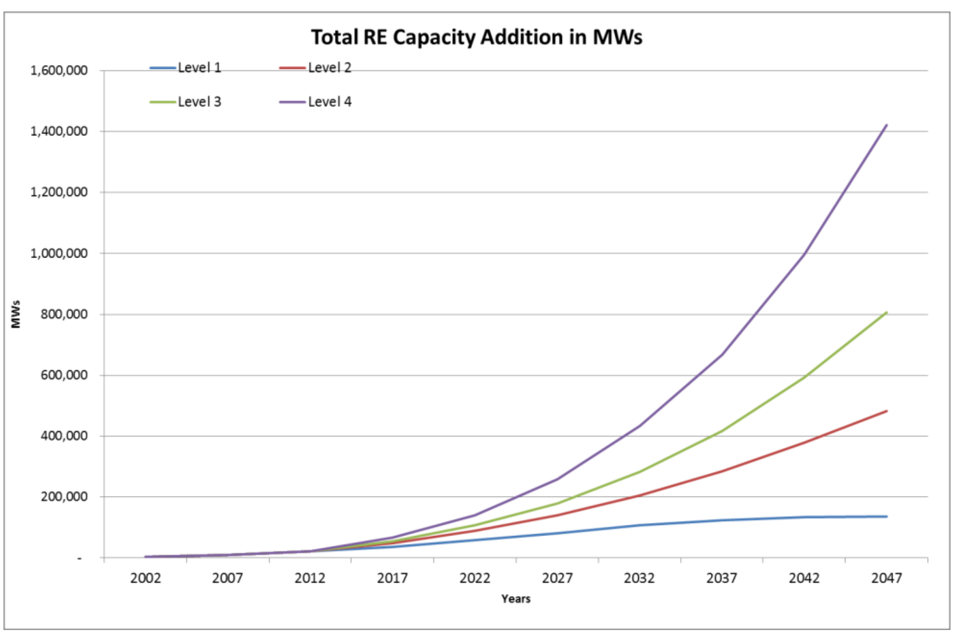




3. SCENARIOS FOR WIND, SOLAR AND SMALL HYDRO POWER

This section details out the scenarios developed for wind, solar and small hydro power from 2012 to 2047. The two figures below capture the aggregate capacity addition and resultant electricity generation from these renewable resources from levels 1-4. The cumulative aggregate growth rate for capacity addition and electricity generation increases from roughly 5.5% in level 1 (from 2012-47) to a high of 13% in level 4. The latter assumes achievement of the 175 GW target (2022) and builds on it.





3.1 OFFSHORE WIND POWER

Presently India does not have any offshore wind power plants in operation. However India has an extensive coastline of 7500 sq. kms which is indicative of a large potential offshore resource. Offshore wind is growing at a fast pace especially in Europe and the EU already has close to 5 GW of installed capacity operational. With next generation turbines having capacities greater than 3 MW, better scheduling and prediction technology offshore wind could play a large role within the RE sector in India.

3.1.1 SECTOR OVERVIEW

Offshore wind power is a potential source of electricity generation primarily due to better quality wind resources along with the absence of land constraints. However as of today the costs of installation and operation are almost twice as more than onshore wind power. These costs are set to decline with technological improvement including increased hub heights, turbine capacity, CUFs and floating turbines. MNRE has come out with a draft offshore wind policy in 2013. The policy suggests setting up of 2 GW of capacity in the southern coast to begin with. While a detailed resource potential for the country is yet to be done, some studies suggest that it could be in the range of 350 - 500 GW[i] which indicates that the resource availability is not a constraint for wind power development. Higher costs, transmission infrastructure and reliable integration of variable generation would be key factors that may limit the uptake of offshore wind power in the future.

3.1.2 DRIVERS

- Draft offshore policy made public in 2013.
- Improved turbine size and capacity utilization factor due to better and more stable wind resource
- Significant untapped potential with no competing land use factor

3.1.3 ASSUMPTIONS

- Life of turbines: 25 years
- Gradual improvement in fleet CUF from 33% (2022) to 37.5% (2047) due to increasing hub heights and rotor sizes.
- Significant cost reduction in future.
- Offshore wind farms established in inter-tidal, offshore and deep sea zones

3.1.4 TRAJECTORIES:

Level 1:

Level 1 assumes that offshore wind takes off very slowly due to higher cost and other barriers especially with regard to regulatory and associated clearances etc. Installations of identified capacity of 1.5 GW along the southern coast are delayed and completed after 2032. 2.5 GW by the year 2037.Capacity rises to 4 GW in 2047 from 0 GW in 2012 and the electricity generated is 13 TWh.

Level 2:

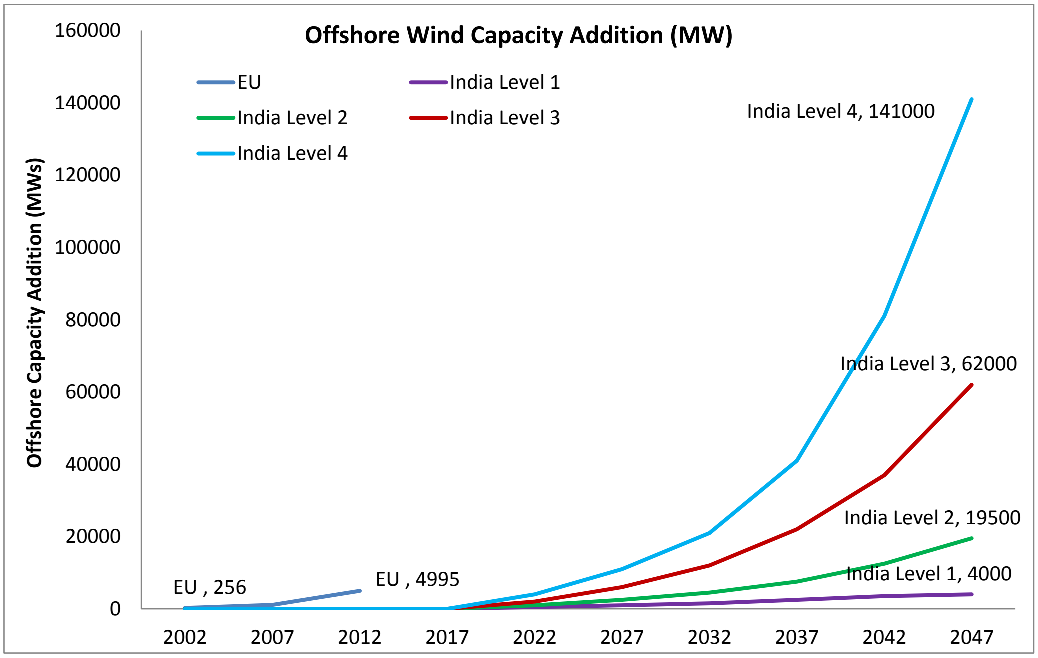
Level 2 assumes that the MNRE policy target of 2 GW is achieved by 2025. Without any further improvement in technology and offshore wind potential assessment the sector witnesses a gradual growth in capacity addition reaching 19.5 GW by 2047. The corresponding electricity generation in 2047 would be 64.3 TWh.

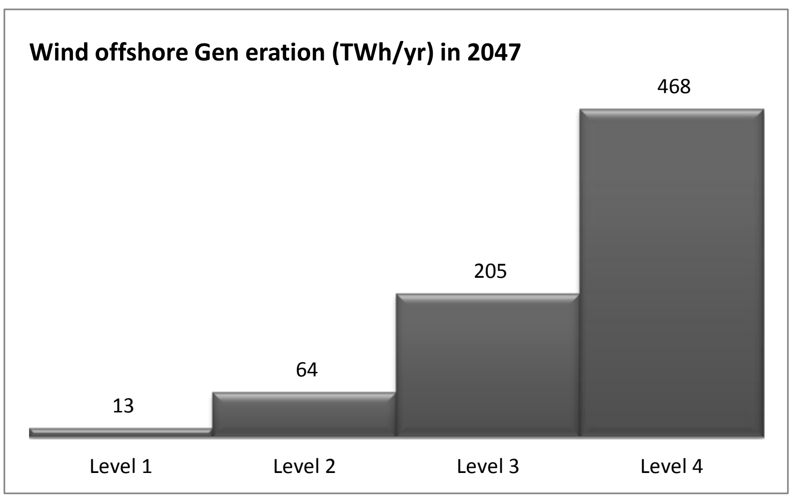
Level 3:

Level 3 assumes that with the improvement in potential offshore site identification and cost reductions India would gradually built up its offshore wind capacity to 2 GW in 2022meeting MNRE offshore wind policy targets, 35 GW by 2040 and 62 GW by 2047. This results in roughly 205.2TWh of generation in 2047. Significant investments would be needed in the transmission and evacuation systems.

Level 4:

Level 4 assumes that offshore wind power does not face any economic or physical constraints and hence sees a rapid growth in capacity addition. Under the level 4 assumptions, India would follow an aggressive strategy towards construction and operation of offshore wind farms leading to generation of 141 GW by 2047**.** The resulting generation would be roughly 468.5TWh**.**


Offshore Wind Capacity Addition (MW)
EU
India Level 1
India Level 2
India Level 3
India Level 4
Offshore Capacity Addition (MWs)
160000
140000
120000
100000
80000
60000
40000
20000
0
India Level 4, 141000
India Level 3, 62000
India Level 2, 19500
India Level 1, 4000
EU , 256
EU , 4995
2002
2007
2012
2017
2022
2027
2032
2037
2042
2047


Wind offshore Gen eration (TWh/yr) in 2047
13
64
205
468
Level 1
Level 2
Level 3
Level 4

3.2 ONSHORE WIND POWER

India was an early adopter of wind power and has been active in this sector since the early 90's. We can see three distinct phases of the sector's development in the country, 1992-2002 (1587 MW addition) where in the sector was mainly driven by subsidies (capital, state sales tax and 100% accelerated depreciation) and the third party sale (open access)/captive market based on incentives like wheeling and banking. The second phase (2002-07; 5466 MW addition) was given a push by the introduction of the RPOs and FiTs and finally the last five years (2007-12; 10259 MW addition) was further incentivized by the introduction of GBI and RECs leading to the emergence of IPPs. The wind industry in India has a fairly large number of turbine manufacturers (with turbines being exported as well), developers and various service providers. As of 2013, according to CWET, the country has roughly 20 wind turbine manufacturers with an availability of roughly 50 turbine models[ii] .As of 2012; the accelerated depreciation benefit has been withdrawn.

3.2.1 SECTOR OVERVIEW

With 23444 MW of wind power installed in the country as on 31st April 2015, it constitutes the mainstay of renewable power in the country, contributing to 65.5% of the total RE capacity most of which is located in the southern and western high solar resource states of Tamil Nadu, Karnataka, Maharashtra, Gujarat and Rajasthan. The target for grid connected wind power under the 12th plan is set for an additional 15 GW. With regard to wind power, while the recently revised official figures stands at 102 GW, various studies point out that the actual potential could be anywhere between 500 - 1000 GW[iii]which indicates that the wind resource availability is not a constraint for wind power development. Availability of land, transmission infrastructure and reliable integration of variable generation would be key factors that may limit the uptake of wind power in the future.

3.2.2 DRIVERS

- Significant policy push for uptake of wind power in the country coupled with steadily increasing RPOs.
- Wind power for captive use of third party sale under open access due to cost competitiveness with consumer tariffs.
- Increased focus on energy security and cost reduction in wind power.

3.2.3 ASSUMPTIONS

- Life of turbines: 25 years
- Gradual improvement in fleet CUF from 20% (2007) to 24.5% (2027) to 29%(2047) due to increasing hub heights and rotor sizes.

3.2.4 TRAJECTORIES

Level 1:

Level 1 assumes that wind power capacity addition would be significantly slower than that prescribed under the 12th Plan or as required to meet guiding NAPCC targets. Reliably integrating variable generation would remain a challenge. The 12th plan addition would only be around 8.5 GW assuming the same annual addition as in 2012-13. 13th Plan addition would be slightly higher at 10 GW. Capacity would increase to roughly 35.8 GW by 2022, and increase to about 67 GW by 2047 from 17.35 GW in 2012**.** The electricity generated in 2047 would rise to 161.8 TWh from 32.2 TWh in 2012.

Level 2:

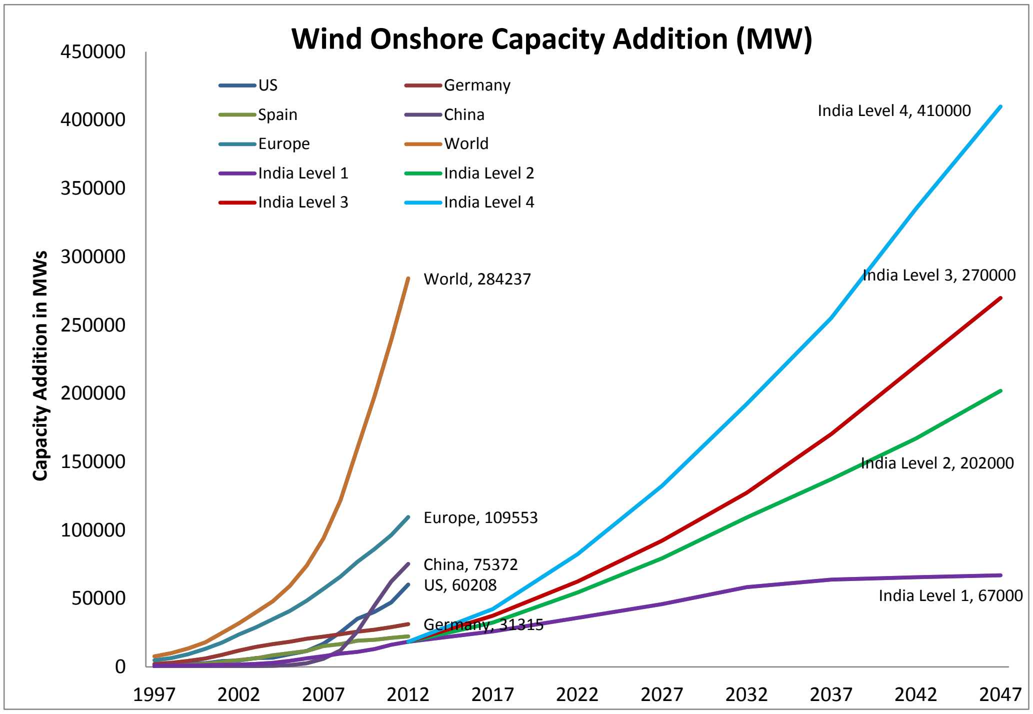
Level 2 assumes that the capacity addition would follow the 12th and 13th Plan trajectory. By 2017, capacity would reach close to 32.25 GW in line with the 12th Plan projections, while by 2022 it would reach 54.35 GW**.** Capacity addition increases strongly thereafter culminating in a cumulative capacity of 202 GW by 2047 and the corresponding electricity generation would be 495.3 TWh. This implies a 35 year CAGR of 7.26% (2007-2047). Additional investments to strengthen transmission and evacuation systems would be put in place. Development of a Green Transmission Corridor[iv] has already been sanctioned very recently.

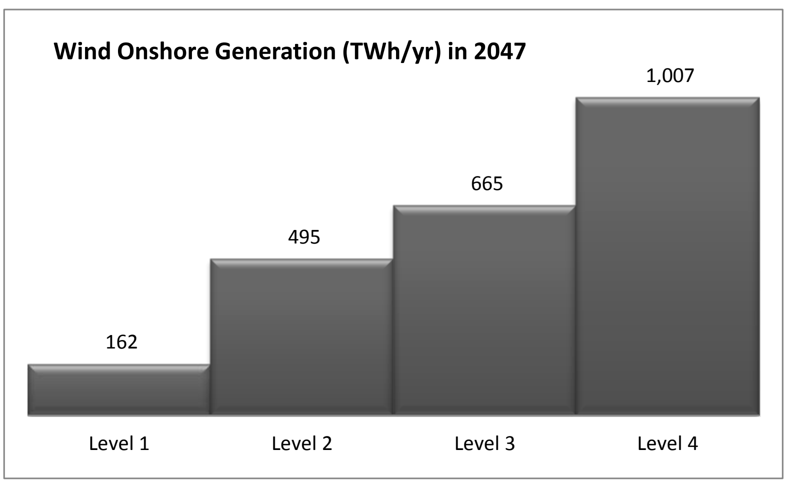
Level 3:

Level 3 assumes a capacity addition in this scenario to be slightly higher than the 12/13th plan requirements resulting in 62.35 GW in 2022. However this would still not be enough to meet the NAPCC targets of 2020. It would cross the 100 GW mark just before 2030 and finally reach 270 GW by 2047. The resulting generation would be to the tune of 665.3TWh. Significant repowering efforts would be undertaken in this level and beyond.

Level 4:

In this scenario, there is absolutely no barrier (economic, social or technical) to the growth of onshore wind power. There is a sharp drop in wind prices coupled with significant increases in fossil fuel prices, especially coal. Fossil fuel externalities are priced. Smart grids, Demand response and storage is in place. Similarly, forecasting/dispatch and reliable grid integration is taken care of. Energy security is consciously factored in energy planning and land is not a constraint. In this level, capacity increases to 82 GW (172 TWh) by 2022in line with the NAPCC requirement of 15% by 2020 (excluding large hydro). By 2040 it reaches ~300 GW and by 2047 a high of 410 GW. The corresponding generation in 2047 is 1007 TWh. In this scenario, we achieve a higher capacity than the 60 GW envisaged for 2022 by MNRE.


Wind Onshore Capacity Addition (MW)
Capacity Addition in MWs
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
1997
2002
2007
2012
2017
2022
2027
2032
2037
2042
2047
US
Germany
Spain
China
Europe
World
India Level 1
India Level 2
India Level 3
India Level 4
India Level 4, 410000
World, 284237
India Level 3, 270000
India Level 2, 202000
Europe, 109553
China, 75372
US, 60208
India Level 1, 67000
Germany, 31315


Wind Onshore Generation (TWh/yr) in 2047
162
495
665
1,007
Level 1
Level 2
Level 3
Level 4

3.3 SOLAR PV POWER

While solar resource was never a bottleneck for development of this sector in India, it was the very high price of solar PV power that prohibited solar PV from being considered a serious contender in the supply mix in India. However with the launch of the Jawaharlal Nehru National Solar Mission under the NAPCC, the solar PV sector got a kick start on a large scale in India. However it was the much lower price of solar power (presently in the range of Rs 6.5-8/kWh) that was discovered through the process of competitive bidding and the predictions of further cost reduction that has allowed solar PV to be considered as one of the mainstay supply options in the coming years.

3.3.1 SECTION OVERVIEW

With 941 MW installed in the country as of 31st March 2012, Solar PV was possibly the smallest in terms of supply from any one resource. The present capacity is 2517 MW[v] (May 2014) most of which is located in the states of western high solar resource states of Gujarat and Rajasthan. The target for grid connected solar power (PV and CSP) under the JNNSM is set at 20 GW by 2022[vi]. However given the present price advantage of PV over CSP it looks likely that a significant share of the 20 GW would be done by PV. Going beyond the JNNSM, the National Tariff Policy was amended in 2011 to have a separate solar RPO for all obligated entities in the country. This is expected to begin with 0.25% in 2012 and increase to 3% in 2022[vii] . According to MNRE, this translates to a need of roughly 34,000 MW in 2022[viii]. Most of the solar PV plants are based on either c-Si or thin film technology.

3.3.2 DRIVERS

- Significant push for solar power in the country under the JNNSM and state policies coupled with steadily increasing RPOs. Target of 3% solar power (PV and CSP) as per National Tariff Policy.
- Low price discovery from competitive bidding and movement towards grid parity. Increasing cost competitiveness with consumer tariffs.
- Low gestation period and development of solar parks in several states facilitating land and related infrastructure development.
- Increased focus on energy security.

3.3.3 ASSUMPTIONS

- Life of project: 25 years
- Gradual improvement in average fleet CUF from 19% (2012) to 20.5% (2047) due to increased use of tracking systems. By 2032, 25% of new installations are with tracking systems while by 2047, nearly 40% of new installations are with tracking.

3.3.4 TRAJECTORIES

Level 1:

Level 1 assumes that solar PV capacity addition would be significantly slower than that prescribed under the JNNSM or as required under the NTP. Costs of solar power would continue to he high while carbon/externalities of power generation would continue to remain un-priced. Similarly reliably integrating variable generation remains a challenge. Capacity would increase to roughly 11 GW by 2022**,** peak at 37 GW in 2047 from 941 MW in 2012. The corresponding generation would rise to 65.4 TWh from 1.6 TWh in 2012.

Level 2:

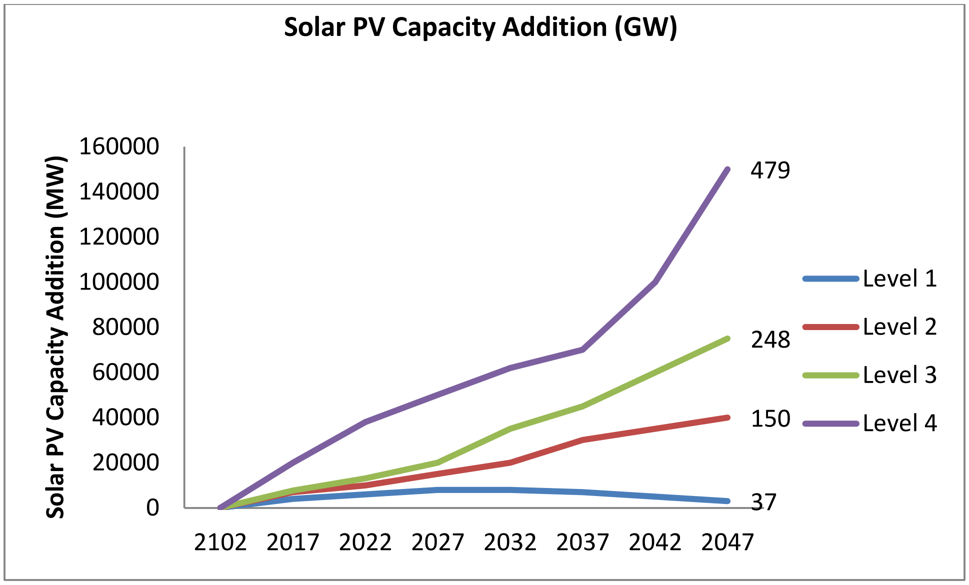
Level 2 assumes that the capacity addition would follow the JNNSM trajectory. By 2017, capacity would reach close to 8 GW **i**n line with the 12th Plan projections, while by 2022 it would reach 17.9 GW. Capacity addition increases strongly thereafter culminating in a cumulative capacity of 150 GW by 2047**.** The electricity generated in 2047 would be 269.6 TWh. This implies a 35 year CAGR of 16% (2012-2047)**.**

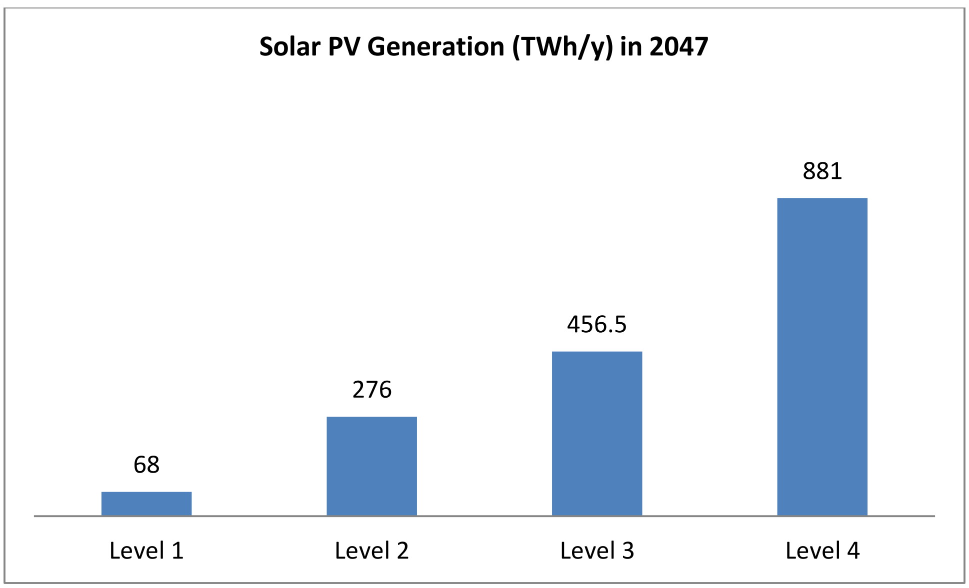
Level 3:

Level 3 assumes steady drop in solar PV prices and the marginal increase in fossil fuels prices thus making solar PV economically competitive. Capacity addition in this scenario would be slightly higher than the JNNSM resulting **in** 21.5 GW in 2022. It would cross the 100 GW mark by 2035 and finally reach 248 GW by 2047. The resulting generation would be to the tune of 456.5TWh.

Level 4:

In this scenario, there is absolutely no barrier (economic, social or technical) to the growth of solar PV. There is a sharp drop in solar and wind prices coupled with significant increases in fossil fuel prices, especially coal. Fossil fuel externalities are priced. Smart grids, Demand response and storage are in place. Similarly, forecasting/dispatch and reliable grid integration is taken care of. Energy security is consciously factored in energy planning and land is not a constraint. In this level, capacity increases to 58.94 GW 2022 in line with the RPO requirement of 3% as directed by the NTP, as well as the MNRE target. By 2042 it reaches 340 GW and by 2047 a high of 479 GW. The resulting generation in 2047 will be 865.2 TWh.


Solar PV Capacity Addition (GW)
Solar PV Capacity Addition (MW)
160000
140000
120000
100000
80000
60000
40000
20000
0
2102
2017
2022
2027
2032
2037
2042
2047
479
248
150
37
Level 1
Level 2
Level 3
Level 4


Solar PV Generation (TWh/y) in 2047
68
276
456.5
881
Level 1
Level 2
Level 3
Level 4

3.4 SOLAR CSP POWER

Concentrating Solar Power is a source of utility large scale electricity generation. Unlike PV, CSP uses only the Direct Normal Radiation fraction of the solar radiation and uses solar heat for steam generation and finally electricity production. This technology has been tried and tested in many parts of the world but relatively new to India. It is most widely used in Spain and USA as of now. The total technical potential of CSP in India (with land use limited to barren areas) according to one study is 2324 TWh/yr[ix]. According to another it is much higher at 10,928 TWh/yr[x]. Like PV, the resource potential is unlikely to be the limiting factor for CSP; it would more likely be due to technology and price development and the use of water for cooling.

3.4.1 SECTOR OVERVIEW

It was the JNNSM that kick started the CSP program in India. Under the phase 1 (2010-13) of the mission, 50% of the allotted capacity was earmarked for CSP. A total of 470 MW were bid out. The first large scale plant of 50 MW was commissioned very recently in the country. Phase 2 of the mission (2013-17) has earmarked roughly 30% of the capacity for CSP. Going beyond the JNNSM, the National Tariff Policy was amended in 2011 to have a separate solar RPO (PV+CSP) for all obligated entities in the country. This is expected to begin with 0.25% in 2012 and increase to 3% in 2022. According to MNRE, this translates to a need of roughly 34,000 MW in 2022. Additionally the SECI would be setting up pilot CSP plants to test out various possibilities in India, namely hybrid and storage projects. While solar thermal electricity is relatively new in India, given the potential it is expected to gain pace in deployment. With reduction in cost of technology and the storage benefit, CSP can contribute a significant portion to the RE share. Since CSP competes with PV for same high solar resource sites, there could be some trade-offs with regard technology choice. While CSP is presently costlier than PV, its ability for storage and supporting the grid with ancillary services could prove very valuable. Similarly CSP also allows the possibility of hybrid plants with natural gas or coal.

3.4.2 DRIVERS

- Significant push for solar power in the country under the JNNSM and state policies coupled with steadily increasing RPOs. Target of 3% solar power (PV and CSP) as per National Tariff Policy.
- Development of solar parks in several states facilitating land and related infrastructure development.
- Ability to have thermal storage thereby increasing CUF and dispatch ability, provision of peaking power and balancing if needed.

3.4.3 ASSUMPTIONS

- Life of project: 25 years
- Gradual improvement in average fleet CUF from 22% (2012) to 46% (2047) due to increasing use of storage based systems. By 2027, 75% of the new CSP installations in all levels are with 8 hour storage, while this number steadily increases to 100% by 2047.

3.4.4 TRAJECTORIES

Level 1:

Level 1 assumes that only 1 GW would be operational in the next 5 years (mainly due to higher costs) beyond which there will be slight increase in generation capacity reaching a maximum of 10.5 GW by 2045. Deployment increases slowly till 2032 after which it starts reducing. After 2042 there is no additional deployment. The cumulative capacity in 2047 would reach 9.5 GW from 0 GW in 2012 and generation would be 35 TWh in 2047.

Level 2:

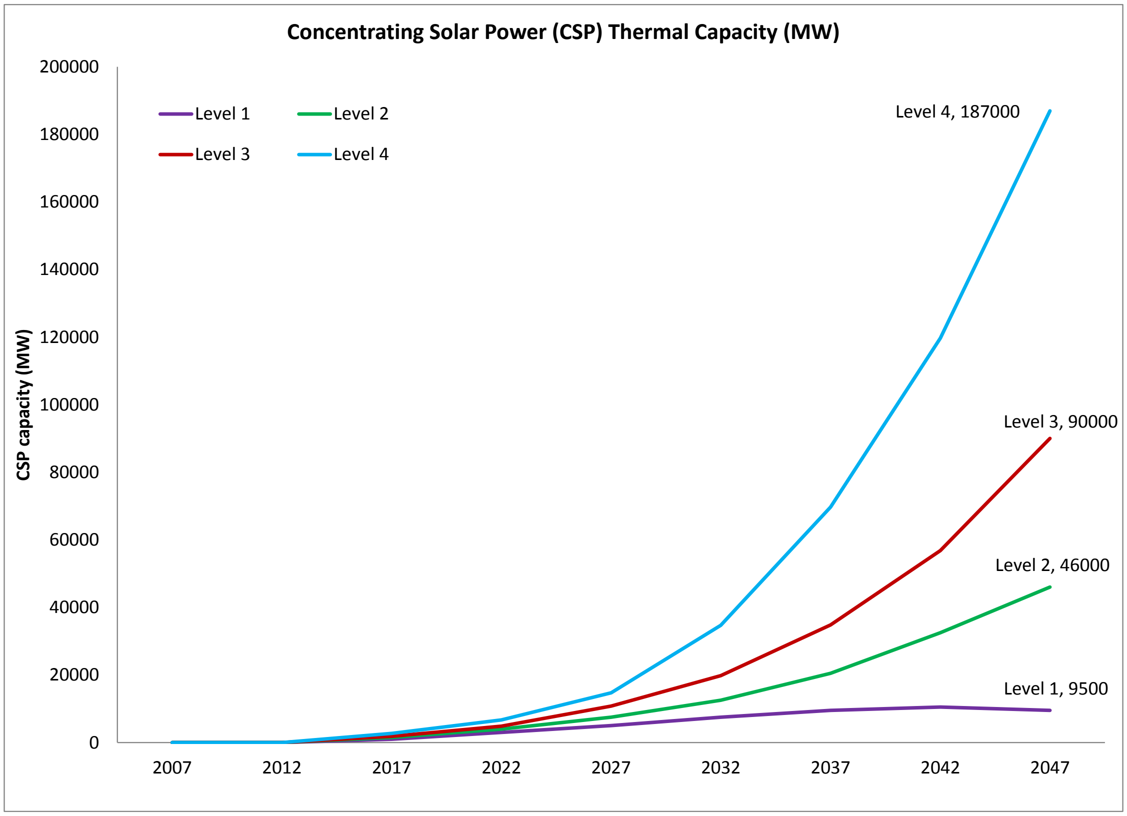
Level 2 assumes that there is slow but consistent growth in capacity addition of CSP. It reaches 4 GW by 2022, i.e. 20% of the total JNNSM target for grid connected solar. The final capacity in this level in year 2047 is 46 GW resulting in a generation of 181.2TWh.

Level 3:

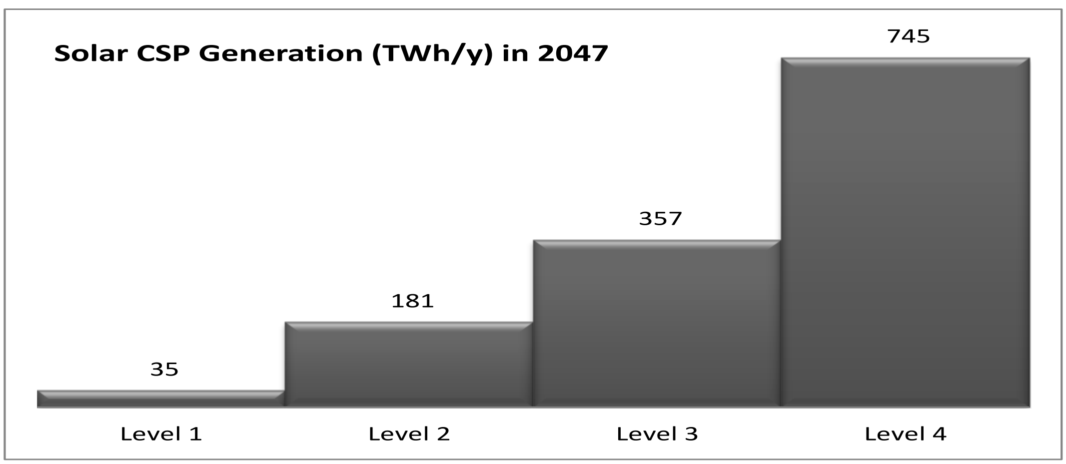
Level 3 assumes that CSP costs come down significantly and that there are no limitations on plant size etc. Improved transmission and HVDC lines together, result in faster capacity addition. 10.8 GW is reached by 2027 increasing thrice to 34.82 GW in the next ten years and culminating in 90 GW by 2047. Generation by 2047 reaches 357 TWh.

Level 4:

Solar CSP becomes one of the prime sources of electricity generation; extended storage facility helps CSP reach maximum potential. Costs of solar system and storage fall as higher temperature technologies are introduced. Supply grows rapidly meeting the NAPCC targets by 2020 resulting in a capacity of 6.7 GW by 2022 and 187 GW in 2047, a CAGR of 15% over 30 years. Generation by 2047 reaches 746TWh.



Concentrating Solar Power (CSP) Thermal Capacity (MW)
CSP capacity (MW)
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
2007
2012
2017
2022
2027
2032
2037
2042
2047
Level 1
Level 2
Level 3
Level 4
Level 4, 187000
Level 3, 90000
Level 2, 46000
Level 1, 9500



Solar CSP Generation (TWh/y) in 2047
35
181
357
745
Level 1
Level 2
Level 3
Level 4

3.5 DISTRIBUTED SOLAR PV

3.5.1 SECTION OVERVIEW

Substantial growth in electricity demand in cities and towns is adding pressure on the electricity utilities to meet their peak electricity demand. Some of this unmet demand is currently being met with the use of diesel generator sets. With an average of 300 sunny days and high solar insolation, distributed solar PV has the ability to play an important role in the coming years. Distributed Solar PV systems can reduce the load on utilities by reducing the electricity peaks, reducing transmission and distribution losses and improving productivity. Distributed solar PV (particularly the rooftop segment) is expected to grow significantly in the coming years due to increase in economic viability for certain consumer segments (commercial, industrial and high-use residential) in particular geographical areas in India. While many states have already put in place favourable net metering policies, some state ERC regulations support rooftop projects through the feed in tariff route. By some estimates, India could install 3 - 5 GW of distributed solar in the next three - five years. Increased clarity on technical inter-connection, safety and metering standards would pave the way for faster deployment.

The JNNSM launched in 2010 has set an ambitious target of deploying 2 GW of off-gird solar power by 2022. MNRE has launched a pilot scheme for promotion of large area grid-connected roof top solar PV projects in cities. It is primarily targeted at cutting the dependence on diesel generators for backup in commercial establishments. A 30% subsidy on the system cost is provided through Solar Energy Corporation of India (SECI).

3.5.2 DRIVERS

- Economic viability of distributed solar (grid parity for the consumer) in various states and for certain consumer categories.
- Significant push for solar power in the country under the JNNSM.
- Policies supporting distributed generation (net metering, roof lease)
- Low gestation period.
- Increased focus on energy security.

3.5.3 ASSUMPTIONS

- Life of project: 20 years
- Increase in average size of system per HH from 1 kW to 3 kW over time.
- Distributed PV includes rooftop and ground based installations.

3.5.4 TRAJECTORIES

Level 1:

Level 1 assumes that there is a very little improvement in distributed PV installations in the residential sector and negligible growth in the industrial and commercial sectors. The penetration rate still remains low of 0.6% HHs in 2047 as compare to 0.01% in 2012. The cumulative capacity rises to 9.3 GW in 2047 from 0.03 GW in 2012. The electricity generated would also increase to 15.5 TWh in 2047 from 0 TWh in 2012. Lack of clarity on technical and safety standards coupled with weak policy regulatory framework hampers growth.

Level 2:

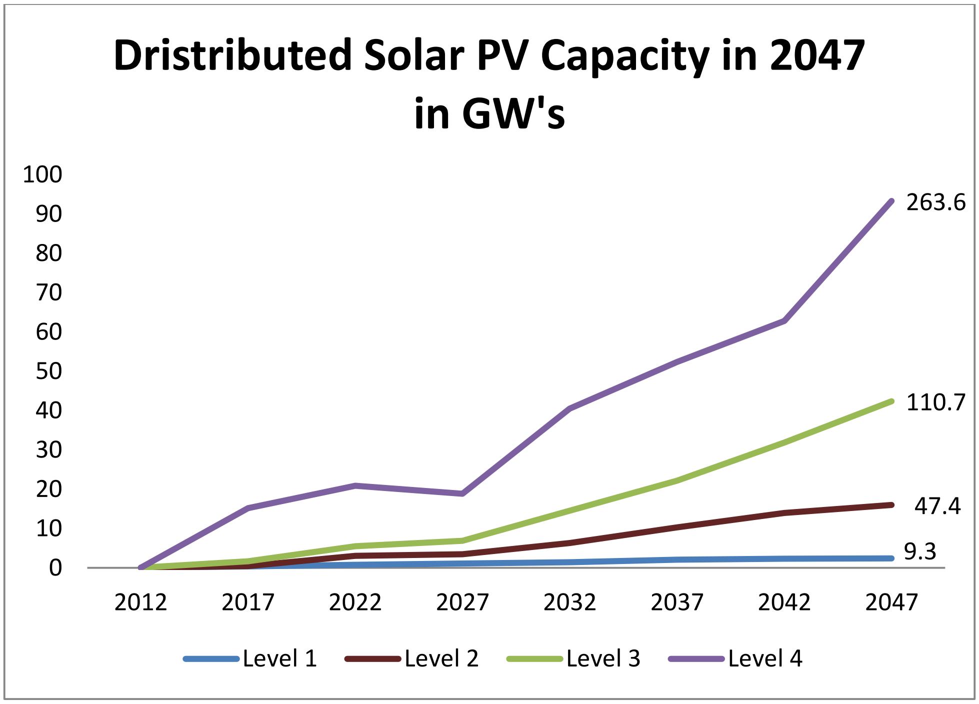
Level 2 assumes that a significant push for PV RFTP under the JNNSM will increase the penetration from 0.01 % in 2012 to 0.6% by 2022, with residential sector remaining the major contributor with a penetration rate of 3% in HHs by 2047. The total capacity reaches 47.4 GWs by 2047 and generates 79 TWh of electricity.

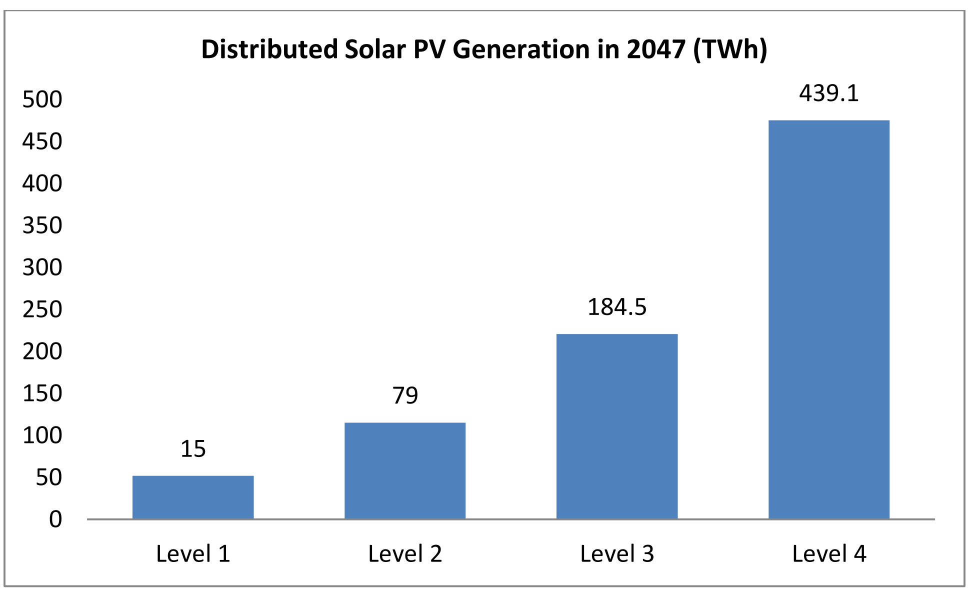
Level 3:

Level 3 assumes that with increase in urbanization the peak demand for electricity would also grow, leading to an increase in penetration levels to 7% by 2047. This would also force industrial, commercial and institutions spaces to adopt distributed PV's lead to a quick increase in capacities. The total capacity and generation will increase to 110.7 GW and 184.5 TWh by 2047 respectively.

Level 4:

Level 4 assumes that there are favorable policies for supporting growth in distributed Solar PV and there is ample rooftop space available in coordination with Solar Water Heaters[xi]. The penetration levels are as high as 17% leading to rapid growth in the residential as well as commercial sectors. Increased penetration levels leads to a total of 263.6 GW of capacity and 439.1 TWh of electricity generation in 2047. Smart grids, advanced inverters, DR, favourable storage costs would aid this process. This scenario is near achievement of MNRE target for 2022.


Dristributed Solar PV Capacity in 2047
in GW's
100
90
80
70
60
50
40
30
20
10
0
263.6
110.7
47.4
9.3
2012
2017
2022
2027
2032
2037
2042
2047
Level 1
Level 2
Level 3
Level 4


Distributed Solar PV Generation in 2047 (TWh)
500
450
400
350
300
250
200
150
100
50
0
15
79
184.5
439.1
Level 1
Level 2
Level 3
Level 4

3.6 SOLAR WATER HEATING

The use of solar thermal energy for domestic purposes is a known phenomenon across India. Solar Water Heating System is one of the most efficient techniques of harnessing this energy. The very first installation of SWHS began in 1980 though pilot plants were setup before 1960. Increasing electricity prices has been the driving force for SWHS installations. These systems are already economically viable in India. Today, India ranks fifth in terms of the number of SWHSs installation, accounting for 1.6% of the total heating capacity through solar water heaters around the world (REN21 Global Status Report 2014). The total installed collector area has increased from 119000 sq. m in 1982 to 11 Million sq. m 2013. This sector has been incentivized by capital subsidies and soft loans in the past.

3.6.1 SECTION OVERVIEW

Until 2001 the commercial and industrial sector contributed to 80% of SWH installations[xii] . As of today the residential sector is the largest sector contributing 80% of installation and sales for SWHS[xiii] . Introduction of mandates for the building sector, provision of capital subsidies and soft loans/ tax rebates have together helped in the growth of the sector. The JNNSM has proposed an ambitious target of achieving 20 million sq. M of collector area by 2022.

3.6.2 DRIVERS

- Significant push for solar power in the country under the JNNSM.
- Significant cost savings compared to conventional heating systems over lifetime.
- Low gestation period.
- Increased focus on energy security.

3.6.3 ASSUMPTIONS

- Life of project: 20 years
- Increase in size of system per HH from 150 LPD at 3 m2 to 200 LPD at 5 m2over time.

3.6.4 TRAJECTORIES

Level 1:

Level 1 assumes that although there is a gradual improvement in SWH installations in the residential sector there is very little growth in the industrial and commercial sectors. The penetration rate remains low i.e. 2% HHs in 2047 which was 0.03% in 2012. The resulting collector area becomes 32 million sq m in 2047 from 6 million sq. m in 2012 with capacity rising to 22.6 GW in 2047 from 4.2 GW in 2012. The corresponding electricity generated in 2047 would be 3.7 TWh in comparison with 0.7 TWh in 2012.

Level 2:

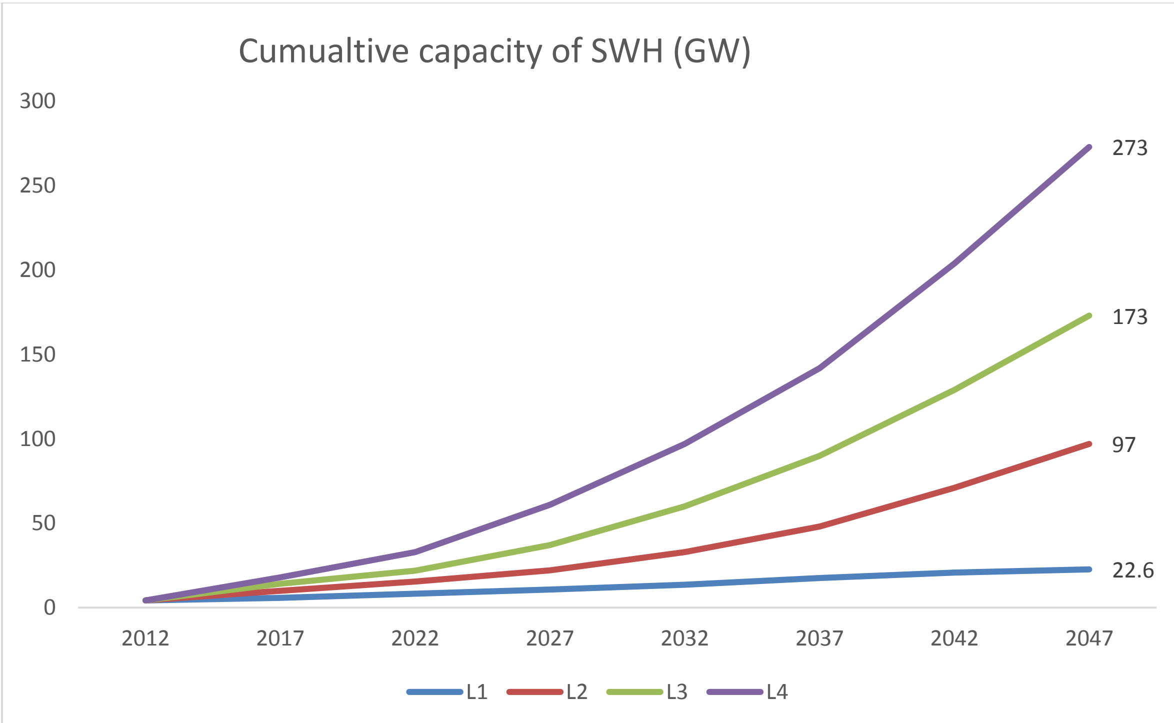
Level 2 assumes that the JNNSM target of 22 million sq. m is met by 2022, with residential sector remaining the major contributor with a penetration rate of 7% HHs by 2047. The total collector space reaches 138 million sq. m. in 2047 with a cumulative capacity of 97 GW and the amount of electricity generated would be 16 TWh.

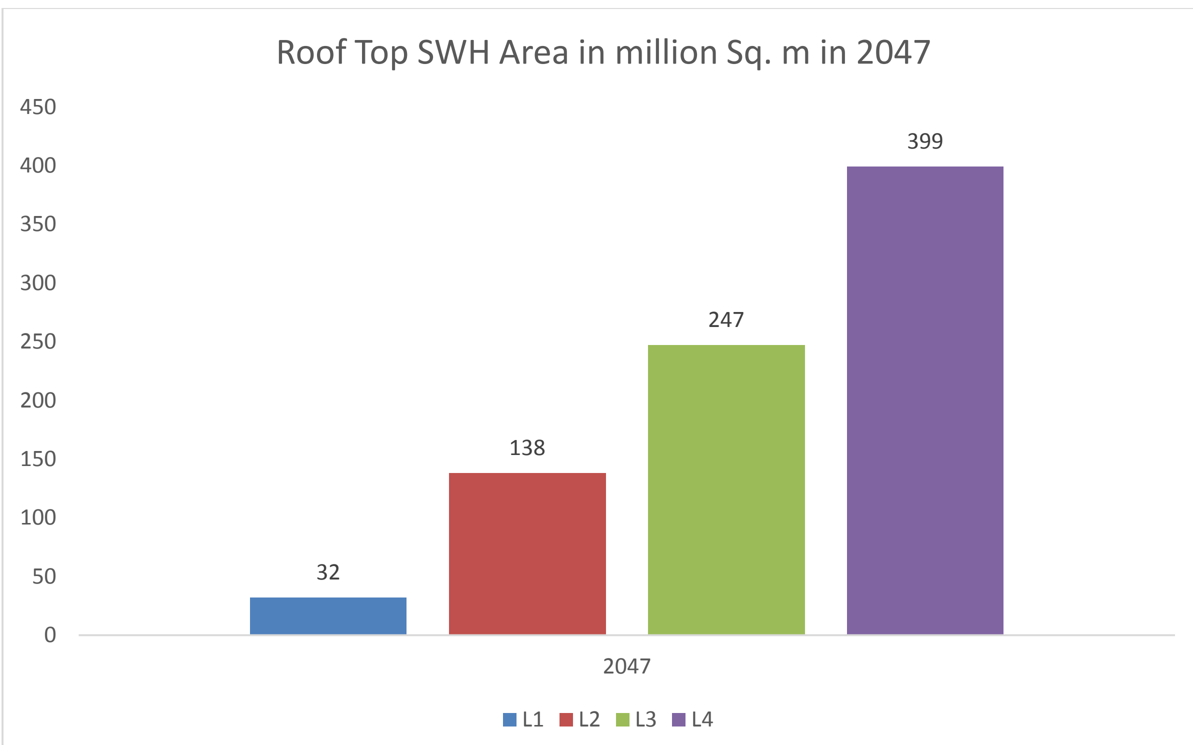
Level 3:

Level 3 assumes that with the increase in urbanization the demand for hot water rises. Also, strict mandates for industrial, commercial and institutions spaces lead to quick increase in SWH capacities and the penetration level increases to 12.5%. The total collector space grows to ~247 million sq. m. The cumulative capacity and generation in 2047 would be 173.2 GW and 28.6 TWh respectively.

Level 4:

Level 4 assumes that there are no economic and social constraints and there is ample rooftop space available in coordination with rooftop PV[xiv]. The penetration levels are as high as 20% leading to rapid growth in SWH installations. Increase in hot water demand leads to a collector space aggregating to 399 million sq. m. For comparison, 10% of Chinese HHs are already using SWHs and the number is expected to rise to 30% by 2020. So, the capacity reaches 279.5 GW resulting in generation of 48.6 TWh in 2047.


Cumualtive capacity of SWH (GW)
300
250
200
150
100
50
0
273
173
97
22.6
2012
2017
2022
2027
2032
2037
2042
2047
L1
L2
L3
L4


Roof Top SWH Area in million Sq. m in 2047
450
400
350
300
250
200
150
100
50
0
32
138
247
399
2047
L1
L2
L3
L4

4. RENEWABLE ENERGY POWER GENERATION COSTS

Cost estimations have been done for the following technologies:

- Onshore Wind and Offshore Wind
- Solar Photovoltaic (PV) and Concentrated Solar Thermal Power (CSP)
- Small hydro power (SHP)
- Solar Water Heating and
- Distributed Solar PV

METHODOLOGY FOR ESTIMATING COSTS

Through an extensive literature review of various publications on present and projected costs (capital as well as operating) data was systematically compiled as the first step (available in the attached excel sheet). The detailed references are listed at the end of this note. We also compiled cost data from ERC tariff orders and other documents from the Central and State Electricity Regulatory Commissions. An important learning from this exercise was that Indian costs were significantly lower than their Western counterparts. This implied that we could not pick up future cost projections from these studies as they were given the wide divergence in 2012 numbers. We could not come across many studies done especially considering the Indian market for future RE costs. Apart from the literature review, we have also discussed this data with various industry stakeholders and incorporated their inputs whenever useful.

Based on a combination of these approaches, we have estimated future capital costs for RE in India beginning with the starting Capex and Opex values from CERC[ii] for 2012. Most estimates for nearly all renewables expect a cost reduction in real terms over the time period in question. However many studies estimate costs for shorter time periods and not till 2047.

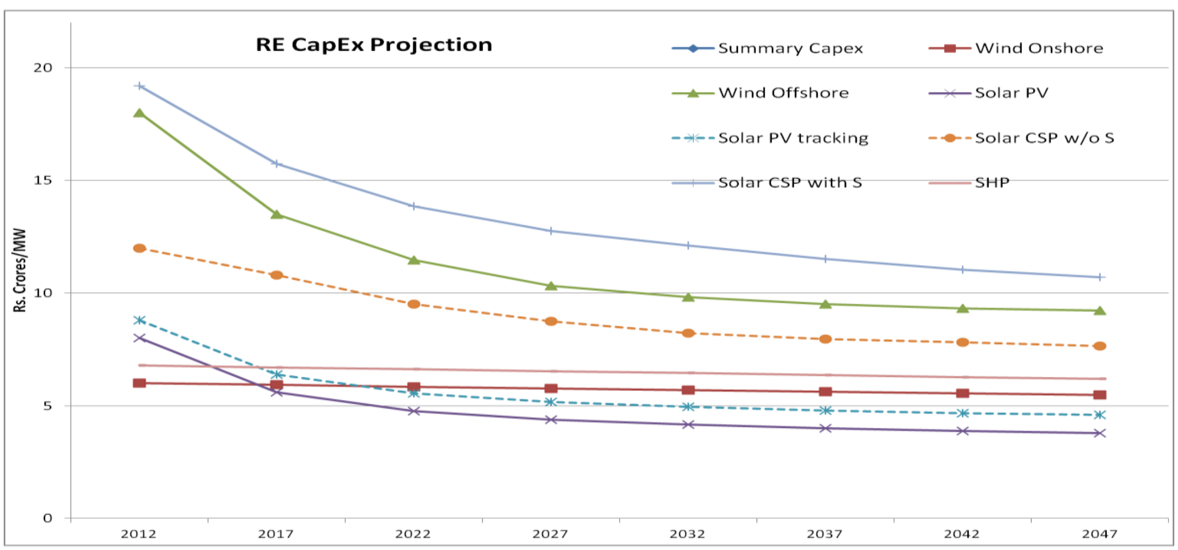
Our low cost estimates reflect a rough attempt at capturing this cost reduction as is evident from the literature and industry discussions. A varying percentage reduction over 35 years (2012-47) is applied for all technologies to arrive at the final estimates. This assumed reduction is necessarily an approximation/guesstimate based on the various studies we have scrutinized. This is by no means an exact number and we mostly eagerly welcome discussion and new data around this much neglected issue. **We treat these estimated numbers as the low estimate, the high estimate being the CERC 2012 Capex numbers remaining constant in real terms over time.** We have assumed the operating costs to be constant for the 35 year period. All numbers are in 2012 Rupees.

Apart from the cost, the table below lists assumptions on life, CUF for new installations and the average CUF for the fleet.

ASSUMPTIONS

Technology	Life (yrs)	CUF for new installations	Weighted average CUF of the capacity fleet (2012-2047)	Reduction in costs (2012-2047)
Onshore Wind	25	20% - 32%	20% - 28%	10%
Offshore Wind	25	33% - 39%	33% - 38%	49%
Solar PV without tracking	25	19%	19% - 20.5%	53%
Solar PV with tracking	25	24%		48%
Solar CSP without Storage	25	23%	22% - 45%	37%
Solar CSP with 8 hour Storage	25	46%		45%
Small Hydro	30	35% - 45%	40% - 44%	10%
Distributed Solar PV	20	16%-19%	16%-18.8%	44%

The graph below captures the **"low estimate"** capital cost (in 2012 rupees) trajectory for RE in India.



- **Onshore Wind:** Given the technology maturity in this well established sector, we assume a modest 10% linear reduction in Capital Expense over 40 years. Opex is as per CERC, at 9 lakhs/MW/yr. Land requirement is assumed to be 30 acres/MW as per MNRE norms for the entire wind farm and 2.4 acres/MW as the footprint (8%) of the total based on industry interactions.
- **Offshore Wind:** The CapEx is derived from discussion with industry experts and public discussions at Rs. 18 Cr/MW[iii]. An overall reduction of 49% over 40 years is assumed, the costs are expected to decrease sharply in the initial years as significant domestic manufacturing kicks in .Operating costs are assumed to be 50% higher than onshore wind at 13.5 lakhs/MW/yr.
- **Solar PV (Without Tracking):** 2012 project costs are as per CERC, at 8 cr/MW and are assumed to decrease by as much as 53% in 40 years. Enhancement in technology and manufacturing scale leads to reduction in costs in a pattern where the first two decades experience a sharp reduction in costs after which the curve flattens. Land requirements for PV are in the range of 4.8-7.4 acres/MW in 2012. The lower range is for c-Si while higher is for thin films. However given the improvements in efficiency land requirements are expected come down proportionately.
- **Solar PV (With Tracking):** Capital Costs are assumed to be 10% higher than solar PV with fixed tilt. Capex projections are in line with solar PV fixed tilt. However the absolute real cost of tracking system remains constant over time. This results in an overall cost reduction of 48% over 40 years. Similarly Opex is assumed to be 10% higher than fixed tilt. Land requirements are 5.2-8.1 acres/MW in 2012.
- **Concentrated Solar Thermal Power (CSP) without storage:** Starting point for 2012 is 12cr/MW as per CERC. Overall cost reduction over 40 years is 37%. First two decades experience a sharp reduction in costs owing to improved technology, manufacturing scale and increased Indian manufacturing after which the curve flattens. Opex is at 15 lakhs/MW. Land requirements start at 6 acres/MW in 2012 and reduce slightly to 5 acres/MW by 2052 due to technology improvements.
- **Concentrated Solar Thermal Power (CSP) with storage**: For Solar CSP with storage Capex is estimated at 19.2 cr/MW in 2012, for an 8 hour storage system by doubling the solar field cost (~ 60% of total Capex without storage). The tool assumes an overall cost reduction of 45% in 40 years. Opex for Solar CSP with storage is assumed to be 60% higher than Solar CSP without storage at 24 lakhs/MW. Land requirement is double that of CSP without storage.
- **Small Hydro Power:** The 2012 CapEx is as per CERC at 5.5 – 7.5 cr/MW and is assumed to be practically the same over time given the technology maturity. A slight 10% reduction is assumed over 40 yrs. The lower estimate is for projects in southern Indian states and the higher estimate is for northern hilly states. Opex varies in the range of 14-25 lakhs/MW/yr and hence assumed to be 19.9 lakh/MW/year. Land estimates for SHP are extremely varied depending on the location and whether the project is storage based of run of the river. To add to the problem, very scant data is available in the public domain on this front. One estimate puts it at 2-4 acres/MW but we believe this might be too low. However more data is needed to substantiate this aspect.
- **Solar Water Heating:** The Capex is estimated to be Rs 7500-11000/m2 as per MNRE data and assumed to remain constant in real terms over time. Opex is estimated at Rs 125/m2/yr.

- **Distributed Solar PV:** The CapEx is estimated to be at 1 Lakh/kWp . Assuming cost reductions slightly lower than in large solar PV. Cost projections for solar PV are highly sensitive, as is seen from the 75% reduction in the last 5 years. The OpEx is assumed to be 1.5% of CapEx on the lines of CERC assumptions for large solar PV.

COST ESTIMATES:

Renewable Energy Technology [All costs are in real terms, in 2012 Rs Cr/MW]	2012	2017	2022	2027	2032	2037	2042	2047	OpEx (lakhs/ MW/yr)
Wind On Shore									
High Estimate CapEx	6	6	6	6	6	6	6	6	9
Low Estimate CapEx	6	5.9	5.9	5.8	5.7	5.6	5.6	5.5	
Land Requirement (acres/MW)	30	30	30	30	30	30	30	30	
Footprint Land Requirement (acres/MW)	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	
Wind Offshore									
High Estimate CapEx	18	18	18	18	18	18	18	18	13.5
Low Estimate CapEx	18.0	13.5	11.5	10.3	9.8	9.5	9.3	9.2	
Solar PV									
High Estimate CapEx	8	8	8	8	8	8	8	8	11
Low Estimate CapEx	8	5.6	4.8	4.4	4.2	4	3.9	3.8	
Land Requirement (acres/MW)	4.8-7.4	4.5-6.6	4.2-5.5	4.0-5.1	3.8-4.4	3.4-4.3	3.3-4.1	3.2-4.0	
Solar PV with Tracking									
High Estimate CapEx	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	12.1
Low Estimate CapEx	8.8	6.4	5.5	5.2	5	4.8	4.7	4.6	
Land Requirement (acres/MW)	5.2-8.1	4.9-7.3	4.6-6.1	4.4-5.6	4.1-4.9	3.7-4.7	3.6-4.5	3.5-4.4	
Solar CSP without storage									
High Estimate CapEx	12	12	12	12	12	12	12	12	15
Low Estimate CapEx	12	10.8	9.5	8.7	8.2	7.9	7.8	7.6	

Land Requirement (acres/MW)	6	6	5.5	5.5	5	5	5	5	
Solar CSP with storage									
High Estimate CapEx	19	19	19	19	19	19	19	19	
Low Estimate CapEx	19	15.7	13.8	12.7	12.1	11.5	11	10.7	24
Land Requirement (acres/MW)	14.4	14.4	13.2	13.2	12	12	12	12	
Small Hydro Power (SHP)									
High estimate CapEx	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	
Low estimate CapEx	6.5	6.5	6.5	6.5	6.5	6.4	6.3	6.2	19.9
Land Requirement (acres/MW)	2.0-4.0	2.0-4.0	2.0-4.0	2.0-4.0	2.0-4.0	2.0-4.0	2.0-4.0	2.0-4.0	
Solar Water Heating									
SWH (Thousand Rs/m2) high estimate	11	11	11	11	11	11	11	11	125 (Rs/m2/yr
SWH (Thousand Rs/m2) low estimate [III]	11	10.5	10	9.5	9	8.5	8	7.5	
Distributed Solar PV									
Fixed CapEx (Rs/kWp) high estimate	100000	100000	100000	100000	100000	100000	100000	100000	1500 (Rs/kWp)
Reducing CapEx (Rs/kWp) Low Estimate	100000	80000	70400	65472	62198	59710	57919	56761	

REFERENCES

I. List of studies referred for estimating cost projections (Ref. table)

II. CERC tariff order 2013-2014 http://www.cercind.gov.in/2013/orders/SO243.pdf

III. Source: http://mnre.gov.in/file-manager/UserFiles/presentations-offshore-wind-14082013/JS-MNRE.pdf

IV. Solar Water Heater FAQ: http://mnre.gov.in/file-manager/UserFiles/faq_swh.pdf

Source	**Document Title**	**Link**
NREL Costs, 2012	Cost and performance data for power generation technologies	http://bv.com/docs/reports-studies/nrel-cost-report.pdf
Open EI	Transparent Cost Database *	http://en.openei.org/apps/TCDB/
ICF _2013	Contribution of renewable power towards eliminating shortages and meeting economic growth Aspiration ; Shakti Foundation	http://www.shaktifoundation.in/cms/uploadedImages/power%20security%20report-%20final%20-%20feb%202013.pdf
WEO_2012	World Energy Outlook Database,Assumed investment costs, operation and maintenance costs and efficiencies in the IEA World Energy Outlook 2012	http://www.worldenergyoutlook.org/weomodel/investmentcosts/
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LEVELIZED COST OF ELECTRICITY FOR RENEWABLE

Based on the above possible low cost trajectories (Capex and O&M) and considering assumptions on ROE, Discount Rate and Term for Loan, we have calculated the resulting LCOE. The results of this exercise are shown in the table and graph below.

ASSUMPTIONS

CERC 2012

CERC Assumptions (2013)	**Value**	**Units**
ROE	20%	
Discount Rate	10.95%	
Term Loan Interest	12%	
Term Loan tenure	12	Yrs
Depreciation (SLM)	5.83% for 12 yrs, 0.87% for 13 years upto 90% of Capex	
Debt-Equity	70-30	

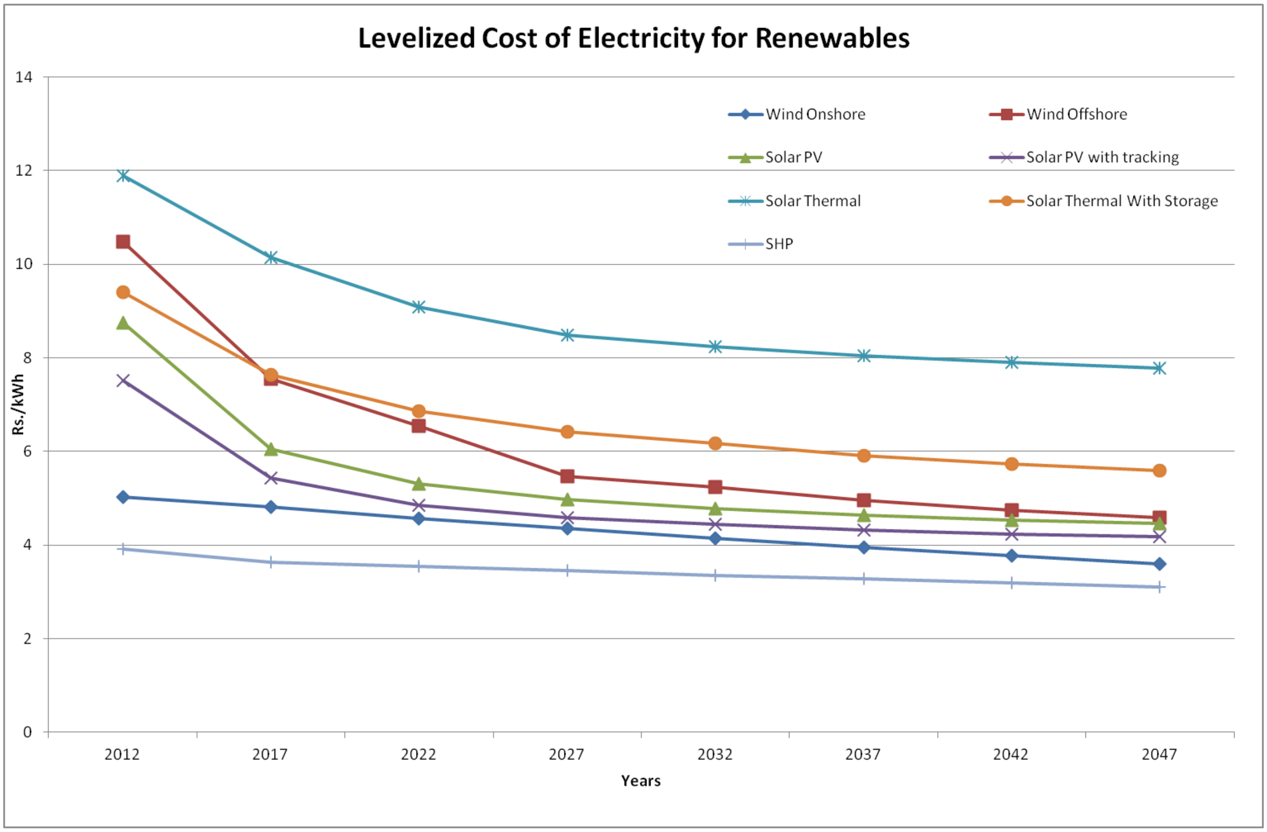
ASSUMPTIONS FOR PROJECTED COST CALCULATIONS

Global Assumptions	**Value**	**Units**
ROE	16%	
Discount Rate	10.34%	
Term Loan Interest	12%	
Term Loan tenure	12	yrs
Depreciation (SLM)	5.83% for 12 yrs, 1.84% for 13 years upto 90% of Capex	
Debt-Equity	70-30	

Levelized Cost of Electricity (all in 2012 Rupees)

Technology	2012	2017	2022	2027	2032	2037	2042	2047
Wind Onshore								
Capex	597*	592.5	585.0	577.5	570.0	562.5	555.0	547.5
Opex	9	9	9	9	9	9	9	9
CUF	25%	24%	25%	26%	27%	28%	29%	30%
Levelized tariff	5.03	4.81	4.57	4.35	4.14	3.95	3.77	3.6
Wind Offshore								
Capex	1800	1350.0	1147.5	1032.8	981.1	951.7	932.6	923.3
Opex	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
CUF	33%	33.0%	33.0%	36.0%	36.0%	37.0%	38.0%	39.0%
Levelized tariff	10.48	7.56	6.55	5.47	5.24	4.96	4.75	4.59
Solar PV								
Capex	800*	560.0	476.0	437.9	416.0	399.4	387.4	379.7
Opex	11.63	11	11	11	11	11	11	11
CUF	19%	19.0%	19.0%	19.0%	19.0%	19.0%	19.0%	19.0%
Levelized tariff	8.75	6.06	5.32	4.98	4.79	4.64	4.54	4.47
Solar PV with Tracking								
Capex	880	640.00	556.00	517.92	496.02	479.38	467.40	459.65
Opex	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1
CUF	24%	24%	24%	24%	24%	24%	24%	24%
Levelized tariff	7.52	5.44	4.86	4.59	4.44	4.32	4.24	4.18

Solar thermal								
Capex	1200*	1080.00	950.40	874.37	821.91	797.25	781.30	765.68
Opex	15.86	15	15	15	15	15	15	15
CUF	23%	23%	23%	23%	23%	23%	23%	23%
Levelized tariff	11.9	10.15	9.09	8.48	8.24	8.04	7.91	7.78
Solar Thermal With Storage								
Capex	1920	1574.4	1385.472	1274.634	1210.903	1150.357	1104.343	1071.213
Opex	24	24	24	24	24	24	24	24
CUF	46%	46%	46%	46%	46%	46%	46%	46%
Levelized tariff	9.4	7.64	6.87	6.43	6.17	5.92	5.74	5.6
Small Hydro Power								
Capex	679	670.5125	662.025	653.5375	645.05	636.5625	628.075	619.5875
Opex	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9
CUF	41%	42%	43%	43%	44%	45%	46%	47%
Levelized tariff	3.92	3.63	3.55	3.46	3.36	3.28	3.2	3.1


Levelized Cost of Electricity for Renewables
14
12
10
8
6
4
2
0
Rs./kWh
Wind Onshore
Wind Offshore
Solar PV
Solar PV with tracking
Solar Thermal
Solar Thermal With Storage
SHP
2012
2017
2022
2027
2032
2037
2042
2047
Years

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