सत्यमेव जयते

NITI AAYOG

Government of India

भारत ऊर्जा सुरक्षा परिदृश्य 2047

INDIA ENERGY SECURITY SCENARIOS 2047

Version 2.0

Part II : Conventional Energy Supply Sectors

भारत ऊर्जा सुरक्षा परिदृश्य 2047

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Version 2.0

Energy Division
NITI Aayog
August 2015

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 datasets, 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

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, 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's website www.indiaenergy.gov.in for detailed insight on how to use the tool, sector specific information, documentation and 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

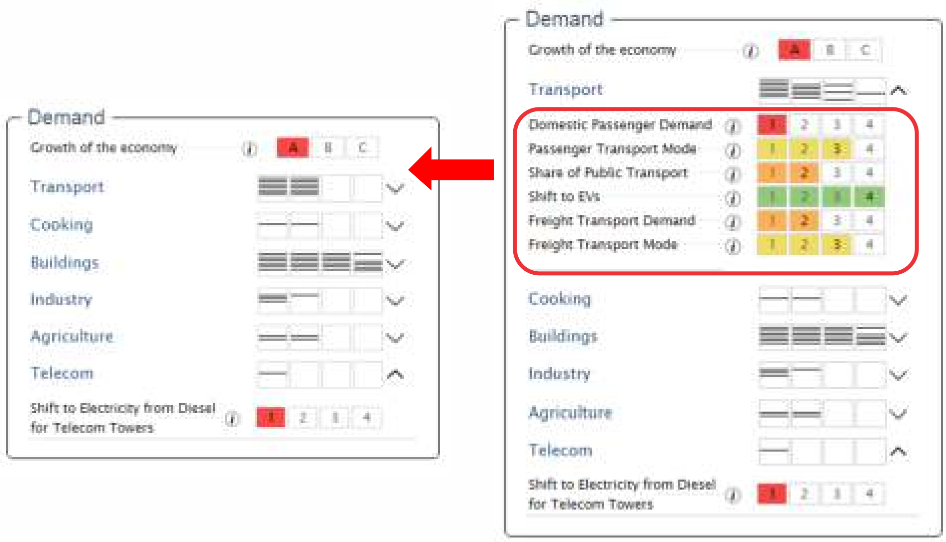
Restructuring of Energy Efficiency scenarios to include more drivers along with the PAT scheme. Even technology options have been adopted in steel and cement sectors which add value to the analysis other than merely autonomous energy efficiency options.

Telecom

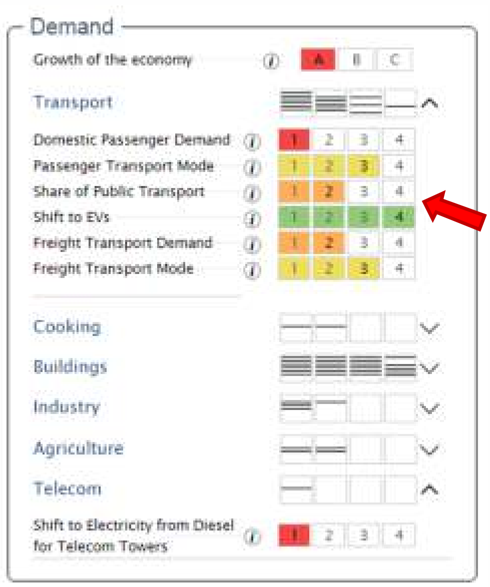
Addition of other solutions for replacement of diesel in the telecom sector. Version 2.0 considers solar rooftop, wind, bioenergy and hydrogen solutions for replacement of diesel, as opposed to only rooftop solar solutions in version 1.0.

1.3 How to use the IESS, 2047

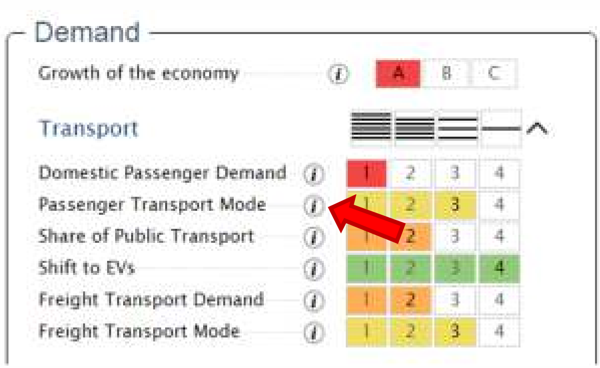
1. Select the Level of effort for Demand sectors, Supply sectors and Network and Systems. Click on downward arrow to select more options for a sector.



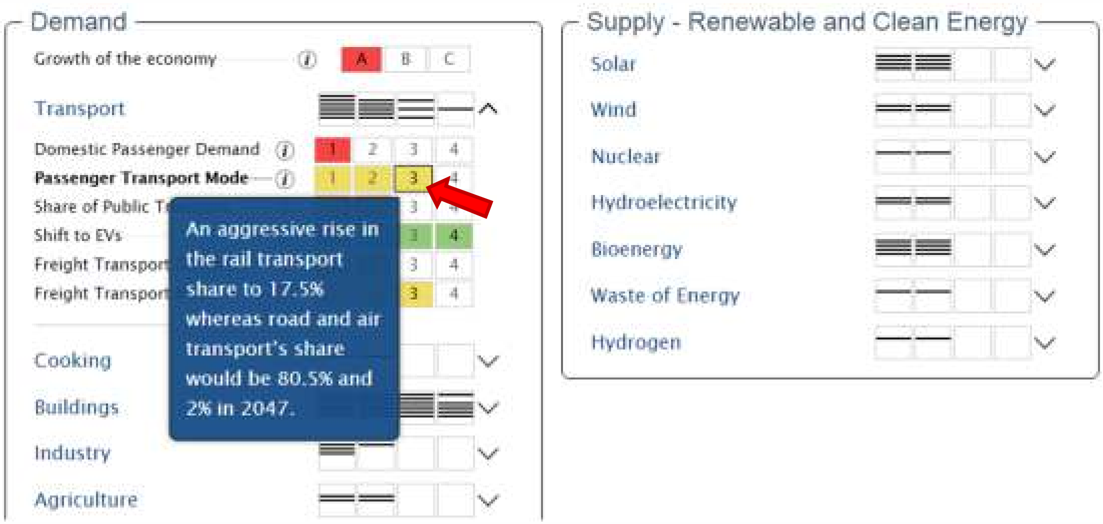
2. Select the scenario (we call them Levels) by clicking on the numbered boxes



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 Coal Production

INTRODUCTION AND A BRIEF HISTORY OF SECTOR EVOLUTION IN INDIA

Coal contributes over half of India's primary commercial energy. Though the share of renewable energy is gradually expected to increase in the coming years, coal is likely to remain India's most important source of energy for the coming decade or two. After nationalization of coal mines in 1973, coal production of India improved significantly. However in spite of an increase in production, there is continued shortage of coal and hence imports have been increasing briskly in the fast few years. Similarly, though coal mining was opened to captive mining in the early 1990s, here too the production has been well short of expectations. Finally while official numbers of coal resources and reserves have been published every year with an average increase of almost 2.5 % per year for last two decades, the quantity of actual techno-economically mineable coal reserves in the country it is still not clear.

ASSUMPTIONS

1. Coal is intended to mean both coal as well as lignite.
2. The average life of a mine is 30 years.
3. The current mineability (ratio of India's techno-economically extractable reserves to proved reserves) of Indian mines is 34.6%, calculated from CMPDI's UNFC classification of CIL's reserves (CMPDI, 2012; CIL, 2010, p. 78).
4. Maximum coal reserves percentage to be mined by underground coal mining is limited to 12.3% of total proved reserves. This is based on assumption that coal reserves up to 300 m will be mined by opencast (OC) method, half of reserves between 300 – 600 m depth would be mined by opencast and underground (UG) method each, and reserves deeper than 600 m will be mined by underground mining.
5. Collieries own coal consumption= 0.08% of their coal production . So, remaining coal production will be considered as net coal production.

TRAJECTORIES

Level 1

Level 1 assumes that only the currently operating, on-going and planned coal mining projects by CIL (437 MTPA) and SCCL (41 MTPA) and currently allocated captive blocks (43 billion ton geological reserves) will come online (CIL, 2012; SCCL, 2012; Ministry of Coal, 2011). Production from current (non-captive) mines will reduce by 17% every 5 years (consistent with mine life of 30 years) due to closure of mines. Production from captive blocks will start reducing from 2027 onwards as most of the currently producing captive blocks are new. Coal reserves and mineability of all reserves will remain at present values. In this scenario, coal production gradually increases from 582 MTPA in 2011-12 to peak of 866 MTPA in 2037 and then it will start declining and reach 619 MTPA in 2047. About 85% of the mineable coal reserves will have been extracted by 2047 in this scenario as no new reserves are added and there is no improvement in mineability. Also, only OC mining, which is easier and cheaper, will be encouraged whereas the UG mining will be discouraged. So, the UG % will reduce from current of about 9% to 6.4% in 2047.

Level 2

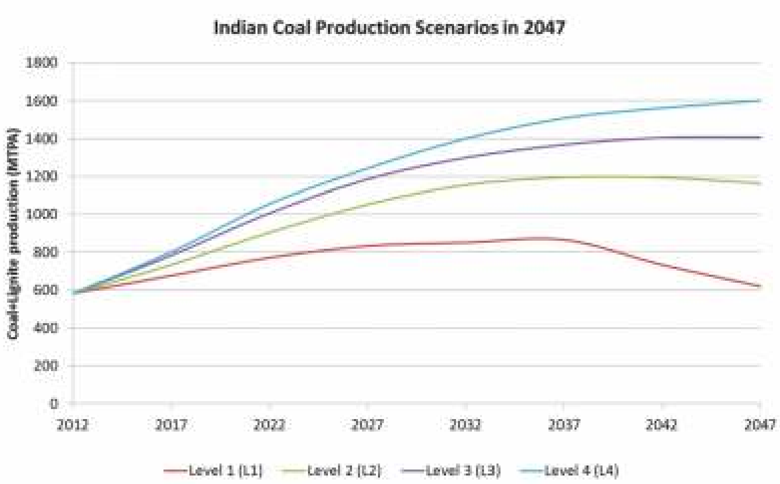
Level 2 projections are consistent with realistic (business as usual) projected scenario based the 12th Five Year Plan till 2022 (Ministry of Coal, 2011, pp. 54,78,79). Given that the production for 2012-13 fell about 18 million tons short of the target of 575 million tons (Ministry of Coal, 2013), we assume that the total shortfall from the target in 2017 would be 50 million tons. This results in an annual production increase of about 5% per annum up to 2017, and about 4% up to 2022. Proved coal reserves will grow at a reduced pace of 1% p.a. as most of the prognosticated coal bearing area (75%) has been explored. There would be some improvement in mineability due to technological improvement. In this scenario, coal production will grow to peak at 1195 MTPA in 2037 and decline marginally by 2047 to 1163 MTPA. About 62% of mineable coal reserves would have been extracted by 2047. OC mining will be encouraged but UG mining will not be paid much attention. So, UG mining's % will increase just slightly from current 9% to 9.3% in 2047.

Level 3

Level 3 is consistent with the optimistic scenario projections till 2022 in the 12th Five Year Plan (Ministry of Coal, 2011, pp. 54,78,79), tempered by slower-than-expected increase in production. The rate of increase of production reduces slightly going forward. Proved coal reserves will grow at about 1.3% p.a. and there would also be further improvement in mineability. With these positive conditions for coal based energy supply, coal production will be 1407 MTPA in 2047. About 55% of mineable coal reserves would have been extracted by 2047. UG mining will also be encouraged progressively to tap deeper coal reserves and its share will increase to 10.7% in 2047.

Level 4

Level 4 is the most optimistic, assuming full encouragement for coal based energy supply. Proved coal reserves will grow at 1.5% p.a., production will reach about 1400 MTPA in 2032 as anticipated in the Integrated Energy Policy document (Planning Commission, 2006, p. 45), and mineability will increase better than in other levels. In this scenario, coal production will increase to about 1602 MTPA in 2047, almost consistent with the high-case scenario of global coal production as per Global Coal Production Outlook (Hööka, Zittel, Schindler, & Aleklett, 2010) . In this scenario, about 48% of mineable coal reserves would have been extracted by 2047. UG mining will be emphasised significantly along with technological advancements but its share will remain confined to 12.3% in 2047 due to geological constraints.



2.2 Oil and Gas Production

INTRODUCTION

This document provides a brief on the working of oil & gas sector in India Energy Security Scenarios (IESS) 2047 Version 2.0. It is an established fact that India is a large importer of oil and gas, and this scenario is not expected to change in the near future. As the aim of the IESS, 2047 V 2.0 is to offer implications of energy related policies on our energy security in the medium to long term, the likely scenarios of oil/gas imports assume importance. Against this background, the projections of domestic oil and gas production have a significant role. It is difficult to project likely oil/gas production as exploration results are probabilistic, especially as India is grossly under-explored. India has an estimated sedimentary area of 3.14 million sq. km comprising 26 sedimentary basins, out of which, 1.30 million sq. km area is in deepwater and 1.84 million sq. km area is in onland and shallow offshore. As on 31st March, 2014, out of total area, 48% has been appraised, 4% area falls under no go areas and remaining 48% is still to be appraised (Appraisal of a sedimentary basin has been defined as the status of knowledge building efforts for evaluating hydrocarbon prospectivity of the basin through Geological studies, Geophysical surveys and exploratory drilling) (DGH).

The conventional hydrocarbon prognosticated resources in 15 sedimentary basins along with deep water areas of the country are of the order of 28.1 Billion Tons of Oil and Oil Equivalent of Gas (Directorate General of Hydrocarbons DGH). As on 31.03.2014 in-place hydrocarbon volume of 10,947 MMT of Oil and Oil Equivalent Gas could be established through exploration by ONGC, OIL and Private/JV companies. So, approximately 17 Billion Tons i.e. 61 % of resources (oil and oil equivalent of gas) are under “yet to be established” category.

The historical growth rate (CAGR) of initial in place hydrocarbon volume (from 2004-05 till 2011-12) is about 2.55%. In the present exercise, an effort has been made to project the likely discovery of 'in place hydrocarbons' on the basis of historical trends. While a more exact approach would be to estimate prospectivity on a basin-wise basis, but the ambition of the present study is not to get into a technical analysis, but concentrate on policy levers. The exploratory effort is likely only to increase as the Government is keen to reduce oil/gas import dependence (presently 80% for oil and 27% for gas), with greater likelihood of establishing more 'finds'. However, as has been witnessed in the past, India has failed to monetize its discoveries. There is a wide gulf between the 'in-place hydrocarbons' established on yearly basis as reported by the DGH, and the 'proved reserves' as indicated by British Petroleum (BP) Statistics. The latter are a sub-set of the former, but the falling percentage of the latter is an area of attention. The instant analysis develops scenarios of oil and gas production by enhancing the pace of conversion of discoveries into producing fields, and raising the recovery factors (R/F).

The projections of oil/gas production of India are being proposed in the absence of strong geological data. In the absence of the latter, our approach is based on the contractual/prevalent regime in exploration. E&P operators report discoveries on the basis of their seismic/drilling activity. Then, as per the NELP Production Sharing Contracts (PSCs) they go on to appraise discoveries and propose a Development Plan for a size of reserve, for which a production profile is approved. Even the NOCs follow a near-similar process in their nominated acreages. In the IESS, 2047 V2.0 we assume the volume of oil/gas that is likely to be discovered, based on the CAGR of discovered resources in the past. This leads to initial-in-place reserves (IIP). The IESS projects the likely production on the basis of four scenarios of conversion of initial-in-place hydrocarbons into ultimate reserves. Naturally, if the reserve levels are higher, then the production will also be commensurately higher. As we move from low levels of reserve conversion to higher levels, the oil/gas production is estimated to rise. Therefore, in this analysis, presuming that exploratory efforts continue un-abated (they may intensify due to Government policy), the analysis reveals that it is the conversion to proved reserves that holds the key to raising oil and gas production. It has been seen that in India, while the operators have reported a large number of discoveries, only a handful have been converted into producing properties. Hence, the problem seems to be in monetizing discoveries and not finding hydrocarbons. It is recognized that not all discoveries are commercial. It is for the Government to spell out as to whether its policy is to encourage domestic self-sufficiency even if the domestic production comes at higher rates than what is prevailing in the international markets or get the best commercial deal. As the present tool is one of energy security, we do not take the price arbitrage into account, and merely highlight the scope of raising oil/gas production from the Indian sedimentary basins.

The scope of the present exercise is merely to seek policy areas for action. This leads us to develop 4 scenarios or Levels - (L-1: Least Effort; L-2; Determined Effort; L-3: Aggressive Effort, and L-4: Heroic Effort) likely percentages of the discovered resource being produced over an assumed number of production years based on recovery factors. If the regime could be geared towards incentivizing operators, or facilitating oil/gas production, India could have a healthy hydrocarbons regime. Therefore, in a nutshell, the present exercise offers an insight into the 'problems' faced by the E&P sector in their inability to convert discoveries into production, and the likely 'upsides' to crude/gas production by putting in place suitable policies to enhance recoveries. The present document explains the working of the domestic oil and gas production scenarios in the instant IESS tool, and helps the user make choices on determination of different crude oil & natural gas production trajectories until the year 2047.

The likely oil and gas demand would be 587 MMT and 308 BCM in 2047 considering Level 2 (Determined Effort) which is the default scenario, respectively. On the other hand the likely production of oil/gas has been estimated to be 59 MMT and 127 BCM in 2047 considering level 2, respectively. Level 2 envisages moderate improvement from the present, and results in robust increase in demand, with only moderate increase in domestic oil/gas supply. Resultantly, when taking into account the likely demand for petroleum products as envisaged by the Calculator in IESS, the oil and gas import shares (against consumption) could be between 88% and 60% in 2047 considering level 2 or Determined effort, respectively.

OVERVIEW OF THE OIL & GAS SECTOR

Managing the petroleum and natural gas sector of India envisages critical challenges as identified in the Twelfth Plan. The demand for petroleum products is expected to expand while the scope for increasing domestic production is limited. Currently, the oil/gas prices are subdued, but decline in exploration/production globally in the light of low prices/over supply may lead to a reversal in the trend. In the medium to long term, oil prices in world markets are expected to be volatile but generally high. The oil and gas import bill is likely to increase in the future from the present level of around 6-7 per cent of GDP.

The recovery factor (R/F) of both oil and gas taken together for private and joint venture (JV) companies in India is higher than that of public sector companies like ONGC and OIL.

While the recovery factor is 41.2% for private and JV companies, it is 36.7% for OIL and 35.2% for ONGC. The average oil and gas recovery factor in India works out to 36.5%. For some countries like Norway, the recovery factor for oil and gas is as high as 44%. In other countries like Iran and USA, the recovery factor is 35% and 32% respectively. Individually, the average natural gas recovery in India is 50.8%, while for oil it is 28%. As far as crude oil recovery is concerned, the PSUs fare better than their private sector counterparts. While the R/F for OIL and ONGC is 29.6% and 28.3% respectively, the private and JV companies stand at 23.7%. In the natural gas segment, the R/F of OIL is 53.9% followed by private and JV companies at 53% while that of ONGC stands at 49.3%. R/F's are largely dependent on geology, but it has also been seen in some cases, that in the same basin the above are at variance from ONGC to OIL. This is typically seen in the North east. In the light of complete exploration, a doubt lingers whether full evaluation of the reserves has taken place or not. Until this happens, the issue of poor R/F will remain alive.

Even though domestic production of energy resources is projected to increase, the import dependence is expected to maintain high levels. Import of crude oil is currently about 80% per cent of total crude demand in the country. 189.23 MMT of crude oil was imported in 2013-14 which increased our oil import bill by 9.27% (from INR 7846 Billion to 8648 Billion) in comparison with the imports in 2012-13. The amount of crude oil imported in 2014-15 was 189.43 MMT and the bill came down in 2014-15 to INR 6873 Billion due to softening of crude price.

The gas supply from indigenous fields was 52.3 BCM in the year 2010-11 (the highest ever) has shown declining trend and in the year 2014-15, the supply was about 33.88 BCM. The import of gas as LNG in 2013-14 was of the order of 13.03 MMT (approximately 17.84 BCM) and has not grown at the expected rate to meet the demand of gas of the power and other sectors. It is a separate policy dialogue as to why India did not go in for LNG imports in a major way to generate power and urea – both of which are in short supply.

The ongoing efforts to explore oil and gas have been satisfactory so far as establishment of new hydrocarbons resources goes on. It may be noted that Indian oil companies have consistently been reporting reserve replacement ratio of more than 1. The discovered resources have been defined as 'initial oil in place' which include proved, probable and possible reserves and contingent resources. . The growth in initial-in- place reserves combined for both oil & gas from 2004-05 till 2011-12 has been at CAGR of 2.55%. During 2013-14, the split between oil and gas has been in the ratio of 63.58% and 36.42% respectively and keeping the past trend of rising share of gas finds into consideration, the likely split between oil and gas has been extrapolated to be 40% and 60%, respectively in 2047. While this is a simplistic assumption, it meets the requirement of the present analysis which is merely a scenario based exercise using Excel model and not a geological exercise. It is definitely an indicator that India has to intensify its exploratory efforts, to establish the reserves and devise suitable policy framework for converting the discoveries into production.

The estimate made by the Directorate General of Hydrocarbon (DGH) of oil and gas potential in 15 sedimentary basins is about 28 billion tons which may increase upon thorough exploration of these 15 basins and the remaining 11 basins. Out of this, 10.94 billion tons of initial in place (IIP) reserves (O+OEG) have been established as of 01.04.2014. The share of oil IIP is 6.96 billion tons (63.4 %) and that of gas is 3.98 billion tons (36.6 %). Government of India has signed contracts for 29 discovered fields, 28 exploration blocks under pre-NELP regime and 254 blocks under NELP regime with National Oil Companies and private (Both Indian and foreign)/ Joint Venture companies. At present, out of 311 exploration blocks/fields awarded so far under various bidding rounds (Discovered Field, Pre-NELP & NELP), 178 blocks/fields are operational. DGH indicates, that so far a total of 200 hydrocarbon discoveries (100 oil and 100 gas) have been made under the Pre-NELP & NELP regime in 54 blocks/fields. Out of total awarded blocks of 288 under 9 rounds of NELP bidding, 130 blocks have been relinquished and 151 is operational.

The analysis of India's exploratory successes and production trends offer an interesting revelation. (The tables below highlight the IIP numbers (DGH) (Table1), proved reserves number indicated by BP (Table 2) and crude oil production numbers for the period 2004 to 2012 (DGH). While we have been reporting discovery of new resources, our production has been stagnant. There is definitely a time lag between discovery and production, but in India's case, the discoveries never seem to be getting monetized only partially. It is purported that the production levels are being maintained by exploiting new discoveries in existing acreages by IOR and EOR. The situation remains ever confusing. At the same time, both ONGC and OIL have been reporting healthy new finds thereby achieving Reserve-Replacement-Ratio (RRR) of 1 and above. Similarly, under NELP, even private sector (public, too) have reported multiple oil and gas discoveries. But, only 4-5 discoveries have been brought under production in spite of having initiated exploration under NELP more than 15 years back. Should these discoveries be monetized, a vast scope appears for improving production. But, the growth in production of oil and gas is near static or on decline. Herein lies the clue for policymakers to focus on the efforts needed to convert growth in reserves into production. The new discoveries add volumes to IIP but the production has been stagnant. R/F would have risen if higher production could come from existing resources. In our case, we are merely able to maintain R/F, but not raise the percentage of exploitation of reserves.

The Table 1 gives us the historical initial in place numbers for oil, gas and oil + oil equivalent of gas (DGH) till 2013-14 and the corresponding projected figures till 2046-47 calculated by taking a CAGR of 2.55%.

Table1: Fixed Assumption of Establishment of Oil and Gas in Place

Year	IIP Oil (MMT)	IIP Gas (MMT)	Total IIP (oil & Oil Equivalent of Gas) (MMT)
2004-05	5660	2581	8241
2005-06	5800	2664	8464
2006-07	6046	2948	8994
2007-08	5895	3240	9134
2008-09	6752	3587	10340
2009-10	6511	3481	9993
2010-11	6489	3621	10113
2011-12	6131	3712	9843
Growth rate			2.55%
2012-13	6745	3889	10634
2013-14	6961	3987	10947
2046-47	9505	14256	23761

Source: DGH

Table 2: Growth of Proved Reserves and Production

Year	Proved Reserves (MMT)	Production (MMT)
2004	759	34
2005	807	32
2006	777	34
2007	745	34
2008	791	34
2009	794	34
2010	796	38
2011	778	38
2012	780	38

Source: Proved Reserves (BP Statistics) and Production (DGH)

The information in Table 2 shows the static proved reserves and production over the years. When compared with the growth in OIP and GIP in the previous table, the asymmetry becomes evident. The in-place reserves are rising but the proven reserves and production is static. The analysis indicates that with the likely growth in initial in place (IIP) reserves, if India were to make 'heroic efforts' or induct technology and encourage policy environment, we could ramp up our proven reserves and hence, oil production from the present 38 MMT level to a much higher level in the year 2047. Similarly gas production could go up phenomenally.

2.2.1 OIL PRODUCTION

ASSUMPTIONS

This section helps the user understand how the scenarios of oil/gas production have been developed. The assumptions sheet is the principal driving sheet for the Calculator. The numbers provided in the assumptions sheet form the basic inputs for building the Levels 1to 4 i.e. alternate scenarios/trajectories. We derive the ultimate reserves from the OIP (oil in place), which would be the total volume of oil that may be produced in India. Now we need to determine the annual production from the above reserves.

The combined growth in IIP for oil and gas @ 2.55% (historical growth rate upto 2047) over the base year 2011-12 is a common assumption number across the 4 scenarios in the tool till 2047. It is only the level of our ability to raise the recovery factor that is different under the four scenarios. The recovery factor across the L-1, L-2, L-3 and L-4 have been assumed as 28%, 30%, 35% and 40% for crude oil and 55%, 60%, 70% and 80% for natural gas, respectively. Historical trends of crude oil production have been taken into consideration while estimating the production trajectories in case of ONGC, OIL and PVT/JVs across the four scenarios. ONGC's JV share is included in the production profile of ONGC.

The above assumptions are based on the technical feasibility of extracting oil & gas as the developed hydrocarbon regimes are already achieving the proposed recovery factor. Applying the above recovery factors for oil and gas on initial in place reserves i.e. 28% in L1 to 40% in L4 and 55% in L1 to 80% in L4 respectively, we get the ultimate reserves which we consider as technically recoverable reserves, or the total volumes that India may be able to produce.

In IESS 2047 Version 2.0, the user is offered the choice to play upon merely the R/F lever. Now we have to make assumptions regarding the likely production of oil and gas in the years to come from the four different scenarios of Ultimate reserves. It has been historically established that the production of oil in different years has been a fixed percentage (or marginally falling) of the Ultimate reserves as per DGH data. The above percentage is 2.3 for oil, a factor which tells us about the production rate from the ultimate reserves. We could assume the same exploitation rate (2.3%) for different Ultimate reserves to derive a uniform rate of production. Simultaneously, we need to ensure that the annual production rate assumed for a level, should not surpass the Ultimate reserve by 2047. The above assumption regarding the production rate for a volume of Ultimate reserve is an approximation of what may be the annual production.

The above table 3 illustrates the maximum annual production that can be sustained in the year 2047 on the basis of the calculations explained earlier.

TRAJECTORIES

Level 1

Projects a pessimistic scene or 'Least Effort Scenario' wherein there is no improvement in recovery factors, and no new fields come into production barring the ones for which Final Investment Decision (FID) have been taken. Hence, discoveries will happen (or may even stop) but there will be poor success in converting them into production. The recovery factor has been assumed almost constant i.e. 28% for oil and 55% for gas.

Level 2

Assumes present policies to improve as per on-going efforts, which confirms to the present initiatives taken, and also takes into account some technological improvements. Hence, it is called the 'Determined Effort' scenario. It would be simplistic to say that Level 2 is BAU, as it also assumes continuing efforts to improve the policy space for improvement in oil and gas discoveries and production. This level experience minor improvement in recovery factor i.e. 30% for oil and 60% for gas.

Level 3

Is more optimistic and is the 'Aggressive Effort' scenario, and considers government policy intervention towards a better future with enhanced production and lower oil/gas imports. This level experience increase in recovery factor i.e. 35% for oil and 70% for gas.

Level 4

Is the most optimistic or the 'Heroic Effort' scenario; it is an ideal situation that is drawn from whatever is physically possible as perceived today. This level experience increase in recovery factor i.e. 40% for oil and 80% for gas. Keeping in mind the combined historical growth rate of 2.55% of initial in-place reserves of oil and gas, the future projection of IIP has been done till 2047. By observing the changing mix of oil and gas discoveries, the

Table 3: Maximum annual production of crude oil under different scenarios (in 2047)

Levels	Oil in Place (MMT)	Recovery Factor	Ultimate Reserves (that can be recovered Technically) (MMT)	Maximum Annual Production (MMT) (2.3% of ultimate reserves)
1	9505	28%	2661.4	61.2
2	9505	30%	2851.5	65.6
3	9505	35%	3326.8	76.5
4	9505	40%	3802.0	87.4

Source: Calculations as per IESS analysis

future discoveries remain in favour of gas, it is expected that the share of oil reserves in 2047 would be 9.5 billion tons (40%) and that of gas 14.25 billion tons (60%). This assumption would be common across the 4 scenarios. As the scenario building exercise is working only on the prognosticated reserves of 15 basins, establishing 23.76 billion tons of reserves by 2047 is assumed to be a realistic phenomenon, yet leaving scope for further reserve establishment within the 15 basins, as well as the balance unexplored 11 basins.

The Table 4 above offers the assumed levels of oil and gas establishment under this exercise upto the year 2047.

TRAJECTORIES

Level 1

It projects a pessimistic scene wherein there is no improvement in recovery factors, and no new fields come into production barring the ones for which Final Investment Decision (FID) has been taken. ONGC has provided its likely production profile upto 2022 and OIL up to 2021. These numbers have been adopted in this exercise. PVT/JVs numbers have been provided by DGH up to 2022 and are taken as it is. For the following period various growth rates have been considered based on historical trend accounting from 2022 onwards. ONGC (-0.5%), OIL (1.4%), PSC Regime (1%)

Most of the fields are under natural decline viz. Ravva, Panna-Mukta. A sharp decline is projected from CAIRN's Rajasthan fields from 7.5 million tons per annum in 2015-16. (As per DGH estimates, most of the fields would be under sharp decline from the year 2016-17 to 2020-21). This discounts the discoveries under consideration/evaluation at various levels as they are not firm as yet. The production in 2047 would become 34.5 MMT..Level-1 assumes no improvement in present recovery factor of 28%. Hence, from the above graph, we find that reserves are not fully brought into production, thus a narrow band is found between cumulative production and ultimate reserves. The crude oil production in 2047 would be 34.5 MMT.

Level 2

This is the normal/present scenario where the Government continues to make efforts to improve the oil/gas production landscape.

Table 4: Projected Oil and Gas in Place on the basis of Historical Trends

Year	OIP (MMT)	GIP(MMT)	% Share OIP	% Share GIP
2004-05	5660	2581	69	31
2005-06	5800	2664	69	31
2006-07	6046	2948	67	33
2007-08	5895	3240	65	35
2008-09	6752	3587	65	35
2009-10	6511	3481	65	35
2010-11	6489	3621	64	36
2011-12	6131	3712	62	38
2012-13	6745	3889	63	37
2013-14	6961	3987	63	37
2047	9505	14256	40	60

Source: Calculations as per IESS analysis

New policies to help monetize discoveries continue to be launched but there is no dramatic change in the policy framework. Additional NELP discoveries which are under various stages of DOC approvals, FDP approval/ appraisal have been considered. 35 discoveries which are under various stages of approvals of DOCs/ FDP /IDP have been considered for production. Keeping above factor into consideration following growth in production has been considered: ONGC (1% from 2017 onwards), OIL (1.7% from 2017 onwards), PSC Regime (1% from 2017 onwards and 1.5% from 2022 onwards).

Level 2 assumes that the recovery factor of 30% would be maintained based on the investment plan of the companies. This would increase the production to about 59MMT/year by 2047.

Level 3

This is an aggressive scenario wherein new fields are envisaged to come into production. It may be noted that there are a number of oil discoveries which are awaiting appraisal and development as of now. This level envisages that a number of them are found to be commercial and they come into production.. Keeping above prospects into consideration, following growth rate has been considered: ONGC: (1.0% growth from 2014-15 and 1.5% from 2017 onwards), OIL: (2% from 2017 onwards) and PSC Regime: (1.5% from 2017 onwards)

Level 3 assumes that a recovery factor of 35% would be maintained. At this recovery factor, the production would reach 68 MMT/year by 2047.

Level 4

This Level envisages contribution from shale oil and tight oil and a recovery factor of 40% is assumed. This envisages the most optimistic scenario with NOCs registering a continuous growth in oil production with a lot of private companies also increasing production. This level assumes the following growth rates:- ONGC: (1.5% growth from 2014-15 and 2% from 2022 onwards), OIL: (2.5% from 2017 onwards) , and PSC Regime: (2% from 2017 onwards).

Assuming a recovery factor of 40%, the crude oil production in 2047 would rise to 78 MMT.

The above table 5 shows the production of crude oil in different years across the four levels/scenarios.

Table 5: Crude Oil Production (MMT) under Different Scenarios

Year	Level 1	Level 2	Level 3	Level 4
2012	38	38	38	38
2017	41	42	43	43
2022	35	44	46	47
2027	35	46	50	52
2032	35	49	54	57
2037	35	52	58	64
2042	34	55	63	70
2047	34	59	68	78

Source: Calculations as per IESS analysis

2.2.2 GAS PRODUCTION

ASSUMPTIONS

Basic or Fixed Assumptions

1. Production profile has been classified into various categories i.e. ONGC (including its private/JV share), OIL and PVT/JVCs, CBM, Shale gas, Underground Coal Gasification (UCG).

2. The Growth of initial in place (IIP) reserve accretion (oil + oil equivalent of gas (O+OEG) from 2004 to 2012 has been at CAGR of about 2.55%%. While making assessment for future growth in initial in place reserves estimate (O+OEG), same growth rate has been extrapolated.

3. Keeping in mind the changing mix of recent discoveries in favour of gas, it is expected that the share of oil reserves in 2047 would be 9.5 billion tons (40%) and that of gas 14.25 billion tons (60%). This assumption would be common across the 4 scenarios.

The likely reserve establishment for oil and gas under the above set of assumptions is the same as given in Table 6.

General Assumptions

1. The past historical data of Natural Gas production in India has been kept in perspective while generating estimates for Levels 2, 3 and 4. BP statistical review numbers for yearly gas production from 1994 onwards (i.e. the year of opening up of Upstream Hydrocarbon Sector) have been considered as historical data.

2. The Levels 2, 3 and 4 also capture production from unconventional sources. Latest technological developments have made Shale Gas development scenario a reality and it has been assumed that Level 2, 3 and 4 production scenarios will include shale gas production, albeit in differing time frames.

3. Recovery factor has also been suitably assumed across the 4 different scenarios. It assumes to establish about 14.25 billion tons of Gas in Place (GIP) in 2047. The ultimate reserves based on the recovery factor and maximum production that can be supported at the reserves in different levels in the year 2047 are provided below:

The Table 6 above gives us maximum production of natural gas that can be sustained in 2047 on the same analogy as in oil, but with a different factor. While, the replacement factor for crude oil which is taken as 0.023 (2.3%), in case of natural gas, this factor is taken as 0.015

Table 6: Maximum annual production of Natural Gas under different scenarios (2047)

Levels	Conventional Gas in Place (MMT)	Recovery Factor	Ultimate Reserves (that can be recovered Technically) (MMT)	Maximum Annual Production (MMT) (1.5% of ultimate reserves)
1	14256	55%	7840.8	117.6
2	14256	60%	8553.6	128.3
3	14256	70%	9979.2	149.7
4	14256	80%	11404.8	171.1

Source: Calculations as per IESS analysis

(1.5%) based on the historical trend which may or may not improve depending upon the environment, regulatory regime and investments made in the E&P sector.

Note: The gas in place reserves, ultimate reserves and the maximum production numbers in Table 6 includes only conventional natural gas, and unconventional sources of natural gas like shale gas, CBM, UCG and gas hydrates have not been included due to lack of data availability as their reserves have not been established with high certainty, and the geological surveys done by different organizations report different numbers.

TRAJECTORIES

With the growth in O+OEG reserves from 2004 to 2012 at a CAGR of 2.55%, total IIP reserves are projected to be 23.76 billion tons in 2047. The share of oil and gas IIP would be 9.5(40%) billion tons and 14.25 billion tons (60%), respectively. The Gas recovery factor is currently in the range of 55-60%. The four Levels of likely gas production leading upto 2047 are based on rising recovery factors (R/F) and production from unconventional sources of gas and UCG. The gas production in four scenarios (levels) are based on the projection of the production profiles of ONGC, OIL and PVT/JVs.

Level 1

Level 1 incorporates only the future production from current discoveries of conventional gas and CBM. It does not include any production from shale or Underground Coal Gasification (UCG). Domestic gas supply reaches about 81.5 BCM in 2047. This Level assumes R/F of 55%. The share of PVT/JVCs in the total production in 2047 would be 19% as compared to 75% of NOC's (ONGC-63% & OIL 12%) and CBM would contribute around 6%. The following growth rates have been assumed, ONGC: (1% from 2017 and 2.3% from 2022), OIL: (2.1% from 2017 and 4.3% from 2022), PVT/JVs: (2.2% from 2017 and 2.25% from 2022).

Level 2

Level 2 assumes moderate activity of CBM development. Shale gas makes its debut at end of the13th Five Year Plan (FYP) i.e. 2021-22. Level-2 assumes R/F of 60%. The domestic gas supply would reach a level of 127.5 BCM in 2047. The share of PVT/JVCs in the total production of natural gas in 2047 would be 37% as compared to 56% of NOCs (ONGC-45% & OIL 11%). The rest (7%) would be unconventional share coming from shale gas and CBM. The growth rates assumed in Level 2 from 2022 onwards are, ONGC: (2.5%), OIL: (5.5%) and PVT/JVs: (6.5%).

Level 3

Level 3 is an aggressive scenario which will require additional policy inputs to spur the growth of natural gas sector evolved in India. Level 3 assumes all presently available CBM reserves will be produced and CBM production would reach to around 8 BCM in 2047. This level assumes moderately optimistic scenario for shale gas development in India. It also assumes gas production coming from underground coal gasification (UCG) from 2027 onwards (15th five year plan), albeit at level of 2 BCM/annum. It is also assumed that R/F will be 70% from the existing fields. Gas supply would reach about 170.5 BCM by 2047. The growth rates assumed in level 3 from 2022 onwards are, ONGC: (3.25%), OIL: (6%) and PVT/JVs: (6.5%).

Level 4

Level 4 is the most optimistic scenario. It assumes an aggressive conventional gas scenario and CBM exploitation, a moderate shale gas production and commencement of UCG from 15th FYP but maximum supply from UCG is about 9 BCM/ annum in the year 2047. The level 4 assumes that a technological breakthrough of gas hydrate takes place and production starts from 2032 onwards. Level-4 assumes R/F of 80% which would safely sustain production level of about 224.5 BCM/year in the year 2047. The share of PVT/JVCs in the total natural gas production in 2047 would be 33% as compared to 52% of NOCs (ONGC-41% & OIL 11%) and the unconventional share would be about 15% comprising shale gas, CBM, UCG and gas hydrates. The growth rates assumed in level 4 are, ONGC: (3.5% from 2017 and 4% from 2022 onwards), OIL: (4.25% from 2017 and 6.5% from 2022 onwards) and PVT/JVs: (6.25% from 2017 and 7.5% from 2022 onwards).

The Table 7 above shows the gas production in different timeframes under the four scenarios. The contribution of gas from different sources may be seen in the Excel sheet (XV.a) which can be downloaded from the IESS 2047 Version 2.0 website.

It is clear that India has the opportunity to increase its gas production (from the same level of reserves) by more than 2.5 times from 2012 to 2047 if Level 2 is considered and the gas production would increase 3.5 times by 2047, by improving R/F if level 3 is taken into account.

COSTS

In the IESS V 2.0 a new feature of cost implications has been added. This will help users of the Tool to evaluate different pathways not only on the basis of parameters of implications on imports and emissions but cost as well. Therefore, we have included our cost projections in the sector Excel sheets as well. In order to estimate cost of petroleum products and gas, we need to start with the price of crude and natural gas paid to the upstream/oil and gas producer. Thereafter, the cost of processing/transporting crude and in the case of natural gas, merely cost of transportation has to be accounted for. As regards imported gas, we have to estimate the cost of handling/tolling at the LNG terminals. The following discussion explains as to how the cost estimates have been derived. It may be added that as there is large uncertainty around prices in the next 3 decades or more, the IESS offers three estimates of prices, allowing the user the choice of adopting the cost as may be preferred. Looking to the recent drastic drop in the prices of crude and gas, there is a large uncertainty around such an exercise. However, when the total cost of a pathway has been

Table 7: Natural Gas production from conventional and unconventional sources (BCM) in different years across four levels

Year	Level 1	Level 2	Level 3	Level 4
2012	47.6	47.6	47.6	47.6
2017	39.2	39.5	41.7	44.0
2022	42.5	46.0	53.2	56.2
2027	48.2	56.8	68.1	76.7
2032	54.8	69.4	85.1	103.1
2037	62.4	84.1	108.1	133.9
2042	71.2	103.0	135.4	173.5
2047	81.5	127.5	170.5	224.5

Source: Calculations as per IESS analysis

derived, the user can undertake sensitivity analysis on oil/gas costs to derive the big picture on the arbitrage involved in moving away from fossil fuels or continuing with it. For an import dependent country like India, it is important to err on the side of higher prices as we need to strategize means of protecting our public finances, which are affected significantly when crude prices rise.

The volatility of oil and gas prices is expected to remain high in the long term, however, the present prices are experiencing a declining trend. High Import dependence of Crude Oil (80%) and Natural Gas (27%) has become a financial drain on the FE reserves of the country. Since, it is difficult to project the oil and gas prices, a range of prices is considered, namely- high, point and low cost scenarios, which will try to capture the likely prices in future. While doing the cost analysis, various taxes levied by the Government have not been taken into account as in India different State Governments have different tax structures, so, only the economic cost is being considered. There is no surety of changes in tax structure either.

As a major chunk of our crude oil requirement is being imported, imported and domestic crude oil prices have been considered identical. The above is as per the extant Government policy, too. The crude prices have been derived from the International Energy Agency's (IEA) World Energy Outlook (WEO) which describes three policy scenarios i.e. Current, New and 450 Policy scenario giving three different prices of crude oil. The current policy scenario is taken as the high cost estimate, new policy scenario as the point cost or default estimate and 450 scenario as the low cost estimate to arrive at the prices. The cost algorithm in the IESS sums up the cost of the pathway for the period 2012-47. The baseline crude price is for the year 2012, and has been taken from the earlier version of IESS, which took the crude price from the information contained in WEO 2013. However, as regards the future oil price projections, we have relied on the latest WEO edition, i.e, WEO 2014. As the WEO is released towards year-end, we are presently using older numbers (2014 version), and could update the same when 2015 edition is released.

The pricing of Natural Gas around the world have been governed by regional markets - Asian market is governed by JCC crude Index price of Japan, European market by UK National Balancing Point and USA by Henry Hub prices. Gas pricing has been an issue of debate in our country. While the price of domestic natural gas has not been market driven, but the prices for both PVT/JVCs and NOC gas is expected to be same in the near future.

As regards influence of international gas prices, it is considered that the country's gas market will evolve beyond 2022 in the Level 3 and 4. In Level 1 and 2, we presume that gas markets have not developed, and there is poor production of gas which results in continued government oversight of pricing and utilization of gas. Although it may be very difficult to deregulate the gas prices immediately, but to send the right signal and show the clear picture to customers/producers, it is desirable to eventually deregulate the gas prices as has been done for petrol and diesel prices. In our analysis, the domestic and imported gas prices vary till 2022 after which they become alike as explained above. The 2012 domestic gas price is taken from the Ministry of Petroleum and Natural Gas (MoPNG) website. The Point Estimate for 2017 domestic price is calculated by moderately increasing the prevailing domestic gas price of \$4.66/mmbtu by 20%. The low estimate for 2017 domestic price is computed by increasing the domestic gas price of \$4.27/mmbtu (as it prevailed in 2012) by 20%. The high estimate for 2017 domestic price is calculated by increasing the price in proportion with low and point estimates.

Apart from the fuel costs, the infrastructure cost of refineries, pipelines and LNG import terminals have also been taken into consideration. This is essential to derive the cost of refined products. While the price of crude/gas can be derived on the basis of international prices, but this is not the case for products. To get a deeper dive into the infrastructure costs, the user can refer to the detail documentation (VII. Costing) for explanation and the excel sheet (XVII.a) to see how the infrastructure costing has been done.

CONCLUSION

The above exercise leads us to conclude that there is a large prospect of oil and gas reserve establishment in India. The DGH data regarding growth in Oil-in-Place and Gas-in-Place as indicated in Table 1 gives us the above assurance. We are also aware that only 15 basins out of 26 basins have so far been evaluated to some degree of confidence yielding a likely prognosticated reserve of 28 billion tons of oil and gas. The IESS analysis is an overall energy tool which relies on existing information regarding resources availability. It does not undertake independent assessment of resource availability, but merely the policy and technology levers that may influence demand and supply of energy. Hence, if we were to rely on the available resource quantification, and develop likely levels of oil and gas supply, it can lead to policy interventions to achieve the maximum potential.

In the case of oil, we can see in Table 5 that there is a potential to increase oil production by one-third in 2047 (and in the intervening period) over the default case. India has the opportunity to increase its gas production (from the same level of reserves) by more than 2.5 times from 2012 to 2047 if Default scenario (Level 2) is considered and the gas production would increase 80% by 2047 over Default scenario, by improving R/F (Table 7). If the above reserves are exploited, as per the technical fact of production rising in the initial years, and then plateauing before it tapers off, a production profile can be generated which has been undertaken in this exercise. As regards production rate from the Ultimate Reserves, the historical relationship between Ultimate reserves and production, separately for oil and gas is assumed. It is merely ensured that at the assumed rate, the total production should not exceed the ultimate reserve levels by 2047. It is granted that oil and gas discoveries and production do not follow a uniform trend, but the discovered resource has to be brought above the ground sooner or later. The instant exercise merely gives the volume involved.

As regards the other sources of hydrocarbons, particularly shale reserves, CBM and UCG, again the IESS identifies their potential on the basis of available information of reserves. Again this helps in understanding the significance of these fuel types, and the effort needed to bring them into production.

As regards import dependence, as the Tool is unique in its use for generating sector wise demand for oil and gas and highlighting the urgency to raise domestic production. This tool may also propose action on demand side to take steps to develop substitutes or make fuel switches. Therefore, the exercise from the supply end is useful to match demand projections at different points of time. The costing exercise is merely to offer numbers to create import bills, cost of pathways and relative cost of energy in calorific terms. As economic costs are taken, we assume international cost of crude and make assumptions about price of gas. Looking to the present dramatic drop in oil and gas prices, it is difficult to make credible assumptions on future prices. Therefore, reliance is being placed on projections of other agencies such as EIA and IEA. The Energy Information Administration (EIA) has projected the oil and gas consumption in India to grow at a CAGR of 3.5% and 4.6% respectively. The IESS model projects the oil and gas consumption at a CAGR of about 3.6% and 3.8% respectively. As regards domestic production, the Kelkar Committee has estimated that the potential to enhance domestic oil and gas production between 'BAU' scenario and concerted efforts by 2030 is in the realm of a factor of 2.5 Therefore, there is indeed a big opportunity of improving the performance of this sector by stepping up efforts.

In the end, it can be said that oil and gas exploration business is probabilistic in nature, and works on the basis of qualified assessments. India is yet to explore more than half of its sedimentary basins, or even acquire basic data of the un-explored basinal area to be able to offer it to E&P companies. Various studies have conjectured the likely resource availability on extrapolation method, but not on a dis-aggregated basis as has been done in IESS. Similarly, on the demand side numbers have been projected on projecting historical growth rates. In IESS, the bottom-up exercise offers leads on demand and supply side interventions. In the oil and gas sector, the analysis of in-place reserves and proved reserves highlights the difficulty being faced on converting 'finds' into production. The link between 'in-place' reserves and proved reserves is more direct as compared to, proved reserves into production. However, the size of the 'prize' is essential to be estimated which is done by estimating likely production should the 'in-place' reserves by converted into proved reserves.

2.3 Thermal Generation

INTRODUCTION

As of 2014, India has low levels of electricity access and per-capita electricity consumption. The share of households using electricity as the primary source of lighting is around 75%, which means about 300 million citizens, do not have access to electricity. Similarly, India's per-capita electricity consumption is very low at only 957 kWh per capita per year, compared to a world average of about 2,700 kWh per year. Therefore, there is a huge pent-up demand for electricity in India which needs to be rapidly met in the coming years.

Thermal power generation capacity based on coal and gas is about 187 GW (164 GW of coal and 23 GW of gas), that is about 69% of India's power generation capacity of about 272 GW (CEA, May 2015).[1] In terms of actual generation, thermal power's contribution was even greater, at over 79%. In future, the share of thermal generation in India's power basket and its implications on other issues such as land requirements, water requirements and CO_2 emissions depend on the path that would be adopted by India. This document presents the key insights regarding thermal power generation in India up to 2047 arising from the IESS tool.

Thermal Generation Capacity

Thermal generation capacity in India will increase significantly in the coming decades. Even in the least effort scenario (L1), it is expected that installed thermal generation capacity will go up from 149 GW in 2012 to 290 GW in 2047, with 253 GW being coal-based and 37 GW being gas-based. This will be 25.3% of India's total power generation capacity in 2047 if the other sources of power generation (such as renewables, large hydro and nuclear) follow a determined efforts trajectory up to 2047. Thus, thermal generation will play a non-trivial role even if in a least-effort scenario.

If thermal capacity addition follows a determined effort pathway (L2), total capacity would be 383 GW in 2047, with 333 GW being coal-based and 50 GW being gas-based. This would form 33.3% of India's 2047 capacity if other sources followed a determined trajectory. If thermal capacity addition follows an aggressive pathway, then capacity would go up to 542 GW, and it would contribute 34% of the capacity in 2047. In the heroic effort scenario, where India focuses on addition of thermal based capacity, the thermal capacity in 2047 would be as high 723 GW. If all sources of power generation, including thermal, follow a heroic effort scenario (L4), thermal based capacity would still have a share of 28% in India's power generation basket in 2047.

Thermal Power Generation

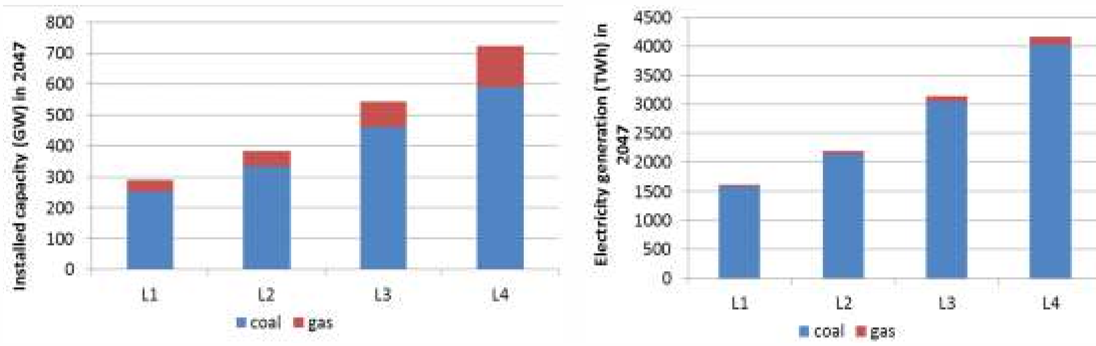
Given that thermal based power generation, particularly coal-based generation, typically has high PLFs and is used to supply base-load power, the share of such capacity in actual electricity supplied is greater than the share of its capacity.

Thus, according to IESS, in 2047, thermal power generation ranges from 1583.2 TWh to 4401 TWh between the least effort and heroic effort scenarios. This translates to a share of between 31% and 68.3% of total electricity generated assuming other sources of power generation follow a determined effort scenario. Note that this amount of generation is equal to about 1.4 to 4 times the total electricity generation in 2012.

Figure 1 shows the installed thermal capacity in 2047 under the various scenarios and the total electricity generated from the same.

[1] Also, there is some, perhaps non-trivial, diesel based generation capacity primarily used as backup generation due to unreliable power supply quality. It is expected that the role of such capacity will become negligible in future as supply quality improves.

Figure 1: Scenarios of installed thermal capacity and thermal power generation in 2047



2.3.1 COAL POWER STATIONS

OVERVIEW

At the end of the 11th five year plan i.e. by 2012, coal based power generation contributed over 125 GW i.e. 62% of India's capacity and 66% of electricity generation (CEA, 2012, pp. 19, 20, 50, 54). India's low per-capita electricity consumption of around 957 kWh (1/3rd of world's average) and low levels of electricity access (25% of the population without electricity access) demands significant addition in electricity supply (CEA, 2012, p. 1; PIB, 2012). In the last decade, coal based power generation capacity was doubled and substantial capacity addition is planned (CEA, 2012, p. 8).

ASSUMPTIONS

1. The capacities mentioned include utility and captive power plants fired by coal or lignite, though a lower PLF is assumed for them as they would be used less often.

2. Captive power plants do not use efficient technologies as they are mostly small sized while newer technologies (e.g. supercritical technology) need larger capacities.

3. The energy generation and coal requirement computed for different capacity addition trajectories shown here also depend on efficiencies of coal-fired thermal power plants. Such efficiency trajectories are given separately in the coal TPP efficiency one-pager.

4. The coal based power capacities have also been roughly cross-checked with coal production scenarios to ensure that imports of coal for power production do not become unrealistic.

TRAJECTORIES

Level 1

Coal based power generation is discouraged due to increasing fuel prices, import dependence, pressure to reduce carbon emissions, reducing prices of renewable energy etc. Installed capacity grows slowly to a high of 271 GW in 2032, corresponding to the least coal scenario of the Integrated Energy Policy (Planning Commission, 2006, p. 46), and will reduce thereafter to 253 GW by 2047 whereas the capacity in 2012 was 125 GW. PLF of power plants remains 73% up to 2032 and improves to 74% in 2047. As a result, total electricity generated in 2047 from coal-fired power plants would be 1453 TWh, compared to 710 TWh in 2012.

Level 2

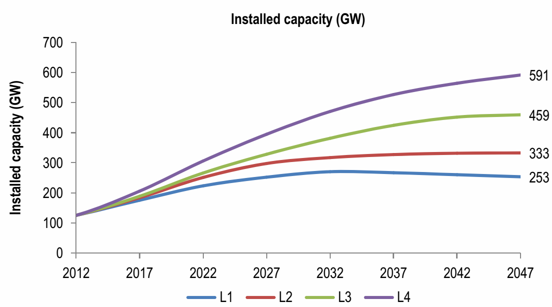
Level 2 projections are in line with Planning Commission's projections for next decade with a reduced growth rate thereafter. Installed capacity will grow rapidly to 297 GW in 2027, and then grow slowly to 333 GW in 2047 due to increasing coal prices, increasing import dependence and increasing pressures to reduce emissions. PLF is assumed to improve to 75% for next two decades and to 76% by 2047. Total electricity generated from coal-fired plants in 2047 would be 1963.4 TWh.

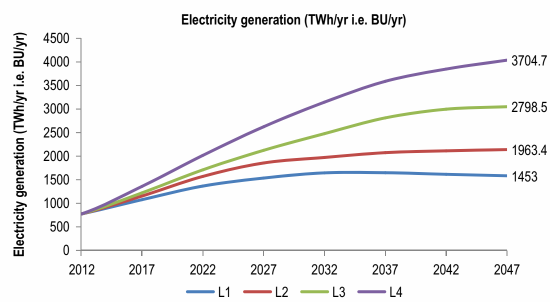
Level 3

Level 3 assumes a coal-fired capacity addition slightly lower than what is assumed for the 8% GDP growth scenario in the interim report of the Expert Group on Low Carbon Strategies for Inclusive Growth (Planning Commission, 2011, pp. 41,42). The growth rate of capacity addition is assumed to reduce subsequently. In this scenario, installed capacity will grow to 381 GW by 2032, and then slow down to reach 459 GW by 2047. Current PLF will improve to 77% for next two decades and to 78% in 2047, resulting in total generation of 2798.5 TWh in 2047.

Level 4

Level 4 assumes a coal-fired capacity addition slightly lower than what is assumed for the 9% GDP growth scenario in the interim report of the Expert Group on Low Carbon Strategies for Inclusive Growth (Planning Commission, 2011, pp. 41,42). The growth rate of capacity addition is assumed to reduce subsequently. Installed capacity will grow to 591 GW in the next 35 years i.e. by 2047 due to improved domestic coal supply, softening of imported coal prices and availability of more carbon space to countries like India. Current PLF will improve to 79% for next two decades and to 80% in 2047, resulting in electricity generation of 3704.7 TWh in 2047.





2.3.2 COAL POWER PLANT EFFICIENCY

OVERVIEW

India's existing coal based thermal power plants (TPPs) are currently based on inefficient subcritical technology, though efforts are now being made to adopt new efficient technologies like super-critical, ultra super-critical technology etc. Super critical technology is proposed to be adopted at a significant scale (38%) during the 12th five year plan (Ministry of Power, 2012). From the 13th five year plan, it is proposed that no subcritical TPPs would be allowed. However the development and deployment of these efficient technologies is sluggish due to the Indian coal with high ash content and low calorific value.

ASSUMPTIONS

1. Average life of a power plant is 40 years
2. Gross calorific value of Indian coal for power generation = 3541 Kcal/kg (CEA, 2012, p. 116)
3. Gross calorific value of imported coal = 5500 Kcal/kg
4. The coal consumption figures shown in this one-pager correspond to level 2 of capacity addition as described in the coal thermal power plant addition one-pager.
5. Specific coal consumption for different technologies for high ash Indian coal is as follows:

Technology	Specific coal consumption (kg/gross kWh)[2]
Subcritical (current India)	0.74
Super critical	0.61
Ultra supercritical	0.53
Integrated Gasification Combined Cycle (IGCC)	0.50

THE ROLE OF EFFICIENCY IN POWER GENERATION

IESS also allows the user to choose adoption rates for different technologies for coal-based power generation which forms the bulk of thermal generation. Note that the technology adoption rates only affect new capacity addition and do not have any impact on existing capacity. If thermal capacity addition follows a determined effort scenario, the shares of different technologies in India's coal-based capacity in 2047 are as shown Figure 2.

In the least effort scenario (A) of technology adoption, very little new technology adoption takes place. Even in 2047, about 40% of coal-based capacity uses sub-critical technology, about 50% uses super-critical technology, while efficient ultra-super-critical and IGCC technologies contribute only about 5% each. In all other scenarios (B-D), sub-critical capacity in 2047 reduces to 36% while the shares of other technologies vary. This is because power plants have a life of 30 years and sub-critical plants continue to get installed until 2017 – which means they do not get decommissioned by 2047. However, one would expect the shares of other efficient technologies in installed capacity to increase rapidly after 2047 as new sub-critical capacity addition stops in 2017 in all scenarios except the least-effort scenario. The shares of ultra-super-critical plants in the technology mix in 2047 are 14% and 17% respectively in the aggressive and heroic effort scenarios. Similarly, the shares of IGCC are 13% and 18% respectively in these scenarios.

As a result of this 'sticky nature' of power plants, the difference in total coal requirement by power plants does not vary much up to 2047 across the four efficiency scenarios though the specific coal requirement for IGCC is nearly 33% lower than for sub-critical technology (see Table 1). For the determined effort scenario of coal-based capacity addition, the difference in coal required in 2047 between the most efficient and least efficient technology adoption pathways is about 84 million tonnes (MT) out of a total demand in the region of 1,300 MT. Once again, it should be noted that the coal demanded by the different technology adoption pathways is expected to rapidly diverge after 2047.

TRAJECTORIES

Level A

New technology development/deployment will be slow. Subcritical capacity addition will stop only after 2022, ultra supercritical technology will be introduced only in 2027 and IGCC is introduced in 2037. The share of IGCC in the coal-fired capacity addition during 2042-47 would be only 30%, and its share of the total capacity in 2047 would be only 18.6 GW at level 2 capacity addition, amounting to just about 6%, while 64% of the capacity would be super-critical. Total demand for Indian grade coal in 2047 in this scenario is 1390 million tons.

Level B

New technology development/deployment will be slightly faster than scenario A. Subcritical plant addition will stop after 2017 as per current Government plans. (Ministry of Power, 2012) Ultra supercritical technology

[2] Source: CEA, 2012, p. 112; IEA, 2012; Mitsubishi; Planning Commission, 2013, p. 138

will be commercialized after 2017 and IGCC after 2027. IGCC will contribute 50% of the capacity addition in the 18th five year plan (2042–47). The share of IGCC in the coal-fired capacity in 2047 would be 10%, and super-critical technology would have a share of 55%. Total demand for Indian grade coal in 2047 in this scenario is 1194 million tons.

Level C

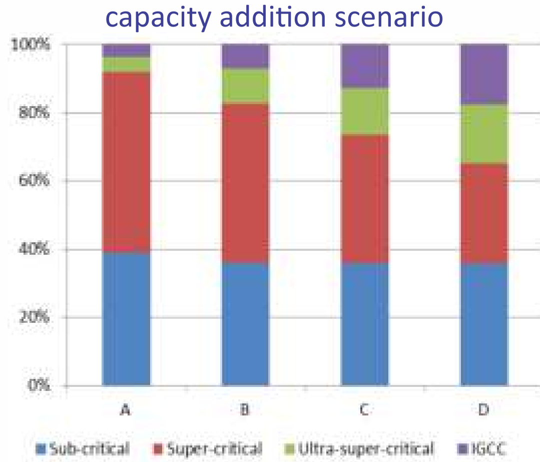
New technology development/deployment will be encouraged and hence its adoption would be faster. Sub-critical capacity addition will stop after 2017, ultra-supercritical technology will be commercialized in 2022 and IGCC in 2027. IGCC's share of the capacity addition in the 18th five year plan (2042–47) would be 65%. In 2047, the share of IGCC in the coal-fired capacity would have increased to 20% and super-critical technology would have reduced to 43%. Total demand for Indian grade coal in 2047 in this scenario is 1165 million tons.

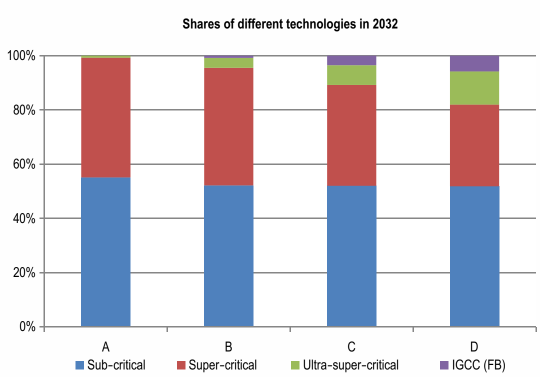
Level D

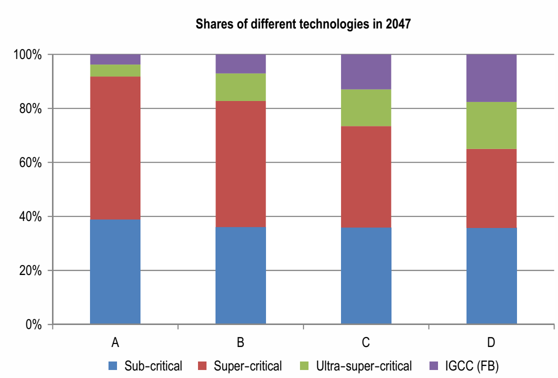
New technology development/deployment will be aggressively promoted and hence adopted very fast. Subcritical capacity addition will stop after 2017. 20% of new capacity addition in the 14th five year plan from 2022 would be ultra-supercritical technology and 20% of new capacity addition in the 15th five year plan from 2027 would be IGCC. Of the capacity addition in the 18th five year plan ending in 2047, 80% would be IGCC, resulting in its share in the total installed capacity in 2047 being 26%. Total demand for Indian grade coal in 2047 in this scenario is 1142 million tons.

The share of different technologies in total coal based installed capacity for these four scenarios in 2032 and 2047 year will be as shown in the following figure. The sub-critical technology based capacity that exists in 2047 is primarily because of existing capacity, which does not retire fully until 2047.

Figure 2: Shares of different technologies in determined effort capacity addition scenario







COSTS

The total cost of fuel for coal based thermal power generation is calculated based on estimation of domestic and imported coal and gas prices. The pithead price of domestic steam coal is about 1080 Rs/tonne for electricity generation and it is about 5120 Rs/tonne for imported non-coking coal in 2012[4] (CCO, 2012, pp. 6.1, 7.1).[5] Coal prices until 2047 are projected based on available literature according to which domestic coal prices are estimated to be between Rs.450/ ton and Rs.2,290 / ton in 2047, while imported coal prices range between Rs. 4578 / ton and Rs. 7748 / ton. The cumulative cost to the economy from coal-based power generation (excluding other costs such as fuel transport, debt financing etc.) up to 2047 works out to be just over 1% of the cumulative GDP for a heroic-effort pathway keeping determined effort pathway as the base/reference case.

2.3.3 GAS BASED GENERATION

OVERVIEW

Gas based generation in India got impetus in the eighties when HVJ (Hajira-Vijaypur-Jagdishpur) gas pipeline was commissioned by Gas Authority of India Limited (GAIL), after discovery of gas in the west coast of India. This led to a number of Gas based CCGTs commissioned along the HVJ pipeline in the Western and Northern parts of India. Apart from the major HVJ gas pipeline, certain isolated gas fields in North -East India, Kaveri basin, Ravva basin etc. helped in development of some off grid gas based capacities in those areas. After the KG- D6 discovery of gas and commissioning of East -West pipeline by RGTIL (to transport the gas from Bay of Bengal fields to the west coast), KG -D6 gas got infused into the system in early 2009.

Natural gas based power generation capacity of India was about 24.2 GW by the end of 11th plan i.e. by 2012, out of which, about 18.3 GW was utility and 5.9 GW was captive power plants (CEA, 2013, pp. 8,50). This capacity constitutes about 10% of total installed capacity whereas its electricity generation constituted about 11% of total electricity generation (CEA, 2013, pp. 8,20,50,54). Due to high cost of electricity generation and flexibility of the natural gas based power generation, it is mainly used for electricity supply for peaking/balancing power rather than base-load (Planning Commission, 2013, p. 148; EIA, 2013). Considering the recent uncertainties in availability of domestic natural gas, PLFs of about 54.5% in 2012 of gas-based plants will further come down. However, it is expected that the situation is likely to improve in the coming years / decades.

ASSUMPTIONS

1. GCV of natural gas= 9000 kcal/kg (MoPNG, 2013, p. 174)
2. Installed capacity addition of gas based power plants includes both utility and captive power plants.
3. Only combined cycle gas turbine power plants will be added[6].
4. Life time of gas power plants is assumed as 40 years. So the total new capacity addition will be replacement for retired capacity plus new capacity addition required to meet the installed capacity target.

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[4] Non-coking or steam coal is mainly used for power generation.

[5] Long term projections for Indian coal are not available. So, the low estimates and high estimates of 2047's projections are done based on other countries' projections (IEA, 2012; DECC, 2014, p. 12).

TRAJECTORIES

Level 1

Level 1 assumes that only the 12th plan's under construction capacity of about 12 GW will be added, though only by 2027 (MoP, 2012, p. 1.14). There will be no gas-based capacity addition later on due to domestic fuel shortage, expensive imports, lack of infrastructure etc. Considering the addition, the total capacity will increase from 24.2 GW in 2012 to 36.5 GW in 2032 and will remain same till 2047. The PLF of gas-based power plants will remain at 40.7% (same as in 2013) throughout the period due to lower gas availability and conversion efficiency will be about 58% by 2047, which is same as that in 2012. So, the corresponding electricity generation will rise from 115.4 TWh in 2012 to 130 TWh in 2047 and the requirement for gas would be about 23.7 BCM.

Level 2

Level 2 assumes that the expected capacity at the end of the 13th five year plan under high gas scenario will be added by 2047[7] (MoP, 2012, p. 1.14). The average CAGR will be about 2.1% and PLF will increase slowly from 42.5% in 2017 to 45% due to slightly improved gas availability and conversion efficiency will be about 62% by 2047. As a result, the corresponding cumulative capacity will reach 50.2 GW, electricity generation will be 198 TWh and gas required would be 36 BCM in 2047.

Level 3

Level 3 assumes that the expected capacity in Natural Gas Pipeline Vision-2030 Document by Petroleum and Natural Gas Regulatory Board (PNGRB) will be added by 2047 (PNGRB, 2013, pp. 21,22). Total capacity will be about 83 GW by 2047. PLF will increase from 45% in 2017 to 55% in 2047 due to improved gas availability. Conversion efficiency will improve to about 64% by 2047 due to technological advancements. As a result, the corresponding electricity generation will be 400 TWh in 2047 and gas used for power generation would be 72.9 BCM.

Level 4

Level 4 assumes that the expected capacity by 2032 as per forced gas scenario of Integrated Energy Policy (IEP) by Planning Commission will be achieved by 2047 (Planning Commission, 2006, pp. 20,41)[8]. Total capacity will be about 132 GW by 2047. The average CAGR under this scenario will be about 5%. PLF increases from 48% in 2017 to 60% due to improved gas availability from both domestic and imported sources and conversion efficiency will be about 66% by 2047 due to improved technologies. As a result, the corresponding electricity generation will be 696 TWh in 2047, with a gas requirement of 126.6 BCM.

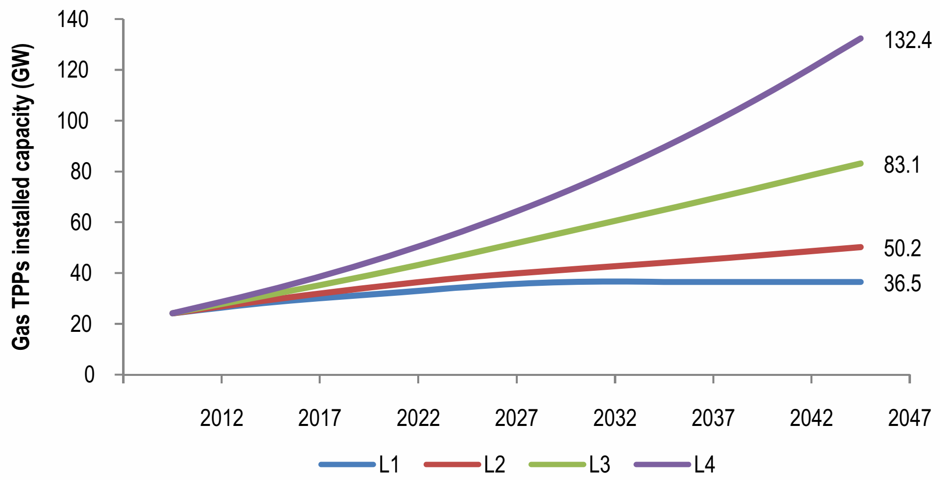
COSTS

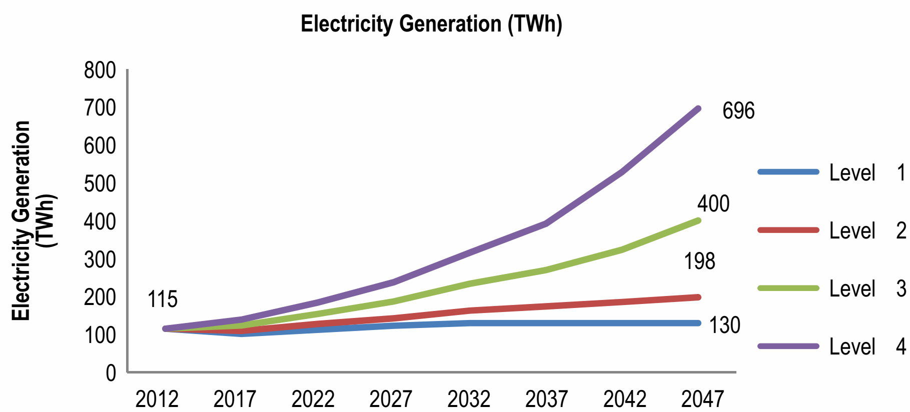
The cumulative cost to the economy from gas-based power generation (excluding other costs such as fuel transport, debt financing etc.) up to 2047 works out to be less than a quarter percent of the cumulative GDP for a heroic-effort pathway keeping determined effort pathway as base/reference case. Also, when the gas power stations are moved to level 4 i.e. Heroic pathway, it is assumed that our domestic gas production would also ramp up to level 4

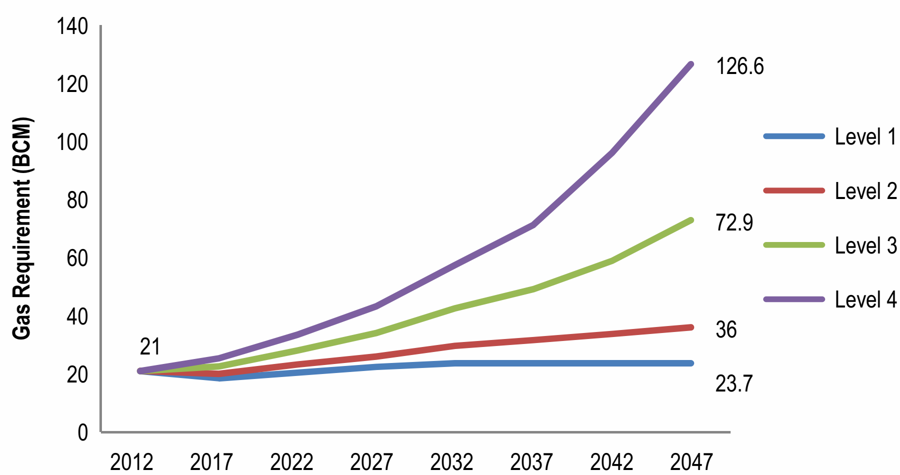
6 We do not consider potential addition of some captive Combined Heat and Power (CHP) plants in this tool for simplicity reasons.

7 The 12th plan working group report for power doesn't give the separate gas based power capacity addition projections for the 13th plan and only gives total thermal power capacity addition of

8 The IEP report doesn't give the installed capacity of gas-based power plants. The capacity is therefore estimated from the % share of gas in total electricity generation assuming a PLF of 50%.


Gas TPPs installed capacity (GW)
140
120
100
80
60
40
20
0
2012
2017
2022
2027
2032
2037
2042
2047
132.4
83.1
50.2
36.5
L1
L2
L3
L4


Electricity Generation (TWh)
Electricity Generation (TWh)
800
700
600
500
400
300
200
100
0
2012
2017
2022
2027
2032
2037
2042
2047
115
696
400
198
130
Level 1
Level 2
Level 3
Level 4


Gas Requirement (BCM)
140
120
100
80
60
40
20
0
2012
2017
2022
2027
2032
2037
2042
2047
21
126.6
72.9
36
23.7
Level 1
Level 2
Level 3
Level 4

2.4 Carbon Capture and Storage

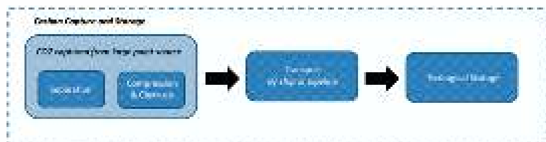
INTRODUCTION

According to IPCC 2014 report, total anthropogenic GHG emissions have continued to increase over 1970 to 2010 with larger absolute decadal increases toward the end of this period. Despite a growing number of climate change mitigation policies, annual GHG emissions grew on average by 1.0 gigatonne carbon dioxide equivalent (GtCO2eq) (2.2%) per year from 2000 to 2010 compared to 0.4 GtCO2eq (1.3%) per year from 1970 to 2000. CO2 emissions from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emission increase from 1970 to 2010, with a similar percentage contribution for the period 2000-2010 (high confidence). Fossil fuel-related CO2 emissions reached 32 (±2.7) GtCO2/yr, in 2010, and grew further by about 3% between 2010 and 2011 and by about 1-2% between 2011 and 2012.

Power Sector is the largest consumer of coal in India. Out of total generation capacity of 272 GW as on May 2015, generation from coal and gas accounts for 70%. India being in an accelerated phase of economic growth, aiming to add more power generation capacity in the next two decades, needs special interventions to restrict CO2 emission to minimize global warming.

Carbon Capture and Sequestration (CCS) (or carbon capture and storage), is the process of capturing waste carbon dioxide (CO2) from large point sources, such as fossil fuel power plants, transporting it to a storage site, and depositing it where it will not enter the atmosphere, normally in underground geological formations. The aim is to prevent the release of large quantities of CO2 into the atmosphere (from fossil fuel use in power generation and other industries). It is a potential means of mitigating the contribution of fossil fuel emissions to global warming and ocean acidification. Although CO2 has been injected into geological formations for several decades for various purposes, including enhanced oil recovery, the long term storage of CO2 is a relatively new concept.

Figure 1: Carbon Capture and Sequestration Flow Diagram



Source: IEA

Majority of India's CO2 emissions come from the power plants, and the development of gigawatt scale power plants in recent years means that the large scale concentrated emission sources that are most suitable for CCS deployment. Hence, CCS deployment in the power sector will have a significant impact on CO2 emission reduction.

CCS is applicable to both the power sector and the industrial sectors, and will therefore play a vital role in the move towards a low-carbon economy. In the power sector, fossil-fuel power plants with CCS is one of the options which has been identified by the UK Government as a major part of the low-carbon energy mix - alongside nuclear and renewables. Countries that develop CCS early will benefit from the export of skills and technology internationally.

DRIVERS

The factors which influence the development of the CCS in India are:

1. Climate Change
2. Energy Security

ASSUMPTIONS

Some of the assumptions considered are as follows:

Policy Assumptions

Some of the basic assumptions which were considered while making the scenarios were as follows:

1. Enhanced support for Research & Development of CCS technology will develop so as to bring in more efficient technology and reduce the cost component required.
2. Government will come out with the policies which will mandate the usage of CCS in various power plants and industries for capturing and storing of CO2
3. Financial support and incentives will be provided by Government so as to help in deployment of CCS technology.
4. Understanding among the public and stakeholders of CCS technology will be improved.
5. In future there may be commercial use of the carbon captured that could offset the cost of the CCS plant and its operation.

Technology Assumptions

Some of the technical assumptions which were considered for the calculation purpose are as follows:

1. Solid Hydrocarbons

a)	Efficiency	:	30%
b)	Load Factor	:	70%
c)	Emission Factor	:	0.94
d)	Fuel Split	:	90%
e)	Input Fuel	:	Coal

2.Gaseous Hydrocarbons

a)	Efficiency	:	42%
b)	Load Factor	:	70%
c)	Emission Factor	:	0.47
d)	Fuel Split	:	10%
e)	Input Fuel	:	Natural Gas

TRAJECTORIES

Decarbonizing (i.e. reducing the carbon intensity of) electricity generation is a key component of cost effective mitigation strategies in achieving low-stabilization levels. In the low-stabilization scenarios, the share of low-carbon electricity supply (comprising CCS) increases from the share of approximately 8 GW in level 1 to around 90 GW in level 4 by 2047.

Level 1

No planned generation plants with CCS till 2025 and rate of CCS technology deployment will be less. Generation with CCS usage till 2025 will be negligible and will start to increase but at very less pace due to lack of efficient and cheap technology, generation with CCS usage will increase to 8 GW till 2047. The electricity generated will rise to 42 TWh in 2047 from 0 TWh in 2012.

Level 2

Generation with CCS usage will be deployed at a slow rate. India will follow projections for US with some time lag. Generation with CCS in 2022 will be around 1 GW and will reach to 35 GW till 2047. The corresponding electricity generation in 2047 would be 185 TWh.

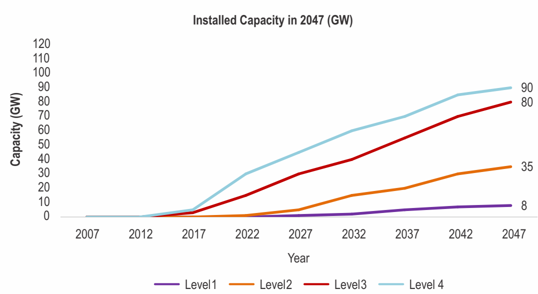
Level 3

The amount of CCS-equipped capacity will grow in India. The absolute growth rate in capture-equipped capacity occurs between

2030 and 2040. Going by IEA roadmap for CCS technology 2013, India will target generation capacity with CCS of 3 GW till 2022 and will increase to 80 GW till 2047 which will generate 423 TWh of electricity in 2047.

Level 4

More generation plants with CCS technology will be deployed which will be result of technology up gradation and reduction in capital requirement. India will begin constructing their own demonstration scale facilities and considering more ambitious CCS projects. India will target generation capacity with CCS of 5 GW till 2022 and will increase to 90 GW till 2047. The electricity generated in 2047 would be 476 TWh.



COSTS

Assumptions for Capital Cost

1. Cost considered for unabated coal power plant is Rs 40 - 50 million/MW
2. Cost considered for Coal CCS for low estimation is 76% more than without CCS (Source:http://www.cbo.gov/sites/default/files/cbofiles/attachments/43357-06-28CarbonCapture.pdf)
3. High estimate cost of coal CCS are considered as per India CCS scoping study done by Global CCS Institute & TERI
4. Cost considered for Gas CCS for High estimation is taken as per cost given by EIA for Utilities of US (April 2013)*
5. Cost considered for unabated gas power plant is Rs 30 - 40 million/MW
6. Cost considered for Gas CCS for low estimation is 60% more than without CCS
7. Point estimates for Coal and Gas CCS are taken as average of high and low costs.
8. As per present technologies for CCS, the cost in India is expected to be significantly higher than that in USA as the Indian coal has high sulphur content which require a de-sulpherization plant before the flue gases from the boiler is sent to de-carbonizing plant.

Assumptions for Operation & Maintenance Costs

1. High estimates of O&M cost are taken as per cost given by EIA for Utilities of US (April 2013)
2. Point estimates are taken as per CERC tariff guidelines 2009 - 2014
3. Low estimates are considered as per India CCS scoping study done by Global CCS Institute & TERI

Section 3

Example Pathways

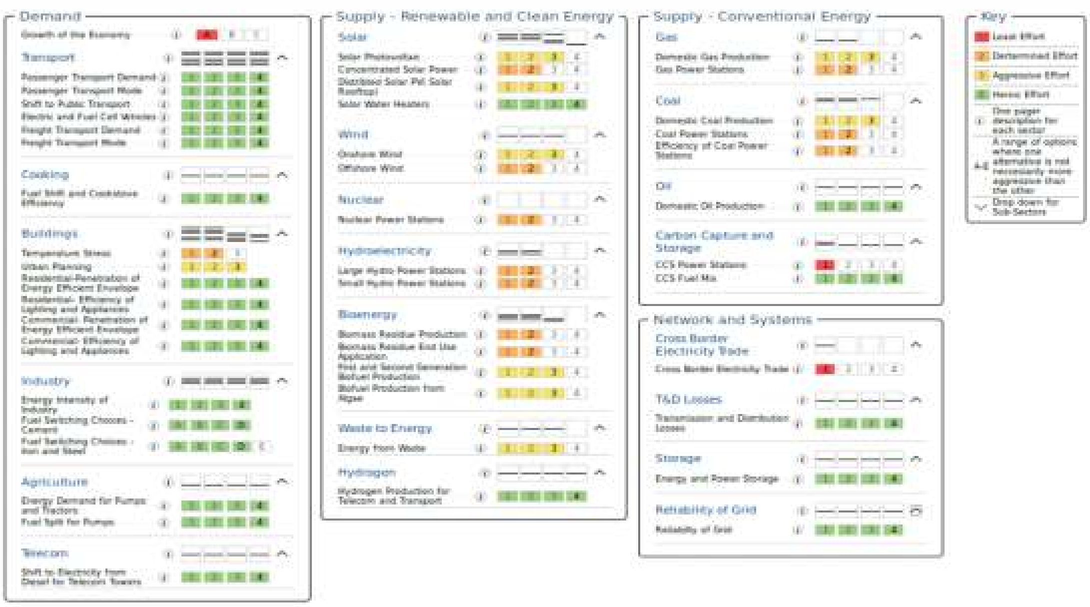
Section 3 : Example Pathways

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.

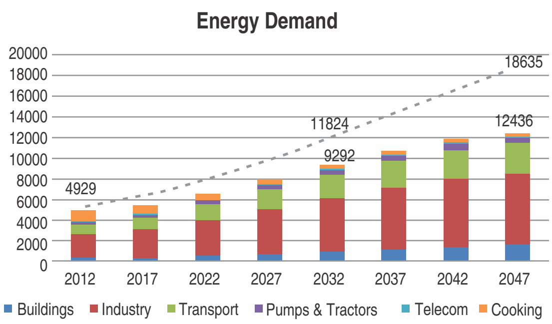
Energy Demand

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

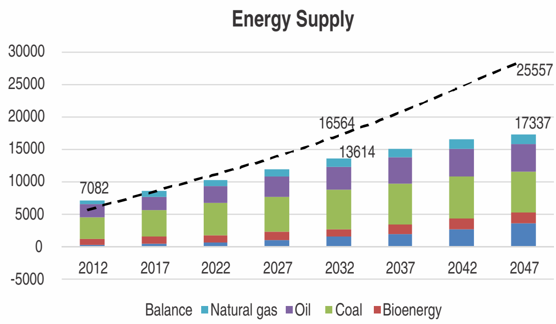
Level 4 i.e Best Available Technologies, their energy demand growth of the Cement and Iron and Steel sectors could be arrested to rise by a factor of in 2 and 3.5 in 2047 respectively (as compared to a factor of 4 and 7 in the Defaultcase). MESP also envisages higher electrification, fuel switching and 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.

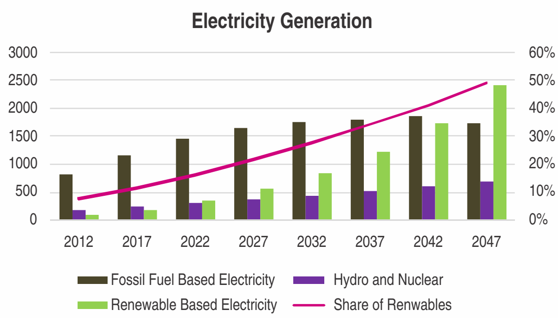


Energy Supply

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:

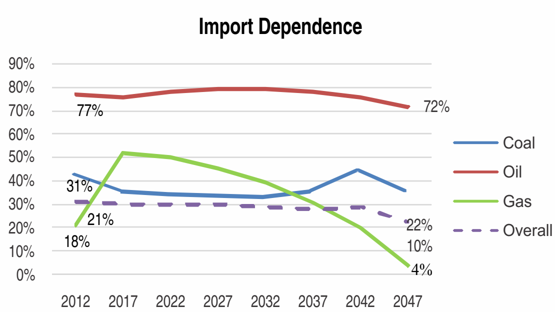
While in this pathway, coal production rises steeply, but due to large doses of other domestic fuels, coal would lose its share in the supply mix, falling from 46% in 2012 to 43% in 2047. The share of renewables in the enhanced proportion of electricity in the energy mix would increase to 40% (it is 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 levels.





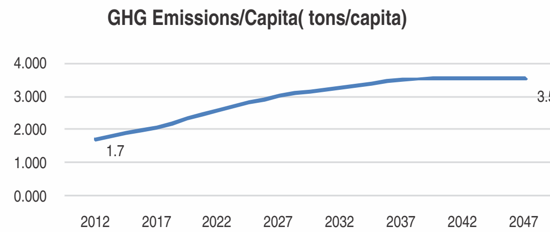
Imports

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.



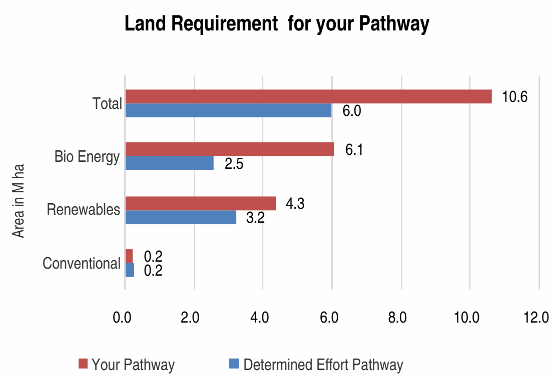
Emissions

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

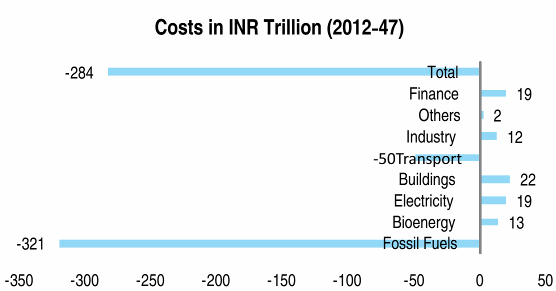
As this pathway focusses on interventions on the fronts of Renewable energy and Bio-energy mainly, to help curb import dependence, it is much more land intensive than the Determined effort pathway. The cumulative land-use in this pathway rises by a factor of nearly 1.7 in 2047 as compared to the Determined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



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)

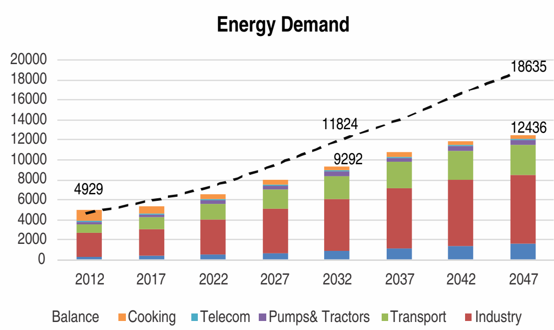
With increasing concerns about sustainability and climate change and India finalising its Intended Nationally Determined Contributions for the first time for discussion in the COP 21 summit, the importance of moving towards an economy which has renewable and clean sources of energy as its mainstay is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

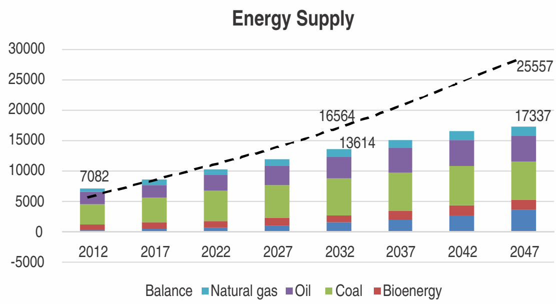
The scope for maximum reduction lies in Transport and Industry sectors, where Level 4 choices (Heroic scenarios) could restrict the demand growth to a factor of 3.2 and 3 respectively, in 2047 from 2012 levels, as opposed to factors of 5 and 4.5 in the default scenario, respectively. These two sectors 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.

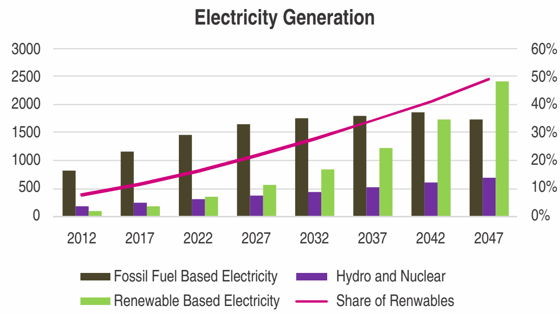


Energy Supply

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:

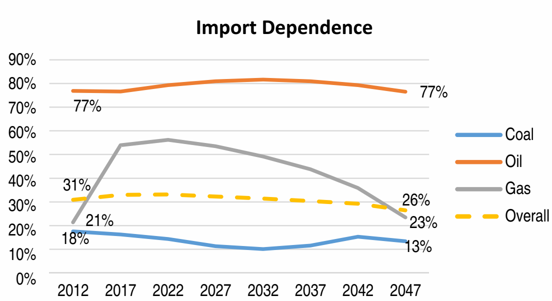
In this pathway, the share of coal will be the lowest as compared to its share in any other pathway because there is increased focus on moving towards a largely renewable and clean energy based economy. Driven by a moderate coal production scenario, coal would lose its share in the supply mix, falling 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.





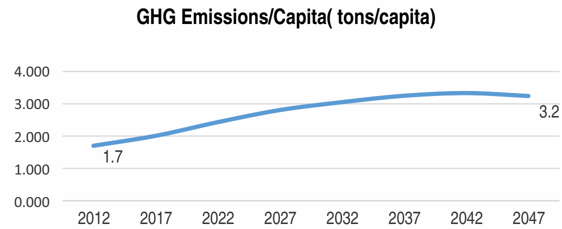
Imports

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.



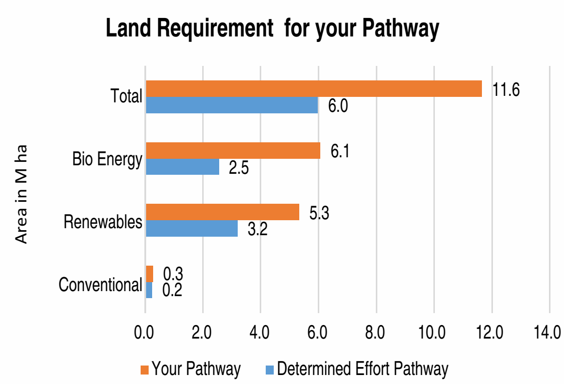
Emissions

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)

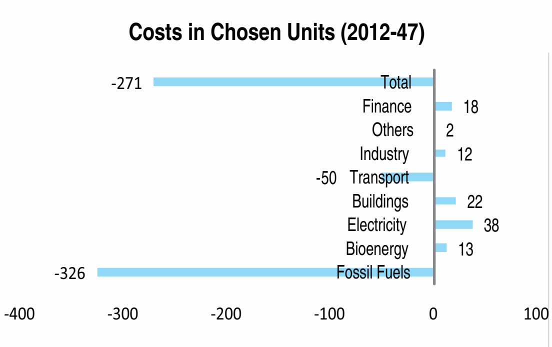


Costs

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

COAL, GAS AND CCS POWER STATIONS WITH DEMAND CONSTANT AT DETERMINED EFFORT (LEVEL 2)

1. Installed Capacity (GW)

Installed Capacity (GW)	2012	Level 2			Level 4			Percentage change (L2 to L4 in 2047)
		2022	2032	2047	2022	2032	2047	
Gas Power Stations	0.9	24	34	41	44	72	132	163.59%
Coal power stations	0	125	251	317	306	470	591	77.74%
Carbon Capture Storage (CCS)	0	0	1	15	30	60	90	157.14%

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	
Gas Power Stations	115	128	163	198	184	316	696	251%
Coal Power Stations	708	1,442	1,811	1,963	1,849	2,886	3,704	89%
Carbon Capture Storage (CCS)	0	5	78	185	156	313	476	157%

3. Share of Conventional Energy supply sources in Electricity Generation

Share in Electricity Generation	2012		Level 2			Level 4	
		2022	2032	2047	2022	2032	2047
Gas Power Stations	115	128	163	198	184	316	696
Coal Power Stations	708	1,442	1,811	1,963	1,849	2,886	3,704
Carbon Capture Storage (CCS)	0	5	78	185	156	313	476

4. Impact on GHG emissions (Mtce)

Sector	2012	Level 2 (2047)	Level 4 (2047)	Per cent Change (L2 to L4 in 2047)
Gas Power Stations	2074	9738	9433	3%
Coal power stations	2074	9738	10178	(5%)
Efficiency of Coal Power Stations	2074	9738	9660	1%
Carbon Capture Storage (CCS)	2074	9738	9494	3%

DOMESTIC COAL, OIL AND GAS PRODUCTION WITH DEMAND CONSTANT AT DETERMINED EFFORT (LEVEL 2)

1. Domestic Production

Production	2012	2022		2032		2047		Increase (2012 2047 in Level 4)
Sector		**Level 2**	**Level 4**	**Level 2**	**Level 4**	**Level 2**	**Level 4**	
Coal Production (MT)	582	904	1053	1152	1399	1157	1608	3 times
Oil Production (MT)	38	44	47	49	57	59	78	2 times
Gas Production (BCM)	48	46	56	69	103	128	225	5 times

2. Impact on Emissions (Mtce)

Emissions (Mtce)	2012	2022		2032		2047		Increase (2012 2047 in Level 4)
Sector		**Level 2**	**Level 4**	**Level 2**	**Level 4**	**Level 2**	**Level 4**	
Coal Production	17.6	27.4	31.9	34.9	44.3	35.7	56.1	3 times
Oil Production	0.3	0.3	0.3	0.3	0.4	0.4	0.5	2 times
Gas Production	21.4	20.6	25.2	31.1	46.2	57.2	100.6	5 times

3. Impact on Overall Import Dependence (%)

Overall Imports (%)	2012	Level 2 (2047)	Level 4 (2047)
Coal Production	31%	57%	49%
Oil Production	31%	57%	57%
Gas Production	31%	57%	54%

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 of 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 shift to a clean energy pathway

Emissions in 2047 ($MTCO_2Eq$)			
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 security pathway

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

Supporting Partners

CSTEP — Center for Study of Science, Technology & Policy

CII — 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,
please write in to the IESS, 2047's team at **iess-2047@gov.in**
For more information: Visit us at **www.indiaenergy.gov.in**