सत्यमेव जयते

NITI AAYOG
Government of India

भारत ऊर्जा सुरक्षा परिदृश्य 2047
INDIA ENERGY SECURITY SCENARIOS 2047
Version 2.0

Sector Specific Insights
Part III :
Renewable & Clean Energy

भारत ऊर्जा सुरक्षा परिदृश्य 2047

INDIA ENERGY SECURITY SCENARIOS 2047

Version 2.0

Energy Division
NITI Aayog
Government of India
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Disclaimer

It should be noted that the IESS, 2047 platform does not 'recommend' or 'prefer' any one scenario or pathway, or suggest NITI Aayog's view of the energy pathway that India may take until 2047. It merely provides the user a way to understand the realm of possible scenarios and their implications. However, these data sets are not purported by NITI Aayog to be a source of authentic Government data. Although, greatest attention has been given to using both historical and future data sets from Government sources, the IESS, 2047 is not intended to be a data base of energy related sectors of India. With respect to costs, it may be noted that the IESS, 2047 is an energy calculator and not one of costs. The cost implications derived for each pathway are meant to give an indicative cost of the energy related investments required for each pathway, which do not include the Infrastructure costs. It may also be noted that the Tool enables users to substitute the given data by their own, and build their own pathway. We would appreciate receiving pathways from users of the IESS, 2047 Version 2.0.

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PREFACE

The India Energy Security Scenarios, 2047 (IESS, 2047) is a tool developed by and housed in the Energy division of NITI Aayog. The first version of this tool was launched on February 28, 2014 and can be accessed at www.indiaenergy.gov.in . (Now archived) The present Version 2.0 is an improved edition with additional inputs and analyses.

An IT enabled webtool, backed by a detailed, open-source excel model, offers user-friendly graphic representations of the energy demand and supply scenarios for the country, which dynamically represent the scenario which the user may choose out of multiple options offered in the tool. While the earlier version (Version 1.0) of the IESS, 2047 offered the user an option to observe the implications of his pathway on import dependence, land-use and carbon dioxide emissions for the scenario chosen by him/her, Version 2.0 of the IESS, 2047 offers an additional set of implications to the user. While using Version 2.0, the user can witness the implications of his choices on cost to the economy and greenhouse gas emissions, in addition to import dependence and land-use. Version 2.0 also has a large set of value additions in terms of added technologies and sectors that are gaining importance in the present landscape, updated datasets, more intensive modelling approaches etc., Version 2.0 also builds in the recent developmental goals of the government to make the tool relevant in the present policy space. For more details, you could refer to the IESS, 2047 V2.0 overall handbook and our website www.indiaenergy.gov.in

The IESS, 2047 V2.0 consists of an **open- source MS Excel model** which contains data for all sectors at five yearly intervals till 2047, and forms the backbone of this entire exercise; **a Webtool** (user-friendly interface with the Excel) which dynamically generates graphs and charts to represent energy demand and supply levels, and implications of the above on imports, emissions, costs etc. ; the **IESS, 2047 V2.0 website, www.indiaenergy.gov.in** which offers detailed insight on how to use the tool, sector specific information, documentation and implications of the users' chosen pathway; and **three levels of documentation** about each of the 33 energy demand and supply sectors.

While the main IESS, 2047 handbook aims to give the user a concise overview about the sectors in the tool and the overall messages that are emerging out of the analysis, the **'Sector Specific Insights'** series, consisting of four parts, talks about each sector in much greater detail. The books in this series aim to give a user who is interested in a particular sphere of the energy sector, an insight into the drivers, assumptions and methodologies used to construct the components of Energy demand, Energy Supply and Energy Network and Systems. However, it may be noted that these write-ups are an **abridged** version of the actual detailed documentation that exists for each sector. In order to view the detailed documentation along with references and the comprehensive methodology, please visit our website www.indiaenergy.gov.in.

Part I of this series talks about the **Energy Demand sectors** of the IESS, 2047 V2.0,

Part II of this series talks about the **Conventional Energy Supply sectors** of the IESS,2047 V2.0,

Part III of this series talks about the **Clean and Renewable Energy Supply sectors** of the IESS, 2047 V2.0 and,

Part IV of this series talks about the **Network and Systems components** of the Energy sectors considered in the IESS, 2047 V2.0

The IESS, 2047 V2.0 is a collaborative effort and has been built with the help of a wide pool of knowledge partners from the Government, Industry, Think Tanks, Non-Governmental organizations, International research agencies and the academia. We are thankful to the sector experts from these institutions who contributed to this initiative by developing sector specific trajectories for the IESS, 2047 V2.0.

For more information, please write in to us at iess-2047@gov.in and/or visit our website www.indiaenergy.gov.in .

The IESS Team

INTRODUCTION

In view of the rising energy demand and sticky import dependency at nearly one-third of all primary commercial energy demand of India, the need for long term energy planning remains as strong as ever. It has also become important to look at the long term, i.e., the next 3-4 decades, looking beyond 2030 and 2031-32, which are the terminal years of several earlier Indian energy studies. As energy sector decisions have huge cost implications, energy related investments also ought to have long term perspective. Keeping the above in mind, the erstwhile Planning Commission, now NITI Aayog, decided to undertake an energy scenario building exercise early in the year 2013, called the India Energy Security Scenarios, 2047. It has been built as a knowledge portal, combining IT applications, behavioural aspects, energy related emissions, local resource endowments, all sources of energy supply and demand, technologies of global scale as and when they are inducted in the Indian system, and cost-time parameters.

An IT enabled webtool, backed by a detailed, open-source excel model, offers user-friendly graphic representations of the energy demand and supply scenarios for the country, which dynamically represent the scenario which the user may choose out of multiple options offered in the tool. While the earlier version (Version 1.0) of the IESS, 2047 offered the user an option to observe the implications of his pathway on import dependence, land-use and carbon dioxide emissions for the scenario chosen by him/her, Version 2.0 of the IESS, 2047 offers an additional set of implications to the user. While using Version 2.0, the user can witness the implications of his choices on cost to the economy and Greenhouse Gas emissions, in addition to import dependence and land-use. Version 2.0 also has a large set of value additions in terms of added technologies and sectors that are gaining importance in the present landscape, updated data sets, more intensive modelling approaches etc., which will be elaborated upon in the following sections. Version 2.0 also builds in the recent developmental goals of the government to make the tool relevant in the present policy space.

The IESS, 2047 is expressly an energy scenario building tool. The guiding ambition of this is to develop energy pathways, at five yearly intervals, leading up to the year 2047, comprising of likely energy demand and supply scenarios. The end demand and supply numbers are generated in light of the adoption of different combinations of energy efficiency measures and technology interventions on the demand side and an increase in indigenous production of the country on the supply side. The tool has been so developed, that it can create hundreds of scenarios with different combinations of levels/efficiencies of energy demand and supply sectors.

The primary use of IESS, 2047 is to project scenarios of percentage of the total energy supply (as per the pathway chosen by the user), that may be met by imports. Hence, while the tool segregates the demand for energy by sectors, and supply numbers by sources, it also generates energy import numbers and cost by source, and aggregates the same to offer total energy imports under different scenarios. The tool also enables the user to witness the implications of his/her choices on land area and emissions. A high share of solar energy and wind, too, would have implications on land requirement, which is a scarce resource for a dense country like

India. As the scenarios generated for different sectors are linear (either rising or falling, as the case may be), the graphic representation of the data sets is simple and easily understandable even by non-energy experts.

The tool has been built with the help of a wide pool of knowledge partners from the Government, Industry, Think Tanks, Non-Governmental organizations, International research agencies and the academia. The networking of top energy related think-tanks with energy Ministries, is a high water mark achieved in this exercise. This has added to the intellectual quality and transparency of the entire exercise.

The tool also has a very strong social media component aiming to disseminate the results and the messages of the IESS, 2047 to the public. It is also a completely open-source tool and can be considered a one-of-a-kind data repository for energy sources in the country.

A detailed examination of the tool will reveal how changes in choices of energy demand and supply, yielding different levels of energy import can help a planner to decide the sector(s) in which interventions can be more effective to meet the desired policy objectives. The tool allows the user to delve deeper into the levers of energy demand for all the demand sectors, and enables finding out the impact of different levers on energy demand. Since the tool also offers fuel-wise data, it is also possible to see as to which demand sectors ought to be influenced through suitable policy measures, to curb consumption of such fuels in which India is more import dependent. Hence, it is a handy tool to use, for those interested in understanding the energy security dimensions of the country.

NITI Aayog has in the past, and is also presently, in the process of conducting nation-wide outreach workshops to promote the usage of this tool and involve more people in the exercise for consensus building and creating awareness about energy policies. Workshops have been conducted in Government ministries (Bureau of Energy Efficiency, Ministry of Coal, Ministry of New and Renewable Energy, Ministry of External Affairs, Ministry of Petroleum and Natural Gas, Ministry of Power, Central Electricity Authority, Ministry of Railways, Directorate General of Civil Aviation, Ministry of Road Transport and Highways etc.), as well as for interest groups such as academia, industry etc. in different parts of the country, witnessing participation from the Industry, local academia, state governments etc. and industry bodies (FICCI, CII etc.) A variety of organizations are aiming to replicate this practice for different states and sectors. The IESS, 2047 has also evoked interest in Indian and international researchers for extension of academic pursuit.

The levels

For each sector, four levels have been developed, the descriptions of which are as follows:

Level 1-the '**Least Effort**' scenario: This assumes that little or no effort is being made in terms of interventions on the demand and the supply side.

Level 2- the '**Determined Effort**' scenario: This describes the level of effort which is deemed most achievable by the implementation of current policies and programmes of the government.

Level 3- the '**Aggressive Effort**' scenario: This describes the level of effort needing significant change which is hard but deliverable.

Level 4- the '**Heroic Effort**' scenario: This considers extremely aggressive and ambitious changes that push towards the physical and technical limits of what can be achieved.

The **first section** of this book aims to give the reader a brief overview about the IESS, 2047 and its components. It also contains a subsection on how to use the IESS, 2047 V2.0 webtool.

The **second section** of this booklet aims to give the reader an in-depth sector overview of the sectors of this series.

The **third section** of this booklet consists of two hypothetically generated example pathways of combinations of these demand and supply scenarios. These pathways map out the extremities of energy demand and supply as well as self sufficiency in terms of domestic fuel production and carbon dioxide emissions. It should be mentioned that these pathways are simply indicative of the feasible scenarios and are not prescriptive.

The **fourth section** of this booklet talks about the detailed results specific to the sectors being spoken about in this book and also summarizes the key findings of the IESS, 2047. It talks about the energy savings in the demand sectors and the increase in indigenous production on the supply side as we transition from level 1 to level 4.

For more information on how to develop your own pathway and detailed documentation for each sector, please log on to our website: www.indiaenergy.gov.in

Section 1:

About the IESS, 2047 Version 2.0

Section 1: About the IESS, 2047 Version 2.0

1.1 Components of the IESS, 2047 Version 2.0

The open-source MS Excel model

The tool is backed up by detailed Excel Sheets for all sectors on both the demand and the supply sides which contain all the sector assumptions, drivers and the methodology used to construct each sector at five yearly intervals till 2047. This data has been obtained from a variety of public sources. Historical data has been sourced from published documents, while the projections up to 2047, have been made by different expert agencies, keeping in mind likely scenarios.

This model is downloadable on the user's computer and amenable to generating implications should the user choose to input his own numbers.

The Webtool

The dynamic and interactive webtool interface which enables the user to play on the levels and choose their own energy pathway. This is the main interface between the user and the detailed excel model. One can choose pathways on the web interface and the same draws from the excel spreadsheet at the backend to generate the results and implications of the chosen pathway.

The One-Pager Documents

The concise one pager documents accessible through the webtool (by clicking on the line items) and also on the website by clicking on the respective sectors in the drop down menu, allow the user to get a glimpse of the trajectories of each sector in one quick view.

The Detailed Documentation

The detailed documentation for each sector present the sectoral background, the assumptions behind each sector, the methodology followed to construct the same and additional sector related information. The same can be accessed at our website www.indiaenergy.gov.in

The IESS,2047 Website

One can visit the IESS 2047'swebsitewww.indiaenergy.gov.in fordetailed insight on how to usethe tool, sector specificinformation, documentationand implications of the users'chosen pathway.

1.2 What is new in the IESS, 2047 Version 2.0?

We, at NITI Aayog, with the support of our wide range of knowledge partners, are constantly working towards improving the analytical credibility of the IESS, 2047. Since the energy scenario of India is changing at a rapid pace, we thought it best to work on newer versions of the model with updated data sets, inclusion of new sectors and technologies that are gaining importance, and factoring in some new implications like the cost to the economy of different interventions etc. to enable the users to make better informed decisions. Also, keeping in mind the rising growth rate of the country and long term perspective , we have also offered three levels of GDP growth to the user, on the basis of which the energy demand outputs are generated. A detailed exercise was undertaken to determine the different elasticity of energy demand in different sectors to three assumed GDP growth rates.

Version 1.0 of the IESS, 2047 created scenarios around our choices of energy demand and supply while analysing emissions and land-use as its implications in the context of energy security. Version 1.0 also tried to incorporate all the major demand and supply sectors of energy and the technologies which will make those demand and supply choices possible. Having learnt from the process of development, engagement of knowledge partners, and feedback from the academia, industry and other stakeholders, it made perfect sense to constantly update the tool and make it more comprehensive. Along with the updation of data and projections in a majority of sectors, to reflect the changing energy scenario, a snapshot of the value additions in version 2.0 are presented as follows:

Additional Choices offered to the user	**Scenarios for the Growth of the Economy** Keeping in mind the fluctuating economic growth conditions of the country, we have offered three scenarios of GDP growth to the user (7.4% CAGR, 6.7% CARGR and 5.8% CAGR, all till 2047), on the basis of which the end-energy demand outputs are generated. Naturally, at higher GDP growth rates, the energy demand is higher. The default scenario is the first one, i.e. 7.4%
	Costing For a policy maker, it's very important to analyse the trade-off of investing a rupee out of public exchequer on incentivising a technology option, or on promoting a particular fuel, viz., energy efficiency and renewable energy options. To bring this quantitatively into perspective, we have included Capital, Operating, Fuel, Infrastructure (only on the supply side) and Finance costs for each of the sectors (both demand and supply) into the IESS Version 2.0. The tool generates scenarios of cost implications of such choices. This gives a broad picture of implications of energy choices on costs in the long run.
	Three options for each of the aforementioned cost categories Keeping in mind the uncertainty of costs that may pan out in the long period, we have generated cost scenarios and offered the user choice between high, low and point estimates for all costs (Demand and Supply sides). Depending on the cost option chosen, the tool aggregates the total costs for the chosen pathway and enables an analysis of the incremental cost of the chosen pathway, with respect to the default scenario (determined effort scenario) and also relate it as a percentage of India's GDP. Hence, the tool does not generate total or absolute costs, but the increment/savings in the chosen pathway vis-à-vis Level 2 choices or default pathway.
	Emissions Keeping in mind the increasing focus of India on improving our air quality especially in urban areas, the IESS, 2047 takes a deeper dive into estimating the energy related emissions by including major Green House Gases (GHGs) - Methane and Nitrous Oxide along with Carbon Dioxide. To enable the user to have a more comprehensive picture, we have also included fugitive emissions from production and mining of fossil fuels. However, this tool does not take into account all emissions (from agriculture etc.) or sinks, as it is merely capturing energy related emissions.
Stress Tests	With the new Renewable Energy targets of 175 GW by 2022 in place, there is increased concern about the ability of our grid to absorb high shares of this infirm variety of electricity. As a stress testing exercise, Lawrence Berkeley National Laboratory, U.S.A has run multiple scenarios of the IESS, 2047 on their Grid Planning and Dispatch model for India. The main objective of this simulation exercise was to assess the preliminary technical feasibility, in hourly intervals, of the identified scenarios of the IESS and broadly identify the storage and balancing

	electricity requirement for the grid integration of renewable energy. This is supplemented by the chosen level of the Storage technologies that have also been built into the tool. High levels of RE will require high storage capacity, so that the latter may supply electricity when intermittency happens.
New Technologies	▪ Technologies for Hydrogen production for Transport and Telecom. ▪ Storage based technologies - segregated by power and energy storage. ▪ Introduction of Fuel Cell Vehicles in Transport.
Government Announcements	▪ Housing for All by 2022 ▪ 175 GW of Renewable Energy ▪ Rural electrification ▪ 100 Smart Cities ▪ 24x7 Electricity by 2022 ▪ Targets for reduction of Oil Import Dependence (10% by 2022, 27% by 2030)
Supply Sectors	**Renewable energy:** ▪ Introduction of scenarios for Solar Water Heaters ▪ Introduction of Solar Roof Top Scenarios ▪ Changing pre-existing scenarios to factor in the new government targets for renewable energy **Fossil Fuel Electricity Generation:** ▪ Scenarios for phasing out of Diesel Based Generation ▪ Separation of Coal production into open cast/underground mining ▪ Calculative of fugitive emissions for fossil fuel production **Electricity Imports and Exports** ▪ Introduction of scenarios for Cross-border electricity trade exports (in addition to imports, presently there in Version 1) **Transmission and Distribution** ▪ Introduction of costs of Transmission Grids and the National Smart Grid Mission
Demand Sectors	**Transport** ▪ Addition of Fuel Cell Vehicles as a technology choice for the user ▪ Costs for rolling stock ▪ Demand activity based on GDP elasticity

Buildings

- Bottom-up approach, based on activity demand and elasticity of building space to GDP, for estimating space cooling and heating demand
- Estimation of space cooling demand based on thermal comfort and heat conducting ability of different building materials
- Offering 3 scenarios each around external temperature rise and the structure of urban spaces till the year 2047.
- Sub-categorization of Residential Urban, Residential- Rural and commercial buildings and estimation of energy demand for each category.
- Estimation of hot water demand for both commercial and residential buildings
- Factoring in 'Housing for All by 2022' and Affordable Housing.
- Appliance ownership patterns depending on GDP elasticity.

Industry

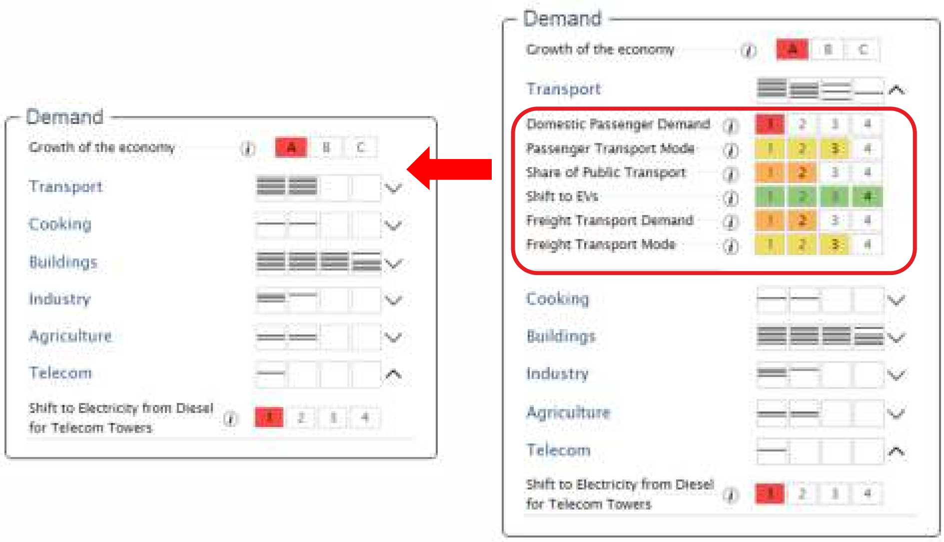
Restructuring of Energy Efficiency scenarios to include more drivers along with the PAT scheme. Even technology options have been adopted in steel and cement sectors which add value to the analysis other than merely autonomous energy efficiency options.

Telecom

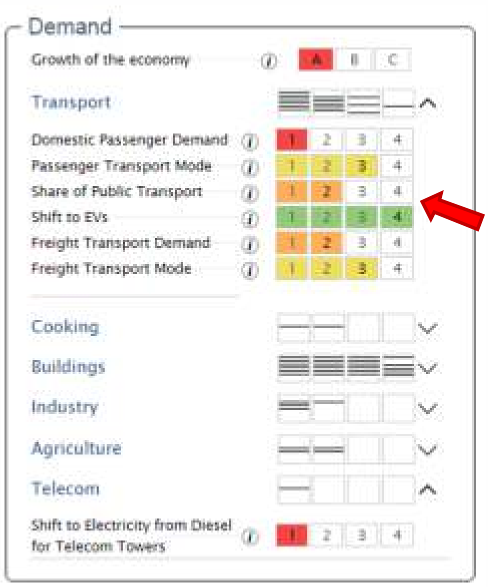
Addition of other solutions for replacement of diesel in the telecom sector. Version 2.0 considers solar rooftop, wind, bioenergy and hydrogen solutions for replacement of diesel, as opposed to only rooftop solar solutions in version 1.0.

1.3 How to use the IESS, 2047

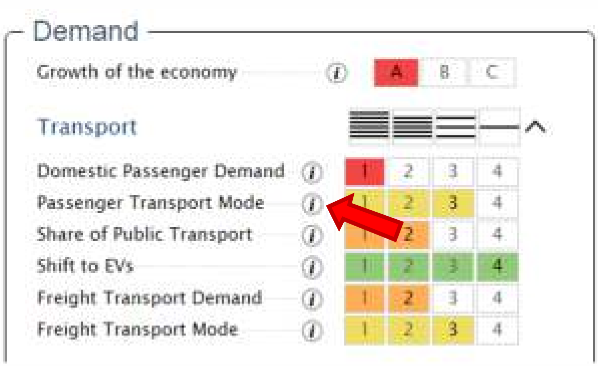
1. Select the Level of effort for Demand sectors, Supply sectors and Network and Systems. Click on downward arrow to select more options for a sector.



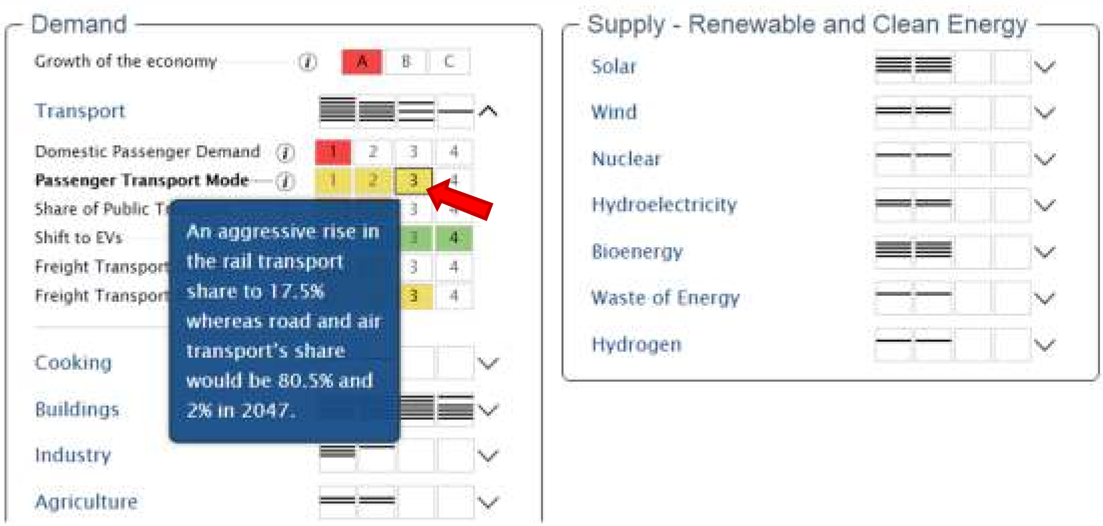
2. Select the scenario (we call them Levels) by clicking on the numbered boxes



3. Click on the Information icon (letter i enclosed in a circle) or Lever name to open a One-pager.



4. Hover over different levels to know what it means (these tool tips can be really useful!).



5. This menu bar gives you a range of options (we call them'Implications'of a pathway) that you can explore for your chosen pathway.

6. Explore more graphs and tables by clicking on individual items.

7. Click on 'Help' to know how to use the webtool and explore some interesting features.

Section 2:
Sector Specific Insights

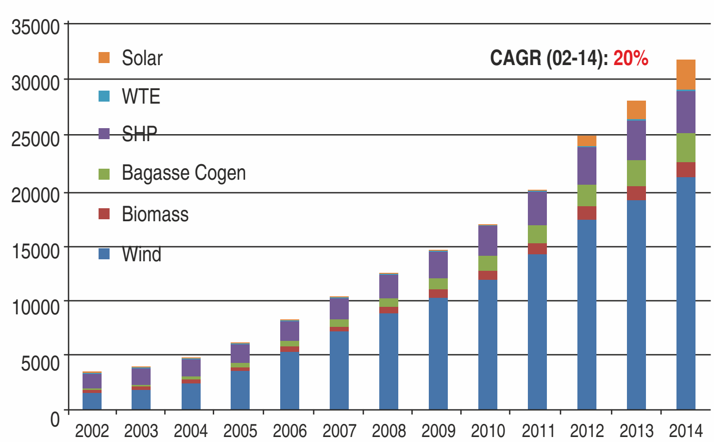
2.1 Renewable Energy Sources (Solar, Wind and Small Hydro)

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.

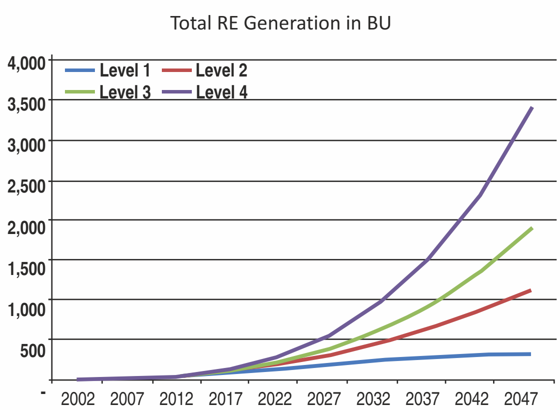
Recognizing the potential benefits of renewable energy (RE), Government of India (GoI) and various State Governments have taken several measures that have led to the increasing share of RE in the electricity mix of the country. These have resulted in nearly 35776 MW (as of May 2015) of grid-connected 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.

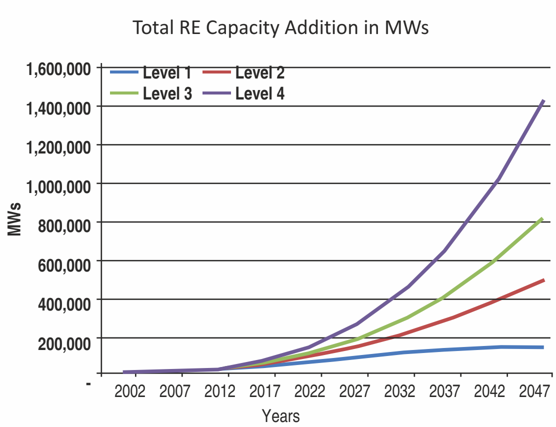
RE Capacity Addition (MW) from 2002-2014



2. 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.





2.1 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.

2.1.1 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. 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 GWwhich 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.

2.1.2 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 13TWh.

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.

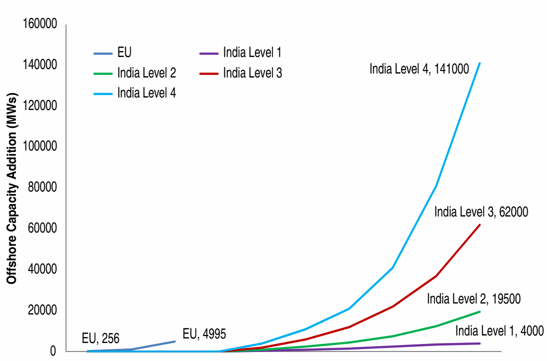
Level 3

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.

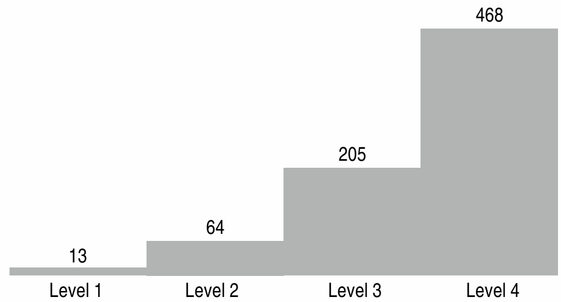
Level 4

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)



Wind offshore Generation (TWh/yr) in 2047



2.2 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. A new target of 60GW for wind sector has now been adopted for 2022.

2.2.1 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 capacitymost 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 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.

2.2.2 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 GWin 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 has already been sanctioned very recently.

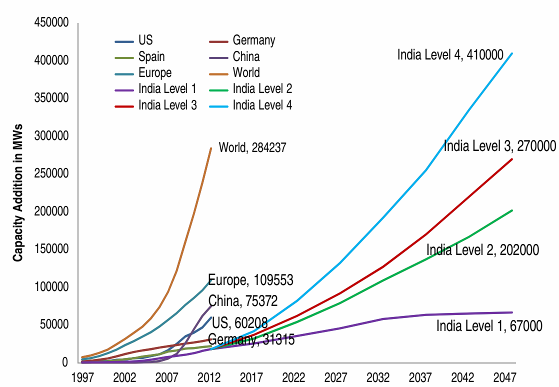
Level 3

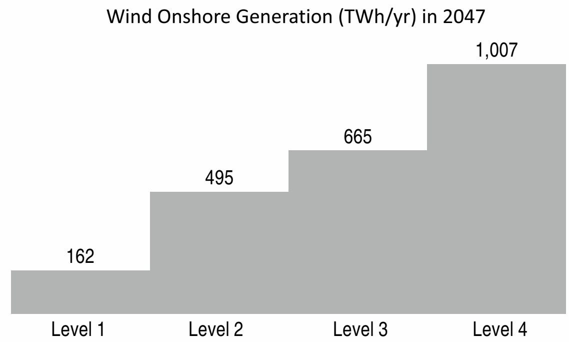
Level 3 assumes a capacity addition in this scenario to be slightly higher than the 12/13th plan requirements resulting in 62.35 GW in 2022. However this would still not be enough to meet the NAPCC targets of 2020. It would cross the 100 GW mark just before 2030 and finally reach 270 GW by 2047. The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





2.3 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 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.

2.3.1 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 (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. 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. According to MNRE, this translates to a need of roughly 34,000 MW in 2022.However, the new target for solar PV is 60 GW by 2022.

2.3.2 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

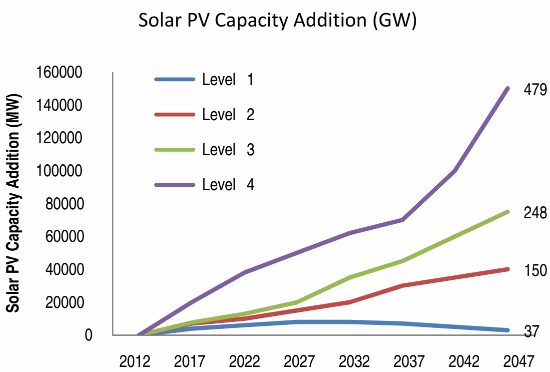
Level 2 assumes that the capacity addition would follow the JNNSM trajectory. By 2017, capacity would reach close to 8 GW in line with the 12th Plan projections, while by 2022 it would reach 17.9 GW. Capacity addition increases strongly thereafter culminating in a cumulative capacity of 150 GW by 2047.The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

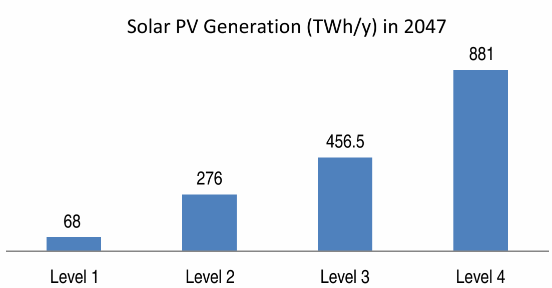
Level 3

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. 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.





2.4 SOLAR CSP POWER

Concentrated 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. The total technical potential of CSP in India (with land use limited to barren areas) according to one study is 2324 TWh/yr. According to another it is much higher at 10,928 TWh/yr. 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.

2.4.1 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. 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.

2.4.2 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.

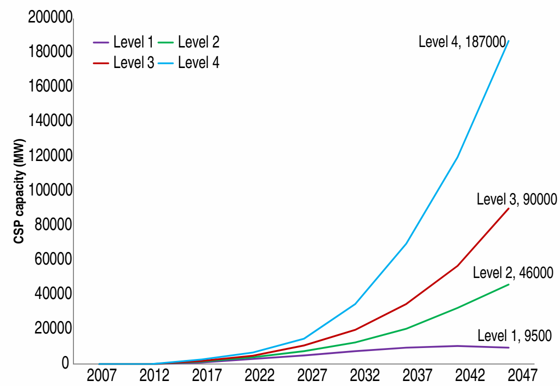
Level 3

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.

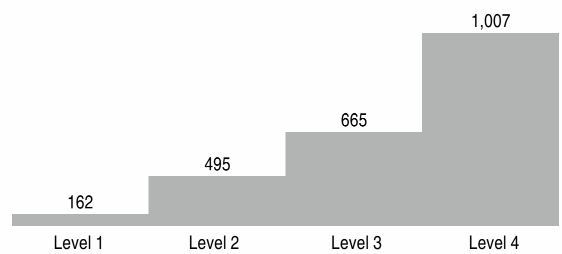
Level 4

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 746 TWh.

Concentrating Solar Power (CSP) Thermal Capacity (MW)



Solar CSP Generation (TWh/y) in 2047



2.5 DISTRIBUTED SOLAR PV

2.5.1 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. 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. Increased clarity on technical inter-connection, safety and metering standards would pave the way for faster deployment.The new target of 40 GW of solar rooftop by 2022 is likely to give a big boost to this technology.

2.5.2 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 cumulativecapacity 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

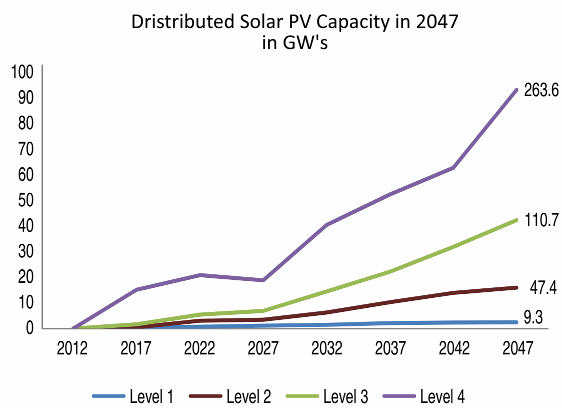
Level 2 assumes that a significant push for PV RFTP under the JNNSM will increase the penetration from 0.01 % in 2012 to 0.6% by 2022, with residential sector remaining the major contributor with a penetration rate of 3% in HHs by 2047. The total capacity reaches 47.4 GWs by 2047 and generates 79 TWh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

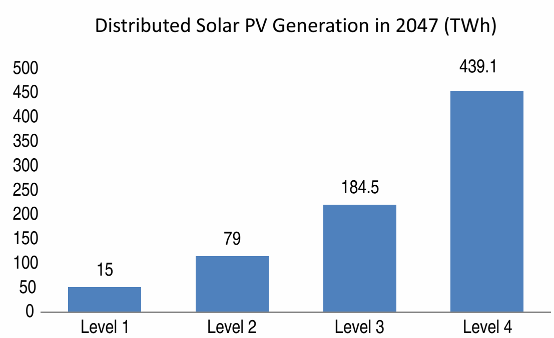
Level 3

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. 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 439.1TWh 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.





2.6 SOLAR WATER HEATING

The use of solar thermal energy for domestic purposes is a known phenomenon across India. 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.

2.6.1 SECTION OVERVIEW

Until 2001 the commercial and industrial sector contributed to 80% of SWH installations. As of today the residential sector is the largest sector contributing 80% of installation and sales for SWHS. 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.

2.6.2 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% House Holds (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

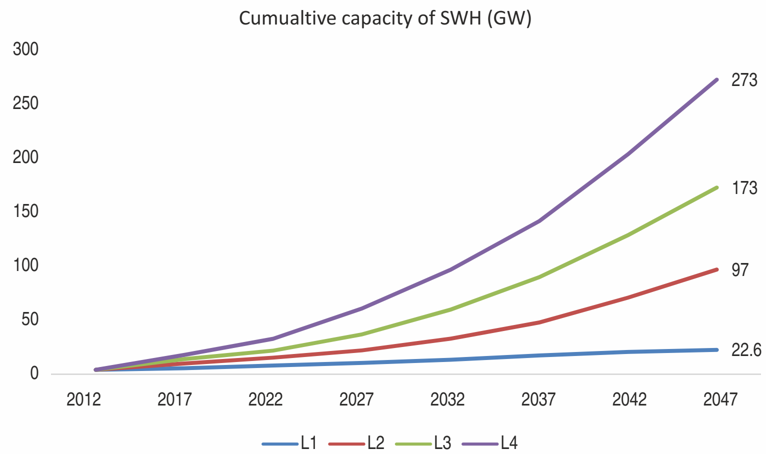
Level 2 assumes that the JNNSM target of 22 million sq. m is met by 2022, with residential sector remaining the major contributor with a penetration rate of 7% HHs by 2047. The total collector space reaches138 million sq. m. in 2047 with a cumulative capacity of 97 GW and the amount of electricity generated would be 16 TWh.

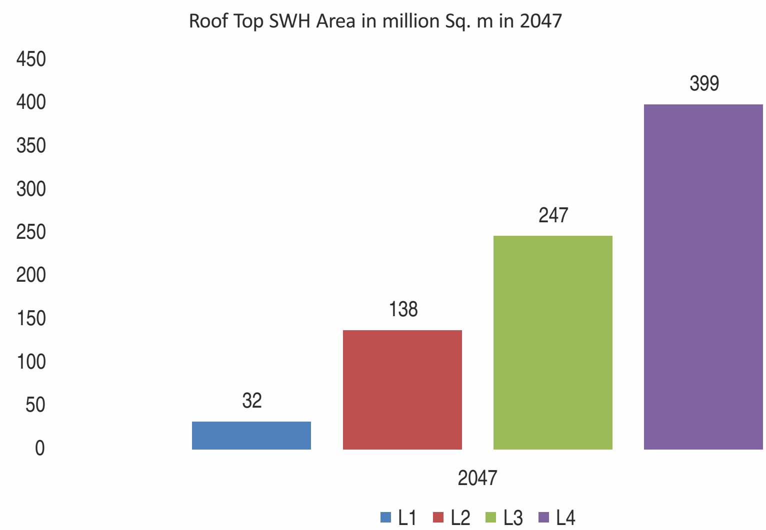
Level 3

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. 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

3. 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

- **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. 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.

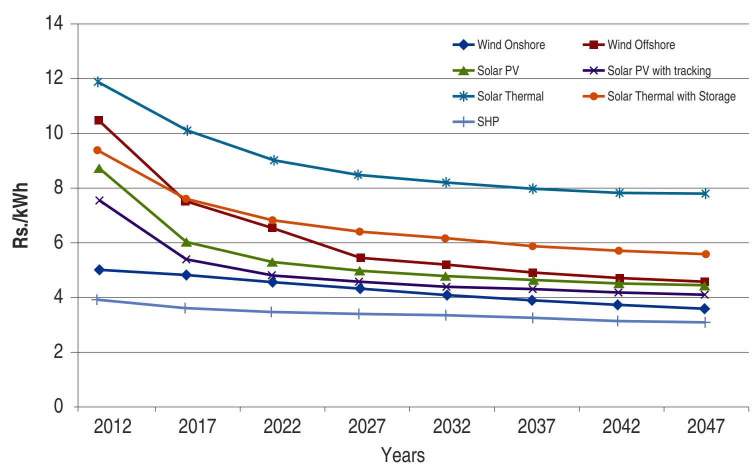
- **Concentrated Solar Thermal Power (CSP) with storage**: For Solar CSP with storage Capex is estimated at 19.2 cr/MW in 2012, for an 8 hour storage system by doubling the solar field cost (~ 60% of total Capex without storage). The tool assumes an overall cost reduction of 45% in 40 years. Opex for 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.

Levelized Cost of Electricity for Renewables



2.2 Nuclear

OVERVIEW OF NUCLEAR SECTOR

The Indian power sector is largely thermal-based, with nearly 68% of the 200 GW of installed capacity in 2012 accounted for by coal, gas, and diesel-based plants. Large hydro and other Renewable Energy Sources (RES - Small hydro, biomass, solar and wind) account for 15% and 13% respectively as of May 2015. Nuclear presently accounts for about 2% of the total installed capacity of 272.5 GW.

Capacity addition in the 12th plan is in accordance with the Government's Low Carbon Growth strategy for sustainable development of the power sector in the long run. The 12th plan estimates a capacity addition of conventional power of about 76,000 MW by 2017, to meet the projected energy demand in the country. Emphasis has been given to clean energy sources of nuclear, hydro and RES in order to reduce greenhouse gas emissions. The target capacity addition in the 12th Plan for these sources is 46,197 MW. Initial estimates of domestic uranium reserves (61,000 tonnes) are sufficient to operate 10,000 MW of heavy water reactors for about 40 years. More reserves have been found recently and the current estimates of Uranium reserves is about 1,97,000 tonnes as of September, 2013. After accounting for various losses including mining (15%), milling (20%) and fabrication (5%), the net uranium would be available for power generation is about 60%.

India has large thorium deposits. However, Thorium (Th232) is not fissile material and has to be converted to U233, using plutonium (Pu239), which is present in small quantities in nuclear reactor spent fuel. Fast Breeder Reactors (FBRs) provide an opportunity for exploiting India's thorium reserves. Therefore, India envisaged a three-stage indigenous nuclear power program:

Phase I: Build Pressurised Heavy Water Reactors (PHWRs): PHWRs use uranium fuel and the spent fuel rods are reproduced to extract plutonium.

Phase II: Reprocess spent fuel and utilise recovered plutonium to build FBR initially (FBR uses a plutonium core and depleted uranium blanket to breed more plutonium than the original output).

Phase III: Increase capacity later, with sufficient stock of plutonium (the plutonium core and thorium blanket yield U-233, and further uses the U-233 core and the thorium blanket).

With the comprehensive capabilities in all aspects of nuclear power, India is poised for a large expansion program, but the challenge is to pursue the three-stage program, develop and commercially deploy technologies for utilisation of thorium and ensure the country's long-term energy security.

India's nuclear capacity would reach to 20,000 MW by 2020 as per DAE, and the National Electricity Plan (Jan, 2012) also recognises this capacity. The Department of Atomic Energy (DAE), also estimates that the nuclear share would grow to 8.6% by 2032 and 16.6% by 2052. On the basis of the assumption of a successful FBR program, nuclear power is expected to reach to 200,000 - 275,000 MW in 2040 under pessimistic and optimistic scenarios respectively. As against this, the present installed capacity is 5,780 MW. About 4,200 MW reactors are under construction, and to be commissioned as per the 12th Five Year Plan (FYP) targets.

DRIVERS

- **Policy environment:** The Indo-US agreement for cooperation in civilian nuclear power permitted India to import uranium, reactors and technology under international safeguards. This has helped to improve the Plant Load Factor (PLF) of reactors from 50% in 2008 to 78% in 2012.
- **Public Acceptance:** The Fukushima nuclear accident has heightened public concerns about safety of nuclear power. This delayed the commissioning of Kudankulam nuclear reactors. There are also concerns about cost and waste disposal.
- **Site availability:** At present, nuclear reactors exist in seven sites. Of these, Kaiga can accommodate two more reactors and Kudankulam can accommodate four more reactors. In addition, eight new sites have been identified as following: Bhimpur, MP (700 MW PHWR), Chutka, MP (700 MW PHWR), Gorakhpur, Haryana (700 MW PHWR), Chayya Mitvirdhi, Gujarat(1100 MW, LWR), Haripur, WB (1000 MW, LWR), Jaitapur, Maharashtra (1650 MW LWR), Kovvada, AP (1500 MW, LWR), and Banswara, Rajasthan (700 MW PHWR).
- **Technology development:** India is relying on Fast Breeder Reactors (FBR), which have to be technically and economically proven. Further, the present reprocessing capacity is inadequate to meet the requirements of an FBR programme.

DATA AND ASSUMPTIONS

- Present plants under construction are commissioned during 12th Plan
- Each of the sites can accommodate up to six reactors. The sites are progressively utilised for reactors. Haripur site is not considered because of WB government's decision
- A limited number of imported Light Water Reactors (LWRs) are built that come with a supply of enriched uranium
- FBR technology is proven commercially
- Commercial thorium-based reactors are not considered till 2047
- New reprocessing plants are developed to meet the requirements of FBR program
- High level waste from reprocessing plants are fixed in glass and stored safely until a Deep Geological Repository is established
- Supply of uranium and enriched uranium continues unrestricted till 2047
- Reactor life of 50 years

Fuel Assumptions

The fuel requirements for various nuclear reactors have been estimated using data from NPCIL and CSTEP's analysis.

Plant Type	Plant Capacity (MW)	Core load (Te)	Reload Estimate (Te/Year)	Fuel Requirement (Te/TWh)
PHWR	220	51	36	23.35
PHWR	540	112	69	18.23
PHWR	700	104	98	19.98
LWR	1000	71	22	3.14
LWR	1100	97	17	2.21
LWR	1650	127	23	1.99
FBR	500	4	-	-

Note: Fuel requirement is estimated assuming 80% PLF.

Cost Assumptions

There is no firm estimate available for nuclear technologies. Therefore, best estimates can be drawn from a number of publicly available sources, essentially to help the user of the IESS tool to make broad comparisons with other sources of electricity. A recent report assessing economic viability of nuclear power for Netherlands assumed cost of a new plant to be EUR 3,000/kW (currently equivalent to INR 250,000/kW or INR 25 crore per MW), the levelised cost (LCOE) of nuclear power from the plant to be EUR 56/MWh or INR 4.7/unit.

A Bloomberg report in 2010 referred to the cost of an EPR (1650 MWe), based on construction currently underway as EUR 3 billion in China, EUR 5 billion in France and EUR 8.5 billion in Finland. As more plants of the same type are built and the design gets standardised, the cost of construction can be expected to drop. Nevertheless, a variation in construction cost is to be expected depending on the geographic location and the problems faced during construction. According to Areva, the post-Fukushima modifications would lead to a revised cost of an EPR in France to EUR 8.5 billion. A report in The Hindu in November 2013 stated that the initial capital cost of the EPR to be built in Jaitapur would be about INR 27-30 crores per MW.

A recent Reuters report stated the cost of eight Westinghouse AP1000 reactors ordered by China as USD 24 billion or USD 3 billion per reactor (equivalent to INR 17 crores per MW). Quoting the Chairman of AEC, India, NEI Magazine reported the cost of 700 MW reactors being built at Kakrapar and Rajasthan to be about INR 12,320 crore for a twin-unit station, or INR 8.3 crores per MW.

The Executive Summary of the EIA for the Chutka project prepared by NPCIL dated March 2013 cites a figure of INR 16,500 crore for the two 700 MW units proposed at the site that works out to about INR 11.8 crores/MW. News release by PIB after the PM laid the foundation for the 4-unit Gorakhpur project, said the cost of the project is estimated at INR 20,594 crore. This works out to about INR 7.5 crore per MW.

Based on these sources and inputs from industry experts, the assumed capital costs of nuclear reactors are described as follows. The high estimate of capital cost for Pressurized Heavy Water Reactor (PHWR) is taken to be 8.3 Cr/MW in 2012 which will increase by 15% over a period of 40 years i.e. by 2052 to 9.54 Cr/MW. The low estimate is taken as 8.3 Cr/MW in 2012 which will decrease by 15% in 2052 to 7.05 Cr/MW, point estimate being 8.3 Cr/MW in 2012 which will decline by 10% in 2052 to 7.40 Cr/MW.

The high estimate of capital cost for Light Water Reactor (LWR) is fixed as 21Cr/MW in 2012 which will rise by 15% in 2052 to 24.15 Cr/MW. The low and point estimate are taken as 21 Cr/MW in 2012 which will fall by 15% in 2052 to 17.85 Cr/MW.

The high estimate of capital cost for Fast Breeder Reactor (FBR) is presumed to be 11 Cr/MW throughout till 2047. The point and low estimate are considered as 11 Cr/MW in 2012 waning by 15% in 2052 to 9.35 Cr/MW.

O&M costs are assumed to be 2.5% of the capital costs for all the three reactors. Fuel cost for domestic and imported natural uranium (used by PHWRs) is assumed to be INR 0.78 crore per tonne equivalent of uranium. One tonne equivalent of low-enriched uranium (LEU, used by LWRs) is assumed to require 10 tonne equivalent of natural uranium. In addition, a cost of INR 6.68 crore per tonne equivalent of LEU is incurred to enrich natural uranium. The cost of plutonium (used by FBR's) is taken as 652.5 crore per tonne.

The capital cost for the chosen trajectory is calculated by multiplying the capacity addition in each nuclear technology (rows 63, 68, and 73) with its investment cost (rows 175, 182, and 190). The O&M cost for the chosen trajectory is calculated by multiplying the cumulative capacity for each technology (rows 23, 32, and 41) with its per unit O&M cost (Rows 198, 206, and 214). Similarly, the fuel cost for the trajectory is calculated by multiplying the fuel used in the trajectory with per unit fuel cost (including cost of enrichment). The total cost associated with each trajectory is derived by aggregating the capital cost, O&M cost, and fuel cost for all technologies and fuels considered in that trajectory.

TRAJECTORIES

The present installed nuclear power generation capacity is 5,780 MW and it contributes 3% of total electricity generation. There are 21 operating reactors in seven sites. Pressurized Heavy Water Reactors (PHWRs) which use natural uranium, account for almost all of present installed capacity. These reactors are operated at PLF of 50-60% because of uranium supply bottlenecks. However, recent uranium imports have allowed the PLF to increase to 80%.

Presently, to run nine of the 21 operating reactors, India relies on uranium imports. Uranium is assumed to be available for imports until 2047 and beyond.

Level 1

Level 1 is a pessimistic trajectory. It assumes that the present reactors under construction (4,200 MW) are completed and commissioned. This will take the cumulative nuclear capacity to 9,980 MW by the end of 12th Plan. However, the present public sentiment regarding nuclear power slows the building of further nuclear power plants in India - only 3000 MW of additional capacity is added between 2017 and 2047. The existing reactors continue to be operated till their lifetime. A few of the older reactors will be decommissioned and thus the nuclear power capacity will become 11,360 MW by 2047 which was 4680 MW in 2012. The electricity generated would rise to 79.7 TWh in 2047 from 26.7 TWh in 2012.

Level 2

Level 2 assumes that new reactors are developed in the eight new sites identified. The government's approval exists for setting up 700 MW reactors in five sites: Gorakhpur (2), Chutka (2), Bhimpur (2), Kaiga (2) and Banswara (4). In addition, there are plans to build two Light Water Reactors each in Kudankulam, Jaitapur, Kovvada and Chaya Mithvirdhi. Further, two more FBRs will be commissioned. Thus, 14,750 MW of new nuclear capacity is added taking the total to 26,110 MW by 2047. The corresponding electricity generated in 2047 would be 183.1 TWh.

Level 3

Level 3 assumes that all the sites identified for PHWRs are fully utilised. Six reactors are assumed per site, except for Kaiga, where two reactors are assumed to be built. Further, three Light Water Reactors are built in Kudankulam, Jaitapur, Kovvada and Chaya Mithvirdhi. In addition, the spent fuel from thermal reactors is used to build 2,500 MW FBR. Thus, the total nuclear power capacity reaches 45,010 MW by 2047 and the electricity generated would be 315.6 Twh.

Level 4

This assumes that three new sites are identified, which can accommodate about 15,000 MW through new PHWRs and LWRs. Also, four reactors are built in Hirapur to add further 4000 MW to the grid. In addition, up to 4,000 MW of FBRs are developed. In this scenario, the nuclear capacity reaches 78,060

MW by 2047. The corresponding electricity generation in 2047 would be 547.4 TWh.

Figures 1 and 2 show the electricity generation and installed capacity trajectories from the four levels, respectively:

Figure 1: Nuclear Electricity Generation under Levels 1 to 4 (TWh)

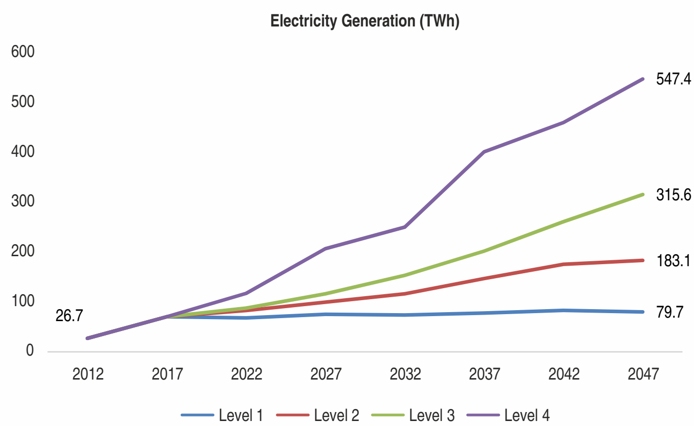
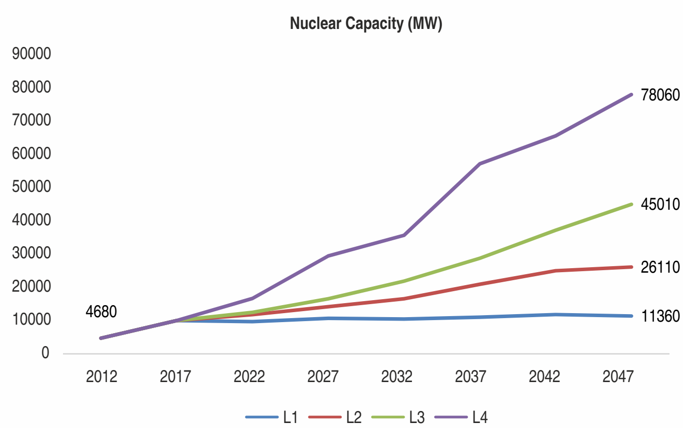


Figure 2: Nuclear power Installed Capacity (Mega Watt (MW)



2.3 Large Hydroelectric Power

OVERVIEW OF HYDRO SECTOR

The Indian power sector is largely thermal-based, with nearly 68% of the installed capacity accounted for by coal, gas, and diesel-based plants. Large hydro and other Renewable Energy Sources (RES - Small hydro, biomass, solar and wind) account for 15% and 13% respectively as of May 2015.

Capacity addition in the 12th plan is in accordance with the Government's Low Carbon Growth strategy for sustainable development of the power sector in the long run. The 12th plan estimates a capacity addition of about 76,000 MW by 2017 from thermal, nuclear and large hydro sources, to meet the projected energy demand in the country. In addition to this, the Ministry of New and Renewable Energy has set a target of 1, 75, 000 MW to be achieved by 2022, with renewable energy sources of solar, wind, small hydro power, and biomass power. Hence, emphasis has been given to clean energy sources for nuclear, hydro and RES to reduce greenhouse gas emissions. In order to accelerate hydro power development in India, the Ministry of Power (MoP) introduced the National Policy on Hydropower Development in 1998. Through various measures, the Government of India (GoI) aims to realise 100% hydropower potential for the country by 2025-26. To this effect, the Central Electricity Authority (CEA) has undertaken feasibility and ranking studies in order to determine the feasible completion of large and small hydro projects that are under development, in the 12th and 13th plans.

As per the CEA, India has nearly 1, 50, 000 MW of economically exploitable large hydro potential. This is available mainly in the Brahmaputra, Indus and Ganga river basins, at a Load Factor (LF) of 60% or lower. Figure 1 and Table 1 represent the major river basins and their share in the installable potential.

Figure 1: Basin-wise Large Hydro potential in India
Source: CEA

Table 1 : Basin-wise Large Hydro potential in India (CEA)

River basin	Probable installed cap. (MW)
Indus	33,832
Ganga	20,711
Central Indian Rivers	4,152
West flowing (Southern)	9,430
East flowing (Southern)	14,511
Brahmaputra	66,065
Total	**1,49,000**

Of the estimated potential, around 41632 MW is currently installed.Large hydro projects, however, are accompanied by significant ecological impacts and displacement of local population and livelihoods, which limits its viability to account for a major share of the electricity generation mix in the long run. (The share of small hydro generation in the power sector has been accounted for in the trajectories on Renewables sector).

In addition to large hydro, Pumped Storage Plants (PSP) provides flexibility to dispatch, if accompanied by short-term storage (pondage). This can be of value in balancing the intermittency that would be introduced by increased penetration of other RE sources such as wind and solar in the electricity mix. Similarly, pumped hydro storage schemes utilise off-peak electricity from intermittent sources to pump water from a river or a lower reservoir, to a higher reservoir to allow its usage during peak times. Other advantages of PSP include increasing the availability of reactive capacity for regulation, provision of spinning reserves in the system to meet sudden load changes in the electricity grid. PSP may result in considerable savings in fuel usage when operated in an integrated manner.

DRIVERS

- Economically feasible potential
- Policy environment in the country
- Level of socio-ecological impact of large hydro construction
- Benefits from Refurbishment & Modernization (R&M), and Life Extension (LE) activities

DATA AND ASSUMPTIONS

- Current Installed capacity and potential estimates are as reported by CEA
- A capacity utilisation factor of 40% has been assumed as per the national norms specified by the Central Electricity Regulatory Commission (CERC)

- Since large hydro plants have long operational lifetimes, current plants are assumed to continue operation without retirement within the timeline of analysis. However, R&M and LE activities are assumed to continue for improved performance

- PSPs are not accounted for in the installed capacity. Usage of PSPs is dependent on the ability of the system to utilise off-peak generation to pump the water for storage. Since the purpose of this exercise is for capacity planning at an aggregate level, scheduling of pumped hydro to meet peaking load is out of its current scope. In each trajectory, a foreseeable installed capacity from PSPs are mentioned for further discussion

- Status of PSPs is as per the latest reassessment study available from CEA.

Cost Assumptions

The capital costs for various large hydro projects in the country are available in the United Nations Framework Convention on Climate Change's (UNFCCC) database which documents the financials of the projects that avail benefits from the Clean Development Mechanism. Based on a sample of 19 projects available from UNFCCC's database, the capital costs for large hydro projects in India lie in the range of INR 4 crores to INR 10 crores per MW (as shown in Figure 4). These costs are highly site specific and represent projects in J&K, Andhra Pradesh, Sikkim, Meghalaya, and Nepal. Consistent with the costing methodology in the IESS, three estimates are being offered - a high cost, low cost, and an average (point) cost scenario.

The highest cost in this sample, treated as an outlier, is INR 14.2 crore per MW and is considered as the high end of the cost estimate. Similarly, the lowest cost is derived from the sample as INR 4.7 crores per MW. An average of the high and low estimates is considered to be a point estimate for estimating the cost trajectories. The point estimate is thus 9.5 INR Cr./ MW. It is comparable to the normative cost of INR 8 Crores per MW for a large hydro project, as specified by the National Electricity Plan of the Central Electricity Authority.

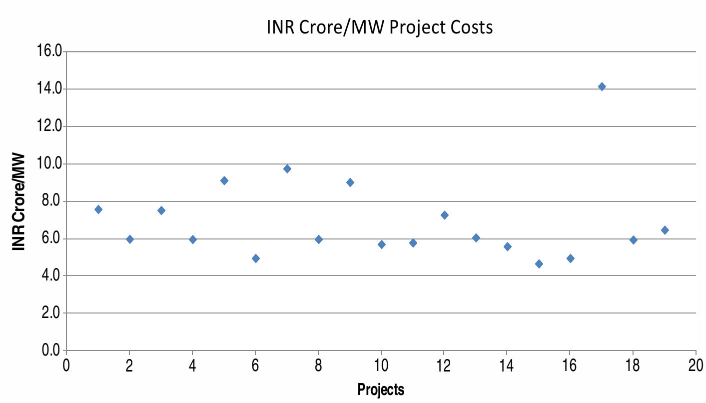


Figure 4: Large Hydro Capital Costs in India

Based on these sources, the assumed capital costs of large hydro projects are shown in Table 2.

Table 2: Costs for Large Hydro Projects

Cost Trajectory	Capital cost (INR Cr/MW)
High	14.2
Point	9.5
Low	4.7

For Operations & Maintenance (O&M) costs, the Central Electricity Regulatory Commission specifies norms of O&M at 4% and 2.5% of project costs for stations < 200 MW and > 200 MW respectively for first year, with an annual escalation of 6.64% for subsequent years. This is assumed as the high and low estimates for O&M costs. The point estimates of capital and O&M are taken as the average of high and low cost estimates.

In order to estimate the trajectories for the unit costs per MW, the base point in 2012 is considered to be the high estimate (i.e. 14.2 INR Cr/MW), to begin with. Starting with this base value, the point estimate gradually reduces over the intermediate years, to the average value of 9.5 INR Cr/MW by 2047. Similarly, the low point estimate reduces to the value of 4.7 INR Cr/MW by 2047. This is shown in below in Figure 5.

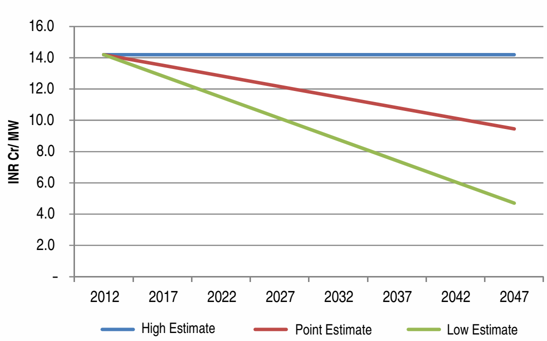


Figure 5: Large Hydro Capital Costs per MW

To the total cost trajectories, the O&M costs are applied at 4% and 2.5% of the high cost and low cost estimates respectively. The point estimate of the O&M cost is the average of the high and low O&M costs.

TRAJECTORIES

Level 1

In this pessimistic trajectory, it is assumed that current plants continue to operate with scheduled maintenance efforts through the period of analysis. Due to unresolved constraints on issues of large-scale ecological damage, resettlement and rehabilitation, only plants which have been commissioned and expected to yield likely benefits during the 12th plan are accounted for in capacity addition till 2017. No new construction is assumed after this, and installed capacity increases to 49 GW in 2047 from 41 GW in 2012. The electricity generated in 2047 would become 171.8 TWh which was 143.8 TWh in 2012.

No new pumped hydro schemes are completed (2047 Installed operational capacity: 2, 600 MW)

Level 2

As per estimates by CEA and the Working Group on Power for 12th FYP, it is assumed that up to 9, 204 MW of large hydro schemes would yield benefits in the 12th plan, and 12, 000 MW in the 13th plan (2047 Installed capacity: 75 GW). Under construction pumped hydro schemes are completed (2047 Installed operational capacity: 3, 680 MW).The amount of electricity generated in 2047 would be 263 TWh.

Level 3

In addition to achievement of govt. plans, level 3 includes the benefits from completion of R&M and Life Extension (LE) efforts. This results in an additional capacity of 4, 064 MW across 12th FYP (as per Report of the Working Group on Power for Twelfth Plan), andis assumed to continue over the 13th Plan. Beyond the 13th Plan, past trends in capacity addition are expected to continue till 2047 and the total Installed capacity would rise to105 GW. The corresponding electricity generation in 2047 would be 368 TWh.

In addition to previous levels, Pumped Hydro Schemes under survey and investigation are completed (2047 Installed operational capacity: 9, 630 MW).

Level 4

Advances in technology development, and R&D efforts in de-silting, integration of regional grids, forecasting etc. are assumed to take place. Benefits from advances in R&M and LE are assumed to increase to 20, 000 MW per FYP for the period of analysis, to reach up to 1, 50, 000 MW (100% of potential) by 2047 which will generate 526 TWh of electricity.

As indicated by various studies, preferable capacity of pumped storage installation for a thermal dominant power system is assumed to be 5% of total installed capacity (2047 Installed capacity dependent on total installed capacity from other sources).

Figures 6 and 7 show the energy generation trajectories from the four levels, and comparison with global trends, respectively:

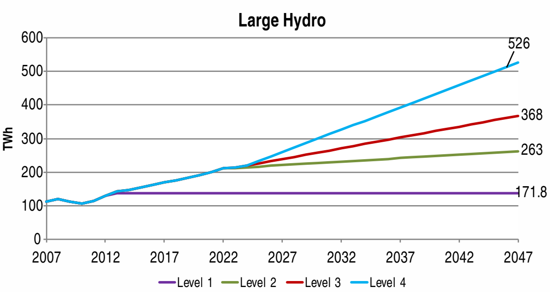


Figure 6: Large Hydro Energy Generation under Levels 1 to 4 (TWh)

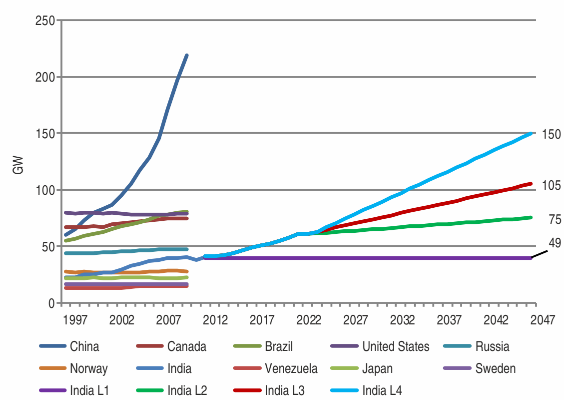


Figure 7: Large Hydro Installed Capacity comparison with global trends (GW)

2.4 Bioenergy

I. OVERVIEW OF THE SECTOR

Bioenergy assumes crucial importance in terms of energy security, environment and economy. It is one of the prime options for local indigenous energy production in the country. The stored form of energy in biomass is as important as its production. This makes it a renewable candidate for power generation and liquid fuel production. Liquid transportation fuel has a critical implication on the nation's economy given the huge strain placed by the crude oil import bill (6,000 billion rupees). Bioenergy would help mitigate carbon emissions and meet future emission requirements.

Bioenergy production is already estimated to be about 1842 TWhr/year (25% of the primary energy production in India and offers a healthy picture of India's use of renewable energy. This refers to mainly the vast quantities of agricultural and forest residue used for household cooking and power generation (95% and 3.5%). The production and the efficiency of utilization are expected to increase and it is also expected to be converted more to higher-value energy forms (electricity, transportation fuels). However, what is of concern is the un-healthy way of using this fuel in inefficentcookstoves. The above is analyzed in the Cooking sector lever in the IESS.

The components that presently make up bioenergy production in India are agricultural residue, forest residue, sugarcane molasses-based bioethanol, Jatropha biodiesel and biogas. In future, lignocellulosic liquid fuels, microalgae, macroalgae and wasteland bioenergy crops are envisioned to be part of the Indian bioenergy sector. As India's transport sector is poised for a major continued growth with rising vehicle ownerships triggered by rising incomes, liquid fuels are likely to play a major role. As India does not have a healthy oil production, biofuels could come to the rescue, especially second generation ones, wherein lignocellulosic processes may be deployed. The present analysis in IESS has captured all the three sources - traditional (first generation - ethanol), emerging (second generation - lignocellulosic) and futuristic (micro and macro algal) biofuels. Therefore, this analysis is complete with all forms of biofuels - solid, liquid and gaseous built into it.

II. DRIVERS

Relevant policy framework needs to be developed for the future generation biofuels that have much larger scope and require R&D - Jatropha and Pongamia biodiesel from wastelands, lignocellulosic liquid fuels and algal biofuels. Proper impetus and future vision must be developed given the importance of such fuels on the energy security and economy of the nation.The drivers for the biofuel planning exercise are

1. Policy environment in India - Clarity, consistency & transparency in policy and pricing mechanism across the value chain for the present biofuels
2. Availability of raw material - Sugarcane Molasses, Jatropha & Pongamia for first generation biofuels and lignocellulosic biomass for second generation biofuels
3. Technological advancement - Lignocellulose biomass to liquid fuels, algae to biofuels

In the present planning exercise, the next-generation biofuel technologies have been estimated to take varying times to be commercially ready (2017-2032) and they follow different rates of development from there on for the different levels 1, 2, 3 and 4. Biogas from anaerobic digestion of cattle and poultry waste, food waste and pressmud is envisaged to play appropriate role in the bioenergy scenario building. India has had a long history of extensive family-size digester installations starting from the 1970s and the design know-how.

III. COMPONENTS OF BIOENERGY (ASSUMPTIONS AND SCENARIOS)

III.a Non-fodder agricultural residue:

Total annual agricultural residue production in India is 619 million tons. Of this, the residue that is not used as animal fodder is 319 million tons. Out of this non-fodder residue, 214 million tons (67%) is already being used as bioenergy (46% household cooking, 5% power generation, 16% other energy applications), while the remaining residue (33%) accounts for other uses. The large quantity of biomass used for cooking is used inefficiently in traditional cookstoves and this presents a vast potential for bioenergy applications in terms of use in improved-efficiency cookstoves, power generation and conversion to liquid fuels. Past agricultural productivity trends and future possibilities have been considered conservatively for future agri-residue projection. The rate of increase in agricultural residue productivity has thus been assumed to be 0%, 0.25%, 0.5% and 0.75% (annual) for Levels 1, 2, 3 and 4. For all the levels, only the present proportion of biomass used for bioenergy (67%) has been considered for various forms of bioenergy applications even if the overall residue production increases. The proportion of biomass classified for other applications has been retained as a constant 33% for all levels and projections, leaving enough scope for other applications and developments (paper industry and other small/medium rural enterprises).

The bio-energy end-use forms of agri-residue have been classified as solid fuel for household cooking, power generation, liquid fuels and other energy applications. Power generation refers to the usage of biomass for electricity production as well as heat applications (industries). Since no comprehensive data exist for exclusive heating applications and it is of relatively less proportion (< 10%), this has been clubbed with electricity production and termed together as power generation). Liquid fuels refer to second-generation biofuels (ethanol and pyrolytic fuels) that are expected to have mature technologies in future. Other energy applications refer to biomass used for applications such as commercial cooking, commercial heat feedstock and energy consumption of local/rural small and micro industries.

In Level 1, the proportions of non-fodder agricultural residue apportioned to household cooking, power generation, other energy applications and liquid fuels start at 46%, 5%, 16% and 0% respectively. The proportions of the residue to power generation and liquid fuels are envisioned to increase to 16% and 6% by 2047. The household cooking proportion of agri-residue reduces to 3% as other advanced cooking technologies penetrate into the market. The proportion to other energy applications increases to 42%. In level 2, the proportions of power generation and liquid fuels increase to 27% and 12% by 2047 and that of other energy applications to 25%. The household cooking proportion remains at 3%. Liquid fuels return the most value as an energy product. Power generation comes next. The suitability of feedstock and the reach of technologies are expected to result in a shift towards the higher value products, power generation and liquid fuel production, in higher levels. In level 3, the proportion of the residue to power generation is envisioned to become 43% by 2047 and liquid fuels are credited with 23% split. The proportion of household cooking reduces to 2% leaving just 0.5% for the other energy applications proportion. In level 4, the proportion of residue towards liquid fuels increases to 30% and that of power generation to 36%. The proportion towards household cooking is set at 1% and that of other energy applications at just 0.1%.

III.b Forest residue:

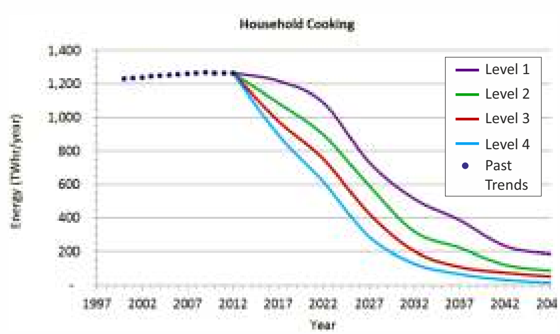
India Forestry Outlook Study (2009) conducted by the Ministry of Environment and Forests, Government of India states that presently 152 million tons of fuelwood is being used for cooking in rural India. 180-200 million tons/year of fuelwood from forest is rated to be the sustainable limit for recovery from forests. This is extended across the four levels accordingly. The forestry biomass is modeled to be used for cooking (household as well as commercial) and other energy applications as solid fuel across all the four levels, but not for power generation or liquid fuel production. The details of this are listed in the sub-sections below.

Sub-components of non-fodder agricultural residue and forest residue:

Household cooking: Part of agricultural residue and forest residue are used for household cooking. This has been used rather inefficiently (15% in traditional cookstoves). In future, improved-efficiency cookstoves and other fuel forms (LPG) are expected to replace this mode of cooking. The agri-residue portion that is used for household cooking is expected to be gradually diverted to power generation and liquid fuel conversion. From 46%, the portion of agri-residue reduces to 37%, 28%, 22% and 18% across the four levels by 2022, 16%, 10%, 5%, 4% by 2032 and eventually to 3%, 3%, 2%, 1% by 2047.

The proportion of forest residue accounting for household cooking remains relatively higher than that of agri-residue because the agri-residue is relatively more organized and easier for collection and diversion for other uses. Being diverted to cooking is seen to be an easier option for forest residue because of the way it is collected. The proportion of forest residue diverted for household cooking changes from the present 70% to 44%, 36%, 26% and 17% across the four levels by 2027 and to 18%, 4%, 3% and 1% by 2047.

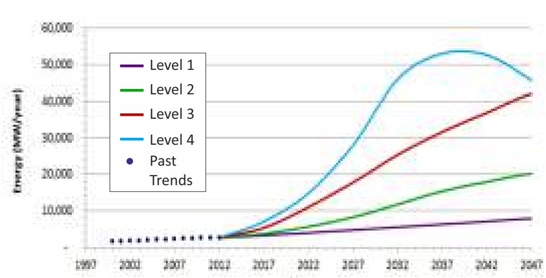
The present energy supply towards household cooking, combining both agri-residue and forest residue, is 1745 TWhr/year. This is projected to reduce to 185, 87, 52 and 15 TWhr/year.



Projection of Biomass as Energy Source for Household Cooking

Power generation: Biomass power plants have been considered for electricity production from agri-residue biomass. Some of the non-fodder agri-residue is already used for rural residential electrification, heating and industrial electricity cogeneration. Less than 10% of the present usage corresponds to heating applications. Biomass gasification, a different technology, is employed for rural electrification and many heat applications, but since no accurate and comprehensive data exists, this has been clubbed with electricity production for accounting purposes as mentioned earlier. The present reported power generation from biomass in India is 2554 MW and this corresponds to about 5% of agricultural residue. Biomass split corresponding to power generation is progressively increased to 16%, 27% and 43% by 2047 for Levels 1, 2 and 3. In Level 4, the agri-residue split towards power generation increases to a higher proportion of 45% much quicker, by 2032-37, but begins to drop off as more biomass is routed to the production of liquid fuels, a product that is of higher value. It reduces to 36% by 2047. The energy conversion efficiency of the power plants does not improve from the present 25% in Level 1. In Levels 2, 3 and 4, the efficiency improves gradually to 35%, 42% and 50% by 2047 as more advanced plants are installed. Baseline electricity cogeneration from agri-residue has been adopted from and was extrapolated for the recent past and the near future.

The overall power generation is projected to increase gradually to 7,819 MW by 2047 in Level 1. It is projected to increase progressively to 20,412 MW and 44,098 MW by 2047 for Levels 2 and 3. The generation reaches a maximum of 53,013 MW by 2037 in Level 4 after which it decreases gradually to 37,557 MW by 2047 as more biomass is shifted towards liquid fuel production as mentioned earlier.



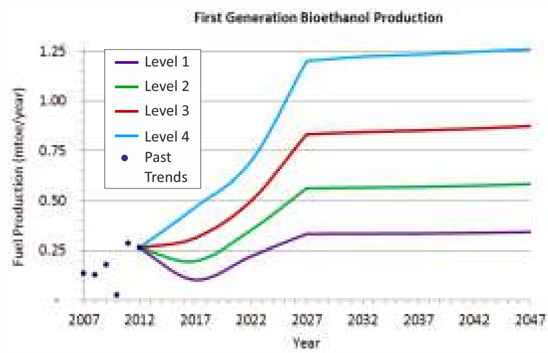
Projection of Power Generation from Biomass

Other energy applications: This refers to the applications of agri-residue and forest residue biomass other than household cooking, power generation and liquid fuels. These include energy requirements of local small and micro industries and enterprises, commercial cooking, commercial heat applications and energy requirements of various other unorganized sectors. This could also be seen as possible surplus bioenergy availability in future that may be used for appropriate demand as necessary. After providing for household cooking, power generation and liquid fuels, the left-over biomass is diverted for this application as follows. From the present 16% split of agri-residue apportioned to other energy applications, the agri-residue split increases to 41% by 2037 and stabilizes under Level 1. The agri-residue split increases to 36% by 2032 and lowers to 25% by 2047 under Level 2. It increases to 30% by 2027 by 2027 and lowers to 0.5% by 2047 under Level 3. It increases in the immediate future itself to 27% and lowers gradually to 0.1% by 2047 under Level 4. The proportion of forest residue increases from the present 30% to 82%, 96%, 98% and 100% by 2047 across the four levels. The energy recovery efficiency is projected as a constant 17% for Level 1 and as a progressively increase to 26%, 31% and 38% for Levels 2, 3 and 4 by 2047. The overall energy supply relating to the other energy applications increases from the present 480 TWhr/yr to 1293 TWhr/yr by 2047 under Level 1. It increases to 1300 TWhr/yr by 2032 and stabilizes thereafter under Level 2. It increases to 1283 TWhr/yr by 2032 and decreases gradually to 936 TWhr/yr by 2047 under Level 3. It reaches 975 TWhr/yr by 2022 and stabilizes from there on under Level 4.

III.c Bioethanol (first generation):

In India, this presently refers to fuel ethanol produced from sugarcane molasses. The sugarcane cultivation area on average varies from 4 to 5 Mha. The current bioethanol production from sugarcane molasses is 0.4 million tons/year (installed capacity: 1.6 million tons/year). Sugarcane is a resource intensive crop. So no substantial increase is considered in its cultivation. It has only limited scope. In fact, the fuel ethanol production is projected to drop in the near future for lower levels as there may be more diversion to other markets. It is envisaged that sugarbeet cultivation would grow in India in future (15,000-30,000 ha) and would contribute towards fuel ethanol production. Cultivation of sweet sorghum has also been considered as feedstock for bioethanol (1,000-10,000 ha). 4.5 to 6 Mha of land is projected for the aforementioned sugar crop plantations in total across the four levels for bioethanol production. This land has been modeled to be diverted from the cultivable land portion. The first generation ethanol production attains saturation (0.5, 0.9, 1.35 and 1.9 million tons/year) by 2027 after which the production stagnates due to feedstock limitation.

Fuel ethanol production from sugarcane molasses is expected to become even lower than the present value for Levels 1 and 2 in 2017 and for Level 1 in 2022. But fuel ethanol is projected to be produced even from sugarcane juice for Levels 3 and 4 in 2015-2024 and for Level 4 in 2027. The fraction of sugarcane molasses allocated for fuel ethanol production starts from 0.1-0.25 for four levels in 2017 and reaches 0.3-0.6 in 2027. The fraction of sugarbeet juice allocated for fuel ethanol production is 0-0.15 in 2017 and 0.4-0.6 in 2027. The fraction of sugarbeet molasses is similar to that of sugarcane molasses. The 2027 saturation values for fuel ethanol from sugarcane molasses, sugarbeet juice, sugarbeet molasses and sweet sorghum are 0.5-1.8 million tons/year, 260-6,490 tons/year, 56-1,141 tons/year and 2,320-24,854 tons/year across the four levels.

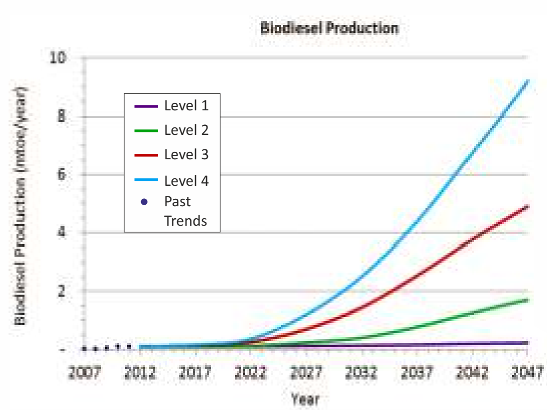


Projection of First-Generation Bioethanol

Note:Ethanol contains only 65% of the energy content of equivalent mass of petroleum oil. Hence one million tons (mt) of ethanol is equal to 0.65 millon tons of oil equivalent (mtoe)

III.d Biodiesel:

Biodiesel production has always been envisioned to be produced from non-edible oil plantations (Jatropha, Pongamia) in marginal/waste lands. The present biodiesel production in India has been estimated to be 0.05 million tons/year. Large scale blending of biodiesel with conventional diesel has not begun extensively in India and it has been reported that biodiesel is mostly utilized by the informal sector locally for irrigation and electricity generation and by the automobile and transportation companies for running their experimental projects. Marginal land areas allocated for the four levels are 0.5, 2, 4 and 6 Mha respectively (increasing progressively to 2047). Oil yields vary from 0.5 to 2 tons/ha/year across the four levels. The biodiesel production is projected to reach about 0.25, 2, 6 and 12 million tons/year by 2047 across the four levels.



Projection of Biodiesel Production from Non-Edible Oil Crops

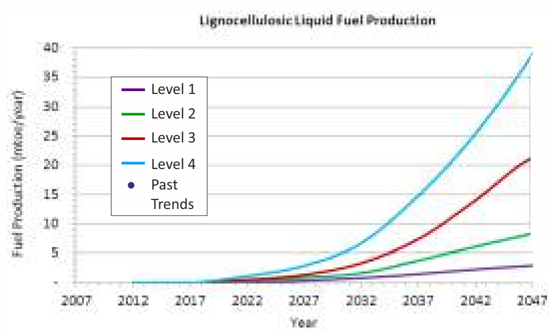
III.e Bioenergy crops from restored wastelands:

Wastelands are envisioned to be reclaimed and planted with bioenergy crops for biomass production. This biomass would be converted to liquid fuels similar to the conversion of agri-residue biomass. The wastelands in India are estimated to be 47.22 Mha. Of this, 24 Mha are estimated to be land that could qualify for bioenergy crop plantation after restoration. The crops could be bamboo, other grass varieties, trees and shrubs (Acacia tortilis, Prosopischinensis, Calotropis spp., Lantana indica, and Euphorbia spp.). In Level 1, no wasteland reclamation or bioenergy crop plantation is envisioned. In Levels 2 through 4, 0.8, 2.5 and 4 Mha of wastelands are envisioned to be reclaimed for bioenergy crop plantations and the plantations are initiated from years 2027, 2022 and 2017 respectively. Biomass productivities are rated to be 3, 5 and 8 tons/ha/year. The biomass production is projected to increase gradually to 2.4, 12.5 and 32 million tons/year across the three levels by 2047.

Sub-component of non-fodder agricultural residue and wasteland bioenergy crops:

III.f Lignocellulosic liquid fuels:

Part of agri-residue and the bioenergy plantations are envisioned to be used as feedstock for the production of liquid transportation fuels. This is seen to be a higher value energy product compared to other end use energy forms of biomass. Presently lignocellulosic ethanol and pyrolytic fuels are among the prominent biomass-derived transportation fuel options for the future ethanol has been taken as a representative liquid fuel from biomass for the Indian context. The present energy yield of lignocellulosic ethanol production is rated to be 20%. The end energy yields projected for the conversion process are 35%, 43%, 50% and 55% by 2047 for Levels 1 through 4. The liquid fuel generated from agricultural residue is projected to reach 2.9, 7.8, 18 and 30 mtoe/year by 2047 across the four levels. The fuel generated from wasteland bioenergy plantations is projected to reach 0.5, 3 and 9 mtoe/year by 2047 for Levels 2 through 4. The combined lignocellulosic liquid fuel production from both agricultural residue and bioenergy plantations (2.9, 8.3, 21, 39 mtoe/year across the four levels) is shown in the figure below.



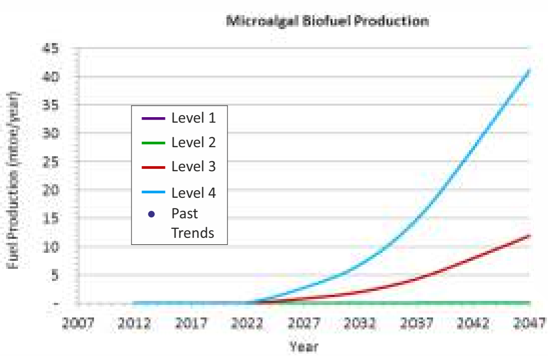
Projection of Lignocellulosic Liquid Fuel Production
(from Agri-Residue and Energy Crops)

III.g Microalgae:

Microalgae are microscopic unicellular suspensions in water. They are among the fastest growing organisms and they produce lipids as they grow. Their lipid yields are 10-50 times higher than the conventional oil crops. The technology is still in the R&D stage. Sea water (marine microalgae) is considered to be the appropriate water source for microalgal fuel production in India given that freshwater is a precious resource in the country. Microalgal production is expected to happen in the coastal locations. The technology qualifies theoretically by resource assessment to cater to the magnitude of India's transportation fuel needs.

Since the technology of microalgal biofuels is considered to be in a relatively earlier stage of development compared to lignocellulosic biofuels, the projection of microalgal biofuels has been kept quite conservative for future projections. The projections for Levels 1 and 2 have been kept low and they are increased for Levels 3 and 4 to hint the potential of this fuel.

500 and 500 ha of land are envisioned for microalgal cultivation for Levels 1 and 2 while 0.35 and 0.65 Mha are envisioned for Levels 3 and 4. Varying microalgal productivity from 25 to 75 g/m2/day and lipid content from 18% to 38% across the four levels, the microalgal fuel production is projected to be 0.005, 0.09, 12 and 41 million tons/year across the four levels by 2047.



Projection of Microalgal Biofuel Production

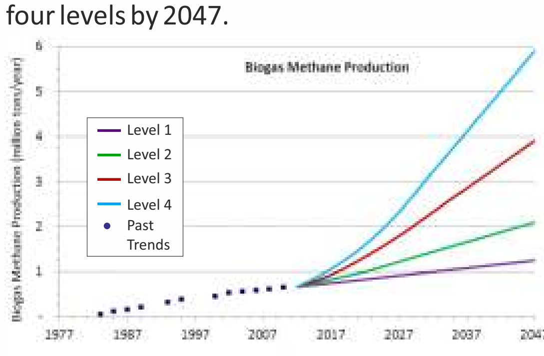
The land area allocated for Levels 3 and 4 could be much higher and it has been restricted to the aforementioned level because of the uncertainly involved with a technology that is yet to be proven as financially viable even if its potential is quite high.

III.h Macroalgae (offshore):

Macroalgae, also known as seaweed, are simple macroscopic plants that grow in seas. They are fast growing organisms; hence there is a reference of weed in their name. Polysaccharides are a predominant composition of macroalgae. They lack lignin, hence they are seen to be an easier feedstock to treat for conversion processes such as lignocellulosic alcohol production. Biofuel production from macroalgae is also a technology that is on a relatively early stage of development. The technology qualifies theoretically by resource assessment to cater to the magnitude of India's transportation fuel needs. Since one such technology (microalgal biofuels) has already been covered in a similar way, this technology has been projected for representative purpose with lower numbers. Whichever of such technologies or combination of such technologies get the chance to be realized, the respective numbers can be used interchangeably. 200 ha, 2500 ha, 0.02 Mha and 0.04 Mha are projected for macroalgae cultivation for the four levels. Varying macroalgal biomass productivity from 25 to 75 g/m2/day and energy yields from 35% to 60% across four levels, the macroalgal fuel production is projected to be 0.002, 0.05, 0.7 and 2.2 mtoe/year across the four levels by 2047.

III.i Biogas:

Biogas is an already established bioenergy component of India. Presently it is estimated to contribute to 0.6% of the total bioenergy production in the country. But it has the potential to contribute up to 9% of bioenergy production even now. Presently 4.31 million family-type biogas plants have been reported to have been set up in the country against an estimated potential of 12 million plants, to recover energy from cattle and poultry waste. The size of the plants is in 1-10 m3/day range. In order to estimate the current energy production from the installed capacity, 3 m3/day average size and 33% operating performance have been assumed. A projection, 16.5 ton/year of methane, has been adopted for Level 1. For Level 2, it starts from 33 ton/year and increases to 55 ton/year. The projection starts from 54 ton/year and increases to 108 ton/year for Level 3 and from 80 ton/year and increases to 180 ton/year for Level 4. The production reaches 1.24, 2.10, 3.91 and 5.90 mt/year (methane) across the four levels by 2047.

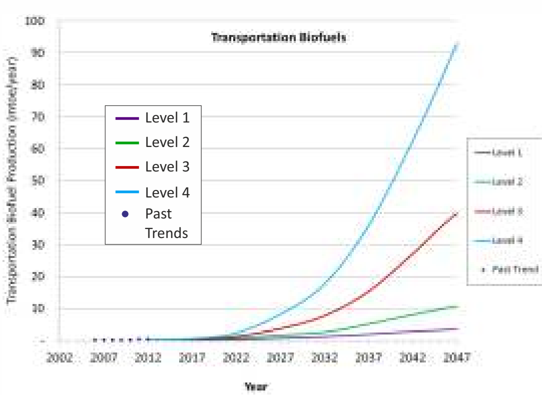


Projection of Biogas Methane Production in India

III.j Transportation fuel:

The present annual transportation fuel demand of India is 92 million tons. This is estimated to reach 400-600 million tons by 2047. The components that make up transportation fuel are first generation bioethanol, biodiesel from Jatropha, liquid fuels from non-fodder agri-residue and bioenergy crop plantations, microalgal biofuels and liquid fuels from off-shore macrolgae. The present biofuel production is estimated to be 0.36 mtoe/year. The total biofuel production that caters to transportation fuel demand is projected to reach 3.5, 11, 40 and 93 mtoe/year across the four levels by 2047.

Liquid fuels from lignocellulosic biomass are estimated to hold the major share of transportation biofuels for Levels 1 and 2 (2.9 out of 3.5 mtoe/year and 8.3 out of 10.8 mtoe/year) by 2047.



Projection of Transportation Biofuels

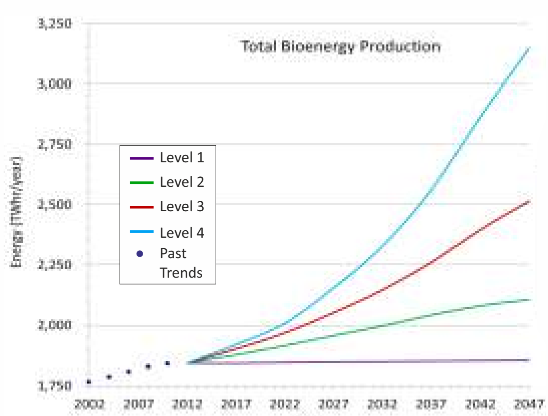
The following table shows the extent to which biofuels can be blended in transportation fuels under the various Levels taking into account the total transportation fuel demand under the respective Levels.

Year 2047	Biofuel Blending in Transportation Fuels
Level 1	0.45%
Level 2	2.6%
Level 3	12%
Level 4	26%

Scope of Biofuel Blending in Transportations Fuels

TOTAL BIOENERGY PRODUCTION:

The present total bioenergy production in India is estimated to be 1842 TWhr/year. This is projected to reach 1,854 TWhr/year, 2,106 TWhr/year, 2,514 TWhr/year and 3,148 TWhr/year for levels 1, 2, 3 and 4. Biomass from agricultural residue and forest residue account for 99% of the total bioenergy production presently and it continues to hold significantly major share in future also, 99%, 98%, 88% and 76% by 2047 through Levels 1 to 4 Advanced biofuels from purpose-grown feedstocks begin to take more pronounced shares in the higher Levels. While calculating total bioenergy production, for feedstocksagri-residue, forest residue and biogas methane which have varied forms of applications-direct use as cooking fuel to converted use as transportation fuel, the energy content of the base feedstock is taken into account for the overall calculation. For advanced biofuels from purpose-grown



Projection of Total Bioenergy Production in India feedstocks such as microalgae, the energy content of fuel only is used. Presently transportation biofuels account for 1.8% of total bioenergy production in the country. This is projected to increase to 7%, 14%, 33% and 50% by 2047 for Levels 1 through 4. This reflects the higher value of liquid transportation fuels and the resulting diversion of biomass feedstocks for transport fuel production.

IV. COST

The cost details of the various bioenergy components have been discussed in detail in the detailed document on the website. It offers costing separately for different uses of bioenergy under the following classification:

IV.a Power Generation

IV.b Ethanol (first generation)

IV.c Bioenergy crops from restored wastelands

IV.d Biodiesel (Jatropha)

IV.e Liquid fuels from lignocellulosic biomass

IV.f Microalgal biofuels

IV.g Macroalgae (offshore) liquid fuels

IV.h Biogas

IV.i Other energy applications

IV.j Total transportation fuel expenditure

Total bioenergy expenditure:

The present total cost of bioenergy is estimated at 105 billion rupees/year. This is projected to reach 143, 222, 322 and 462 billion rupees/year by 2022 for the four levels. From there it increases at a higher rate (much higher rate for Levels 3 and 4) reaching 512, 1144, 3345 and 7012 billion rupees/year by 2047.

2.5 Hydrogen

INTRODUCTION

Hydrogen is already widely produced and used, but it is now being considered for use as an energy carrier for stationary power and transportation markets. Major current uses of the commercially produced hydrogen include oil refining (hydro-treating crude oil as part of the refining process to improve the hydrogen to carbon ratio of the fuel), food production (e.g., hydrogenation), treating metals, and producing ammonia for fertilizer and other industrial uses.

In addition to the conventional hydrogen production methods of steam methane reforming (SMR) and grid-powered electrolysis, a new suite of renewable production options is emerging.

These include using renewable power directly for electrolysis, various biogas production options using gasification or pyrolysis processes or biomass fermentation with microorganisms, and newly developed photo-electrochemical and thermo-chemical processes including using microbial electrolysis cells as well as tailored molecules that can facilitate the splitting of water molecules into hydrogen and oxygen with lower energy requirements than conventional electrolysis.

Challenges to expanded use of hydrogen for stationary power production include better education and training of local codes-and-standards officials on the processes for hydrogen system permitting, continued efforts to bring down the costs of electrolysers to enable renewable hydrogen production, improved efficiency and performance of steam methane reformers (particularly in smaller sizes), current relatively high costs for hydrogen storage and piping systems, and improvements in other scientific processes and technologies for producing hydrogen with low to zero emissions of greenhouse gases and costs that can ultimately be competitive in the energy marketplace.

CURRENT MARKET STATUS

For purposes of understanding the hydrogen market, it is useful to distinguish between captive hydrogen production (where the hydrogen is produced and used onsite, such as at oil refineries) and merchant hydrogen where the hydrogen is produced for delivery to other locations as an industrial gas. Further, a distinction can be drawn between on-purpose hydrogen, where hydrogen production is the main goal, and by-product hydrogen, where hydrogen is produced as a by-product from another process (e.g., chlor-alkali production)

VARIOUS PRODUCTION METHODS

Hydrogen in molecular form can be produced from many different sources, and in many different ways. In the context of energy systems, hydrogen is best thought of as an energy carrier, more akin to electricity than the fossil fuels that we extract from the earth's crust. Hydrogen can be produced from any hydrocarbon fuel because by definition these fuels contain hydrogen. Hydrogen can also be produced from various biological materials and from water. The "water-splitting" process is called electrolysis, and it is the oldest known electrochemical process. Hydrogen is most typically produced today through the steam reformation of natural gas, but also is produced through electrolysis and as a by-product of some industrial processes such as chlor-alkali production.

STEAM-METHANE REFORMING

Steam reforming of methane is currently used to produce industrially, as it is the most economic technology. Natural gas reacts with steam with nickel as a catalyst in the primary reformer at temperatures of 1,200ºK and at a total pressure of 20-30 atmospheres. Given that natural gas contains sulphurous impurities, a preliminary cleaning stage is needed to avoid degrading the catalyst. The clean methane flow is then reacted in a reactor containing a nickel catalyst. The gas produced is high in hydrogen but contains a proportion of carbon monoxide, which is in turn transformed in a second or third reactor to produce extra hydrogen through a reaction with water vapour.

GASIFICATION OF COAL AND OTHER HYDROCARBONS

Coal Gasification works by first reacting coal with oxygen and steam under high pressures to form synthesis gas, a mixture primarily consisting of carbon monoxide and hydrogen. The synthesis gas is cleaned of impurities and the carbon monoxide in the gas mixture is reacted with steam via the water-gas shift reaction to produce additional carbon dioxide and hydrogen. Hydrogen is removed by a separation system and the highly concentrated CO2 stream can eventually be captured and sequestered.

ELECTROLYSIS OF WATER

Electrolysis is the process by which water molecules are split directly into hydrogen and oxygen molecules using electricity and an electrolyser device. The two most common types of electrolysers are alkaline (use a potassium hydroxide electrolyte) and PEM (use a solid polymer membrane electrolyte). The electrolysis reaction produces pure oxygen as a by-product along with pure hydrogen.Hydrogen can be produced via electrolysis of water from any electrical source, including utility grid power, solar photovoltaic (PV), wind power, hydropower, or nuclear power. Electrolysis is currently done at a wide range of scales, from a few kW to up to 2,000 kW per electrolyser.

HYDROGEN FROM BIOMASS

Biomass conversion technologies can be divided into thermo-chemical and biochemical processes. Thermo-chemical processes tend to be less expensive because they can be operated at higher temperatures and hence they have higher reaction rates. They involve either gasification or pyrolysis (heating biomass in the absence of oxygen) to produce a hydrogen-rich stream of gas known as "syngas" (a blend of hydrogen and carbon monoxide). They can utilize a broad range of biomass types. Pyrolysis of biomass, another production option, also offers potentially low costs of delivered hydrogen, with factory bulk costs potentially as low as about $1 per kilogram possible with large-scale production and pipeline delivery in the longer term.

HIGH TEMPERATURE FUEL CELLS

High temperature fuel cells based on molten carbonate (MCFC) or solid oxide (SOFC) technology operate at sufficiently high temperatures to run directly on methane. This is sometimes called "internal reforming." Thus, MCFC and SOFC systems do not need a pure or relatively pure hydrogen stream as do proton exchange membrane (PEM) and phosphoric acid (PAFC) systems, but can run directly on natural gas or biogas or landfill gas. Furthermore, such systems can be designed to produce additional purified hydrogen as a by-product (e.g. for use as a vehicle fuel), by feeding additional fuel and then purifying the hydrogen-rich "anode tail gas" from the fuel cell into purified hydrogen.

HYDROGEN PRODUCTION COSTS

The detailed document in the website offers "internally consistent" set of hydrogen production costs (i.e., not including delivery) by various methods that are either used at present or that are possible in the future, as reported by the US EIA and based on analysis by the National Academies and the US Department of Energy. These and other estimates were used to report the production cost ranges by production methods that were discussed in the preceding sections of this paper. Note that some of the cleanest methods of producing hydrogen are currently the most expensive (e.g. based on electrolysis from wind or other clean electricity sources) but biomass gasification offers a renewable hydrogen pathway with costs that can potentially be competitive with fossil sources.

Following are the drivers of a hydrogen economy-

- **Emerging markets**- With the development of a new demographic of energy-intensive industries, the demand for alternative fuels will increase as traditional fuels will not be able to meet their requirements.
- **Sustainable Development**- Focus on sustainable development and climate change will push the hydrogen economy forward.
- **Deregulation**- Fall of fully-funded state energy production industries gives rise to private organizations willing to invest in new technologies.
- Dynamism in financial markets and convergence of different markets.

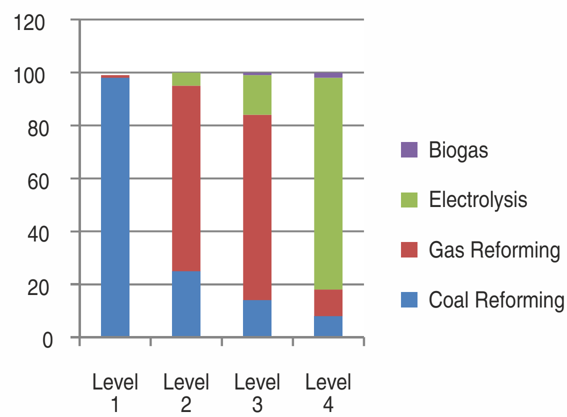
Constraints in a growing hydrogen economy-

- **Natural Gas reforming**- Liquefying hydrogen in small-scale steam reformers is costly and requires a lot of space. Since reforming depends on the availability of natural gas, it is important that the filling stations for hydrogen fuel-driven cars are situated close to the natural gas pipelines. Carbon emissions, which are approximately 140 g/MJ are a major disadvantage. CCS methods which can be used during natural gas reforming add up to 25-30% of the total costs.
- **Coal gasification** is a promising option for hydrogen production, but mainly in large plants. Existing conventional systems have a capacity of about 130 000 Nm3/h of hydrogen and over. The high complexity of the technology and the integration of carbon capture and storage systems make small-scale production plants unattractive on both economic and environmental grounds. There is a need for R&D to overcome these problems.
- **Biomass gasification**- The raw materials are extremely volatile, a problem which is managed in a two-step process. In the first step, the biomass is pyrolysed in the absence of air, producing pyrolytic oil and water. The pyrolyticvapours are then reformed with steam to produce a hydrogen-rich gas. The process can be implemented in a single reactor (with a fixed or fluidised bed) or in a two-stage reactor, depending on the nature of the biomass raw material. High temperature gas processing, including reforming of hydrocarbons and the optimisation of the water-gas shift need to be further investigated.
- **Electrolysis of water**- The main disadvantage of water electrolysis is that it requires large amounts of electricity. Efforts are being made to increase the efficiency and reduce electricity use. For instance, electrolysers operated at temperatures between 700 and 1000°C and at high pressure are more efficient, but work on these systems is still at the R&D stage.

HYDROGEN SCENARIOS

Level 1

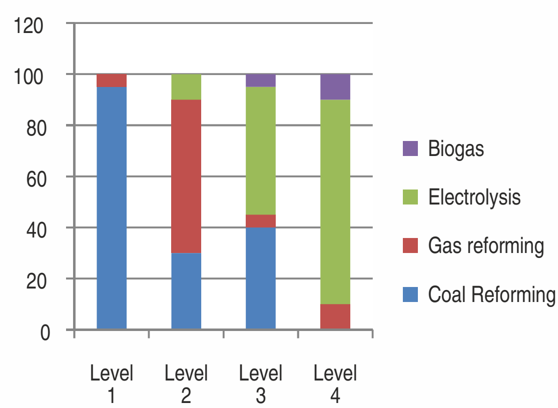
This scenario assumes maximum penetration of hydrogen production methods like coal gasification and natural gas reforming because of the availability of the basic resources in the country and the commercial feasibility of these technologies. 95% of the demand for hydrogen fuel is fulfilled by coal gasification and 50% by natural gas reforming.



Year 2022

Level 2

This scenario considers the advent of CCS technology in India and a slight penetration of electrolysis of water and electro-chemical water-splitting technology using renewable resources. At the same time a decline in the usage of natural gas reforming technology to reduce the burden on imports will be observed. 10% of the demand will be taken up by the electrolysis technology, 30% by coal gasification and 60% by natural gas reforming.



Year 2047

Level 3

Under this scenario, a higher share of the entire hydrogen fuel demand is fulfilled by electrolysis and electro-chemical technology and a more drastic decline is observed in the usage of natural gas reforming. Electrolysis takes up 50% of the demand while 40% is taken by coal gasification, 5% by natural gas reforming and 5% by Biomass gasification.

Level 4

This scenario considers a high upgradation of electrolysis technology and CCS technology is installed in all coal gasification plants. 80% of the entire hydrogen fuel demand is fulfilled by electrolysis, 5% by coal gasification, 5% by natural gas reforming and 10% by biogas reforming.

Section 3

Example Pathways

Section 3 : Example Pathways

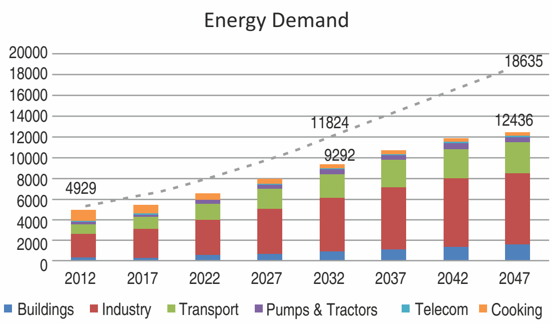
3.1 Maximum Energy Security Pathway (MESP)

In the IESS, 2047, a restricted interpretation of the term 'Energy Security' has been adopted to denote import dependence. With rising energy imports, Indian policy makers have targeted reduction in the same as an important policy objective. India imported nearly 31% of its total primary energy supply in the year 2011-12, and this number has further risen since. Therefore, the present energy exercise (IESS) is aimed at helping the policy makers in choosing policy interventions, in the light of scenarios of India's import dependence in the coming decades. The MESP comprises of choices of those levels (out of 4 Levels) in different Demand and Supply sectors, which would reduce the energy import dependence of India by the year 2047.

Energy Demand

It is obvious that the first effort to reduce energy imports ought to be made on curbing energy demand itself. Therefore, in this pathway, we assume that the energy sector makes 'Heroic efforts' in all energy consuming sectors (all Level 4 choices adopted). India's primary energy demand was 4929 TWhin 2012 which could rise to 18635 TWh in the default case (Level 2 or Determined effort) by 2047. However, if heroic efforts were made to reduce energy demand, the same could be brought down to 12436 TWh by 2047.

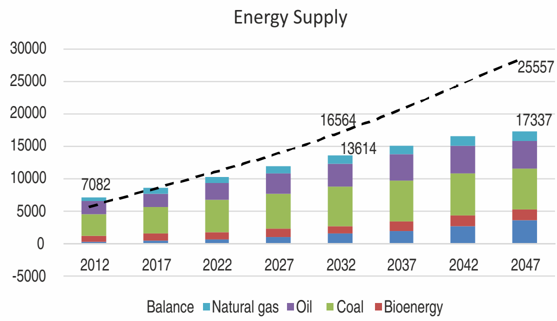
The scope for maximum reduction lies in Transport and Industry sectors, where Level 4 choices (Heroic scenarios) could restrict the demand growth to a factor of 3.2 and 3 respectively, in 2047 from 2012 levels, as opposed to a factor of 5 and 4.5 in the default scenario. These two sectors would comprise of nearly 80% of the total energy demand in 2047. Within the transport sector (freight and passenger transport), maximum reduction in energy demand (12%) would come from reducing the actual need for transportation (by better urban planning, Transit oriented development etc.), followed by raising the share of the more efficient mode of transport – rail, which contributes towards reducing 8% of the total energy demand for transport. On the Industry side, maximum energy reduction takes place by enhancing efficiency in Cement and Iron and Steel industries, which comprise of nearly 40% of the total energy demand in the Industry segment in 2012. By adopting Level 4 i.e Best Available Technologies, their energy demand growth of the Cement and Iron and Steel sectors could be arrested to rise by a factor of in 2 and 3.5 in 2047 respectively (as compared to a factor of 4 and 7 in the Defaultcase). MESP also envisages higher electrification, fuel switching and better urban planning to reduce the demand for transport. The share of electricity in primary energy demand in 2012 which was 16% rises to 29% in this scenario by 2047.

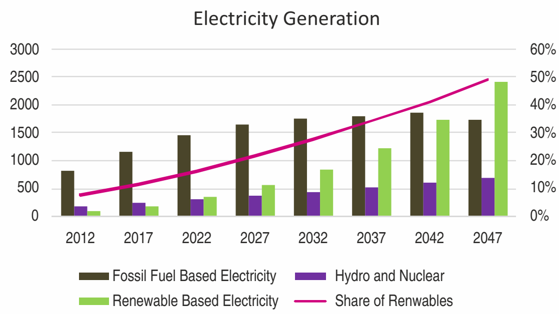


Energy Supply

On the supply side, this pathway would envisage moderate reduction in demand for fossil fuel, raising of domestic production of all fuels and higher uptake of new technologies such as second generation bio-fuels, including micro and macro algal fuels. This scenario would naturally envisage large uptake of renewable energy as India has unlimited availability of solar power and a huge wind potential. However, the volume of renewable energy that can be ramped up would depend on the challenges of grid balancing, and integration of renewable energy in the grid. Even demand side interventions are important in determining fuel choices. For example, the transport sector options of Electric Vehicles and CNG fuelled vehicles in preference over petrol/diesel vehicles would be essential in uptake of electricity/gas. The choice of production technology in Industries would drive energy demand for particular fuels (gas/electricity in place of solid fuel such as coal in steel/cement industries). Within the above challenges, the MESP on the supply side would emerge as follows:

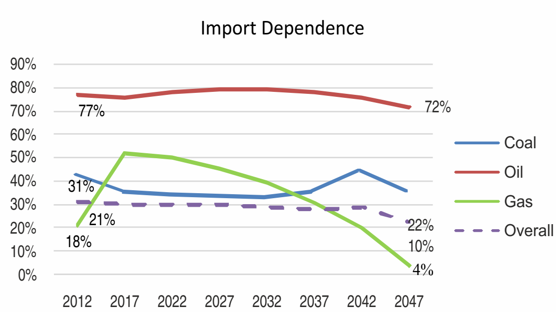
While in this pathway, coal production rises steeply, but due to large doses of other domestic fuels, coal would lose its share in the supply mix, falling from 46% in 2012 to 43% in 2047. The share of renewables in the enhanced proportion of electricity in the energy mix would increase to 40% (it is 7% in 2012). The share of coal is lower than in Determined effort oriented scenario, but higher than the 37% share in maximum clean energy scenario. Similarly, RE is ramped up to enhance domestic sources in place of imported coal and oil/gas. But, RE share is lower than in the maximum clean energy scenario where it rises to 49% share in electricity. It may be noted that the integration of renewable energy (RE) and storage (batteries/pumped storage etc) for balancing it, have also been offered as levers in the Tool. The user may tick maximum exploitation of storage capacity to support high levels of RE. Separately, the grid balancing exercise is also useful to determine what quantum of RE can be dispatched at different levels of energy demand. The oil sector would also see a major ramp-up in domestic production, but reduced imports are witnessed due to reduced demand in the transport sector (Level 4 choices on demand side). In this scenario, it is significant to know that the domestic production of all fuels including fossil fuels is also expected to rise to the maximum possible levels. It is assumed that the policy framework and pricing scenario would favour large domestic exploratory efforts for coal, oil and gas, resulting in the efforts rising to the highest levels. The prognosticated resources of the above three fuels rise, thereby supporting a higher production which peaks during the study period and reduces the energy import





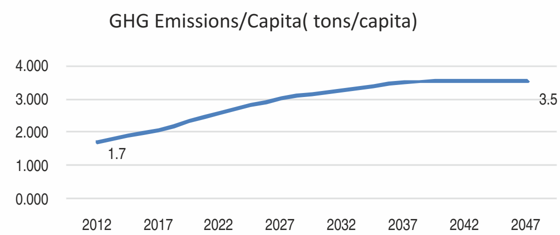
Imports

The current share of imports in the primary energy mix of the country is 31%. This is expected to rise to 57% in the default scenario. The MESP reduces energy demand by heroic efforts, which addresses the import situation to a large extent on its own. Then, owing to large additions to domestic energy production by higher level choices on coal and other sources of energy (renewable energy included), the domestic supply also ramps up. In the MESP, the import dependence comes down from 31% in 2012 to 22% in 2047.



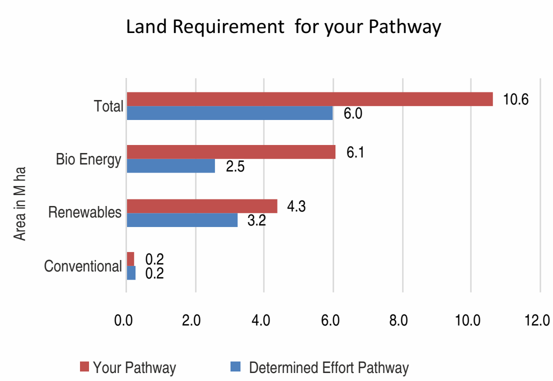
Emissions

This pathway, due to its increasing emphasis on Renewable Energy sources attains a reduction in emissions as a co-benefit of addressing import dependence. The Greenhouse Gas emissions per capita increase from 1.7 tons of CO2eq/ capita in 2012 to 3.5 tons of CO2eq/ capita in 2047. (As compared to 5.7 tons of CO2eq/ capita in 2047 in the Determined effort case)



Implications on land

As this pathway focusses on interventions on the fronts of Renewable energy and Bio-energy mainly, to help curb import dependence, it is much more land intensive than the Determined effort pathway. The cumulative land-use in this pathway rises by a factor of nearly 1.7 in 2047 as compared to the Determined effort pathway to support the interventions. (10.6 Million Hectares in 2047 as compared to 6 Million Hectares in the Determined effort pathway)

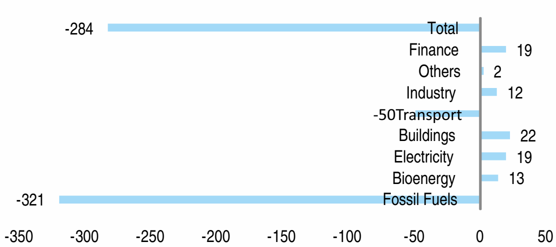


Costs

The cost implications of this pathway would be explained in a two-fold manner. Firstly, on the demand side, due to an increase in energy efficiency and electrification, the economy as a whole would be a net saver in terms of costs, as lesser energy would be required to supply the same amount of services. It needs to be kept in mind that the IESS, 2047 is an efficiency calculator and not one of costs. The IESS does not include the infrastructure costs associated with undertaking these interventions, it merely reflects the benefits that these interventions would accrue to the economy. If the infrastructure costs were to be considered, the aggregate cost of these pathways would be much more. Secondly, on the supply side, even though the economy would incur costs on the production of various forms of energy supply, due to the decrease in the import dependence, the country would save a tremendous amount of its import bill, which will be reflected a savings in fossil fuels.

Therefore, the maximum energy security pathway would lead to a cumulative savings of 284 Trillion INR in 2047 (1.71% of its cumulative GDP in the year 2047) over and above the Determined effort pathway i.e if the economy were to move to a path of Maximum Energy Security as opposed to its default pathway, till the year 2047, it would accrue savings of 284 Trillion INR over what it would have spent while progressing on the default path. These savings could be redirected to other sectors of the economy.

Costs in INR Trillion (2012-47)



Conclusion

In conclusion, the Maximum Energy Security Pathway gives a rosy picture for the Indian energy sector in the year 2047, wherein import dependence drastically falls even from the present level of 31% of the primary energy demand in 2012 to 22% in 2047. Both demand and supply sectors work in unison, in first reducing energy demand and then, supplying it largely by domestic sources. In many ways, this pathway is nearly similar to Maximum Clean and Renewable Energy Pathway, as both pathways adopt heroic efforts on demand reduction choice. It is only on the supply side that there are differences. While both pathways believe in ramping up domestic energy supply sources, in the energy security pathway, fossil fuels are preferred as there is a large domestic endowment. But, in the clean energy pathway, clean energy sources are preferred over fossil fuel supply. However, this is a highly improbable scenario, and while we could perhaps attain a large improvement over the default case, but not the one generated in the maximum energy security scenario owing to the following reasons:

- First, this scenario envisages a nearly 34% reduction in energy demand from the default case which is challenging requiring significant urban planning reform, and public choices moving from private transport to public transport.
- Second, this would also envisage a very high level of capital expenditure in creating physical infrastructure, particularly in the transport sector (for a shift to rail/public transport), the cost of which is beyond the scope of the present exercise.
- Third, it is assumed in this scenario that fossil fuel based energy system would be replaced by a renewable energy based one, without taking into account the fact that many fossil fuel based power plants would not have completed their economic life but are forced to retire giving way to renewable solutions. This would cause a big cost to economy which cannot be compensated either by the State or consumers.

However, this scenario is a useful analysis to indicate the direction or choices which need to be made for reduction in energy demand and raising supply. It also gives an overview of the potential of demand reduction, raising of supply, the potential of emerging technologies and the implication of the above on emissions, costs, land requirement and import dependency.

3.2 Maximum Clean and Renewable Energy Pathway (MCREP)

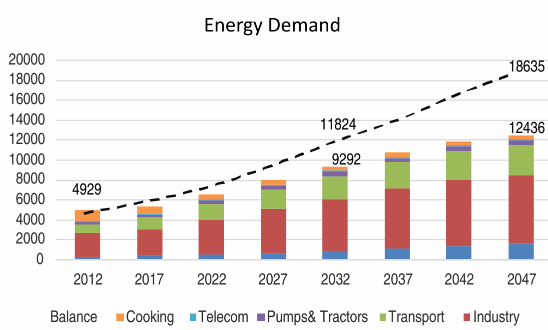
With increasing concerns about sustainability and climate change and India finalising its Intended Nationally Determined Contributions for the first time for discussion in the COP 21 summit, the importance of moving towards an economy which has renewable and clean sources of energy as its mainstay is increasingly being deliberated upon.

India's per capita Greenhouse Gas emissions stood at 1.7 tons of CO2 equivalent/ Capita in 2012, which is likely to rise. The present energy exercise (IESS) is aimed at helping the policy makers in choosing policy options, in the light of scenarios of India's adoption of renewable energy and meeting its energy needs, in a sustainable manner. The MCREP comprises of choices of those levels (out of 4 Levels) in different Demand and Supply sectors, which would increase the country's share of clean and renewable forms of energy by the year 2047.

Energy Demand

It is obvious that the first effort in the energy strategy of the economy ought to be towards curbing energy demand itself. If due to demand side interventions, the country can reduce its energy demand, and also supply the reduced energy demand by renewable and clean sources, it would be able to achieve emissions reduction as a direct benefit. Therefore, in this pathway, we assume that the energy sector makes 'Heroic efforts' in all energy consuming sectors to reduce demand to the minimum (all Level 4 choices adopted). India's primary energy demand was 4929 TWhin 2012 which could rise to 18635 TWh in the default case (Level 2 or Determined effort) by 2047. However, if heroic efforts were made to reduce energy demand, the same could be brought down to 12436 TWh by 2047.

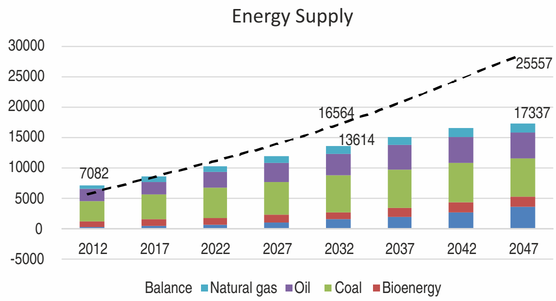
The scope for maximum reduction lies in Transport and Industry sectors, where Level 4 choices (Heroic scenarios) could restrict the demand growth to a factor of 3.2 and 3 respectively, in 2047 from 2012 levels, as opposed to factors of 5 and 4.5 in the default scenario, respectively. These two sectors would comprise of nearly 80% of the total energy demand in 2047. Within the transport sector (freight and passenger transport), maximum reduction in energy demand (12%) would come from reducing the actual need for transportation (by better urban planning, Transit oriented development etc.), followed by raising the share of the more efficient mode of transport – rail, which contributes towards reducing 8% of the total energy demand for transport.On the Industry side, maximum energy reduction takes place by enhancing efficiency in Cement and Iron and Steel industries, which comprise of nearly 40% of the total energy demand in the Industry segment in 2012. By adopting Level 4 (maximum reduction by adoption of autonomous energy efficiency), energy demand growth of the Cement and Iron and Steel sectors could be arrested to rise by a factor of in 2 and 3.5 in 2047 respectively (as compared to a factor of 4 and 7 in the Default case). MRCEP also envisages higher electrification, fuel switching and better urban planning to reduce the demand for transport. The share of electricity in primary energy demand in 2012 which was 16% rises to 29% in this scenario by 2047.

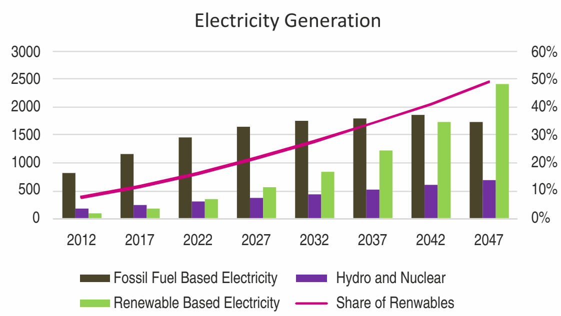


Energy Supply

On the supply side, this pathway would envisage reduction in demand for fossil fuel, a shift in the supply mix away from conventional energy and a higher uptake of new technologies such as second generation bio-fuels, including micro and macro algal fuels. This scenario would naturally envisage maximum uptake of renewable energy as India has unlimited availability of solar power and a huge wind potential. However, the volume of renewable energy that can be ramped up would depend on the challenges of grid balancing, and integration of renewable energy in the grid. Even demand side interventions are important in determining fuel choices. For example, the transport sector options of Electric Vehicles and CNG fuelled vehicles in preference over petrol/diesel vehicles would be essential in uptake of electricity/gas. The choice of production technology in Industries would drive energy demand for particular fuels (gas/electricity in place of solid fuel such as coal in steel/cement industries). Within the above challenges, the MCREP on the supply side would emerge as follows:

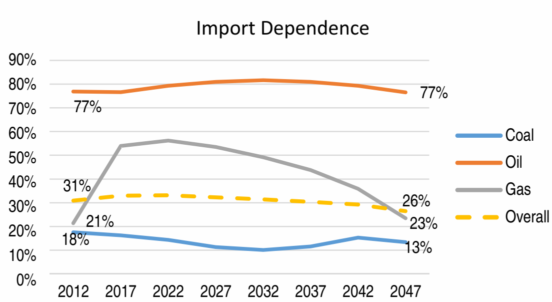
In this pathway, the share of coal will be the lowest as compared to its share in any other pathway because there is increased focus on moving towards a largely renewable and clean energy based economy. Driven by a moderate coal production scenario, coal would lose its share in the supply mix, falling from 46% share in the primary energy supply in 2012 to nearly 37% in 2047. Additionally, moderate fossil fuel production scenarios also contribute to reducing the fugitive emissions from mining and production processes. The share of renewables in the enhanced proportion of electricity in the energy mix would be 49% (it is 7% in 2012). It may be noted that the integration of renewable energy (RE) and storage (batteries/pumped storage etc) for balancing it, have also been offered as levers in the Tool. The user may tick maximum exploitation of storage capacity to support high levels of RE. Separately, the grid balancing exercise is also useful to determine what quantum of RE can be despatched at different levels of energy demand (provided separately in the tool). Along with different forms of Solar, Wind and Hydro gaining importance, this pathway also gives prominence to Bio-energy as a source of energy. Increased production of first and second generation bio-fuels would contribute to meeting 38% the liquid fuel demand in the transport sector. This pathway assumes technical and physical limits to drive the point that there is a major push for a move towards renewable and clean energy sources of energy. Inherent in this scenario is the assumption that there are no barriers (economic, social or technical) to the realization of renewable and clean energy potentials.





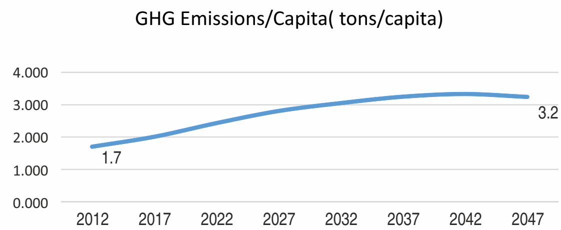
Imports

The current share of imports in the primary energy mix of the country is 31%. This is expected to rise to 57% in the default scenario. The MCREP reduces energy demand by heroic efforts, which addresses the import situation to a large extent on its own. Then, owing to an increase in Renewable and Clean Energy sources, the domestic supply also ramps up. However, owing to moderate domestic production scenarios of fossil fuels, the import dependence is more than that in the Maximum Energy Security pathway. Yet, in the MCREP, the import dependence comes down from 31% in 2012 to 26% in 2047.



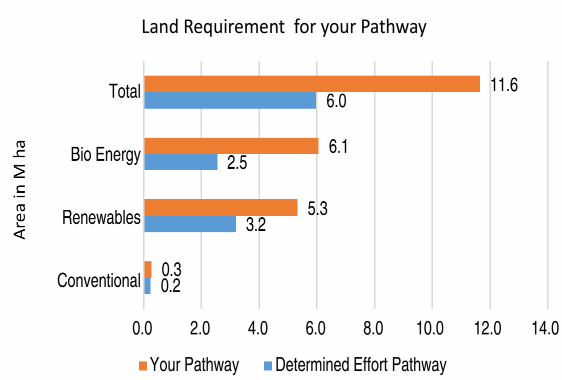
Emissions

The Maximum Clean and Renewable Energy pathway, as the name suggests contributes to a large decrease in the emissions for India till the year 2047. A high penetration of Renewable and Clean sources as well as an increased impetus on Bioenergy as an alternative source, brings down the emissions from 5.7 tons of CO2eq/ capita in 2047 in the Determined effort case to 3.2 tons of CO2eq/ capita in 2047.



Implications on land

As this pathway focusses on aggressive interventions on the fronts of Renewable energy and Bio-energy mainly, to help curb import dependence, it is much more land intensive than the Determined effort pathway. The cumulative land-use in this pathway rises by a factor of nearly 2 in 2047 as compared to the Determined effort pathway to support the interventions. (11.6 Million Hectares in 2047 as compared to 6 Million Hectares in the Determined effort pathway)

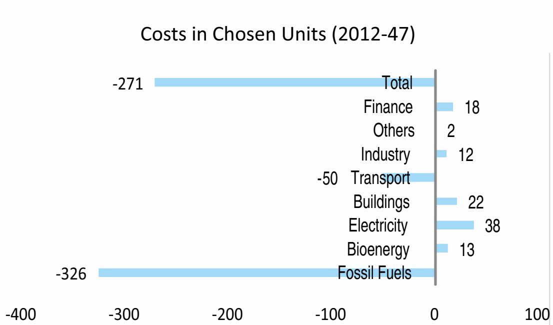


Costs

The cost implications of this pathway would be explained in a two-fold manner. Firstly, on the demand side, due to an increase in energy efficiency and electrification, the economy as a whole would be a net saver in terms of costs in the long run as lesser energy would be required to supply the same amount of services. It needs to be kept in mind that the

IESS, 2047 is an efficiency calculator and not one of costs. The IESS does not include the demand side infrastructure costs associated with undertaking these interventions, it merely reflects the benefits that these interventions would accrue to the economy. The gains on demand side cannot be achieved without these large expenses. If the infrastructure costs were to be considered, the aggregate cost of these pathways would be much more. Secondly, on the supply side, even though the economy would incur costs on the production of various forms of energy supply, due to a massive push for renewable and clean energy sources including bioenergy, the pathway is cheaper again on a life-cycle basis. However, again we know that the capital costs on RE are very high and need to be spent upfront, which is a major challenge for developing economies.

Therefore, the MCREP would lead to a cumulative savings of 271 Trillion INR in 2047 (1.63% of its cumulative GDP in the year 2047) over and above the Determined effort pathway i.e if the economy were to move to a path of Maximum Renewable and Clean Energy as opposed to its default pathway, till the year 2047. This would accrue savings of 271 Trillion INR over what the country would have spent while progressing on the default path. These savings could be redirected to other sectors of the economy.



Conclusion

In conclusion, the Maximum Clean and Renewable Energy Pathway lays out the scenario of moving towards an aggressively high penetration of Renewable and Clean energy sources in the energy mix of India. A transition of this extent would considerably contribute to arresting the growth of emissions to a factor of 2.7 in the year 2047 as opposed to a factor of 4.7 in the default-determined effort scenario. Both demand and supply sectors work in unison, in first reducing energy demand and then, a shift to cleaner sources of energy is facilitated. In many ways, this pathway is nearly similar to Maximum Energy Security Pathway, as both pathways adopt heroic efforts on demand reduction choice. It is only on the supply side that there are differences. While both pathways believe in ramping up domestic energy supply sources, in the energy security pathway, fossil fuels are preferred as there is a large domestic endowment. But, in the clean energy pathway, clean energy sources are preferred over fossil fuel supply. However, this is a highly improbable scenario, and while we could perhaps attain a large improvement over the default case, the absolute realization of the aforementioned benefits is quite improbable owing to the following reasons:

- First, this scenario envisages nearly a 34% reduction in energy demand from the default case which is challenging requiring significant urban planning reform, and public choices moving from private transport to public transport.
- Second, this would also envisage a very high level of capital expenditure in creating physical infrastructure, particularly in the transport sector (for a shift to rail/public transport), the cost of which is beyond the scope of the present exercise.
- Third, it is assumed in this scenario that fossil fuel based energy system would be replaced by a renewable energy based one,

without taking into account the fact that many fossil fuel based power plants would not have completed their economic life but are forced to retire giving way to renewable solutions. This would cause a big cost to economy which cannot be compensated either by the State or consumers.

- Fourth, this pathway assumes no barriers (economic, social or technical) in the realization of such vast potentials of renewable and clean energy.

However, this scenario is a useful analysis to indicate the direction or choices which need to be made for reduction in energy demand and shifting the energy mix in favour of cleaner sources. It also gives an overview of the potential of demand and emission reduction, the potential of emerging technologies and the implication of the above on emissions, costs, land requirement and import dependency.

Section 4

Key Results

4.1 Sector Specific Results

1. Installed Capacity (GW)

Capacity (GW)	2012	Level 2			Level 4			Percentage change (L2 to L4 in 2047)
		2022	2032	2047	2022	2032	2047	
Nuclear power	4.7	12	17	26	17	36	78	198.97%
Hydro Power Generation	41.0	61	66	75	61	93	150	100.00%
Solar PV	0.9	18	53	150	59	171	479	219.33%
Solar CSP	-	4	13	46	7	35	187	306.52%
Onshore Wind	17.4	54	109	202	82	192	410	102.97%
Offshore Wind	-	1	5	20	4	21	141	623.08%
Small Hydro	3.4	9	13	15	11	22	30	98.01%
Distributed Solar PV	0.0	4	13	47	36	80	264	456.19%
Biomass	4.7	6	8	11	8	12	20	76.60%
Waste to Electricity	0.1	0	1	4	0	1	6	65.35%

2.Electricity Generation (TWh/Year)

Generation (TWh/year)	2012	Level 2			Level 4			Percentage change (L2 to L4 in 2047)
		2022	2032	2047	2022	2032	2047	
Nuclear power	26.7	82.5	116.1	183.1	116.8	250	547	198.97%
Hydro Power Generation	143.8	213.9	231.4	263.0	213.9	326	526	100.00%
Solar PV	1.6	30.2	91.7	269.6	99.4	297	865	220.86%
Solar CSP	-	11.3	43.9	181.2	18.9	128	746	311.68%
Onshore Wind	32.2	112.0	240.0	495.3	172.5	428	1,007	103.36%
Offshore Wind	-	2.9	13.9	64.3	11.6	65	468	629.06%
Small Hydro	12.1	32.9	50.2	57.9	39.9	82	115	99.07%
Distributed Solar PV	0.0	5.5	20.1	79.0	54.6	125	439	456.19%
Biomass	33.2	43.8	56.2	78.3	53.8	81	138	76.60%
Waste to Electricity	0.6	7.1	22.5	86.9	8.9	33	144	65.35%

3.Impact of sub-sectors on aggregate share of Renewable Energy in Electricity Generation (From the Determined efforts scenario)

Sector	**2012**	**Level 2 (2047)**	**Level 4 (2047)**
Solar	7%	26%	50%
Wind	7%	26%	44%
Small Hydro	7%	26%	27%
Energy from Municipal waste	7%	26%	27%
Bioenergy	7%	26%	27%
TOTAL RENEWABLES	7%	26%	58%

4.Impact of Renewable Energy sub-sectors on aggregate Emissions (From the Determined effort scenario)

Sector	2012	Level 2 (2047)	Level 4 (2047)	Per cent Reduction (L2 to L4 in 2047)
Solar	2074	9738	8879	9%
Wind	2074	9738	8879	9%
Small Hydro	2074	9738	9684	1%
Electricity from Municipal waste	2074	9738	9684	1%
Bioenergy	2074	9738	9439	3%
TOTAL RENEWABLES	2074	9738	8637	11%

5.Impact of Renewable Energy sub-sectors on overall Import Dependence

Sector	**2012**	**Level 2 (2047)**	**Level 4 (2047)**
Solar	31%	57%	51%
Wind	31%	57%	51%
Small Hydro	31%	57%	57%
Electricity from Municipal waste	31%	57%	57%
Bioenergy	31%	57%	50%
TOTAL RENEWABLES	31%	57%	43%

6. Impact on land area requirement from the determined effort scenario in 2047 (in Million hectares)

Sector	Determined Effort (Level 2s)	Heroic Effort (Level 4s)
Conventional	0.2	0.2
Renewables	3.2	7.5
Bio Energy	2.5	9.4
Total	6.0	17.1
India's Land Area	328.7	
Land Area as % India's area	1.82%	5.20%

4.2: Overall Results of the IESS, 2047 Version 2.0

1. Potential of Demand Reduction from Determined Effort Scenario to Heroic Effort Scenario

Sector	**Demand in 2012 (TWh)**	**Demand in 2047 (TWh)**		
		Determined Effort	**Heroic Effort**	**% Savings**
Buildings	238	2287	1540	33%
Industry	2370	10430	6912	34%
Transport	929	4414	2975	33%
Pumps & Tractors	237	798	533	33%
Telecom	83	184	66	64%
Cooking	1072	522	410	21%
Total	4929	18635	12436	33%

2.Subsector Analysis: Determining the impact of different interventions on the energy demand of Passenger Transport

	Demand in 2047 (TWh)	**% Savings**
Determined Effort (Reference)	2377	-
Transit Oriented Development	2034	14%
Shift to more efficient modes of transport	2264	5%
Shift to Public Transport	1864	22%
Shift to Electric and Hybrid Vehicles	2004	16%
Heroic Effort	1370	42%

From the above analysis, the user can observe how much each sub-sector in the Passenger Transport segment contributes individually to reducing the energy demand for the sector. The line item for Heroic Effort talks about how much reduction in energy demand is possible for the Passenger Transport segment if all subsectors collectively feed into each other at the Heroic Effort level.

3. Supply side analysis: Impact on Primary Energy Supply as a result of changes in Demand pathways

Primary Energy Supply in 2047 (TWh)			
Sector	**Determined Effort on Demand Side**	**Heroic Effort on Demand Side**	**% Savings**
Renewable and Clean Energy	1986	2078	(5%)
Coal	13159	7770	41%
Oil	6832	4434	35%
Natural Gas	2075	1753	16%
Bioenergy	1413 –	1413	
Total	25465	17448	31%

4. Supply side analysis: Changes in fuel composition in different pathways

Primary Energy Supply Pathway in 2047 (TWh)		
Sector	**Maximum Renewable and Clean Energy Pathway**	**Maximum Energy Security Pathway**
Renewable and Clean Energy	3638	2560
Coal	6210	7263
Oil	4194	4194
Natural Gas	1563	1675
Bioenergy	1732	1732
Total	**17337**	**17424**

5. Emission analysis: Reduction in emissions by a shift to clean energy pathway

Emissions in 2047 ($MTCO_2$ Eq)			
Sector	**Determined Effort Pathway**	**Maximum Renewable and Clean Energy Pathway**	**% Savings**
Industry	5935	3559	40%
Transport	1118	709	37%
Agriculture	72	43	40%
Telecom	37	3	92%
Thermal Generation	2678	1409	47%
Bioenergy	-304	363	(19%)
Fossil Fuel Production	93	93	-
Fossil Fuel Transfer	109	73	33%
Total	**9738**	**5526**	**43%**

6.Import dependence analysis: Reduction in imports by a shift to Maximum energy securitypathway

Import Dependence			
	2012	**Determined Effort (2047)**	**Maximum Energy Security (2047)**
Coal	18%	59%	10%
Oil	77%	88%	72%
Gas	23%	44%	4%
Overall	31%	57%	22%

7. Overall analysis: Summary of results

Scenario	Demand in TWh				Implications			
	Demand (2012)-TWh	Demand (2047)-TWh	Demand/ Capita (2012) - KWh/Capita	Demand/ Capita (2047)- KWh/Capita	Renewable Energy Penetration	Import Dependence	Emissions/ Capita (2012)	Emissions/ Capita (2047)
Least Effort	4929	22140	4053	12991	6%	84%	1.7	7.9
Determined Effort	4929	18634	4053	10934	26%	58%	1.7	5.7
Heroic Effort	4929	12436	4053	7297	39%	34%	1.7	4.3
Maximum Energy Security	4929	12436	4053	7297	40%	22%	1.7	3.5
Maximum Clean and Renewable Energy Pathway	4929	12436	4053	7927	49%	26%	1.7	3.2
Determined Effort Overall and Heroic Effort on Electric Vehicles	4929	18262	4053	10716	25%	57.10%	1.7	5.68
Determined Effort Overall and Shift to Public Transport	4929	18121	4053	10634	26%	56.50%	1.7	5.62
Determined Effort Overall and Modal Shift to Rail Freight	4929	18262	4053	10716	25%	57.00%	1.7	5.68
Determined Effort Overall and Heroic Effort in Transport	4929	17196	4053	10090	25%	54.90%	1.7	5.5
Determined Effort Overall and Heroic Effort in Fuel Switching in Industry	4929	16976	4053	9961	23%	56.40%	1.7	5.17

Scenario	Demand in TWh				Implications			
	Demand (2012)-TWh	Demand (2047)-TWh	Demand/ Capita (2012) - KWh/Capita	Demand/ Capita (2047)- KWh/Capita	Renewable Energy Penetration	Import Dependence	Emissions/ Capita (2012)	Emissions/ Capita (2047)
Determined Effort Overall and Heroic Effort in Industry	4929	15117	4053	8870	25%	51%	1.7	4.36
Determined Effort Overall and Heroic Effort in Buildings	4929	17840	4053	10468	31%	53%	1.7	5.21

NOTES

NOTES

Supporting Partners

CSTEP — Center for Study of Science, Technology & Policy

Confederation of Indian Industry

FICCI

ISGF — India Smart Grid Forum

IRADe — Integrated Research and Action for Development

BERKELEY LAB

PRAYAS ENERGY GROUP

SHAKTI SUSTAINABLE ENERGY FOUNDATION

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Department of Energy & Climate Change

For suggestions or questions,
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