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NITI Aayog

IEE
JAPAN
The Institute of Energy Economics, Japan

ENERGIZING INDIA

A Joint Project Report of NITI Aayog and IEEJ

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NITI Aayog

The National Institution for Transforming India, also called NITI Aayog, was formed via a resolution of the Union Cabinet on January 1, 2015. NITI Aayog is the premier policy 'Think Tank' of the Government of India, providing both directional and policy inputs. While designing strategic and long term policies and programmes for the Government of India, NITI Aayog also provides relevant technical advice to the Centre and States.

At the core of NITI Aayog's creation are two hubs –Team India Hub and the Knowledge and Innovation Hub. The Team India Hub leads the engagement of states with the Central government, while the Knowledge and Innovation Hub builds NITI's think-tank capabilities. These hubs reflect the two key tasks of the Aayog. NITI Aayog is also developing itself as a State of the Art Resource Centre, with the necessary resources, knowledge and skills, that will enable it to act with speed, promote research and innovation, provide strategic policy vision for the government, and deal with contingent issues. More information about the NITI Aayog can be found at: http://niti.gov.in

The Institute of Energy Economics, Japan

The Institute of Energy Economics, Japan (IEEJ) was established in June 1966 and certified as an incorporated foundation by the Ministry of International Trade and Industry in September that year. The aim of its establishment is to carry on research activities specialized in the area of energy from the viewpoint of the national economy as a whole in a bid to contribute to sound development of the Japanese energy-supplying and energy-consuming industries and to the improvement of people's life in the country by objectively analysing energy problems and providing basic data, information and reports necessary for the formulation of policies.

With the diversification of social needs during the three and a half decades of its operation, IEEJ has expanded its scope of research activities to include such topics as environmental problems and international cooperation closely related to energy. In October 1984, the Energy Data and Modelling Centre (EDMC) was established as an IEEJ-affiliated organization to carry out such tasks as the development of energy data bases, building of various energy models and econometric analyses of energy. In July 1999, EDMC was merged into IEEJ and began operating as an IEEJ division under the same name, i.e., the Energy Data and Modelling Centre. More information about the IEEJ can be found at: https://eneken.ieej.or.jp/en/

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**This report is a compilation of four research studies carried out under NITI-IEEJ Statement of Intent*

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FOREWORD

One of the important mandates of NITI Aayog is to encourage academic research and collaborate with institutions and think thanks in India and abroad. NITI Aayog has engaged with some of the reputed national and international organizations like Institute of Energy Economics, Japan (IEEJ), International Energy Agency (IEA), Energy Information Administration (EIA), Prayas, TERI and others to collaboratively undertake research on some of the most important issues in the energy and climate change space.

India Energy Security Scenarios (IESS) 2047 and draft National Energy Policy (NEP) serve as fine examples of engaging a wide range of private and public institutions which has encouraged a healthy debate among the research community in the field of energy and climate change. Collaboration of NITI and Institute of Energy Economics Japan (IEEJ) is a step further to dive deeper into some of the mutually important issues for India and Japan. Energy accounts for around a quarter of the total value of imports in India making it imperative for the Government to fulfill the energy needs of the country independently and that too in a sustainable manner. India's import dependence has been constantly rising as it fulfilled 82%, 45% and 23 % of its crude oil, natural gas and coal requirements through imports in 2016-17 respectively. Japan is equally highly import dependent for its energy needs as it imported 92% of its energy requirements in 2016. The three topics of research viz. assessing the natural gas demand and analysing the impact of its increased uptake on the energy scenario, impact of increased penetration of renewables on the grid and clean coal technologies (CCT) on the overall energy scenario of both the countries hold a lot of importance as these three sources of fuel are at the centre stage in India and Japan.

This report seeks to give direction to the policy makers while they formulate medium term and long term policies for the country. The team in Energy Division of NITI Aayog led by Shri Anil Kumar Jain, Additional Secretary (Energy & Climate Change) has come out with detailed reports on the above topics along with a report on overall energy scenario of India which integrates the three research studies. I hope this exercise would help the policy makers to make informed decisions and give them deep insights on the above three topics. I do hope that academicians, policy makers and the whole research fraternity take note of this Report and adopt some of the key take-aways in their work.

(Arvind Panagariya)

Dated: 16th June, 2017

स्वच्छ भारत
एक कदम स्वच्छता की ओर

अमिताभ कांत
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PREFACE

Energy plays a very important role in the growth of an economy. India's energy sector is on the cusp of transformation as it has set itself quite ambitious targets in the energy space. The present Government accords high priority to the energy sector which is reflected from its efforts to make available energy to every citizen of the country at affordable prices through its initiatives like Power for All by 2022, Pradhan Mantri Ujjwala Yojana, 175 GW of installed capacity of renewable energy by 2022 and focus on energy efficiency through programmes like UJALA.

In December, 2015, NITI Aayog (erstwhile Planning Commission of India) signed a Statement of Intent (SoI) with Institute of Energy Economics, Japan. The broad mission of this cooperation is to analyze common issues related to energy sector in India and Japan by experts of both institutions. The present report is the result of the joint research carried out by research team of NITI Aayog and IEEJ, along with EPIC-India and UPES, who are academic partners of NITI Aayog.

Both India and Japan are world's leading economies and this cooperation added great value to energy policy and planning for both the countries. The three topics chosen for joint study in the first year of the cooperation, viz. – Impact of Clean coal technology, Impact on the grid due to high penetration of renewables and estimating the LNG Demand by 2047, are of great relevance to both the countries as both countries are heavily dependent of energy import to meet their demand. Overall analysis of energy demand and supply scenario for both India and Japan were also carried out as part of the study. The studies were carried out for the year 2047 which marks 100 years of India's Independence.

I compliment the research team at NITI, IEEJ and knowledge partners Energy Policy Institute at University of Chicago (EPIC) – India, University of Petroleum and Energy Studies (UPES) and Lawrence Berkeley National Lab (LBNL) for their efforts in carrying out this joint research. Furthermore, this report is meaningful primarily due to participation of policy makers, think tanks and other stakeholders who shared thoughtful insights and suggestions during the consultation organized by NITI Aayog.

I would like to place on record deepest appreciation to all the young researchers of NITI Aayog – Sh. Manoj Kumar Upadahyay, SRO; Sh. Ripunjaya Bansal, YP and Ms. Ruchi Gupta, YP who worked relentlessly to make their respective projects successful. I would also like to appreciate the efforts made by Sh. Harendra Kumar, Joint Adviser, NITI Aayog for taking up initiative and providing his able leadership to make the joint study successful. Finally, I would also like to commend the entire Energy Division under Sh. Anil Kumar Jain, Additional Secretary (Energy) who worked with passion and enthusiasm to build a Knowledge Hub within NITI Aayog. I am sure that this Report would stimulate a healthy debate on some of the most important issues in the energy sector.

Date: 14/6/2017

(Amitabh Kant)
CEO, NITI Aayog

OVERALL ENERGY SCENARIO OF INDIA TILL 2047

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List of Abbreviations

APM – Administered Pricing Mechanism

AT&C – Aggregate Technical & Commercial

A-USC - Advanced Ultra-Supercritical

BAU - Business-As-Usual

BCM – Billion Cubic Metres

BF-BOF – Blast Furnace – Basic Oxygen Furnace

BP – British Petroleum

BU – Billion Unit

CAGR - Compound annual growth rate

CBM – Coal Bed Methane

CCS - Carbon Dioxide Capture and Storage

CCTs - Clean Coal Technologies

CEA – Central Electricity Authority

CGD – City Gas Distribution

CNG – Compressed Natural Gas

CO - Carbon Monoxide

CO2 - Carbon Dioxide

CSP – Concentrated Solar Power

DGH – Directorate General of Hydrocarbons

DRI – Direct Reduced Iron

E&P – Exploration and Production

EDMC - Energy Data and Modelling Centre

EIA – Energy Information Administration

EPS - Electric Power Survey

FCVs – Fuel Cell Vehicles

FY – Financial Year

GDP - Gross domestic product

GHG – Green House Gas

GW – Giga Watt

GW – Gigawatts

HELE – High Efficiency and Low Emission

HELP – Hydrocarbon Exploration Licensing Policy

IEA - International Energy Agency

IEEJ – Institute of Energy Economics Japan

IESS - Indian Energy Security Scenario

IGCC - Integrated Gasification Combined Cycle

INDCs - Intended Nationally Determined Contributions

JCC – Japanese Crude Cocktail

kWh - Kilowatt-hour

LNG - Liquefied Natural Gas

LPG – Liquefied Petroleum Gas

MMBTU – Million Thermal British Units

MMSCMD - Million Metric Standard Cubic Meter Per Day

MPa – Megapascal

MT – Million Tones

Mtce – Million Ton of coal Equivalent

Mtoe – Million Ton of Oil Equivalent

MU – Million Unit

MW – Megawatt

NELP – New Exploration Licensing Policy

NOX - Nitrous Oxides

OECD - Organization for Economic Co-operation and Development

PAT – Perform Achieve Trade

PLF – Plant Load Factor

PMUJY – Pradhan Mantri Ujjwala Yojana

PNG – Piped Natural Gas

PPAC – Petroleum Planning and Analysis Cell

PSDF – Power System Development Fund

PTKM – Passenger Transport Kilometers

PV – Photo Voltaic

RE – Renewable Energy

RES - Renewable Energy Sources

SOI – Statement of Intent

TWh – Terawatt hour

UCG – Underground Coal Gasification

UNFCCC – United National Framework Convention on Climate Change

USC - Ultra-supercritical technology

WEPS+ - World Energy Projection System Plus

WHO – World Health Organization

OVERALL ENERGY SCENARIO OF INDIA TILL 2047

By Ripunjaya Bansal*

*Ripunjaya Bansal is working as a Young Professional with NITI Aayog, Government of India.

Disclaimer: This research report is intended for use by decision-makers, academicians, researchers and other stakeholders, nationally as well as globally. The assumptions, analysis and views of the authors are personal and it does not represent the views of either Government of India or NITI Aayog. They are intended to stimulate healthy debate and deliberations in the field of energy and climate change.

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to Shri Anil Kumar Jain, Additional Secretary (Energy, Climate Change & Overseas Engagements), NITI Aayog who has been the major driving force behind this project. His continuance guidance throughout the project and valuable inputs on all the three topics mentioned below gave me important insights while doing the analysis. Also, I would like to acknowledge the efforts made by Shri Harendra Kumar, Joint Advisor, NITI Aayog who initiated this study and provided able leadership to this project.

ABSTRACT

A statement of Intent (SOI) was signed between NITI Aayog and IEEJ under which three joint studies were done by NITI Aayog and IEEJ for India and Japan:

- Assessing natural gas demand and analyzing the impact of its increased uptake on the overall energy scenario
- Analyzing the increased penetration of renewables on the grid
- Analyzing the impact of Clean Coal Technology (CCT) on the overall energy scenario

The following report seeks to give an overview of the energy scenario of India by 2047 if the country were to adopt a multipronged strategy to achieve its energy objectives. The following points were kept in mind while doing the analysis:

1. This exercise focusses on increasing the share of natural gas in the energy mix as it is a cleaner source of fuel in comparison with other fossil fuels, can replace the usage of liquid fuels and is cheaper than crude oil on a calorific value basis. Moreover, natural gas is envisaged to play a significant role in the energy scenario of India as gas based power plants would be required for balancing renewables and a thrust to improve the air quality in India would lead to increased penetration of Compressed Natural Gas (CNG) vehicles and Piped Natural Gas (PNG) for cooking.

2. India's renewable energy aspirations have been taken into consideration. India has been pursuing its agenda on renewables quite aggressively which is evident from the ambitious target of 175 GW of installed capacity by 2022. The installed capacity of solar has increased from 1 GW in 2011-12 to 12.2 GW in 2016-17 and that of wind has increased from 17.35 GW in 2011-12 to 32.2 GW in 2016-17. The enhanced penetration of renewables seeks to address India's key energy objectives of increasing energy security, reducing energy poverty and improving energy sustainability. The significant decline in per unit cost of solar and wind power in auctions (INR 2.97/ kWh in the Rewa Solar plant in Madhya Pradesh and INR 3.46/kWh for wind power plants) have made renewables economically competitive with other fossil fuel sources. However, the cost of balancing the renewable electricity has to be taken into account which would bring out the actual cost of electricity generated from renewables.

3. India's reliance on coal will persist even in 2047 with an envisaged share of 42%-50%in energy mix. India would like to use its abundant coal reserves as it provides a cheap source of energy and ensures energy security as well. However, the imports of coal have risen at a CAGR of 18% from 2005-06 (39 MT) to 2015-16 (200 MT). The modeling exercise of NITI shows that India will achieve peak production of coal in 2037, after which the production will decline and India will depend on imports to meet its requirements. Therefore, India would like to use its coal reserves efficiently. Keeping in mind the adverse impacts of climate change, it becomes pertinent to explore clean coal technology options in India.

Therefore, India Energy Security Scenarios (IESS) 2047 has been used to capture the above three objectives and come out with a comprehensive quantitative analysis. Moreover, three separate studies have also been undertaken in order to have a deeper dive in the above three topics.

1. INTRODUCTION

India's energy sector is set for a sea change with recent developmental ambitions of the Government of India – 175 GW of installed capacity of renewable energy by 2022, 24X7 Power for all by 2022, Housing for all by 2022, 100 smart cities mission, 10% reduction of oil and gas import dependence by 2022 from 2014-15 levels and provision of clean cooking fuels. India is envisaged to play a key role in the global energy scenario amidst the present trends in the favor of energy buyers rather than suppliers which are likely to continue in the medium term. India is likely to account for 25% of the rise in global energy demand by 2040 (International Energy Agency). As India's energy and electricity demand is likely to grow at a CAGR of 3.7%-4.5% and 5.4%-5.7% respectively till 2047, the pressure on natural resources to fuel the demand would only rise in the future. With a share of 18% in the world population, India consumes only 6% of the world's primary energy. This is evident from the low per capita energy consumption of India (521 kgoe in 2014) which is one-third of the world's average. Moreover, India houses nearly 304 million people without access to electricity (25% of the global population without access to electricity) and 800 million people without access to clean cooking fuels (30% of the global population without access to clean cooking fuels). India certainly aims to reduce its energy poverty in a sustainable manner keeping in mind the energy independence and the impact of these objectives on economic growth. The energy mix of India and the world is given below to give a snapshot of the fuels used to meet the energy demand:

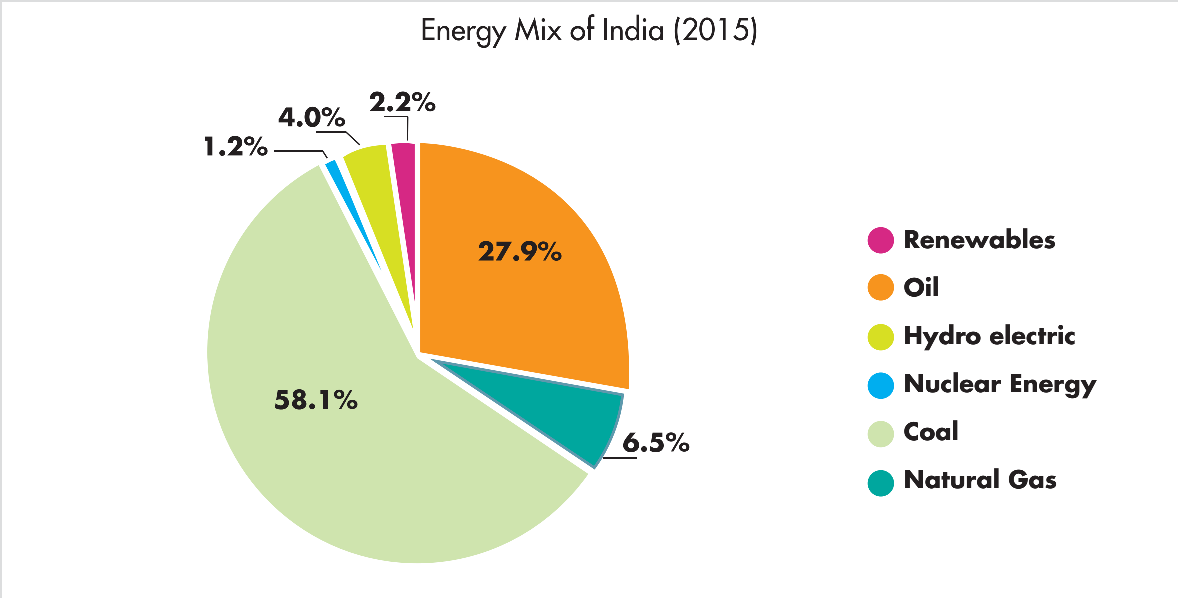

Figure 1- Source: BP Statistics (2016)

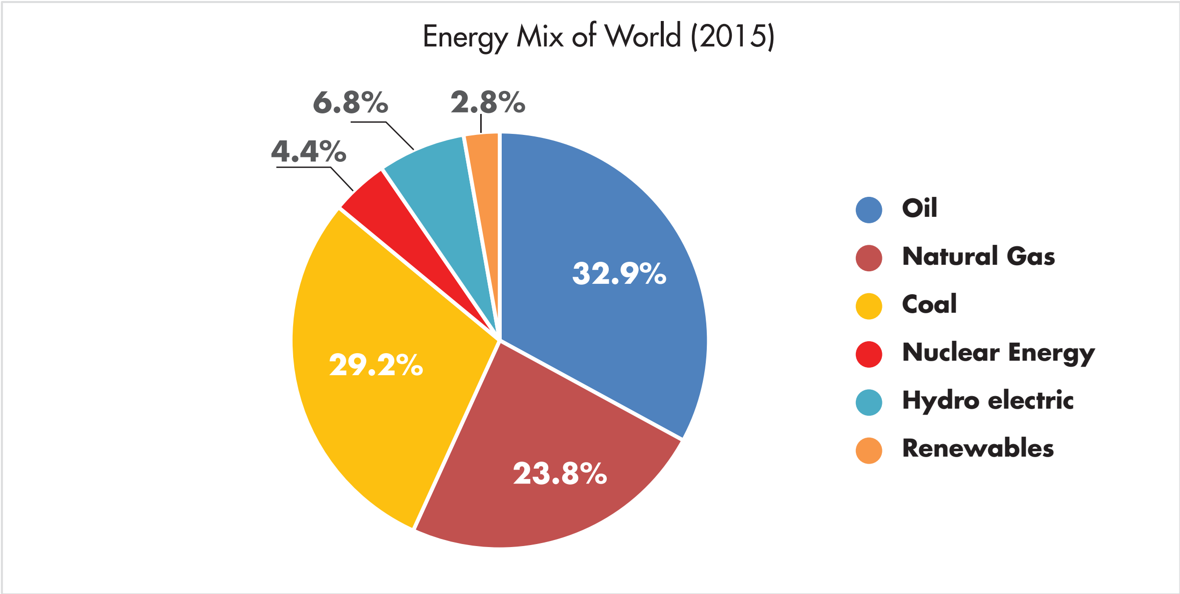

Figure 2- Source: BP Statistics (2016)

It can be analyzed from Figures 1 and 2 that the energy mix of India and the world is not very different except the share of coal and gas. The share of coal in the energy mix for India and the world is 58% and 29% respectively, whereas that of natural gas is 6.5% and 24% respectively. Natural gas has the potential to replace solid and liquid fuels in almost all sectors whether it be Industry, Transport, Cooking, Telecom or Agriculture. Therefore, there is a lot of potential to increase the share of natural gas in the energy mix of India.

2. DRIVERS OF THE PROJECT

The following are the driving forces behind this project:

- With India and Japan ratifying the Paris deal in October, 2016 and November, 2016 respectively, both the nations are striving to achieve their developmental ambitions with a low carbon footprint. The three topics chosen under this joint project converge towards reducing the emissions by India and Japan.
- Apart from climate change, the deteriorating air quality of Indian cities is an important factor that drives it to meet its energy requirements sustainably. India is home to 22 of the 50 most polluted cities in the world (WHO data).
- As coal is going to remain the mainstay of India's energy future (share in energy mix – 42-50% in 2047), it would be pertinent to analyze the impact of clean coal

technologies (CCT) in India. Also, India having the 4th largest coal reserves, it would like to use its abundant coal reserves efficiently to maintain its energy security. And Japan's reliance on coal has certainly increased, post Fukushima disaster for power generation and it is cheaper to import in comparison with LNG or crude oil. Moreover, ultra super-critical technology accounts for 40% of the total coal fired installed capacity of 42 GW (2014) in Japan and it's a major developer of high efficiency low emission (HELE) technology, which acts as a source of revenue generation for it. So, the above reasons compel Japan to analyze the impact of CCT on their energy scenario along with India's energy scenario.

- With an ambitious target of 175 GW of installed capacity of renewable energy by 2022 in India and 80 GW by 2030 in Japan, both the countries are set to increase the share of renewables in energy and electricity mix. So, it is important to analyze whether the grid would be able to handle the increased penetration of this intermittent source of supply.

- The share of natural gas in primary energy mix was 6.5% and 22.7% in 2015 for India and Japan respectively. India wants to move towards a gas based economy by increasing the penetration of gas in its ecosystem and has also set a target of increasing the share of gas to 15% in the energy mix by 2022. India's LNG imports are set to rise as it has already signed long term contracts of 22 MT by 2022 and is gearing to increase its regasification capacityto 47.5 MT by 2022. However, this move would come in conflict with the goal of energy security, but the trade-offs between importing gas instead of crude oil, as the former is a more efficient fuel and cheaper on calorific value basis is also to be kept in mind. Japan is the largest importer of LNG (85 MT in 2015) in the world and relies heavily on it for power generation. Moreover, gas based generation capacity would be required for balancing as both the countries want to increase the share of renewables in electricity mix. Therefore, keeping the above points in mind, analyzing the demand for natural gas for India and Japan assumes a lot of significance.

3. METHODOLOGY

India Energy Security Scenarios (IESS) 2047

IESS 2047, an energy modeling tool developed by NITI Aayog has been used to generate the modeling results for this exercise which would give an overview of India's energy scenario and the three studies listed above. Suitable variations have been made in existing IESS model in order to derive the results. The subsequent sections would explain in detail about the assumptions and how the scenarios have been generated.

4. FIXED ASSUMPTIONS

The analysis for this exercise is based on certain assumptions of GDP growth rate, population, urbanization, share of manufacturing etc. A majority of these assumptions are in line with India's internationally declared targets. A detailed explanation on the assumptions is given below:

4.1. GDP growth rate:

The GDP of India is assumed to grow at a CAGR of 8.5% between 2012 and 2047 which is different from the predefined three scenarios of GDP created in the IESS. However, different research exercises by various institutions have assumed different growth rates of GDP, an 8.5% growth rate is assumed to reflect the ambitions of India. As evident from figure 3, the GDP growth rate plateaus at 10% in 2022-27 interval and gradually comes down to 7.4% in the interval, 2042-47. Exercises to determine how the activity demand of sectors change with a higher level of GDP were undertaken to arrive at the level of service demand for each sector.

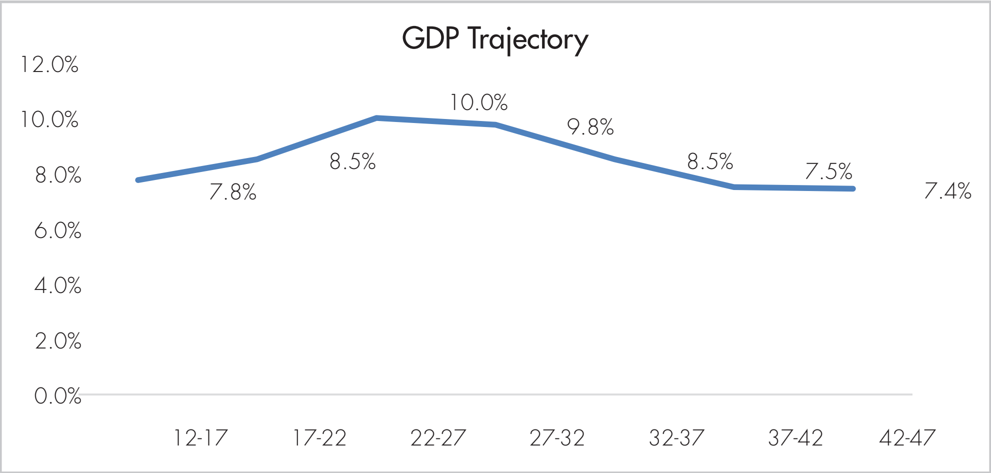

Figure 3 - Source: Derived from IESS

4.2. Population Growth and rate of Urbanization:

The population of India is assumed to grow from 1.2 billion in 2012 (census 2011) to 1.7 billion in 2047 (Population Foundation of India, Scenario B). India's urbanization would grow from 31% in 2012 to 51% in 2047, thereby increasing the urban population. The increasing population with rising urbanization would influence how the energy is consumed in India, e.g. people moving towards cleaner cooking fuels, increased penetration of efficient electrical appliances etc.

4.3. Share of Manufacturing:

The share of manufacturing would rise to 34% in 2047 from 16% in 2012, thereby increasing the share of energy demand by industry by 2047.

4.4. Achieving India's developmental targets:

Both the scenarios assume achievement of India's developmental ambitions and are in line with the internationally declared commitments of the Country. The following targets are taken into account:

- 175 GW of installed capacity of renewable energy by 2022
- 24X7 reliable supply of Power for all by 2022
- Housing for all by 2022
- 100 Smart Cities Mission
- Provision of clean cooking fuels.
- Meeting the INDC target as committed in COP 21 in Paris.

5. HOW THE SCENARIOS HAVE BEEN GENERATED

IESS offers 4 different levels on the demand and supply side which are based on the energy efficiency measures and technology interventions, and raising domestic resource production respectively. Two scenarios have been created i.e. Business as Usual **(BAU) scenario and Ambitious scenario** to get a sense of India's overall energy sector. The fixed assumptions in both the scenarios have been kept constant.

The BAU scenario has a high energy demand in comparison with Ambitious scenario as the latter assumes a greater penetration of energy efficiency measures and technological interventions in the demand sectors – transport, buildings, cooking, industry, telecom and agriculture. On the supply side, the indigenous resource production in BAU scenario is less than Ambitious as the latter assumes aggressive efforts being done to raise the fossil fuel production and energy generation from thermal power plants, renewable sources and others. It is to noted that BAU scenario is nevertheless ambitious too, as it incorporates all the developmental ambitions of the Government, however Ambitious scenario is yet more ambitious. A detailed description of the interventions done in the demand and supply sectors in the two scenarios is given below:

5.1. Demand Sectors:

5.1.1 **Transport (Passenger and Freight transport):** There is a greater shift towards transient oriented development, enhanced use of public transport, increased penetration of electric and hybrid vehicles and a shift towards public transport from private(rail transport from road) in the ambitious scenario in comparison with BAU. Moreover, there is better logistical planning assisted by information technology along with introduction of dedicated freight corridors to complete the golden quadrilateral in the ambitious scenario. So, the energy demand in the ambitious scenario is less than the BAU.

5.1.2 **Buildings (Residential and Commercial):** The ambitious scenario considers a shift towards more efficient building materials for the construction of buildings (better building envelope optimization), strengthening of the existing policy framework i.e. enhanced compliance of the Energy Conservation Building Code (ECBC) of the Bureau of Energy Efficiency (BEE) which seeks to set out the minimum requirements of the energy efficient design and construction of the buildings, high penetration of efficient appliances and technologies and better urban planning than BAU scenario. This would lead to a decreased energy demand in the ambitious scenario.

5.1.3 **Agriculture:** The ambitious scenario considers increased efficiency of diesel pump sets, a shift towards electric and solar pumps from diesel pumps and increased fuel efficiency of the tractors which would lead to a decrease in overall energy demand in this sector in the ambitious scenario in comparison with BAU.

5.1.4 **Telecom:** There is a shift from diesel run telecom towers towards electricity based towers. Moreover, there is an enhanced use of renewable sources such as solar and wind to fuel the telecom towers. The combined action of the above measures would decrease the specific fuel consumption by telecom towers, thereby reducing the energy demand.

5.1.5 **Industry:** An increased penetration of energy efficiency measures through Perform, Achieve, Trade (PAT) scheme which envisages a shift towards best available technologies and introduction of energy efficiency measures in the industries which are not covered under PAT is taken into account. Furthermore, technological interventions have been taken into consideration in the two major energy guzzling sectors of the industry – Cement (Increased waste heat recovery, Increased electricity from the Grid, and Increased Alternate Fuels and Raw Materials) and Iron & Steel(Switch to electric furnace, Increased gas based direct reduced iron, Increased electricity from the grid, and Increased Scrap) which envisage a shift away from solid and liquid hydrocarbons towards electricity and other fuels. The overall energy demand in the ambitious scenario would be reduced in comparison with BAU, however, electricity demand would be increased if we opt for the electric solutions in cement and iron & steel sectors.

5.1.6 **Cooking:** An increased penetration of clean cooking fuels like Liquefied Petroleum Gas (LPG), Piped Natural Gas (PNG) and electricity in the urban and rural areas have been considered in the ambitious scenario as people move away from biomass. The increased penetration of LPG in rural areas is in line with the Government's Pradhan Mantri Ujwalla Yojana (PMUJY). Also, the efficiency of the biomass, LPG, PNG and electric cook-stoves increase in the ambitious scenario. The above would lead to a drastic decrease in the overall energy demand in the cooking sector as the inefficient biomass is replaced with more efficient fuels like LPG, PNG and electricity, however, the demand for liquid and gaseous hydrocarbons, and electricity would increase in the ambitious scenario. So, cooking would be the only sector whose energy demand would decline in 2047 in both the scenarios in comparison with 2012.

The difference between the two levels of energy demand highlights the potential of energy demand reduction through energy efficiency measures and technology interventions in various demand sectors.

a. Energy Demand:

Sector	**2012**	**2047**	
TWh		BAU	Ambitious
Buildings	239	2971	2450
Industry	2367	12855	9907
Transport	929	5528	3604
Pumps& Tractors	237	798	636
Telecom	83	231	131
Cooking	1066	522	463
Total	4920	22905	17192
Potential energy demand reduction in 2047 between BAU and Ambitious scenarios (%)	25%		

Table 1

The Table 1 highlights that energy demand can be reduced by 25% in the ambitious scenario in comparison with BAU through energy efficiency measures and technology interventions in 2047.

b. Energy Intensity of GDP:

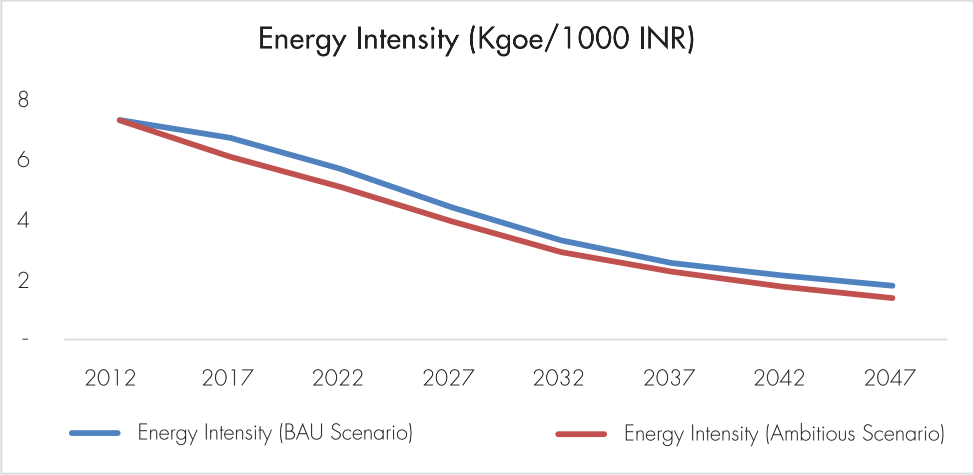

Figure 4

The Figure 4 gives the Energy Intensity of GDP in BAU and Ambitious Scenarios. The reduction in energy intensity from 2012-47 is higher in ambitious scenario (81%) than BAU scenario (75%) indicating higher penetration of energy efficiency measures in the former.

c. Electricity Demand:

Sector	**2012**	**2047**	
TWh		BAU	Ambitious
Buildings	240	3016	2472
Industry	336	1692	1891
Transport	79	296	275
Pumps& Tractors	136	501	353
Others	14	145	153
Total	805	5651	5144
Potential reduction in electricity demand in 2047 in BAU and Ambitious scenario (%)	9%		

Table 2

It is evident from Table 2 that there is a 9% potential for the reduction in electricity demand in ambitious scenario by 2047. India's per capita electricity consumption would rise to 3581-3588 KWh in BAU and Ambitious scenario respectively in 2047, whereas the per capita electricity consumption was 1075 KWh/capita in 2015-16.

d. Share of electricity in energy demand:

Parameter	**2012**	**2047**	
		BAU	Ambitious
Share of electricity in energy demand	16%	25%	29%

Table 3

Currently, the share of electricity in final energy demand in India is only 16%, whereas that of OECD is 24%. The Table 3 depicts that the likely share of electricity in energy demand would be 25% and 29% in BAU and Ambitious scenario respectively. This indicates electrification in demand sectors in the ambitious scenario, for e.g. the industrial processes in iron & steel sector would shift away from solid and liquid hydrocarbons towards electric processes which would increase the share of electricity in final energy demand in ambitious scenario in comparison with BAU scenario.

e. Segregation of energy demand by fuel:

	2012	**2047**	
Mtoe		BAU	Ambitious
Liquid Hydrocarbons 151	688	471	
Solid Hydrocarbons	174	637	418
Gaseous Hydrocarbons30	157	138	

Table 4

The Table 4 gives the segregation of energy demand by fuel. Since, the Ambitious Scenario is more efficient than BAU, the fuel requirements are lesser in the former scenario.

5.2 Supply Sectors:

5.2.1 **Domestic Fossil Fuel Production:** Mechanisms to enhance the domestic crude oil, natural gas and coal production have been taken into account in the ambitious scenario with an aim to reduce the import dependence of India. Apart from conventional fossil fuel supplies, the exercise also considers the production of unconventional fuels like shale oil/gas, Underground Coal Gasification (UCG) and Coal Bed Methane (CBM).

5.2.2 **Thermal Power Generation:** There is an increased penetration of efficient and cleaner technologies (super-critical, ultra super-critical and IGCC) in the coal power plants. An increase in the gas based power generating capacity is well acknowledged to encourage the cleaner sources of power generation along with balancing requirement for renewable energy capacities. The potential for Carbon Capture and Storage (CCS) in coal and gas based generation capacities in the medium to long term is also taken into account.

5.2.3 **Renewable Energy:** As stated above, both the scenarios, BAU and Ambitious meet the 175 GW target of renewable energy installed capacity by 2022. The ambitious scenario assumes yet more penetration of renewables with enhanced deployment of solar CSP, onshore wind, offshore wind, small hydro, solar water-heaters apart from solar PV and waste to energy. Moreover, the maturity of renewable energy technologies and creation of market based framework would lead to autonomous growth of this sector post 2022.

5.2.4 **Hydro-Power and Nuclear Generation:** These two sources of power generation would further diversify the sources of electricity generation in India. Though, India was able to add just above 2 GW of hydro power capacity in the 12th five year period and the nuclear power capacity remain unchanged, the ambitious scenario considers increased deployment of these two sources.

5.2.5 **Storage Capacity:** Since, the penetration of renewables is high in both the scenario, adequate storage capacities, both Battery and pumped hydro would be required in order to check the intermittency of the renewable sources of electricity generation. The storage capacity requirement is higher in ambitious scenario than BAU.

5.2.6 **Biofuels:** Enhanced use of liquid biofuels (1st and 2nd generation, advanced biofuels) would try to curb the country's oil imports. And biogas could be used for cooking in rural areas.

5.2.7 **Aggregate Technical and Commercial (AT&C) Loses:** A reduction in AT&C loses, introduction of smart grids, enhanced reliability of grid and trade of electricity with a transnational grid in place is taken into account while creating the two scenarios.

5.2.8 **New Technologies:**Enhanced hydrogen production is envisaged in the ambitious scenario to cater for the increased demand from fuel cell vehicles (FCVs) in transport sector and hydrogen run telecom towers.

Since, the Ambitious scenario assumes a higher penetration of renewables than BAU, the energy supply from renewables would be higher in the former scenario. And overall, a lower amount of energy would be required to fuel the energy demand in the ambitious scenario because of the reduced demand in ambitious scenario due to efficiency measures and technology interventions.

a. Energy Supply:

	2012	2047	
TWh		BAU Scenario	Ambitious Scenario
Nuclear	76	523	902
Renewable Energy	190	2205	2878
Agriculture/waste	1060	1510	1936
Coal	3272	15155	9790
Oil	1938	8434	5385
Natural gas	571	2331	2402
Total	7108	30158	23294

Table 5

The Table 5 depicts an increased quantity of renewable energy supplied in the ambitious scenario and decreased use of coal and oil. However, an increased quantity of natural gas would be required in the ambitious scenario as it assumes higher penetration of the same in industry, cooking, transport and gas power stations. The per capita energy consumption would rise from 500 kgoe/capita to 1175-1522 kgoe/capita in the BAU and ambitious scenario respectively.

b. Installed Capacity:

	2012	2047	
GW		BAU Scenario	Ambitious Scenario
Gas Power Stations	24	50	83
Coal power stations	125	333	459
Carbon Capture Storage (CCS)	0	35	80
Nuclear power	5	26	45
Hydro Power Generation	41	75	105
Solar PV	1	306	346
Solar CSP	0	90	131
Onshore Wind	17	213	230
Offshore Wind	0	20	62
Small Hydro	3	20	30
Distributed Solar PV	0	191	216
Biomass	5	11	23

Waste to Electricity	0	6	6
Total	221	1375	1816

Table 6

It is evident from Table 6 that the ambitious scenario has enhanced capacity of renewables and gas power stations. The capacity of coal power stations is also higher in ambitious scenario as it also seeks to enhance the installed capacity of coal with more efficient and cleaner technologies.

c. Domestic Production:

Fuel	2012	2047	
		BAU	Ambitious
Coal (Mtce)	582	1157	1400
Oil (Mtoe)	38	59	68
Gas (BCM)	48	128	170

Table 7

The Ambitious scenario considers aggressive efforts to step up the domestic fossil fuel production which is evident in the Table 7.

d. Import Dependence:

	2012	2047	
		BAU Scenario	Ambitious Scenario
Coal	17%	65%	34%
Oil	77%	90%	78%
Gas	22%	51%	33%
Overall	31%	61%	36%

Table 8

Since, the ambitious scenario has reduced demand and increased domestic supply, the import dependence in this scenario will be less than BAU scenario (Table 8). The import dependence can be brought down from 61% in BAU scenario to 36% in ambitious scenario showing that we have to make simultaneous interventions in the demand and supply sectors to reduce energy imports in India.

e. Energy Mix of India:

	2012	2047	
TWh		BAU Scenario	Ambitious Scenario
Nuclear	1%	2%	4%
Renewable Energy	3%	7%	12%
Agriculture/waste	15%	5%	8%
Coal	46%	50%	42%
Oil	27%	28%	23%
Natural gas	8%	8%	10%

Table 9

The Table 9 gives the primary energy mix of India in 2047 for both the scenarios – BAU and Ambitious. It is evident from Table 9 that coal is going to remain the mainstay of India's energy mix with a share of 50% and 42% in BAU and ambitious scenario respectively. Whereas, the share of renewable energy would rise to 12% in the ambitious scenario in 2047 in comparison with 7% in BAU scenario. Though, the consumption of natural gas would increase in both the scenarios, the share of natural gas would rise only by 2% in the ambitious scenario in 2047 in comparison with BAU.

f. Greenhouse Gas (GHG) Emissions:

i. Total GHG Energy Related Emissions:

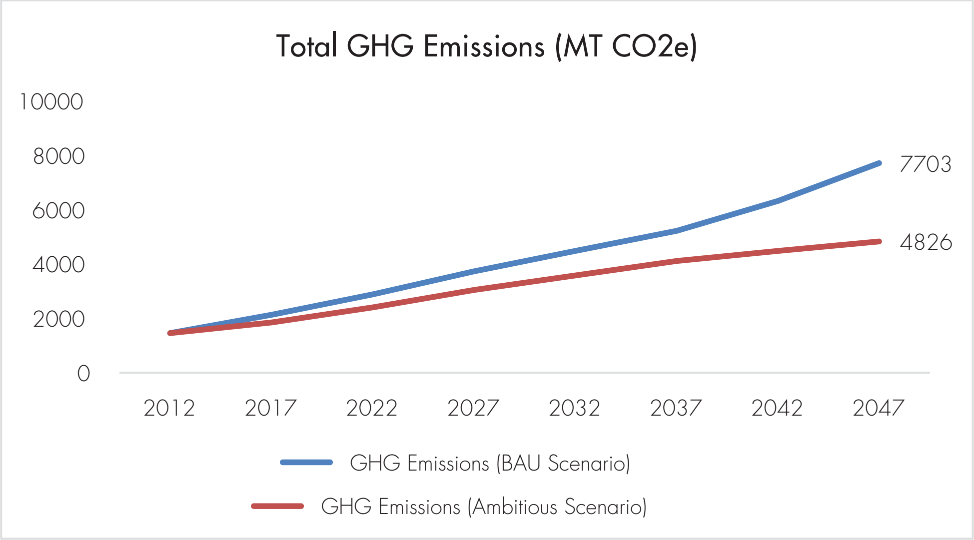

Figure 5

The Figure 5 gives the Energy related GHG Emissions which account for 75% of the total GHG emissions of the country. It is evident from Figure 5 that the Total GHG Emissions in the ambitious scenario are 37% less in comparison with BAU Scenario. Since, the ambitious scenario considers a higher penetration of renewables along with enhanced efficiency, the emissions are lower than BAU scenario. Though, India's total GHG emissions rise, the per capita emissions are likely to remain much below than that of other countries. For instance, presently the per capita emissions of India are 1.6 tons CO2e/capita, whereas that of China are 7.7 tons CO2e/capita and the United States are 16.2 tons CO2e/capita. The per capita emissions of India are not expected to reach even the present per capita levels of China and US even in 2047.

ii. Per-capita GHG energy related emissions:

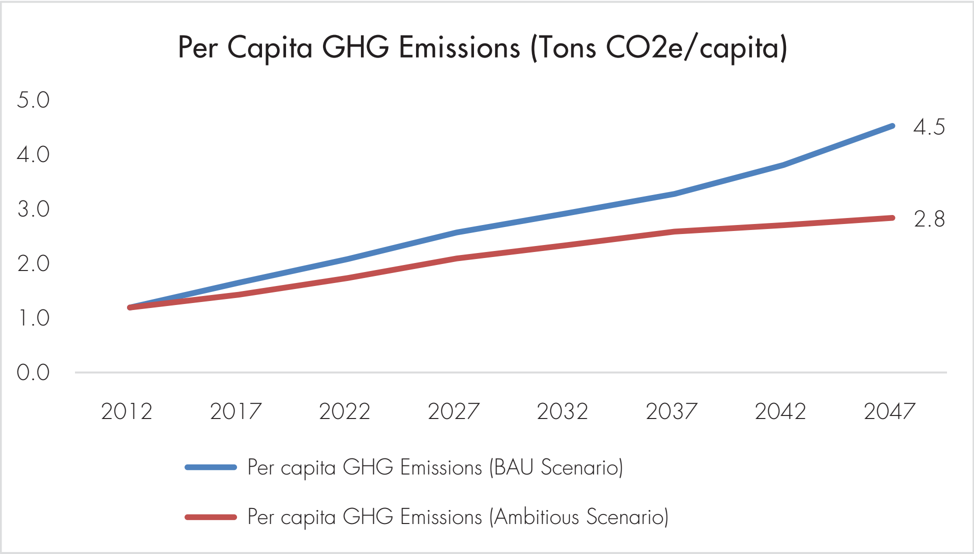

Figure 6

The Figure 6 highlights that even in the BAU scenario in 2047, India's per capita emissions would be lower than China's present per capita emissions.

g. Emissions Intensity:

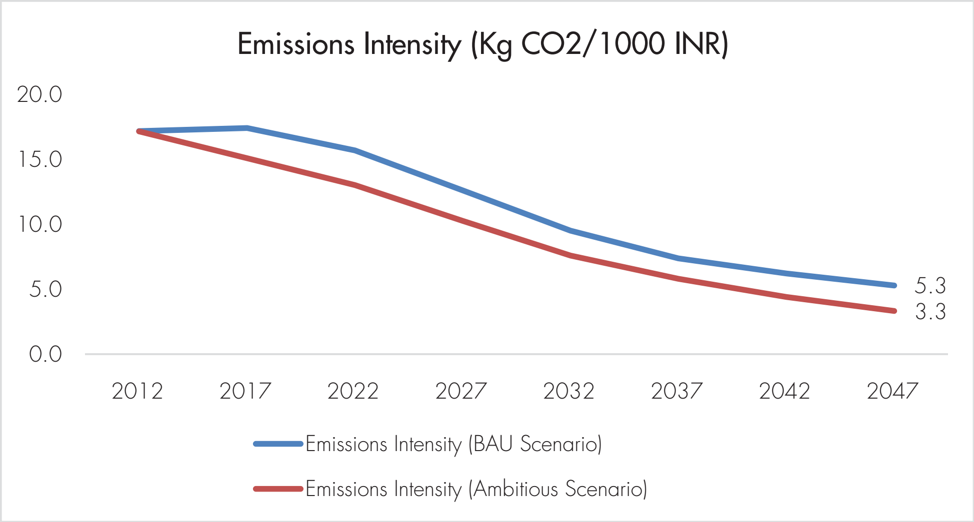

Figure 7

The Figure 7 gives the emissions intensity of GDP (Kg CO2e/1000 INR) @ 2011-12 prices. The emissions intensity reduces by 70% in the BAU scenario, whereas it reduces by 81% in the ambitious scenario by 2047 in comparison with 2012 levels. The reduction of 71% in the BAU scenario implies that the BAU pathway which considers the developmental ambitions of the Government are ambitious enough to achieve such a high reduction in emissions intensity.

It is to be noted that this analysis takes into account the ambitions and objectives of all the three studies mentioned above. The ambitious scenario assumes greater penetration of renewables, increased use of natural gas for power generation, cooking and industrial purposes, and introduction of efficient and cleaner technologies in the coal power plants including CCS. This exercise aims to give an integrated picture for the three studies (mentioned in abstract) and provide a direction to each of them, whereas the sectoral studies have been undertaken to analyze the details and have a deeper dive by using different models and creating various scenarios for their respective sectors. A brief of sectoral studies is given below, whereas separate reports for the three different studies have been prepared to provide the user with the detailed results.

6. BRIEF ON SECTORAL STUDIES

6.1. Analyzing the demand for Natural Gas and the impact of its increased uptake on the overall energy scenario:

Analyzing the natural gas demand for India and Japan is one of the most significant topics of research undertaken by both the institutions. NITI has assessed the demand for natural gas in India till 2047 using India Energy Security Scenarios (IESS) 2047. Moreover, World Energy Projection System (WEPS+) model has also been used to arrive at the natural gas demand in India by 2040, where Energy Policy Institute at the University of Chicago (EPIC) – India also provided inputs using WEPS+ model. A separate report is prepared giving the detail of above analysis.

6.2. Analyzing the increased penetration of renewables on the grid:

Renewable Energy is another area which is high on agenda of both India and Japan. India's ambitious target of 175 GW of installed capacity makes it imperative for the policy makers and technocrats to see whether it would be feasible to integrate the large amount of infirm supply of renewable electricity in the grid. Therefore, NITI used IESS and PLEXOS model to see whether the grid would be able to absorb the electricity generated from renewable sources. Also, an hourly grid dispatch was worked out for the three seasons in India. Lawrence Berkeley National Lab (LBNL) provided critical inputs with regards to PLEXOS.

6.3. Analyzing the impact of Clean Coal Technology (CCT):

Since, coal is envisaged to play a major role in case of India with a share of 42%-48% in the energy mix in 2047, it becomes really important to analyze the impact of clean coal technology on the overall energy scenario of India in the wake of increasing threats posed by climate change. India Energy Security Scenarios (IESS) 2047 has been used to analyze the impact of CCT including CCS in India. Inputs on this topic were also given by the University of Petroleum and Energy Studies (UPES), Dehradun.

7. KEY TAKEAWAYS

1. From the above analysis, a conclusion is reached that India needs to adopt a multi-pronged strategy which would be a mix of conventional and renewable sources of energy and within renewables – a mix of centralized and decentralized solutions along with a focus on energy efficiency to reduce energy demand and enhance domestic supply in order to achieve its overall developmental ambitions in the energy space.

2. Coal is going to remain the mainstay of India's future energy mix with a share of 42%-50% in the BAU and ambitious scenario in 2047 respectively.

3. Energy efficiency has a lot of potential to reduce the energy demand in India i.e. a demand reduction of 25% can be achieved by 2047 if India were to follow the ambitious pathway. The energy intensity of India would reduce from 7.3 kgoe/1000 INR in 2012 to 1.4-2 kgoe/1000 INR in 2047 in the ambitious and BAU scenario respectively which clearly indicates an increase in energy efficiency, thereby decoupling the growth of economy and increase in energy demand.

4. There is a huge scope of electrifying energy demand in India in all the demand sectors like industry, telecom, transport, agriculture, buildings and cooking. So, electricity, which is a much more efficient way of consuming energy, can replace the use of solid and liquid fuels in industry, telecom, transport, agriculture and cooking. For e.g. in industries, electricity can be used for generating heat rather than solid/liquid fuels (i.e. coal, fuel oil, naphtha etc.). This would also result in reducing the emissions at the consumption center. Therefore, electrification of energy demand can increase the share of electricity in energy demand from the present 16% to 25%-29% in 2047.

5. It is also to be noted that the BAU scenario is nevertheless ambitious enough as it incorporates all the developmental ambitions of the Government in the energy space. The BAU scenario envisages a 70% reduction in emissions intensity of GDP in the energy sector by 2047 in comparison with 2012 levels which is significant.

6. The share of Renewable Energy in the energy mix would rise from 3% in 2012 to 7%-12% in 2047 in the BAU and ambitious scenario respectively. The increased share of renewables and clean energy in the Ambitious scenario would be a win-win situation for India as it would help in reducing imports, emissions and simultaneously increasing the energy accessibility.

7. The interventions on the demand side through various energy efficiency measures and technology interventions, and on the supply side by augmenting the indigenous fossil fuel production of coal, oil and gas including unconventional fuels (Coal Bed Methane, Underground Coal Gasification and Shale oil/gas) will curb the rising energy import dependence of India. The overall energy import dependence of India which is likely to rise to 61% in 2047 in BAU scenario can be brought down to 36% in 2047 in ambitious scenario which was 31% in 2012.

8. In 2047, the per capita electricity consumption of India is envisaged to become 3581-3588 KWh/capita from 1075 KWh/capita in 2015-16 which indicates that even in 2047, India's per capita electricity consumption would be still lower than that of the present per capita electricity consumption in the US (12000 KWh/capita), China (4000 Kwh/capita) and Germany (7000 Kwh/capita).This highlights the increasing penetration of energy efficient technologies in India in different demand and supply sectors.

9. Also, the per capita emissions (this exercise takes into energy related emissions) would be quite low in 2047 ranging 2.8-4.5 tons CO_2e/capita, whereas the per capita emissions presently are 1.6 tons CO_2e/capita. The present per capita emissions of China are 7.7 tons CO_2e/capita and the United States are 16.2 tons CO_2e/capita indicating that India's per capita emissions, even in 2047 would be lower than the present per capita emissions of China and the US.

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ASSESSMENT OF NATURAL GAS DEMAND IN INDIA

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Disclaimer: This research report is intended for use by decision-makers, academicians, researchers and other stakeholders, nationally as well as globally. The assumptions, analysis and views of the authors are personal and it does not represent the views of either Government of India or NITI Aayog. They are intended to stimulate healthy debate and deliberations in the field of energy and climate change. For any queries contact at ripunjaya1@gmail.com

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ABSTRACT

Under the joint project between NITI Aayog and IEEJ, one of the important topics was to assess the natural gas demand of India and Japan till 2047 and analyze the impact of increased penetration of gas on the overall energy scenario of India and Japan.

This report aims to arrive at the natural gas demand in India till 2047 and analyze in detail the impact on energy mix, electricity mix, installed capacity, energy intensity, emissions intensity etc. Two models are used for carrying out the above exercise i.e. India Energy Security Scenarios (IESS) 2047, which is an in house model developed by NITI and World Energy Projection System (WEPS+) model, which is used by the United States Government's Energy Information Administration (EIA). This is done in order to make this study more robust and comprehensive and see how the results vary using these two different modeling techniques – IESS follows a bottoms-up approach, whereas WEPS+ is a model that converges to a price-consumption equilibrium.

This exercise assumes importance in the backdrop of constant efforts of the Government of India to increase the share of gas in its energy mix, however, it has not been able to do so because of many reasons, primarily being the volatility of high priced Liquefied Natural Gas (LNG). The share of gas in energy mix has dropped from a high of 11% in 2009 to 6.5% in 2015 as the domestic production of India started declining from 2010 onwards. Natural gas can be a preferred fuel for India as gas based capacity is ideal to balance renewables and increased penetration of Compressed Natural Gas (CNG) vehicles for transportation and Piped Natural Gas (PNG) for cooking would lead to higher consumption of natural gas. However, there should be a commensurate expansion in the City Gas Distribution (CGD) network and other infrastructure like LNG terminals and trunk pipelines. Moreover, deteriorating air quality and increasing greenhouse emissions also make it attractive to move towards natural gas which is the cleanest fossil fuel. It is to be noted that natural gas has the potential to displace liquid fuels in all the sectors and is also cheaper than crude oil on a calorific value basis. This report also seeks to help policy makers take informed decisions while they plan the role of natural gas in the future energy mix of India.

Therefore, this exercise arrives at the natural gas demand of India using IESS and WEPS+ models and finally gives a comparison of the results derived from the two different modeling approaches. Though, the two models follow an entirely different approach to arrive at the final results, a comparison of the modeling results from IESS and WEPS+ is done in order to analyze the variations. .

1. INTRODUCTION

Gas has increasingly become a preferred choice of fuel globally as it is a cleaner source of energy in comparison with other conventional fuels (coal and oil), is found in abundance in the world as the production of natural gas has been on a rise and is more efficient way of producing useful energy and is cheaper on calorific value basis than oil. The share of gas in energy mix in India in 2015 was 6.5% whereas globally, the share was 24%. The Figure 1 gives the trend of natural gas production, consumption and import over the period 2005-06 to 2015-16 in India. The production of natural gas in India has been declining since 2010-11, however, there was a rise in production from 2008-09 to 2011-12 when the discovery of KG D6 came on stream. On the other hand, the imports have been rising at a CAGR of 12% from 2005-06 to 2015-16 as is evident from Figure 1. The policy makers have to take a call which energy fuel sources and technologies have to be prioritised in a way that simultaneously drives economic growth and encourages sustainable development.

This report seeks to quantify the natural gas demand in India through different modeling exercises by creating various scenarios.

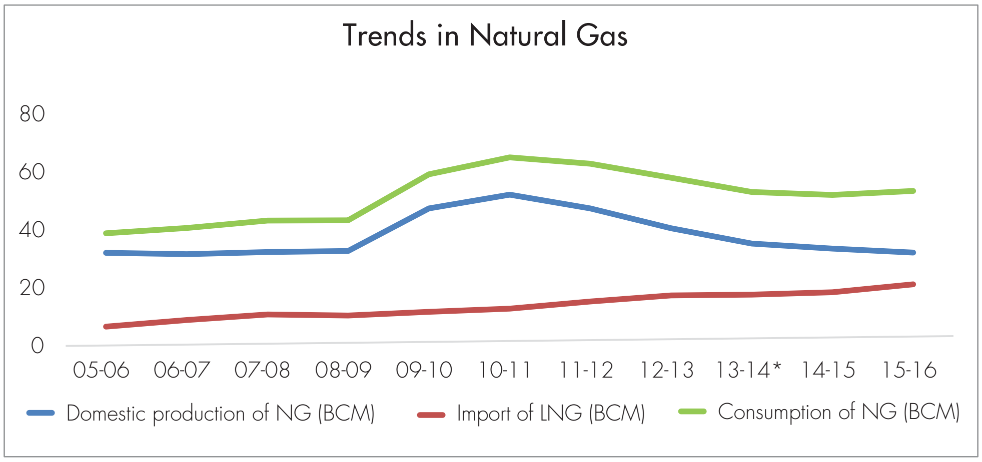


Figure 1

2. ROLE OF NATURAL GAS IN INDIA

1. Power and Fertilizer sector account for 60% of the gas consumption in India, so, these are the two major consumers, however, the former is not able to completely absorb the high cost of imported LNG, though, a Power System Development Fund (PSDF) initiative was started in March, 2015 to revive the stranded gas based capacity of 14305 MW, but it has not been very successful. Consequently, the PSDF scheme has been scrapped and will not continue after 2016-17. The Government has worked out a pooling mechanism for the Fertilizer sector so that the fertilizer plants become viable and this mechanism was started in July, 2015 and is still continuing. However, it is to be kept in mind that pooling of gas is a short term solution for reviving the stranded gas based power and fertilizer plants, whereas these plants have to absorb the cost of imported LNG in the long run in order to become self-sustainable.

2. Gas based installed capacity would be required for balancing the electricity generated from renewables.

3. Natural gas will also aid the clean cooking initiative of the Government through increased penetration of piped natural gas (PNG), especially in the urban areas. Moreover, increased penetration of compressed natural gas (CNG) vehicles in the transport sector would help in improving the air quality of the cities and mitigate emissions.

4. Gas is also required as a feedstock for the steel, sponge iron and refineries.

3. NATURAL GAS PRICING IN INDIA

The pricing of natural gas became a complex issue as a differential pricing regime was followed in India for the Administered Pricing Mechanism (APM) gas, Pre-NELP and NELP gas. Presently, the Government regulates the price of domestic natural gas through a formula which is linked to the prices of the US Henry Hub, UK's National Balancing Point, Canada's Alberta Hub and Russian hub prices, but excludes Japanese Crude Cocktail (JCC) prices. The price of domestic natural gas arrived at through the formula is $2.48/mmbtu (for the period of April, 2017 to September, 2017), which keeps on changing every 6 months.

However, it is to be noted that the Government has come out with a premium pricing for the gas to be produced from deep/ultra-deep water fields and High Temperature and High Pressure (HPHT) fields. A price of $5.56/mmbtu (for the period of April, 2017 to September, 2017) is fixed for the gas to be produced from the above fields, but the production from these fields is negligible at present.

Moreover, the Government has taken a slew of measures in order to move towards market determined prices. The Discovered Small Fields Policy and Hydrocarbon Exploration Licensing policy (HELP) gives the Exploration & Production (E&P) companies complete marketing and pricing freedom which is indeed a major development in this sector. With regards to imports of LNG, the Government has no intervention and the buyer can strike a deal on spot or long term basis.

Though, the Government has taken some major steps to reform the gas sector as explained above which move towards a market based mechanism, the action on the ground is still to be seen as the gas based power plants (~ 14305 MW) and steel plants (9.3 MT) are stranded because they are not able to absorb the prices of imported LNG and become uncompetitive. The reasons for unviability can be many and be debated, however, we need to identify whether we need to reform our gas sector even more, or the solution lies in reforming the coal sector which is a major competitor for gas as a fuel, or both. Since, significant investments have been made in power and steel sector, we have to find out a solution so that the imported LNG could be absorbed and Japan can be an excellent example which can be referred to, as it imports 92% of its primary energy requirement and is the largest importer of LNG in the world with 85 MTPA in 2015.

4. MODELING APPROACH

Two models have been used to arrive at the natural gas demand in India and analyze the implications thereof.

- The India Energy Security Scenarios (IESS) 2047, developed by NITI Aayog has been used to assess the natural gas demand in India till 2047. It is a bottoms up analysis which takes into consideration the penetration of natural gas in different sectors like Transport, Industry, Cooking and Power Plants.
- World Energy Projection Systems (WEPS+) is a model that converges to a price-consumption equilibrium which has also been used to calculate the natural gas demand in India till 2040. WEPS+ is a global energy modeling system used by the Energy Information Administration (EIA) to produce the International Energy Outlook.

It is to be noted that the two modeling exercises were done to give more robustness to this exercise. Moreover, the fixed assumptions like GDP, population, urban & rural households and rate of urbanization for both the modeling exercises have been quite similar with very little deviations. Since, the two models follow an entirely different approach to calculate the natural gas demand in India, it would not be pertinent to do a direct comparison of the results. However, a comparison of the results of these two studies is still done in order to understand the deviations.

5. ASSESSMENT OF NATURAL GAS DEMAND USING INDIA ENERGY SECURITY SCENARIOS (IESS) 2047

Two Scenarios i.e. Business as Usual (BAU) Scenario & High Gas Scenario have been created for computing the natural gas demand in India till 2047 using NITI's India Energy Security Scenarios (IESS) 2047. The assumptions entailing these scenarios will come up in the following section.

1. BAU Scenario:

   The BAU scenario comprise a moderate penetration of natural gas in different gas consuming sectors, along with an overall higher energy demand due to moderate penetration of energy efficiency measures & lower domestic production on supply side. The BAU scenario considers high penetration of Renewable Energy (RE) (takes into account 175 GW RE target) in line with the Government's agenda.

2. High Gas Scenario:

   The High Gas scenario assumes increased penetration of natural gas in different sectors through possible interventions, along with a lower energy demand due to various energy efficiency measures on the demand side and higher indigenous production on supply side. The High Gas scenario considers yet even higher penetration of RE in comparison with BAU scenario.

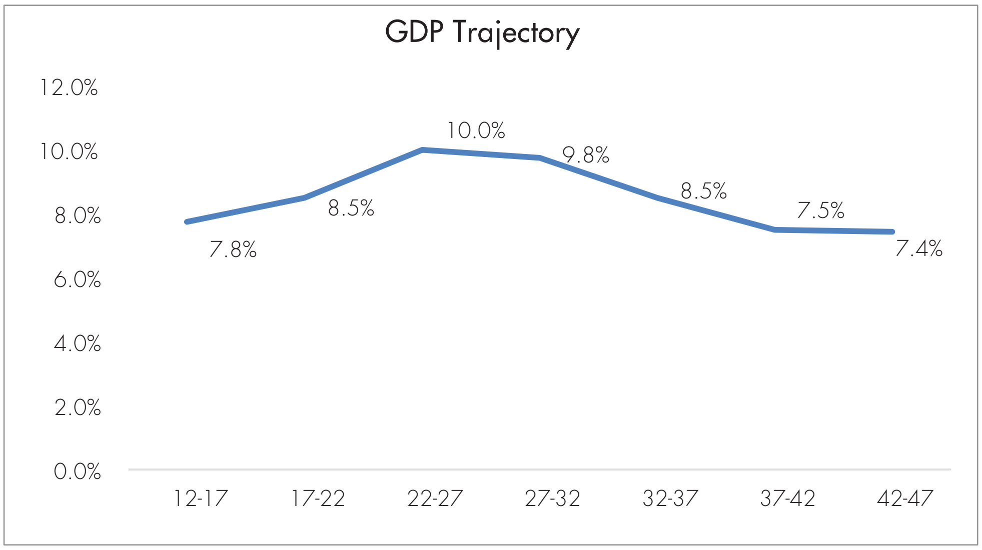
   Various sectors have been identified on the demand & supply sides for the possible areas of intervention to increase the natural gas demand. The demand side sectors are Industry, Cooking and Transport, whereas the supply side sectors are Gas Power Stations and Carbon Capture & Storage (CCS).

5.1. Fixed Assumptions:

The fixed assumptions on GDP growth rate, population, share of manufacturing and urbanization would remain same in both the scenarios i.e. BAU and High Gas Scenario.

5.1.1. GDP Growth Rate:

A GDP growth rate of 8.5% (CAGR) between 2012 and 2047 is assumed. The graph below clearly depicts the GDP trajectory followed by India.



5.1.2. Population, Rate of Urbanization and Share of Manufacturing:

The population of India will rise from 1.2 billion in 2012 to 1.7 billion in 2047. (Population Foundation of India). The urbanization rate, in line with the patterns followed by many major economies, is assumed to increase to 51% in 2047 from 31% in 2012. (United Nations World Urbanization Prospects, 2014). The share of manufacturing would rise to 34% in 2047 from 16% in 2012, thereby increasing the share of energy demand by industry by 2047.

5.1.3. Attainment of India's Development Ambitions:

Both the scenarios i.e. BAU & High Gas scenario takes into account the developmental ambitions of the Government – 175 GW of Renewable energy capacity by 2022, 24X7 power for all by 2022, Housing for all by 2022, 100 smart cities mission, meeting of India's INDC targets etc. Therefore, the BAU scenario is nevertheless ambitious too as it incorporates all the developmental targets of the Government, but, the High Gas scenario is even more ambitious.

5.2. Gas Demand in the demand side sectors:

Three sectors have been identified on the demand side where the gas is fed in – industry, cooking and transport. The BAU scenario considers a moderate penetration of gas in the above three sectors, but, the High Gas Scenario considers a higher penetration of gas in these sectors.

5.2.1. Industry :

Natural gas is used in various sectors such as Iron & Steel, Textiles, Chlor-Alkali, and Pulp-Paper etc. in Industry. IESS 2047 gives the user different technology options in the steel sector which could lead to fuel switching in that sector. Therefore, a technology option of high gas based DRI is chosen in the high gas scenario which will increase the penetration of gas, whereas the BAU scenario considers the default technology option which assumes high penetration of solid fuels rather than gas. Also, the high gas scenario assumes increased efficiency of industrial process over the BAU scenario. Therefore, we tried identifying the impact on the gas demand on the entire industry sector if there were a fuel switch in the steel sector towards gas based technology from the present reliance on the Blast Furnace – Basic Oxygen Furnace (BF-BOF) technology which consumes coal.

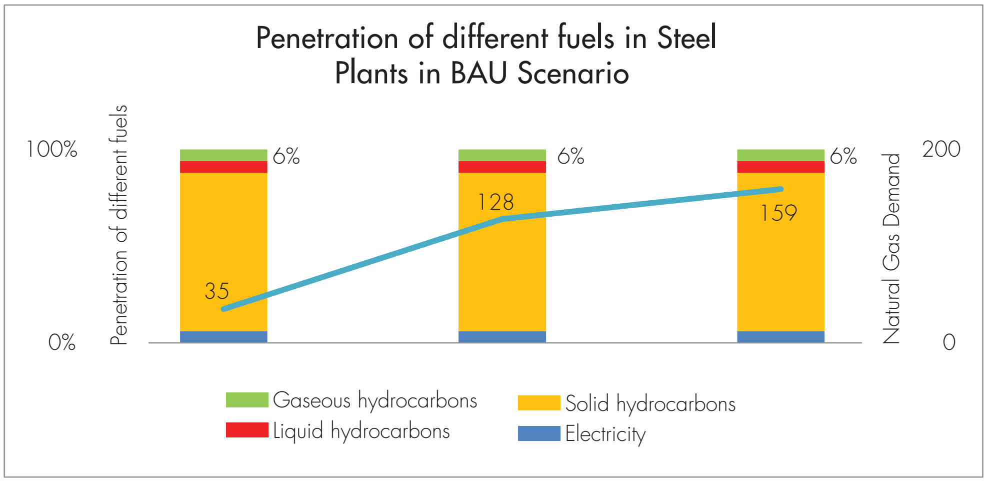


Figure 2[1]

Figure 2 gives the penetration of different fuels like solid, liquid, gaseous or electricity in the steel sector along with the natural gas demand in the industry sector in the BAU scenario. In the BAU scenario, the penetration of gaseous hydrocarbons remains the same i.e. 6% till the year 2047. The natural gas demand rises from 35 BCM in 2012 to 159 BCM in 2047 in the Industry sector in BAU scenario.

[1]The % in the Figure 2 depicts the penetration of different fuels in the steel sector, whereas the absolute numbers depict the natural gas demand in the industry sector.

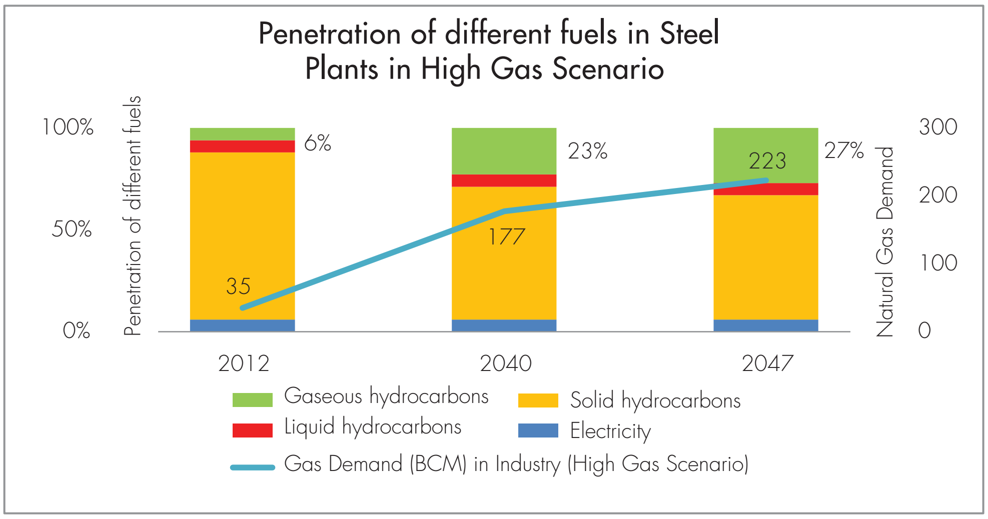


Figure 3[2]

Figure 3 above shows the penetration of different fuels in the High Gas scenario. The penetration of gaseous hydrocarbons increases from 6% in 2012 to 27% in 2047 in the High Gas scenario, whereas the same was kept constant at 6% in the BAU scenario (refer Figure 2). This happens because the high gas scenario considers a fuel switch towards gas based technology from the BF-BOF technology that primarily uses coal. The increased penetration of gaseous hydrocarbons for steel production would lead to an increased demand for natural gas in High Gas scenario. Thus, the gas demand in high gas scenario rises from 35 BCM in 2012 to 223 BCM in industry in 2047, whereas in the BAU scenario, the gas demand in 2047 was only 159 BCM. Therefore, an increase of 64 BCM is registered in the High Gas scenario in comparison with BAU scenario in 2047.

5.2.2. Cooking – Urban Areas:

India houses nearly 30% of the global population i.e. 819 million people without access to clean cooking fuels. The provision of clean cooking fuels has gained a lot of traction in the past couple of years in India. The Government launched the Pradhan Mantri Ujjwala Yojana in May, 2016, which aims to increase the penetration of Liquefied Natural Gas (LPG), especially in rural areas and help people to substitute biomass for cooking. Against a target of 50 million LPG connections by 2019, 19 million have already been distributed and it is envisaged that the target would be accomplished ahead of deadline.

[2] The % in the Figure 3 depicts the penetration of different fuels in the steel sector, whereas the absolute numbers depict the natural gas demand in the industry sector.

Since, the fuel used for cooking varies considerably in the urban and rural areas of the country, IESS considers the penetration of different fuels for cooking separately in the urban and rural areas of India. In the urban areas, penetration of different fuels like LPG, Piped Natural Gas (PNG), biomass, kerosene and electricity is taken into consideration. In general, there is a shift from solid biomass and kerosene towards cleaner cooking fuels like LPG, PNG or electric cooking. The High Gas scenario in the cooking sector in urban areas considers a greater penetration of PNG in comparison with BAU scenario. This is also in line with the Government's policy of increasing the penetration of PNG in the cities, whereas the LPG displaced by PNG in urban areas would be diverted to rural area. Moreover, the Government aspires to increase the penetration of City Gas Distribution (CGD) network from the present 67 cities to 326 cities by 2022.

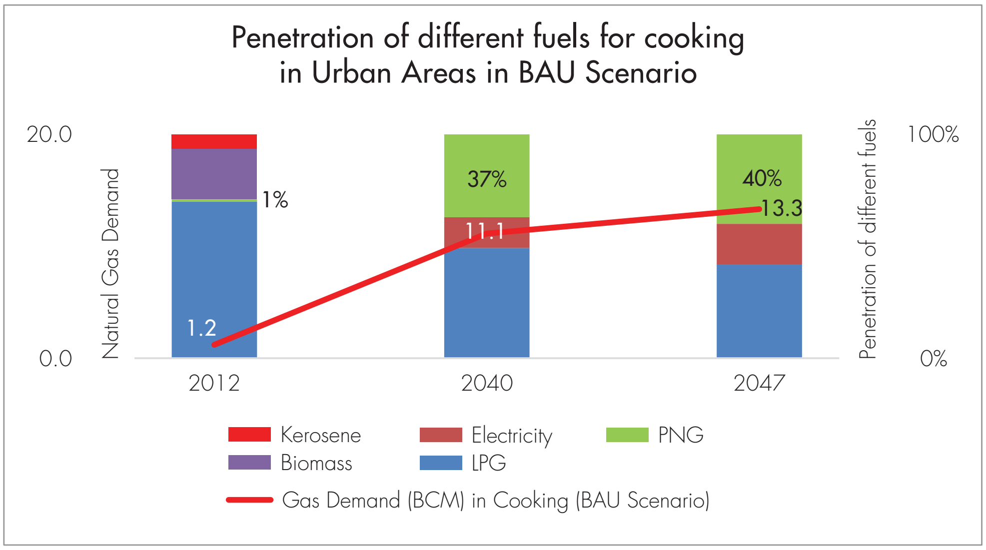


Figure 4[4]

In the BAU scenario, it is evident from Figure 4 that the penetration of PNG in the cooking sector in urban areas increases to 40% by 2047 from 1% in 2012. This will also spur the natural gas demand in this sector from 1.2 BCM in 2012 to 13.3 BCM in 2047.

[3]International Energy Agency
[4]The % in the Figure 4 depicts the penetration of different fuels in the cooking sector, whereas the absolute numbers depict the natural gas demand in the cooking sector.

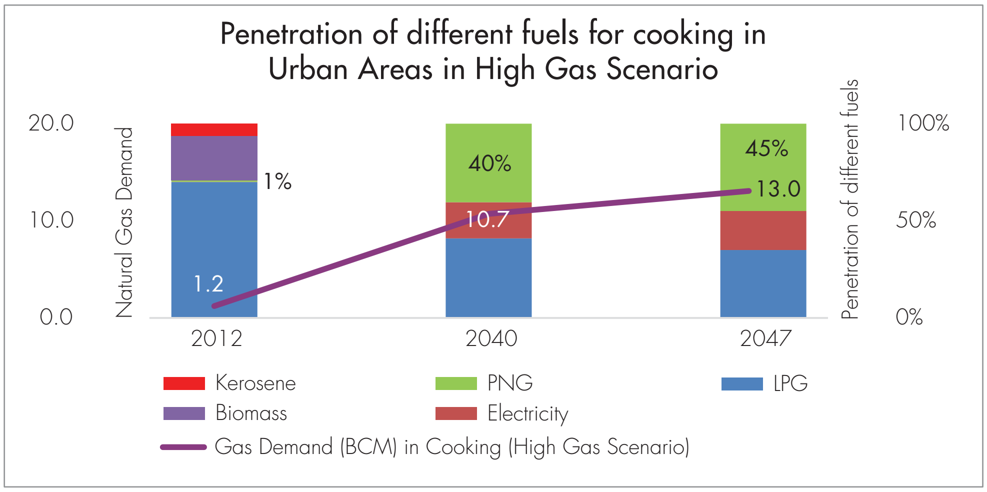


Figure 5[5]

Figure 5 shows the penetration of different fuels like LPG, PNG, biomass etc. in urban areas for cooking in High Gas scenario. The penetration of PNG rises to 45% in 2047 from 1% in 2012 in the High Gas scenario, whereas the same was 40% in 2047 in the BAU scenario. Therefore, the High Gas scenario considers a 5% increase in the PNG penetration in the urban areas.

The interesting fact to be noted here is that, inspite of the increased penetration of PNG in the High Gas scenario, the natural gas demand in the High Gas scenario in 2047 (13 BCM) slightly declines in comparison with the gas demand in BAU scenario. This is so because the High Gas scenario also considers a higher penetration of enhanced efficiency cooking appliances (PNG cookstoves) in comparison with BAU scenario.

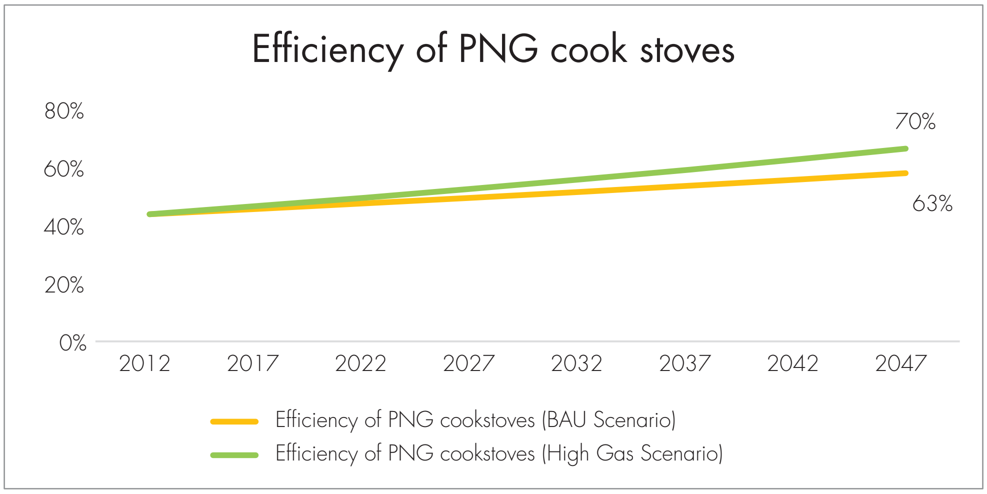


Figure 6

[5] The % in the Figure 5 depicts the penetration of different fuels in the cooking sector, whereas the absolute numbers depict the natural gas demand in the cooking sector.

Figure 6 shows that the efficiency of PNG cookstoves increases to 70% in the High Gas scenario in comparison with 63% in the BAU scenario in 2047. This offsets the increase in gas demand in the High Gas scenario. Therefore, it shows that energy efficiency can play a very important role as it has twin benefits. The revenue saved due to reduction in the energy demand can be used for increasing the penetration of clean cooking fuels like PNG.

5.2.3. Cooking – Rural Areas:

Since, the above section (2.1) discussed the scenario of natural gas demand in the urban areas, this section would entail the impact on natural gas demand in rural areas due to increased penetration of LPG and PNG. The penetration of different fuels like LPG, PNG, biomass, biogas and electricity is taken into consideration in rural areas while analyzing the natural gas demand in the BAU and High Gas scenarios. In rural areas, there is a shift away from solid biomass towards cleaner cooking fuels like LPG, PNG, biogas and electricity.

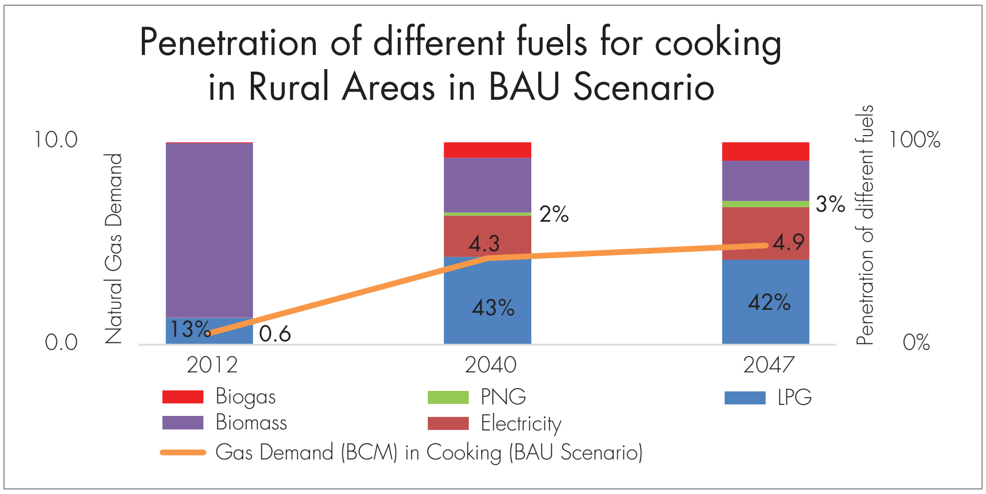


Figure 7[6]

Figure 7 shows the penetration of different cooking fuels in rural areas in the BAU scenario. In 2012, the penetration of biomass in rural areas was 85%, whereas that of LPG was 13% and PNG was nil. However, the penetration of LPG and PNG would increase to 42% and 3% respectively in 2047 and the natural gas demand would become 4.9 BCM in 2047 from 0.6 BCM in 2012 in rural areas for cooking.

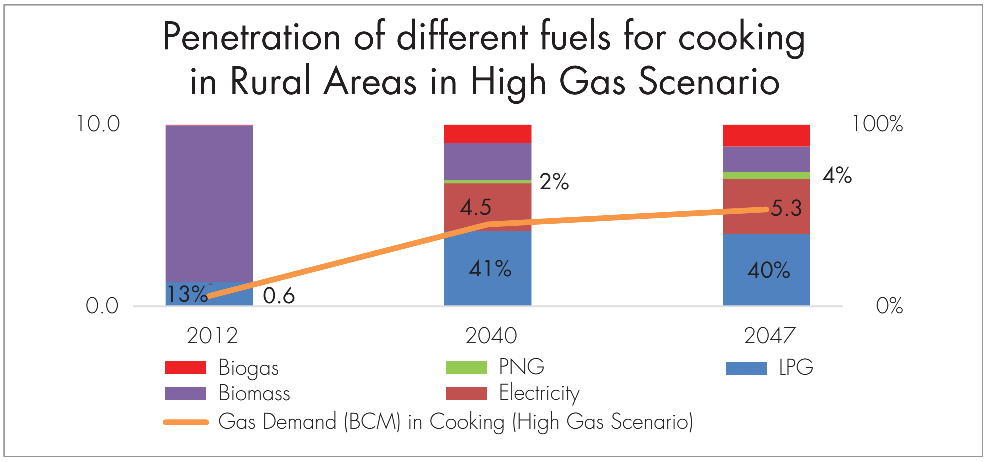


Figure 8[7]

Figure 8 shows the penetration of different cooking fuels in rural areas in the High Gas scenario. The biomass is largely replaced by cleaner sources of fuel like LPG, PNG, biogas and electricity. It is to be noted that, it may take still more time for the PNG infrastructure to reach the rural areas due to which the penetration of PNG is quite less even in the High Gas scenario in 2047. However, this does not mean that the rural population of India would be devoid of clean cooking fuels, every effort would be done to provide them with other clean fuels like LPG, biogas and electricity. The penetration of PNG and LPG increases to 4% and 40% in 2047 respectively in the High Gas scenario. So, the natural gas demand in High Gas scenario slightly increases to 5.3 BCM in 2047 from 0.6 BCM in 2912, whereas the same was 4.9 BCM in 2047 in the BAU scenario.

The electric cooking can be a game changer in urban and rural areas by 2047 as it could be dovetailed with the Power for All target by 2022 of the Government. The penetration of electric cooking increases in both, BAU and High Gas scenario and accounts for 26% and 30% of the total share of cooking fuels respectively by 2047.

5.2.4. Transport:

Transport is one of the major sectors where the demand for natural gas would increase with increased penetration of Compressed Natural Gas (CNG) vehicles. The deteriorating air quality in our cities has even put more pressure to make a transition towards cleaner sources of fuel like CNG or electric vehicles. The uptake of e-vehicles require a significant reduction in the cost of battery to make them affordable along with requirement of a huge infrastructure (charging stations etc.) and reliable supply of electricity. Whereas, the CGD network is already in place in 67 cities, which provides a

[6][7]The % in the Figure 7 & 8 depict the penetration of different fuels in the cooking sector, whereas the absolute numbers depict the natural gas demand in the cooking sector.

huge potential for the vehicles to shift from liquid fuels to CNG.

IESS gives the penetration of different fuels like petrol, diesel, CNG, electricity, fuel cell vehicles (FCVs) in different categories of vehicles like 2 Wheelers, 3 Wheelers, Cars, Buses, Omni Buses and Taxis. Therefore, the penetration of CNG across different categories of vehicles is analyzed in order to assess the natural gas demand in BAU and High Gas scenarios.

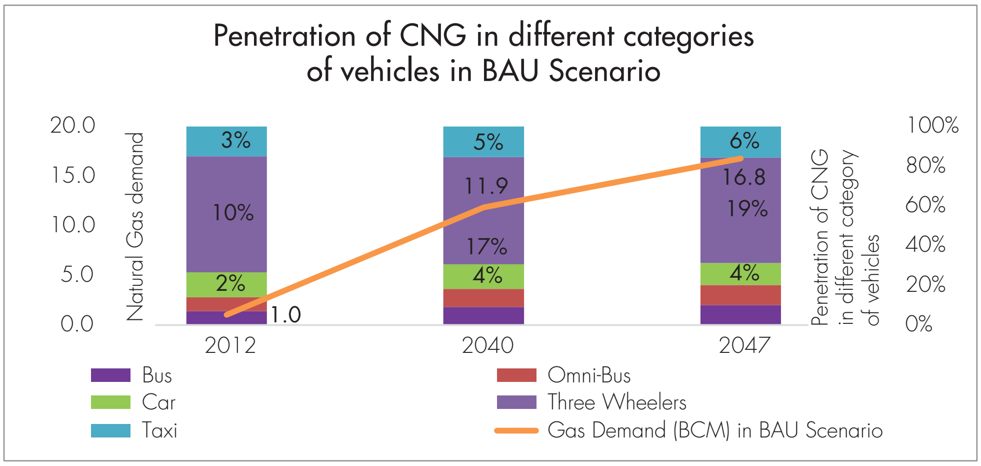


Figure 9[8]

Figure 9 shows the penetration of CNG across different categories of vehicles in the BAU scenario. The share of CNG in 3 Wheelers would rise to 19% in 2047, whereas the rest would run on other fuels like Petrol, Diesel etc. Similarly, the penetration of CNG in other categories of vehicles is evident from the Figure 9. The natural gas demand rises to 16.8 BCM in 2047 from 1 BCM in 2012.

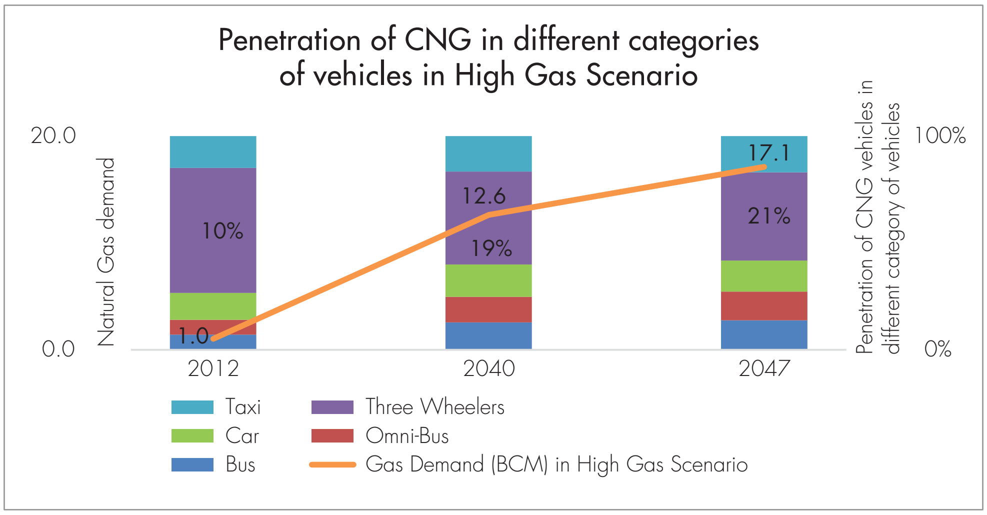


Figure 10

[89]The % depict the penetration of CNG vehicles across different categories of vehicles and the absolute numbers in gives the gas demand in BAU & High Gas scenario in Transport sector.

Figure 10 shows the penetration of CNG vehicles in the different categories of vehicles in the High Gas scenario. The penetration of CNG vehicles across all the categories like 2 or 3 Wheelers, cars, taxis or omnibuses increases in the High Gas scenario in comparison with BAU scenario. For e.g. the penetration of 3 Wheelers in the BAU scenario was 19%, whereas it was 21% in the High Gas scenario in 2047. Similarly, the penetration of CNG vehicles also increases in the cars in the High Gas scenario to 8% in comparison with 4% in BAU scenario in 2047.

The natural gas demand in the Transport sector rises to 17.1 BCM in 2047 from 1 BCM in 2012 in the High Gas scenario. On the other hand, the gas demand in Transport sector in BAU scenario rises to 16.8 BCM in 2047.

Inspite of a considerable increase in the penetration of CNG vehicles in the High Gas scenario in comparison with BAU, the demand for natural gas does not rise significantly in the former scenario. This is so because the High Gas scenario considers a shift towards transit oriented development where the transport demand per capita would decrease in comparison with BAU scenario.

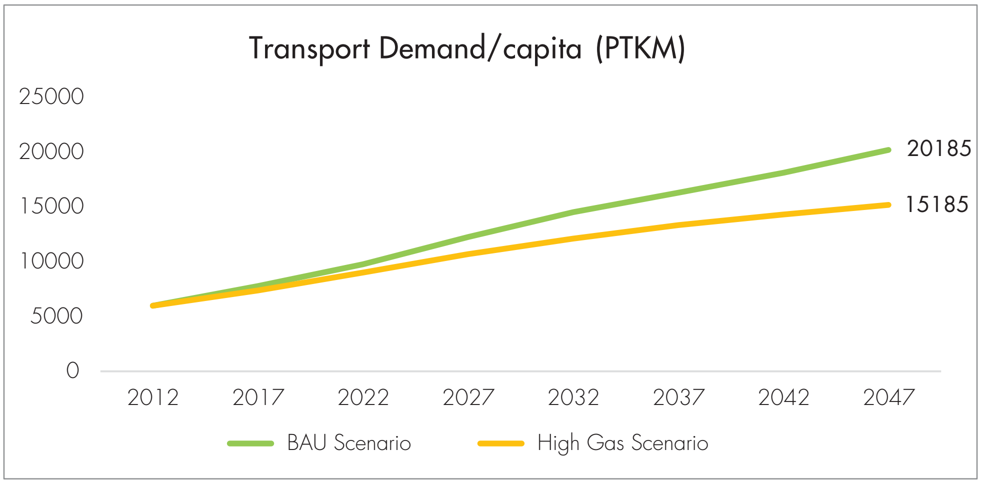


Figure 11

The transport demand per capita in the BAU scenario comes out be 20185 km, whereas the transport demand per capita in the High Gas scenario decreases to 15185 km in 2047. Therefore, the reduction in travel would lead to reduction in overall energy demand in the transport sector. This offsets the increase in natural gas demand in the High Gas scenario inspite of increased penetration of CNG vehicles in comparison with BAU scenario.

5.3 Gas Demand in the Supply side sectors:

Two sectors have been identified on the supply side which consume gas. These are namely – Gas Power Stations and Carbon Capture & Storage (CCS).

5.3.1. Gas Power Plants:

The BAU scenario considers a moderate penetration of gas power plants in India, whereas the High Gas scenario considers an aggressive penetration of gas power plants. The situation of gas based power plants in India has not been very encouraging. During the 12th five year plan, a mere 1.2 GW of capacity was added and the Plant Load Factor (PLF) has fallen from around 50% in 2012 to less than 20% and a capacity of 14305 MW was stranded. Though, a PSDF initiative was launched in March, 2015 to revive the stranded gas based power plants, it could not be much successful and would discontinue after March, 2017. The reasons for the low capacity utilization of gas based power plants are many and need to be debated separately.

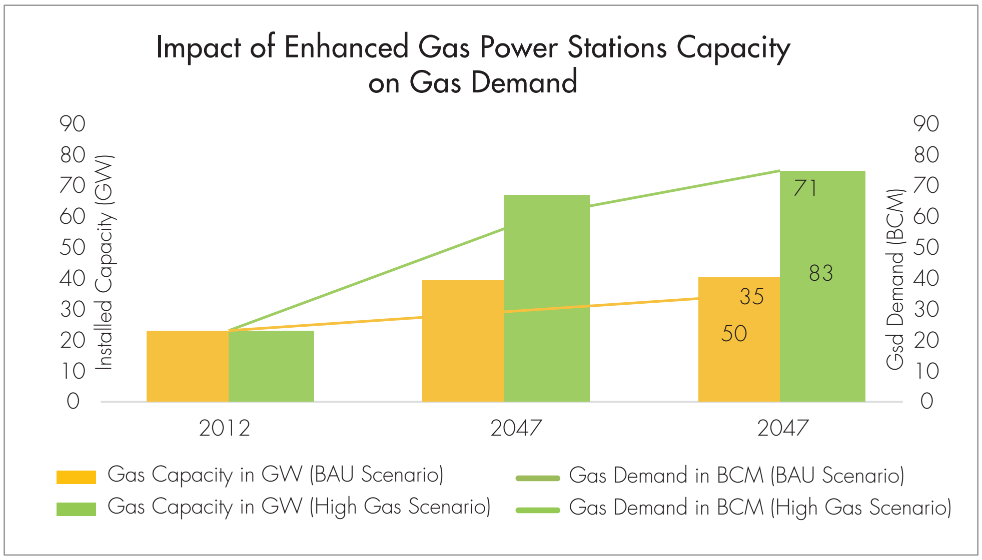


Figure 12

Figure 12 gives the gas based installed capacity and natural gas demand in the BAU and High Gas scenario. The gas based installed capacity becomes 83 GW in 2047 from 24 GW in 2012 in the High Gas scenario, whereas the same rose to only 50 GW in 2047 in the BAU scenario. Therefore, there is an increase of 33 GW by 2047 in the High Gas scenario in comparison with BAU scenario. This leads to increased demand for natural gas in the High Gas scenario i.e. the gas demand rises to 71 BCM in 2047 in the High Gas scenario, whereas the gas demand would be only 35 BCM in 2047 in the BAU scenario.

5.3.2. CCS Plants:

The deployment of CCS plants has been very limited across the World with only 16 plants in operation as of March, 2017. A moderate penetration of gas based CCS in India is envisaged in the BAU and High Gas scenario in the subsequent years.

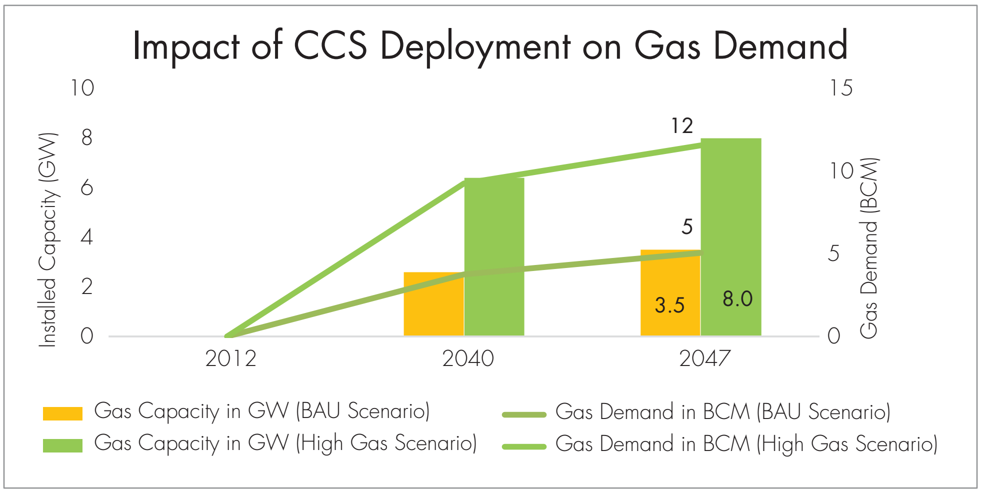


Figure 13

Figure 13 gives the installed capacity of gas based CCS plants in India along with the natural gas demand by these plants in the BAU and High Gas scenario. The installed capacity of gas based CCS would rise to 8 GW by 2047 in the High Gas scenario while the same would be 3.5 GW in the BAU scenario in 2047. The increased capacity would lead to increased natural gas demand in the High Gas scenario as compared with BAU scenario. The gas demand becomes 12 BCM in 2047 in High Gas scenario, whereas it would be only 5 BCM in 2047 in BAU scenario.

6. SNAPSHOT OF TOTAL NATURAL GAS DEMAND ACROSS DIFFERENT SECTORS

Total Natural Gas Demand (BCM)					
	2012	2040		2047	
Sector		BAU	High Gas	BAU	High Gas
Industry	35	128	177	159	223
cooking	1.8	15.4	15.2	18.2	18.3
Transport	1	11.9	12.6	16.8	17.1
Gas Power Stations	20	32	53	35	71
CCS	0	4	9	5	12
Total	58	191	267	234	341

Table 1

Table 1 gives an overview of the natural gas demand across different demand and supply sectors discussed above. The gas demand would rise from 58 BCM in 2012 to 234 BCM in 2047 in the BAU scenario and would rise to 341 BCM in the High Gas scenario. Therefore, there is a 46% increase in gas demand in 2047 in the High gas scenario when compared with BAU.

7. OVERVIEW OF INDIA'S ENERGY SCENARIO – RESULTS DERIVED FROM IESS 2047

Having explained the natural gas demand in BAU and High Gas scenario in the above sections, this section further seeks to give an overview of India's Energy Scenario till 2047 in BAU and High Gas Scenario. The following sections would give primary energy supply, energy demand, installed capacity and electricity generation etc. which would give a better understanding of the overall energy scenario of India.

7.1. Energy Demand:

Energy Demand (TWh)			
	2012	2047	
		BAU Scenario	High Gas Scenario
Buildings	239	2971	2450
Industry	2359	12855	10279
Transport	929	5528	3604
Agriculture	237	798	636
Telecom	83	231	131
Cooking	1066	522	463
Total Energy Demand	4912	22905	17565

Table 2

Table 2 gives the energy demand till 2047 for BAU and High Gas scenario. Since, the High Gas scenario assumes greater penetration of energy efficiency measures than BAU, the energy demand in the former is less than the latter. For e.g. the specific energy consumption for the industrial processes would reduce through energy efficient appliances, increased penetration of efficient appliances in the buildings sector, enhanced penetration of fuel efficient vehicles along with transit oriented development etc., all these interventions lead to reduced demand in the High gas scenario.

7.2. Installed Capacity:

Installed Capacity (GW)			
	2012	2047	
		BAU Scenario	High Gas Scenario
Gas Power Stations	24	50	83
Coal power stations	125	459	459
Carbon Capture Storage (CCS)	0	35	80
Nuclear power	5	26	45
Hydro Power Generation	41	75	105
Renewable Energy (RE)	27	1105	1117
Total Installed Capacity	222	1751	1890

Table 3

Table 3 gives the Installed Capacity in BAU and High Gas scenario. The gas based installed capacity is 83 GW in 2047 in the High Gas scenario, whereas the same is 50 GW in 2047 in BAU scenario. Also, the High Gas scenario has an increased penetration of RE installed capacity i.e. 1117 GW in 2047, whereas the installed capacity of renewables is 1105 GW in 2047 in BAU scenario.

7.3. Primary Energy Supply:

Primary Energy Supply (TWh)			
	2012	2047	
		BAU Scenario	High Gas Scenario
Renewables and Clean Energy	267	3266	3817
Agriculture/waste	1060	1510	1936
Coal	3272	13959	12229
Oil	1938	8434	5409
Natural gas	562	2331	3263
Total	7100	29500	26654

Table 4

Table 4 gives the primary energy supply in 2047 for BAU and High Gas Scenario. Since, the High Gas scenario considers a higher penetration of natural gas and renewables than BAU, the energy supply from these two sources is higher in the former scenario. The share of natural gas in energy mix comes out to be 8% in 2047 in BAU scenario and 12% in High gas scenario.

7.4. Electricity Generation:

Electricity Generation (TWh)			
	2012	2047	
		BAU Scenario	High Gas Scenario
Gas Power Stations	115	198	401
Coal power stations	708	2719	2799
Carbon Capture Storage (CCS)	0	185	423
Nuclear power	27	183	316
Hydro Power Generation	144	263	368
Renewable Based Electricity	80	2649	2730
Total Electricity Generation (TWh)	1074	6198	7037

Table 5

Table 5 gives the electricity generation for BAU and High Gas scenarios. Since, the High Gas scenario assumes a higher gas based installed capacity, the electricity generation in High Gas scenario is 401 TWh in 2047 in comparison with BAU scenario of 198 TWh in 2047. Moreover, the electricity generation from renewables is also higher in High Gas scenario (2730 TWh) in 2047 than BAU (2649 TWh) as the former assumes a higher penetration of RE.

7.5. Import Dependence of Natural Gas:

Parameter	2012	2040		2047	
		BAU	High Gas	BAU	High Gas
Natural Gas Demand (BCM)	58	191	267	234	341
Domestic Natural Gas Production (BCM)	48	95	124	128	170
Natural Gas Import Dependence	22%	55%	56%	51%	52%

Table 6

Table 6 depicts the domestic gas production, demand and import dependence. The increase in domestic natural gas production in High gas scenario by 2047 offsets the imports of natural gas required to fulfill the gas demand. Therefore, the import dependence in High Gas scenario is 52% in 2047, whereas it is 51% in BAU scenario.

7.6. Emissions Trends[9] :

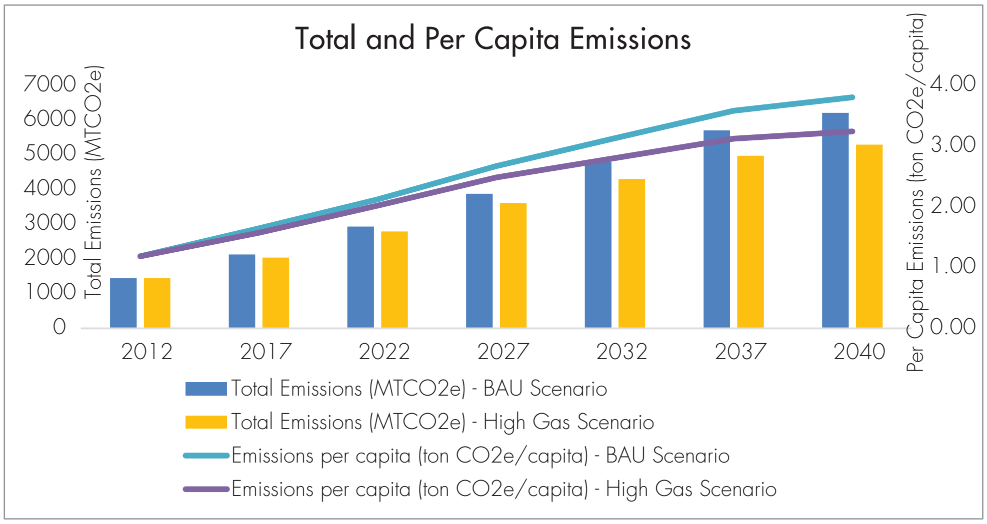


Figure 14[9]

Figure 14 gives the Total Emissions and Per Capita Emissions of India in BAU and High Gas scenario. Though, the emissions of India rise by 2040, the per capita emissions of India in 2040 would still be much lower than the present per capita emissions of china i.e. ~7ton CO2e/capita. The per capita emissions in the BAU and High Gas scenario would rise to 3.8 ton CO2e/capita and 3.24 ton CO2e/capita in 2040 respectively from the present 1.6 ton CO2e/capita. Moreover, there is a 15% reduction in emissions in the High Gas scenario in comparison with BAU scenario because the High Gas scenario is more efficient and considers greater penetration of renewables than BAU scenario.

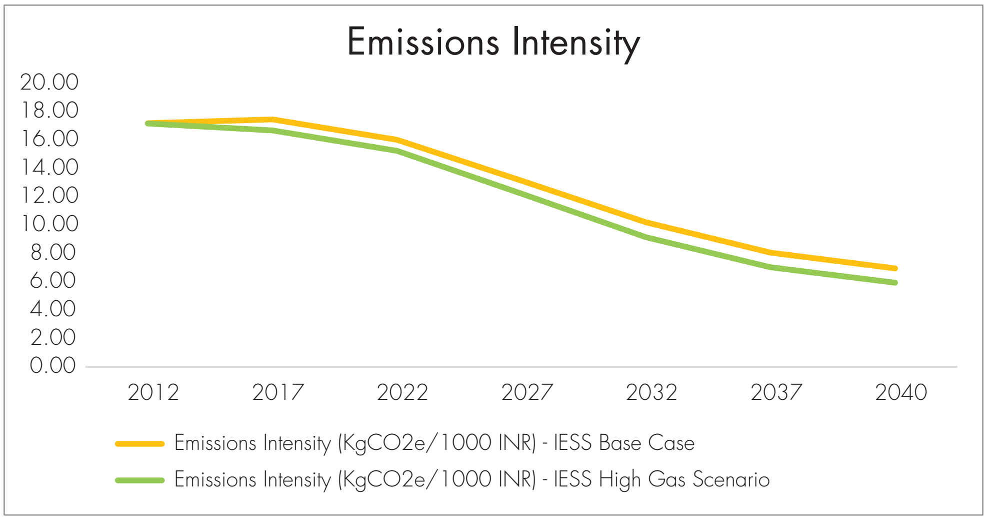


Figure 15

[9] Includes only energy related emissions

Figure 15 gives the emissions intensity in the BAU and High Gas scenario. Since, the High Gas scenario is more efficient and considers higher penetration of renewables than BAU, the reduction in emissions intensity is 65% in the former scenario, whereas it is 59% in the latter one.

8. ASSESSMENT OF NATURAL GAS DEMAND USING WORLD ENERGY PROJECTION SYSTEMS (WEPS+)

This section calculates the natural gas demand in India till 2040 using the WEPS + model. As already explained earlier in this report, WEPS + is a modular price-consumption equilibrium converging energy model unlike IESS 2047 which calculates the gas demand based on a bottoms up analysis. Different scenarios have been constructed to understand how the short, medium and long term regulations on natural gas prices will impact the natural gas demand in India. As coal is a regulated commodity in India and also impacts the natural gas demand, we have attempted to study the impact of different coal market regulations as well. The penetration of renewables in India shall also have an impact on the extent of natural gas use. Keeping this in mind the following scenarios were created:

1. Base Case/ Realistic Market Driven:

   In the base case scenario it is assumed that the natural gas and coal markets are solely market driven by 2025 and 2030 respectively. In the years where prices are under government regulation, the model assumes inbuilt escalation rates based on the model's supply and demand estimates. Renewable Energy (RE) targets are achieved according to current policies with 100 GW of solar, 60 GW of wind and 15 GW of other renewables installed by 2022.

2. Long Term Regulations

   In this scenario, the government keeps natural gas and coal prices regulated until 2040. However, this is quite an unlikely scenario as the Government has already taken some major steps to move towards market prices, especially in case of natural gas. The purpose of this scenario was to see how the natural gas demand will be impacted if the market is regulated till 2040. Renewable targets are achieved by 2022.

3. Immediate Market-Driven:

   Natural Gas and coal prices are solely determined by international markets from as early as 2022. It would be interesting to see how natural gas demand in India is impacted if the Government allows market forces to prevail. Renewable targets are achieved by 2022.

4. High Natural Gas Prices:

This scenario assumes that the natural gas and coal prices would be market driven from 2025 and 2030 onwards respectively as we have assumed in the Base case scenario. But, after gas markets are opened in 2025, a 50% increase in natural gas prices is assumed, in order to see the impact of high natural gas prices on gas demand. RE are achieved by 2022 as well in this scenario.

5. Low Natural Gas Prices:

Prices for gas and coal remain regulated as per the base case/realistic market driven scenario and are market determined from 2025 and 2030 onwards respectively. After markets are opened, a 50% decrease in natural gas prices is assumed, in order to analyse the impact of low natural gas prices on gas demand. The RE targets are also met in 2022.

6. Low RE Achievement:

Prices for gas and coal remain regulated as per the realistic scenario until 2025 and 2030 respectively. After markets are deregulated, natural gas and coal prices would be market determined. It is to be noted that in this scenario, the Renewable Targets are not met by 2022 but by 2030. This scenario would help us to analyse the gas demand, in case if the ambitious RE target of 175 GW of the Government is not met by 2022.

	Scenarios	Regulations on Natural Gas Price	Regulations on Coal Price	Renewable Targets Achievement Year
A.	Base Case/ Realistic Market Driven	Till 2025	Till 2030	2022
B.	Long-term Regulations/ Long Term Market Driven	Till 2040	Till 2040	2022
C.	Immediate Market Driven	Till 2022	Till 2022	2022
D.	High Natural Gas Price	Till 2025; 50% increase in global market prices after 2025	Till 2030	2022
E.	Low Natural Gas Price	Till 2025; 50% decrease in global market prices after 2025	Till 2030	2022
F.	Low RE	Till 2025	Till 2030	2030

Table 7

Table 7 summarizes the 6 scenarios that are developed to analyze the gas demand in different scenarios in India till 2040 using WEPS + model.

It is to be noted that the long term market driven scenario and low natural gas price scenario assume that the price of natural gas would be regulated till 2040 and there would be 50% decrease in natural gas prices after 2025 in comparison with base case scenario respectively. Both these scenarios are highly unlikely to happen, but they were included in the analysis to actually see how the demand for natural gas would be impacted if the prices of natural gas were to remain low.

8.1. Macroeconomic Assumptions:

The macroeconomic assumptions in both modeling exercises i.e. IESS and WEPS+ have been kept same. The user can refer to the Fixed Assumptions section (V.a) in this report to see the macroeconomic assumptions that are taken into account while doing this exercise.

Parameter (for 2015)	Value	Source
Share of Imported Natural Gas (2015-16)	40%	PPAC
Cost of Domestic Natural Gas in 2016	2.5 USD/MMBTU	PPAC[10]
Cost of Imported Natural Gas in 2016	6.5 USD/MMBTU	Stakeholder input[11]
Average Cost of Natural Gas in 2016	4.1 USD/MMBTU	

Table 8

Table 8 gives the prices of domestic gas and imported LNG for 2016 that are taken into account in this exercise.

8.2. Pricing inputs for Natural Gas and Coal:

The Natural Gas and Coal prices are one of the most important inputs for the WEPS+ modeling exercise. Therefore, this section would entail how the different scenarios have assumed different prices of gas and coal.

Parameter	Value	Source
Share of Imported Coal (2015-16)	23%	Ministry of Coal
Cost of Domestic Coal in 2016	3.2 USD/MMBTU	CIL
Cost of Imported Coal in 2016	4.6 USD/MMBTU	Stakeholder input
Average Cost of Coal in 2016	3.5 USD/MMBTU	

Table 9[12]

[10] The domestic natural gas price changes every six months. This price is for the period October, 2016 to March, 2017.

[11] It is well known that the LNG prices are volatile and keep on changing. The above price was taken after a stakeholder consultation.

[12] The coal prices are only those of thermal coal. The coal prices are the sum of coal prices as well as freight charges. The freight charges are assumed as 2500 Rs/tonne for a delivered distance of 500 km.

Table 9 depicts the price of domestic and imported coal for the year 2016 which is taken into account in the WEPS model.

Now, coming on to the pricing projections for natural gas and coal in different scenarios.

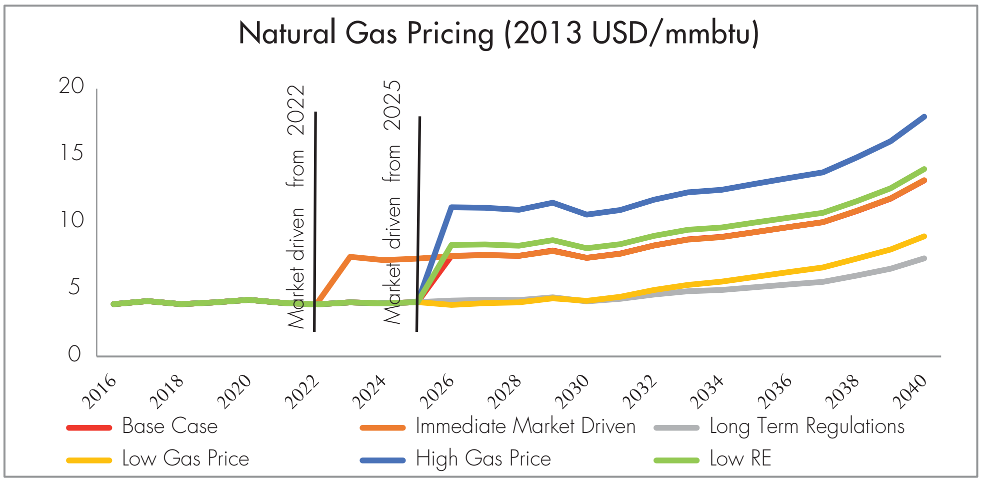


Figure 16

Figure 16 gives the natural gas prices till 2040 for different scenarios. It can be noted, with the exception of the long-term regulations and low natural gas price scenario, there are sudden spikes in the trend line when markets get opened. This is because domestic prices of natural gas in India are currently considerably lower than global market prices and when markets are opened, the prices go up steeply. The long term scenario has the lowest prices even in 2040 as the government artificially keeps price of natural gas low. This implies that by regulating market prices domestically, prices of natural gas remain even less than half the price of global markets.

The low and high gas price scenarios are more or less parallel to the base case as they assume a 50% increase and decrease in the natural gas price considered in the base case from 2025 onwards respectively. In the low RE scenario, the price of gas increases slightly, perhaps because there will be increased demand for gas to compensate for the reduced amount of renewable capacity.

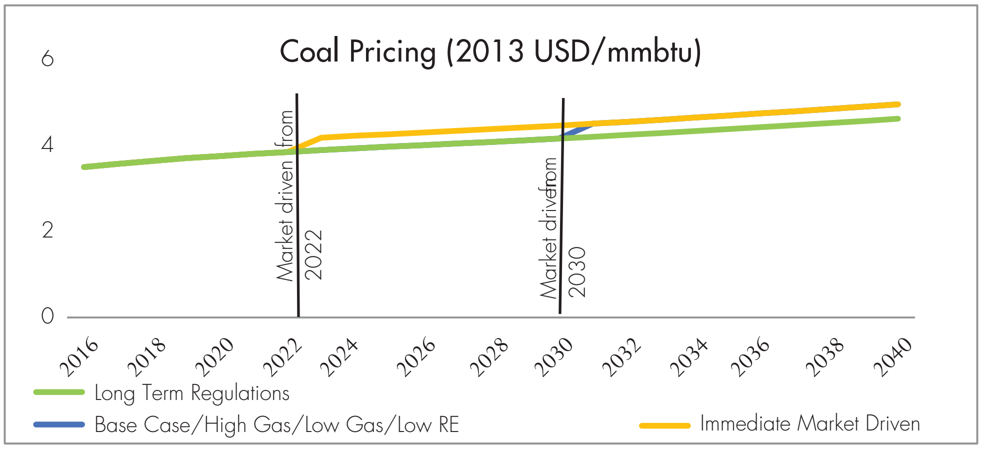


Figure 17

Figure 17 gives the coal prices till 2040 for different scenarios. The domestic and international market prices of coal do not differ as much as natural gas prices. This can be observed in Figure 17 as when the markets are opened up, there are no large spikes in the price of coal. Similar to natural gas, the prices of coal are lowest in the long term regulations scenario as they remain regulated by the government. Moreover, the coal prices remain same for the 4 scenarios other than immediate market driven and long term regulation scenarios.

9. RESULTS DERIVED FROM WEPS +

9.1. Primary Energy Demand:

The primary energy demand for India increases at a CAGR of 4.3% from 2012-2040 in the WEPS+ study. The model works in a manner such that the primary energy demand remains the same in various scenarios and the energy mix changes with change in pricing assumptions of natural gas and coal.

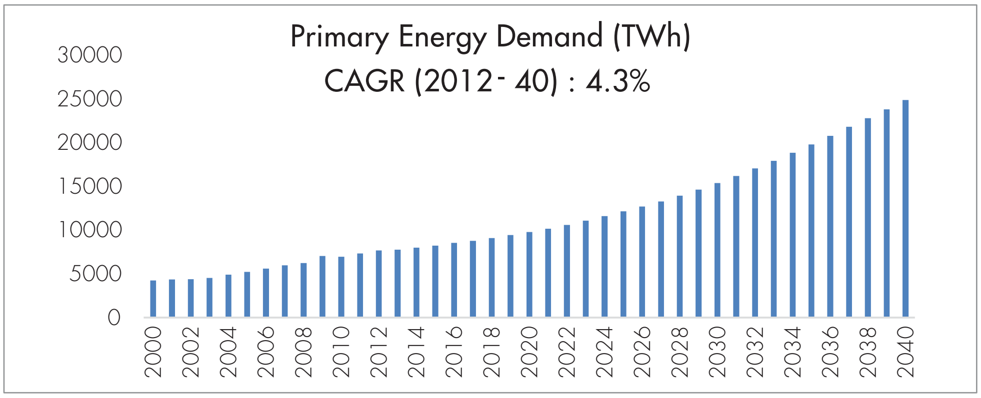


Figure 18

[13]WEPS model does not take into account non-commercial energy sources (biomass).

The primary energy demand becomes 24864 TWh in 2040 as is evident from Figure 18.

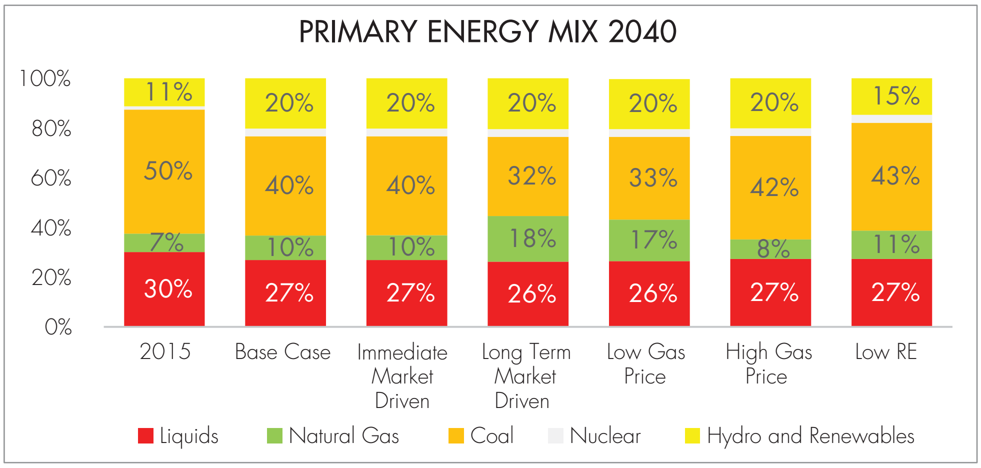


Figure 19

Figure 19 gives the energy mix in different scenarios. The share of natural gas in energy mix is in the range of 8% - 11% in Base Case, Immediate Market Driven, High Gas price and Low RE scenario, whereas the share of natural gas in energy mix rises to 17% and 18% in the Low gas price and Long term market driven scenario respectively. This is so because, the price of natural gas (refer Figure 16) in the latter scenarios is lower by $7-9/mmbtu in comparison with other scenarios due to which the country is able to absorb more gas. The impact of long term pricing regulations (till 2040) has a larger impact on natural gas than on coal, with 2040 prices of coal not differing as drastically as natural gas as mentioned in Figure 17. This modeling exercise shows us that coal will always be the dominant energy source for India as natural gas will be more expensive than coal and India has abundant coal reserves.

9.2. Final Energy (Delivered Energy) Demand:

The final energy demand becomes 16148 TWh in 2040 and rises at a CAGR of 3.9% between 2012 and 2040.

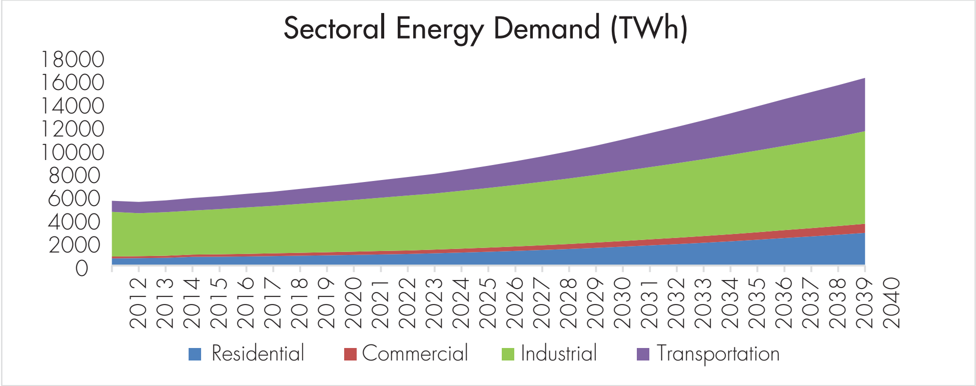


Figure 20

Figure 20 gives a break-up of final energy demand sector wise. By 2040, Industry accounts for 49% of the total final energy demand and Transport accounts for 28%, whereas the share of residential sector would be 17%. The share of commercial sector would not rise beyond 5% in 2040 in the final energy demand.

9.3. Installed Capacity (GW):

The total installed capacity in India rises to 1056 GW in 2040 from 310 GW in 2016 as per the WEPS + modeling exercise.

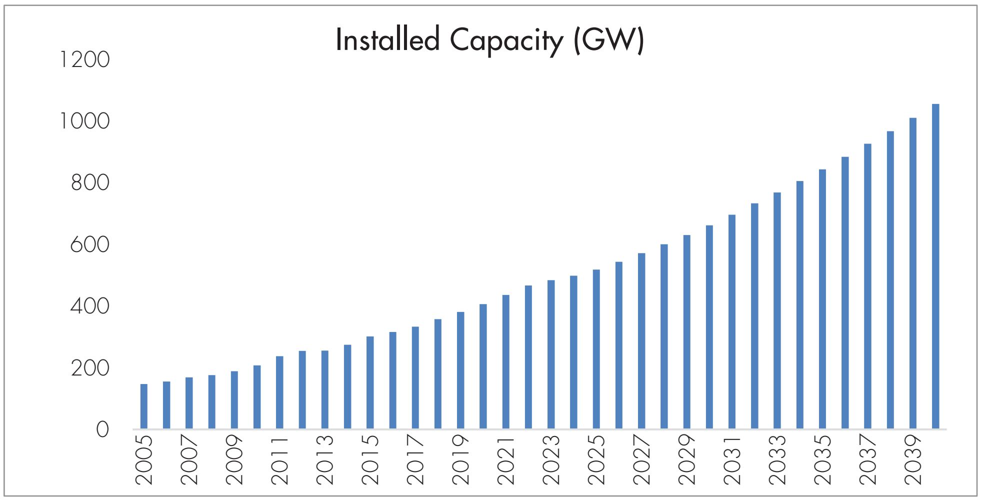


Figure 21

Figure 21 gives the total installed capacity in 2040. The break-up of installed capacity is given separately in the next figure.

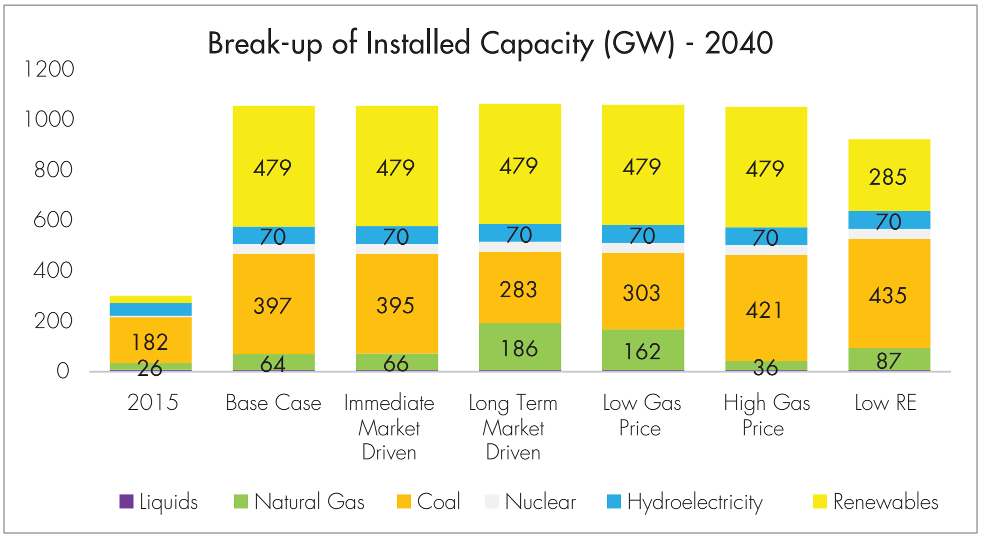


Figure 22

Figure 22 gives the break-up of installed capacity. The total installed capacity is lower in Low RE scenario i.e. 918 GW in 2040 in comparison with other 5 scenario in which the total installed capacity is 1056 GW in 2040. Moreover, the installed capacity of solar and wind is 291 GW and 159 GW in 2040 in all the scenarios except Low RE scenario. In the Low RE, which assumes that the 175 GW RE target of India is achieved by 2030, the installed capacity of solar and wind becomes only 172 GW and 92 GW in 2040 respectively. Since, the Plant Load Factor (PLF) of conventional power plants is more than the renewable plants, the total installed capacity required to meet the same amount of electricity demand reduces. Moreover, the gas based installed capacity rises significantly in the Long term market driven scenario (186 GW in 2040) and low gas price scenario (162 GW in 2040) as the gas prices remain much lower than the other scenarios. The gas based capacity would decline to 36 GW in 2040 in high gas price scenario because the gas price in this scenario ($18/mmbtu in 2040) is highest amongst all the scenarios and India would not be able to absorb gas at such high prices. Another point to be noted is that coal power plants would continue to play a significant role in the electricity generation mix of India. Though, the coal based capacity is seen to be replaced by gas based capacity in Low gas price and Long term market driven scenario due to low gas prices, this would be not be possible in other scenarios.

Therefore, the WEPS+ model shows us that fuel prices impact the installed capacity of electricity generation in India significantly. This is because the installed capacity of India is growing rapidly with increasing energy demand and variations in fuel prices can influence what fuel power plants to install.

9.4. Electricity Generation and Mix:

The total electricity generation rises to 4591 TWh in 2040 as per the WEPS + modeling analysis. Electricity Generation grows at a CAGR of 5.4% from 2012-40.

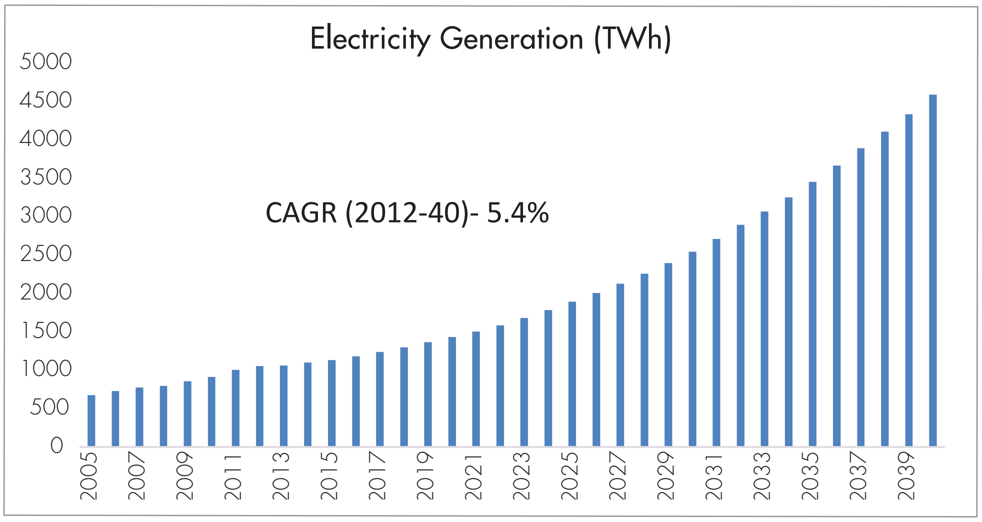


Figure 23

Figure 23 depicts the electricity generation in India till 2040. The electricity mix in India in different scenarios is given in the following figure.

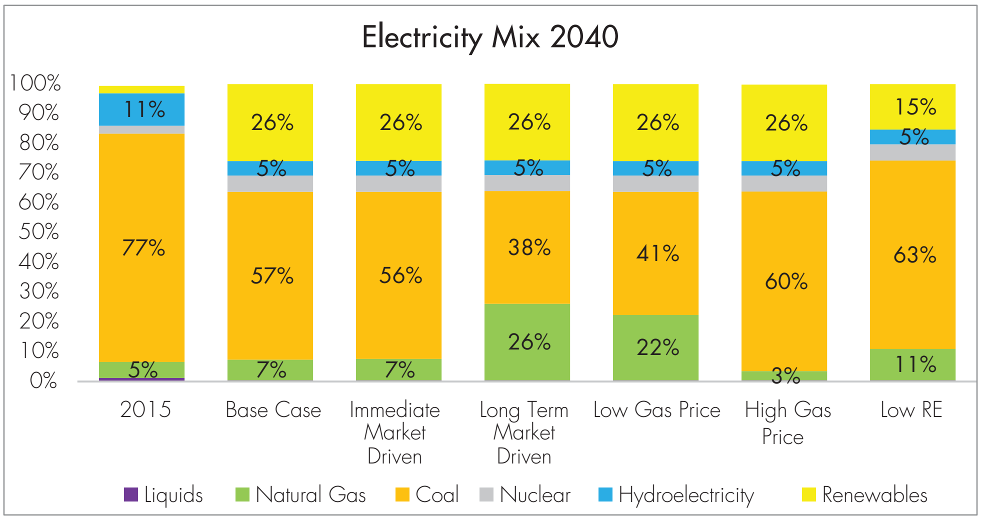


Figure 24

Figure 24 gives the electricity mix of India in 2040 in various scenarios. The coal has a dominant share in the electricity mix even in 2040 ranging from 56% - 63% except in the Low gas price and Long term market driven scenario. Because, the gas based installed capacity significantly rise in the latter scenarios, the share of coal based electricity declines and comes in t range of 38% - 41% in 2040. Moreover, the share of RE based electricity remains the same at 26% in all the scenarios except Low RE scenario where the share dips to 15% in 2040 because the total RE capacity is only 285 GW in 2040 in Low RE scenario in comparison with 479 GW in other 5 scenarios in 2040.

9.5. Sectoral Natural Gas Demand as per WEPS+:

As already mentioned above, the consumption of natural gas in India is highly price sensitive as would vary significantly upon changes in price. Since, the natural gas production of India has been declining from the last 5 years, India would have to largely depend on the imported LNG to meet its requirements. The natural gas consumption in India was 54 BCM in 2015-16 which is expected to rise by 2040 and the rise would depend on various scenarios as given in the figure below.

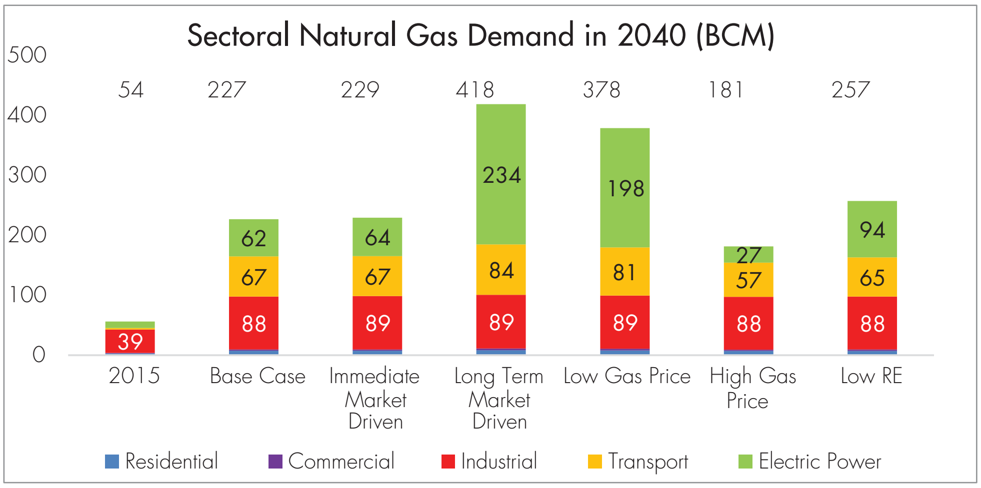


Figure 25

Figure 25 depicts the natural gas demand sectorally in India in 2040 in all the 6 scenarios. The natural gas demand lies in the range of 227-257 BCM in 2040 in the Base case, Immediate market driven and Low RE scenarios. Whereas, the gas demand rises significantly in the Low gas price and Long term market driven scenario to 378 BCM and 418 BCM in 2040 respectively because the natural gas prices are lower in the latter scenarios in comparison with the former ones (refer Figure 16 for natural gas prices). Moreover, the consumption of natural gas in the High gas price scenario is the lowest and falls to 181 BCM in 2040 because of the highest gas price in this scenario. The WEPS+ modeling exercise envisages gas power plants to be the major gas consumers in the Low gas price and Long term market driven scenarios which is followed by Industrial and transport sectors. The gas consumption in commercial and residential sectors is very less in comparison with other sectors as is evident from the Figure 25.

9.6. Emissions Trends:

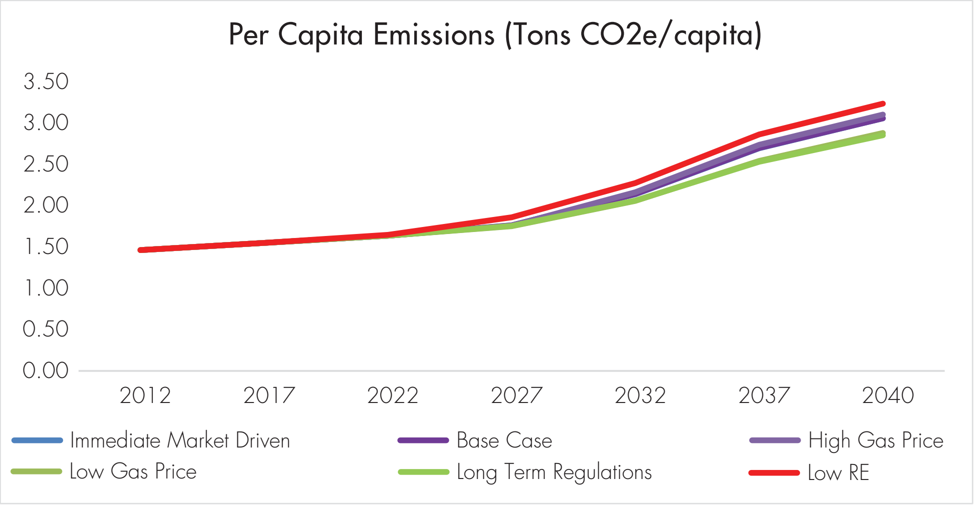


Figure 26

Figure 26 gives the per capita emissions in 6 different scenarios. The per capita emissions in all the 6 scenarios are quite close (2.85-3.24 tons CO2e/capita), but it would be lowest in the Long Term Market Driven scenario as this scenario assumes the highest share of gas and lowest share of coal in energy mix and the per capita emissions would be highest in the Low RE scenario as this scenario assumes lowest penetration of RE and highest share of coal in energy mix along with a low share of has in energy mix.

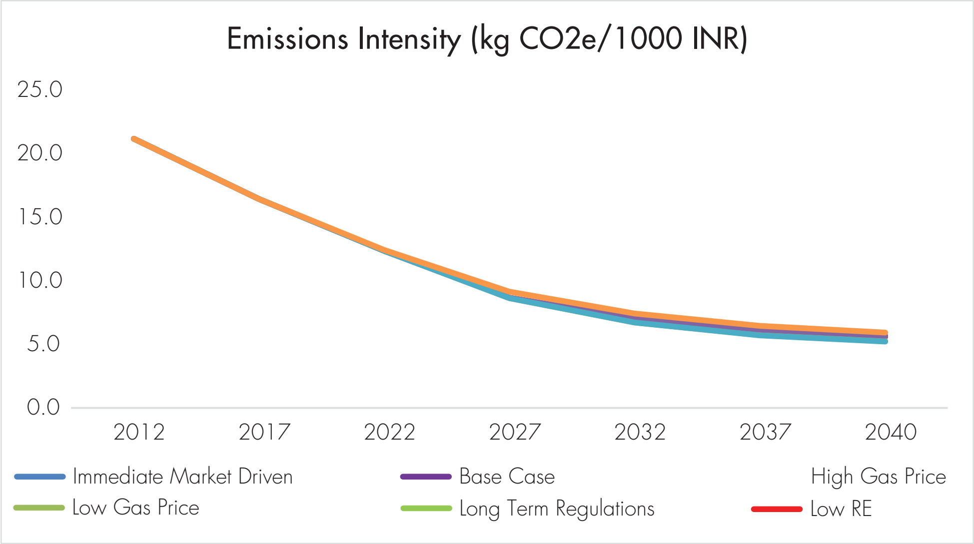


Figure 27

Figure 27 gives the emissions intensity for the 6 different scenarios. Since, the emissions in all the 6 scenarios do not deviate much, the emissions intensity also follows the same trend. The reduction in emissions intensity varies in the range 72%-75.4% from 2012-40 for the 6 scenarios.

10. COMPARISON OF THE RESULTS OF IESS AND WEPS+ MODELING EXERCISE[14]

Two models i.e. IESS and WEPS+ were used to calculate the natural gas demand in India. This was primarily done to make this exercise more comprehensive and robust and actually see, how the natural gas demand of India and other parameters like energy supply and demand, installed capacity and electricity generation etc. would vary if two entirely different models were used to arrive at the final results. Moreover, IESS 2047 captures a longer time frame till 2047 in comparison with WEPS+ which gives the results till 2040. However, the results obtained through the two modeling exercises are not directly comparable as they employ different approaches to arrive at the end results, a comparison for the two studies is given below in case the user still wants to compare the results from the two different models.

10.1. Comparison of Primary Energy Supply:

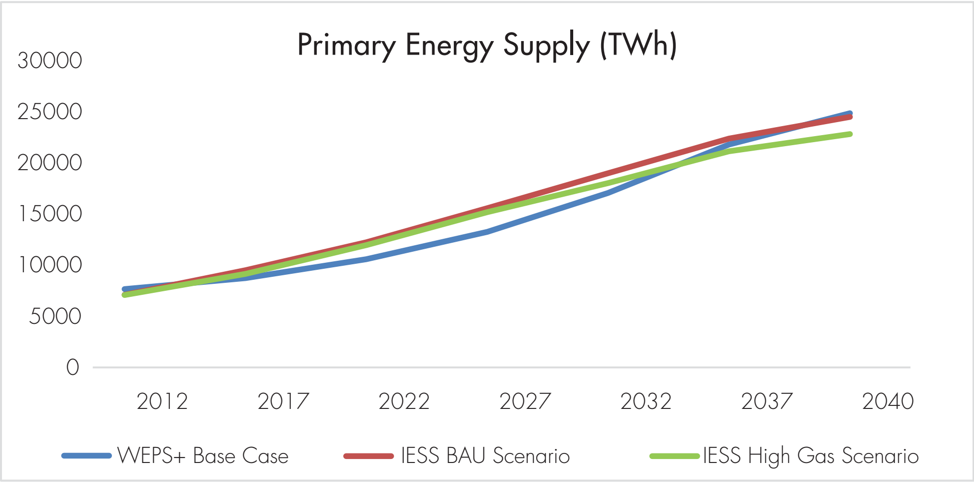


Figure 28

Figure 28 gives the comparison of primary energy supply derived from IESS and WEPS+ models. The primary energy supply for the IESS BAU scenario (24500 TWh) and WEPS+ Base case (24864 TWh) in 2040 are quite similar, but the energy supply in the IESS High gas scenario in 2040 (22821 TWh) is lower than the other two because it considers higher energy efficiency that reduces specific energy consumption per unit of service rendered on the demand side.

10.2. Comparison of Primary Energy Supply and Energy Mix[15] :

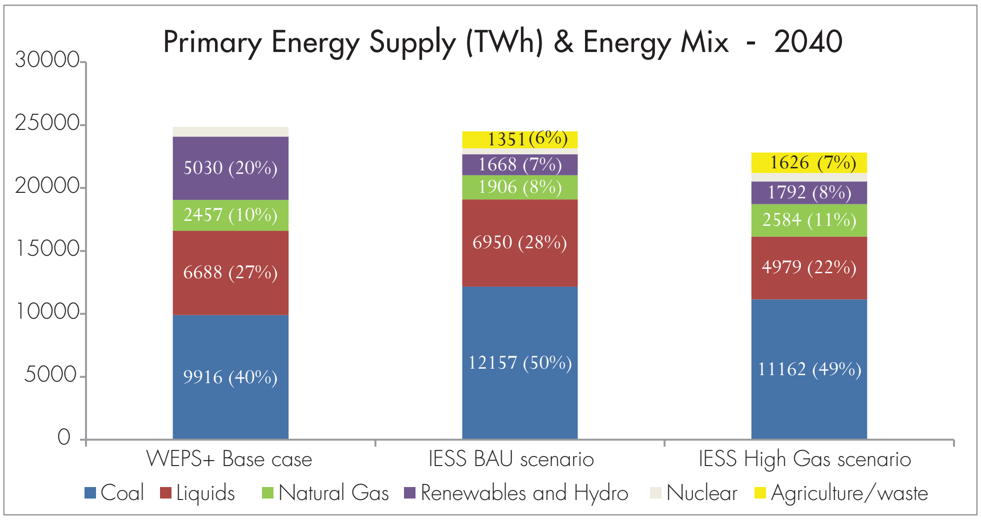


Figure 29

[14] The baseline number for IESS and WEPS+ for 2012 can vary minutely as the former considers the numbers financial year wise and the latter considers the numbers calendar year wise. For the comparison exercise, only WEPS+ Base case is considered because 6 scenarios were created in the WEPS modelling exercise and comparing 6 scenarios with 2 scenarios of IESS would make the picture very complicated.

Figure 29 gives the comparison of primary energy supply for WEPS+ and IESS along with the energy mix. As evident from the above figure, coal remains a dominant source of fuel for India even in 2040 as its share in energy mix is envisaged to be 40% in WEPS and 49%-50% in the IESS model. The absolute consumption of natural gas certainly rises from the present 510 TWh to 2457 TWh in WEPS+ and 1906 in IESS BAU scenario and 2584 TWh in IESS High Gas scenario in 2040, however, the share of gas in energy mix hovers in the range of 8%-11% in the two studies, whereas the share was 6.5% in 2015. The share of renewables in energy mix comes out to be 20% in the WEPS+ model, whereas it is 7%-8% in the IESS in 2040. This is so because WEPS+ envisages that renewables would displace a large amount of coal being consumed in industry sector, whereas IESS does consider displacement of solid and liquid fuels in different demand sectors like industry but not as high as WEPS. The share of nuclear and liquid fuels in energy mix is quite close in both WEPS and IESS.

10.3. Comparison of Energy Intensity:

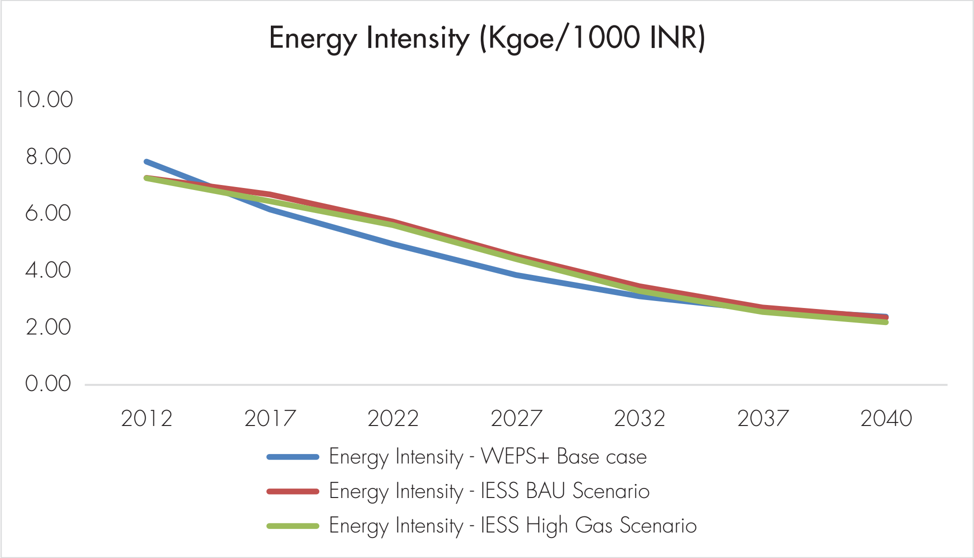


Figure 30

Figure 30 gives a comparison of energy intensity for the IESS and WEPS+ modeling exercise. The reduction in energy intensity in the IESS BAU scenario and WEPS+ Base case is 68% and 69% from 2012-40 respectively which is quite close. Since, the IESS High Gas scenario is more efficient, the reduction in energy intensity is 71% from 2012-40. Therefore, this means that in the IESS BAU scenario and WEPS+ Base case scenario, same amount of energy would be required to achieve a per unit increase in GDP, whereas the energy required would be lesser in IESS High Gas scenario due to various efficiency measures employed in the latter scenario.

[15] Agriculture/waste is solid biomass (non-commercial) used primarily for cooking in India.
WEPS model does not include non-commercial (agriculture/waste) energy supply.

10.4. Comparison of Installed Capacity:

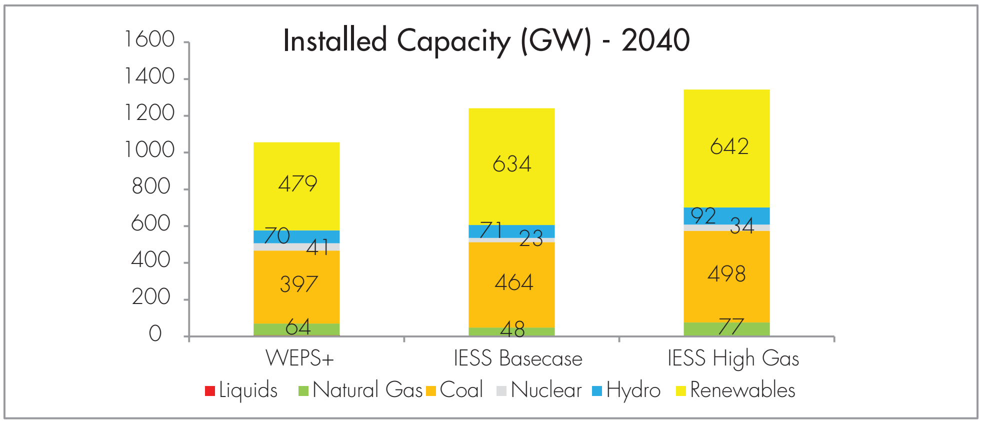


Figure 31

Figure 31[16] gives a break-up of installed capacity of electricity generation for WEPS and IESS. WEPS model envisages a total installed capacity of 1056 GW in 2040, whereas the BAU and High Gas scenario of IESS gives a total capacity of 1241 GW and 1344 GW respectively in 2040. The difference is due to higher coal based capacity and renewables capacity. Keeping in view the present thrust on renewables in India, IESS assumes a higher capacity addition in comparison with WEPS+. So, the CAGR for RE capacity addition in WEPS is 5.7% and in IESS is 7.2% from 2022-40 as till 2022, both the exercises assume that India would achieve its 175 GW RE target. Moreover, the coal based capacity is higher in IESS than WEPS keeping in view the reliance on coal by India.

10.5. Comparison of Electricity Generation and Electricity Mix:

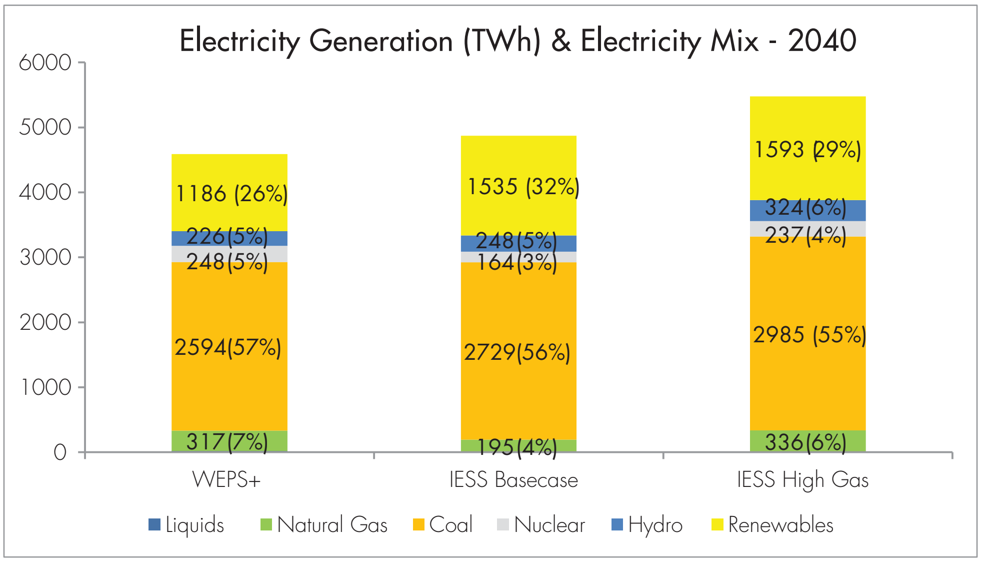


Figure 32

Figure 32 gives the comparison of electricity generation and mix for IESS and WEPS modeling analysis. The total electricity generation in WEPS is 4591 TWh in 2040, while the total generation is 4871 TWh and 5476 TWh in IESS BAU and High Gas scenario respectively in 2040. Since, the total installed capacity is 184 GW more in IESS BAU scenario and 287 GW higher in IESS High Gas scenario in comparison with WEPS Base case (refer Figure 27), the electricity generation is also higher in the former scenarios. The share of coal based power in electricity mix is quite similar in the two studies and lies in the range of 55%-57%. The share of gas based electricity generation with 317 TWh is 7% IN WEPS in 2040, whereas the same is 4% in IESS BAU scenario and 6% in IESS High Gas scenario in 2040.

10.6. Comparison of Natural Gas Demand:

Sector	WEPS+ Base Casel (BCM) – 2040	ESS BAU Scenario (BCM) - 2040	IESS High Gas Scenario (BCM) - 2040
Industry	62	128	177
Transport	67	12	13
Power Plants (including CCS)	62	36	62
Total	226	191	267

Table 10

Table 10 compares the natural gas demand in the WEPS base case and IESS BAU and High Gas scenarios in the year 2040. The total natural gas consumption in both models is similar in 2040. However, the model has different sectoral results for natural gas consumption, with industry using twice as much natural gas in the IESS model. This is because the IESS has laid emphasis on policy levers in the industrial sector such as fuel switching towards gas based technologies in the steel industry. However, the WEPS+ model which is based primarily on economic optimisation as well as availability of natural resource finds it more cost effective to continue using other fuels in industries as they are cheaper than natural gas.

In the case of transport, the use of natural gas in the WEPS+ is 5 times larger than that in the IESS model. This can be because natural gas becomes more economically competitive to liquids as a transportation fuel in the WEPS+ model in 2040. However, in the IESS there is a greater focus on a shift towards electric vehicles, hence reducing the role of natural gas in the transportation sector in 2040.

The natural gas demand in the 6 scenarios comes in the range of 181-257 BCM in 2040 (refer Figure 25), however, there are 2 outliers with consumption of 378 BCM and 418 BCM in Low

[16]The IESS modeling exercise also considers the coal and gas based CCS capacity which is included in the cumulative coal and gas based installed capacity.

Gas price scenario and Long Term Market driven scenario as the natural gas prices in these 2 scenarios are well below in comparison with other scenarios of WEPS.

10.7. Comparison of Per Capita Emissions[17] :

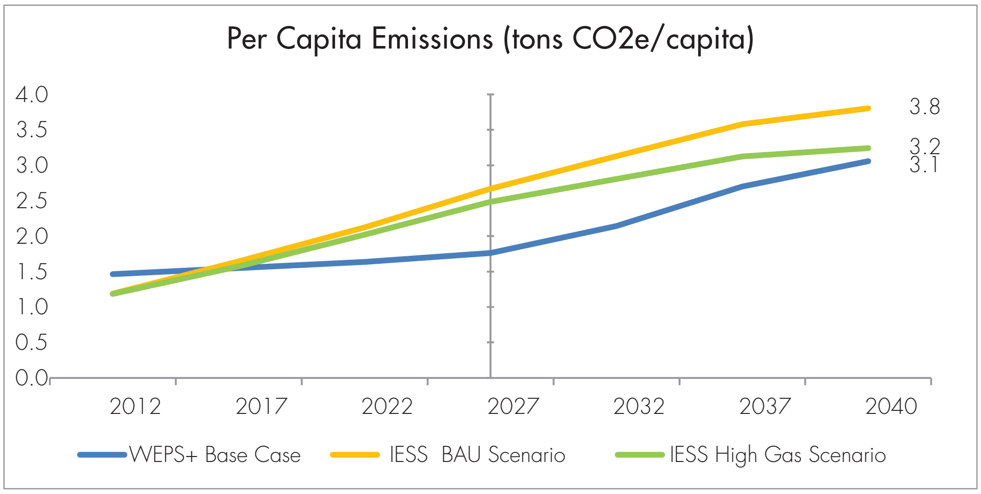


Figure 33

Figure 33 gives a comparison of Per Capita Emissions of WEPS and IESS in the energy sector. The Per capita emissions in the WEPS base case and IESS High Gas scenario are very close, whereas the per capita emission are higher in the IESS BAU scenario as the latter considers lower penetration of renewables and energy efficiency. As explained above, the per capita emissions of India in 2040 would be even lower than the present per capita emissions of China, US, Brazil or other major developed and developing countries.

10.8. Comparison of Emissions Intensity:

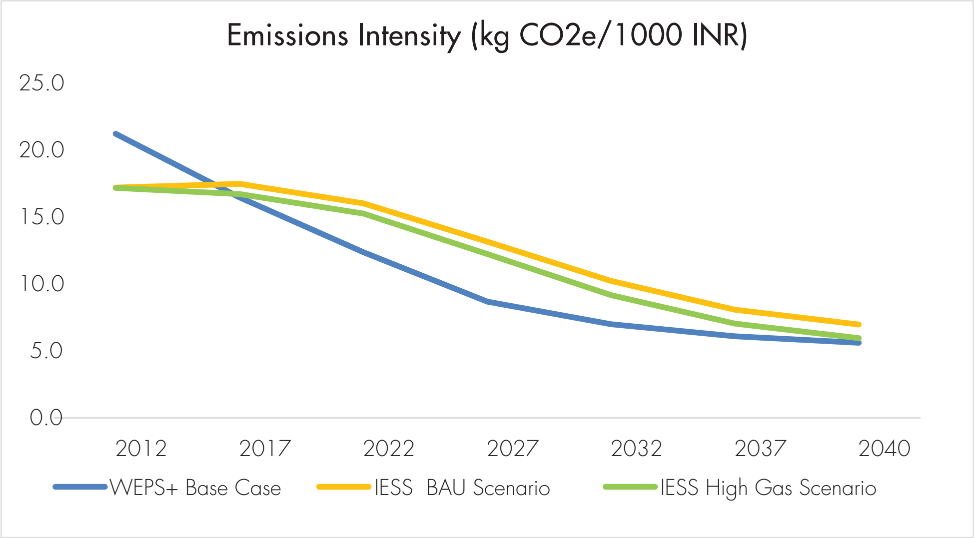


Figure 34

Figure 34 compares the Emissions Intensity for IESS and WEPS. There is a 59% and 65% reduction in emissions intensity from 2012-40 in the IESS BAU and High Gas scenario respectively. Since, the High Gas scenario assumes a higher penetration of renewables along with energy efficiency, the reduction in emissions intensity in also higher. The WEPS envisages a reduction of 74% from 2012-40. The reason for difference in emissions intensity between WEPS+ and IESS is that there is a bit of difference in emission numbers for 2012. However, the absolute emissions intensity number for 2040 is quite close for the 2 studies.

11.KEY TAKEAWAYS

It is clear that India has just begun the transformation of its energy sector and has some ambitious developmental targets in the energy space. It is very important for policy makers to take informed and right decisions on what sources of energy would have to be prioritized which will ultimately lead to eradication of energy poverty in India and at the same time will ensure energy security along with sustainability. It is well evident from this exercise that India's energy demand is set to rise by more than 4 times by 2047. The following are the key takeaways from this exercise:

1. Coal would remain at the centre stage in India with its share in energy mix not declining below 46% in 2047. Moreover, the penetration of renewables is definitely going to increase with its share rising to 11%-14% in 2047 from 3.7% in 2012.

2. India has a lot of potential for natural gas demand, however, the price volatility in the international market and the low cost of domestic coal in India make the former uncompetitive. India is a price sensitive energy market, due to which the demand for natural gas would drastically vary upon changing prices. This is also evident from the broad range of natural gas demands which has been arrived at through two different modeling exercises (refer Figure 25).

3. The natural gas demand in India is envisaged to lie between 191-267 BCM (IESS modeling) or 181-257 BCM (WEPS+ modeling) in 2040. However, as India is a price sensitive energy market, the demand for natural gas can significantly increase to 378 BCM and 418 BCM as envisaged in low gas price and long term market driven scenario respectively.

4. The share of natural gas in energy mix would lie in the range of 9%-12% depending on the different scenarios generated in the two modeling exercises. However, its share would rise to 17%-18% in the low gas price and long term market driven scenario respectively because the price of natural gas in these two scenarios ($7.3-9/mmbtu) is around half the price in other scenarios ($13.2-18/mmbtu).

[17]Both the models have considered only energy related emissions. Since, India does not have an emissions inventory, there can be some difference in the 2012 baseline numbers for WEPS and IESS.

5. The above three points give a very strong conclusion that natural gas would not become a dominant fuel in India.

6. India has around 14305 MW of gas based installed capacity stranded. The share of natural gas in electricity mix in India peaked in 2010-11 at 12%, when the domestic production of natural gas was also at peak due to increased supply from KG D6 basin, however, the same has fallen to 4% in 2015-16. The two modeling exercises also envisage a very moderate share of gas in electricity mix i.e. 6%-11% in 2040 depending upon different scenarios. However, the share of gas based electricity can go up to 22%-26% in the low gas price and long term market driven scenario respectively due to lower prices in the latter scenarios.

7. Since, natural gas based plants would be required for balancing support for the electricity generated from renewables, the gas based installed capacity is envisaged to increase to around 50-87 GW by 2040 from the present 25.3 GW. As explained above, the gas based installed capacity would show a steep increase in low gas price (162 GW) and long term market driven scenario (186 GW).

8. Coal is going to constitute a major share in electricity mix i.e. 55%-63% in 2040. And the share of renewable based electricity would significantly increase to 26%-32% by 2040 from 6% in 2015-16.

9. India is likely to achieve a 60%-74% reduction in emissions intensity by 2040 from 2012 levels indicating its thrust on clean energy sources and energy efficiency. Moreover, India's per capita emissions (3.1-3.8 ton CO_2e/capita) in 2040, would be lower than the present per capita emissions of China (6.7 ton CO_2e/capita) and the United States (16.2 ton CO_2e/capita).

Therefore, India has to keep its options open to all the fuels in order to meet its rising energy requirements.

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ASSESSING IMPACT OF HIGH PENETRATION OF RENEWABLE ELECTRICITY ON THE INDIAN GRID IN FY 2046-47

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ABSTRACT

Electricity sector in India is growing at rapid pace. In 2015, Government of India announced about its ambitious plan of achieving 175 GW of Renewable Energy (RE) by 2022 which includes 100 GW of solar and 60 GW of wind. The growth of RE is going to be enormous in coming decades. The variability and intermittency of solar and wind power has to be managed and supplemented by other energy technologies sources to ensure stability and security of the power system. The study assesses the technical feasibility of integrating aggressive Renewable Energy targets across different seasons, when demand and capacity of conventional plants remains same for the financial year 2046-47 (April 2046 through March 2047). The analysis is conducted by simulating the hourly grid operation in FY 2046-47 for number of renewable energy penetration scenarios using PLEXOS which is industry standard grid dispatch simulation software. India Energy Security Scenario (IESS), 2047 was used to create demand assumptions based on growth of electricity consumption in the country and efficiency of electricity utilization. The hourly demand curve for FY 2046-47 was then simulated based on the historical hourly demand patterns in the country.

The study finds that in all scenarios and seasons, most of the available coal and nuclear units are operated as base load units. RE provides significant support during afternoon peak demand period during summer (mainly solar) as well as monsoon (mainly wind). In both seasons, gas based generation (or other flexible source) is needed for evening ramp-up support and meeting evening peak demand. In Winter, both solar and wind generation drop significantly; albeit demand is also much lower. Solar CSP (with storage) helps in meeting the evening peak demand in all seasons. Since conventional capacity can back down to a limited level, one could see significant RE curtailment in case of high RE scenario in all seasons. The model was also run to see how power system would be operated in case of extreme events/days such as very high load day, high renewable energy generation day, or sudden variability in renewable energy generation etc.

The study also finds that as we move towards aggressive renewable energy penetration, the PLF of coal based thermal power plants decreases, which could imply that either the growth of coal based plants has to curb or the system would not be feasible. As we move towards high RE, we could see that the gas plants operate with annual capacity factor of 8% in medium RE case to even 1% in case of high RE scenario, implying that there is so much RE in the system already that no energy support from gas is required.

This analysis uses several assumptions, especially related to power systems in 2047. We could not carry out the cost assessment of integrating various levels of RE on the grid, mainly because of uncertainty in assumptions related to cost and technology in the year 2047, which leaves significant scope for future work.

1. INTRODUCTION

1.1. Overview of the Indian Power Sector

Electricity sector in India is growing at rapid pace. With the peak electricity demand of about 159 GW and the total installed capacity of about 310 GW (generation mix of Thermal (69.4%), Hydro (13.9%), Renewable (14.8%) and Nuclear (1.9%)), India has one of the largest electricity transmission and distribution systems in the world (CEA 2016-17).The electricity generation target for the year 2016-17 has been fixed as 1178 Billion Unit (BU) i.e. growth of around 6.38% over actual generation of 1107.822 BU from the previous year (2015-16). The generation during 2015-16 was 1107.822 BU as compared to 1048.673 BU generated during April- March 2015, representing a growth of about 5.64% (MOP, 2017). Economic growth and increasing prosperity, coupled with factors such as growing rate of urbanization, rising per capita energy consumption and widening access to energy in the country, are likely to further raise the energy demand in the country (GIZ, 2015).

1.2. Renewable Energy Scenario in India

India's Renewable Energy (RE) stands at 45.9 GW out of the total 310 GW total installed capacity as on Dec, 2016 (CEA, Dec 2016).Out of 45.9 GW of RE capacity, wind installed capacity is around 28 GW and solar contributes around 8.5 GW. Although the share of RE in the total electricity mix has been increasing, India still have vast and largely untapped potential.Recent estimates have shown that at 20% capacity factor and above, total wind energy potential in India is in excess of 3000 GW (Phadke, Bharvirkar et al. 2012). Similarly, total solar PV potential in India is as high as 11,000 GW (Ramachandra, Jain et al. 2011; Sukhatme 2011; Deshmukh and Phadke 2012).As per India Energy Security Scenarios (IESS) 2047, India has the potential of achieving as high as 551 GW of wind and 807 GW of solar capacity by 2047. The potential of biomass and small hydro is also significant. Thus, renewable sector has the potential to anchor the development of India's electricity sector.

1.2.1. Renewable Energy Targets for India

Government of India has an ambitious plan of achieving 175 GW of RE by 2022 which includes 100 GW of solar, 60 GW of wind, 10 GW of biomass and 5 GW of small hydro. The growth of RE is going to be enormous in the next few years as illustrated in the graph below:

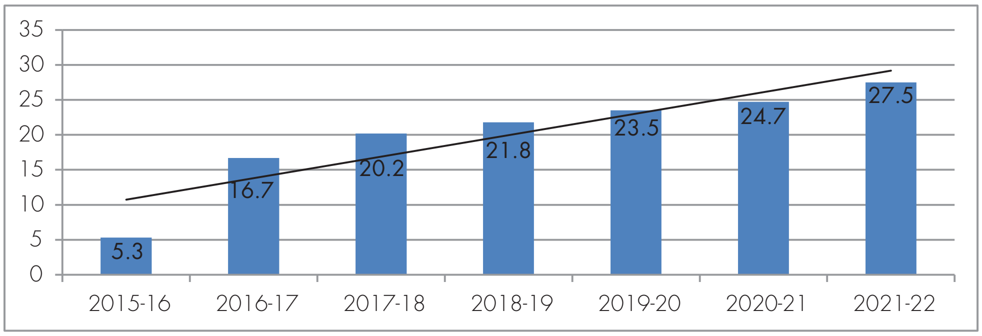

Figure – 1- Year-Wise Split of Targeted RE Installed Capacity (GW)

Considering the higher RE targets, increasing share of RE in the total electricity mix, regional concentration of RE etc., issue of grid integration of renewable energy is going to be critical in years to come.

1.2.2. Need for Renewable Energy Integration

The variability and intermittency of solar and wind power has to be managed and supplemented by other energy technologies sources to ensure stability and security of the power system.With limited potential of gas and hydro in the country, coal based generation along with other energy storage solutions becomes a major option to meet and match the fluctuations due to RE in the grid.The adaptation of coal based thermal power plants to fluctuating renewable energy generation offers many challenges, both for existing as well as new upcoming plants. The real success of this energy transition towards renewables depends on better flexibility of the thermal power plants to meet the new scenario in the power sector.

The objective of this simulation exercise is to assess the technical feasibility of integrating aggressive Renewable Energy targets across different seasons, when demand remains at the same level.

2. DATA AND METHODOLOGY

We built a grid planning and dispatch model for India and simulated the hourly grid operation in FY 2047 (April 2046 through March 2047) for number of renewable energy penetration scenarios using PLEXOS which is an industry standard grid dispatch simulation software. Based on the electricity demand and supply scenarios defined in the India Energy Planning Tool, we run the simulation chronologically through all hours of the financial year 2047 (April 2046 through March 2047) in hourly intervals for four seasons.

2.1. Scenarios for Energy Pathway in FY 2046-47

We conducted this exercise for the following three energy pathways identified in the Indian Energy Security Scenarios (IESS) model (v2.0) for the FY 2046-47:

i. High RE Pathway – This scenario assumes highest level of renewable energy penetration as per level IV of the IESS v2.0. for financial year 2046-47. For RE, this scenario assumes the total installed capacity of 551 GW of wind, 807 GW of solar, 50 GW of other RE (small hydro and biomass combined) by FY 2047; the total installed capacity including the conventional technologies is assumed to be about 2184 GW by FY 2047. This scenario translates to total share of RE in annual generationto48% by 2047.

ii. Medium RE Pathway -This scenario assumes medium level of renewable energy penetration as per level III of the IESS v2.0. for financial year 2046-47. For RE, this scenario assumes the total installed capacity of 293 GW of wind, 449 GW of solar, 43 GW of other RE (small hydro and biomass combined) by FY 2047; the total installed capacity including the conventional technologies is assumed to be about 1561 GW by FY 2047. This scenario translates to total share of RE in annual generation to 28% by 2047.

iii. Low RE Pathway - This scenario assumes business as usual scenario of renewable energy penetration as per level II of the IESS v2.0. for financial year 2046-47. For RE, this scenario assumes the total installed capacity of 222 GW of wind, 243 GW of solar, 26 GW of other RE (small hydro and biomass combined) by FY 2047; the total installed capacity including the conventional technologies is assumed to be about 1267 GW by FY 2047. This scenario translates to total share of RE in annual generation to 18 % by 2047.

Four seasons have been considered for study across each energy pathway given as under:

1. Summer – April – May, 2046
2. Monsoon – June – September, 2046
3. Autumn – October – November, 2046
4. Winter – December – February, 2047

2.1.1. Assumptions on Capacity of Other Technologies

In all the three energy pathways (High, Medium and Low RE), it is assumed that coal, gas, hydro and nuclear capacity addition remains the same (Level III in IESS).The following table shows the total installed capacity (national) of RE and other technologies for each scenario.

Installed Capacity (GW)										
	Coal	Gas - CCGT	Nuclear	Hydro	Biomass+ Cogen	Small Hydro	Wind	Solar	Waste to Electricity	Total
High RE	539	83	45	105	20	30	551	807	4	2184
Med RE	539	83	45	105	23	20	293	449	4	1561
Low RE	539	83	45	105	11	15	222	243	4	1267

Table 1: Total installed capacity (national) of RE and other technologies for each scenario

The tables below shows the annual energy generation in TWh/yr and the percentage share of each technology in the annual generation:

Annual Energy Generation (TWh/yr)										
	Coal	Gas - CCGT	Nuclear	Hydro	Biomass+ Cogen	Small Hydro	Wind	Solar	Waste to Electricity	Total
High RE	2537	0	356	273	6	0	1325	1512	1	6010
Med RE	3704	0	356	278	14	0	733	891	2	5979
Low RE	4088	0	356	278	19	0	564	479	7	5790

Share in Annual Generation										
	Coal	Gas - CCGT	Nuclear	Hydro	Biomass+ Cogen	Small Hydro	Wind	Solar	Waste to Electricity	Total
High RE	42%	0%	6%	4%	0%	1%	22%	25%	0%	100%
Med RE	61%	1%	6%	5%	0%	1%	12%	15%	0%	100%
Low RE	67%	4%	6%	5%	0%	1%	9%	8%	0%	100%

Table 2: Annual energy generation in TWh/yr and the percentage share of each technology in the annual generation

2.1.2. Hourly Demand Forecast by Season

IESS creates four levels of demand – each with different assumptions on the growth of electricity consumption in the country and efficiency of electricity utilization. Using these demand levels, we simulated an hourly demand curve for the financial year 2046-47 based on the historical hourly demand patterns in the country, load growth, and projected urbanization.

The following charts show the average daily load curve for summer (April-May), monsoon (June-September), autumn (October-November) and winter (December through February) in FY 2046-47 for demand level II.

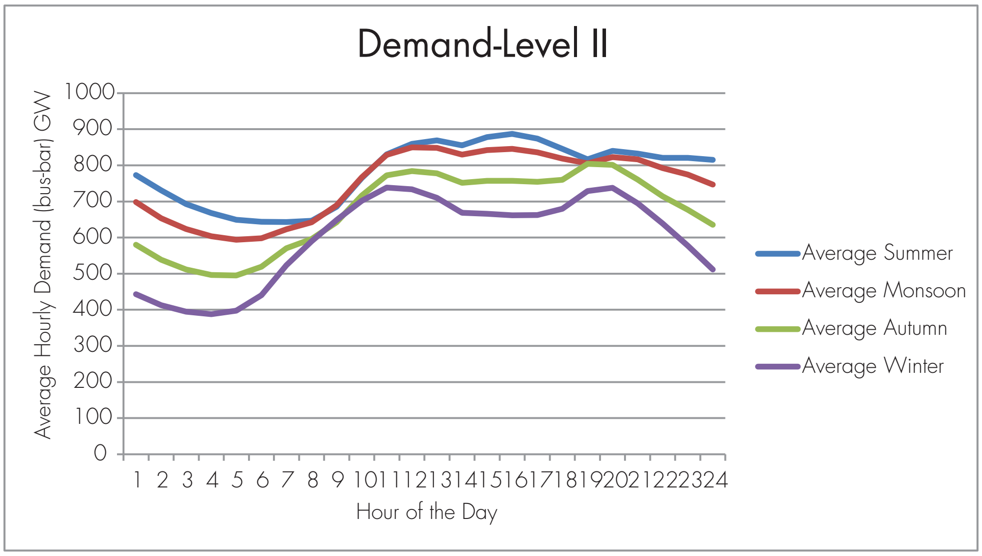

Figure 2- Demand across different seasons in 2047

Electricity Demand for all other demand levels follow a similar pattern but for this study, we have taken demand at same level (Level II) for the three selected energy pathways.

2.1.3. Hourly Wind and Solar Generation Forecast by Season

Hourly wind generation patterns (onshore) have been extrapolated from the historical actual wind generation profiles in the key states like Maharashtra and Tamilnadu. Same pattern (with higher capacity factors) are assumed for offshore wind. For estimating the hourly solar generation profile, we chose 100 sites spread over all 5 regions with best quality solar resource (measured in DNI and GHI kWh/m2) using the national solar energy dataset for India developed by the National Renewable Energy Laboratory that contains hourly irradiance data for every 5kmx5km grid in India. The solar irradiance data was then fed into the System Advisor Model (SAM) also developed by the National Renewable Energy Laboratory. SAM takes the historical solar irradiance data and projects the expected hourly PV output. Same irradiance pattern is used for CSP, albeit with dispatchable storage. The following charts show the average seasonal profiles of onshore wind and solar PV generation at National level.

The following charts show the average daily load curve for summer (April-May), monsoon (June-September), autumn (October-November) and winter (December through February) in FY 2046-47 for demand level II.

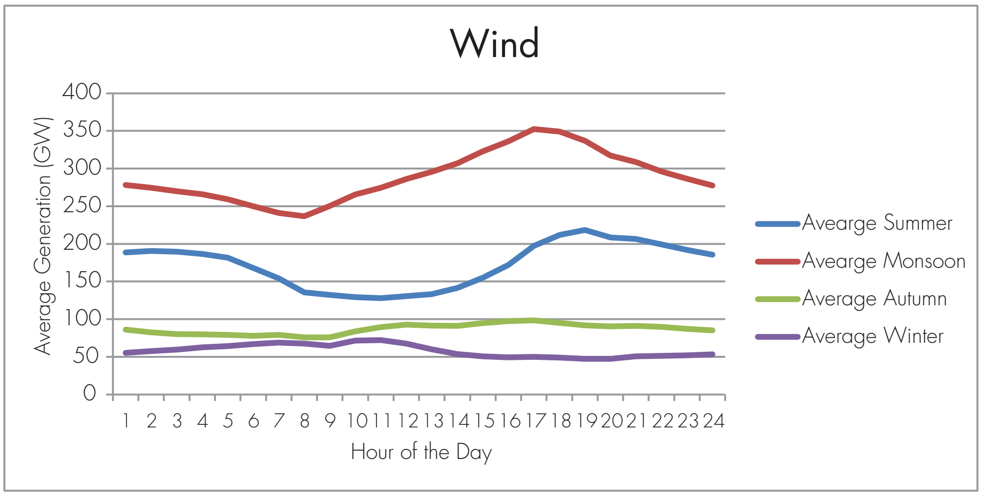

Figure 3 - Generation through wind across different seasons

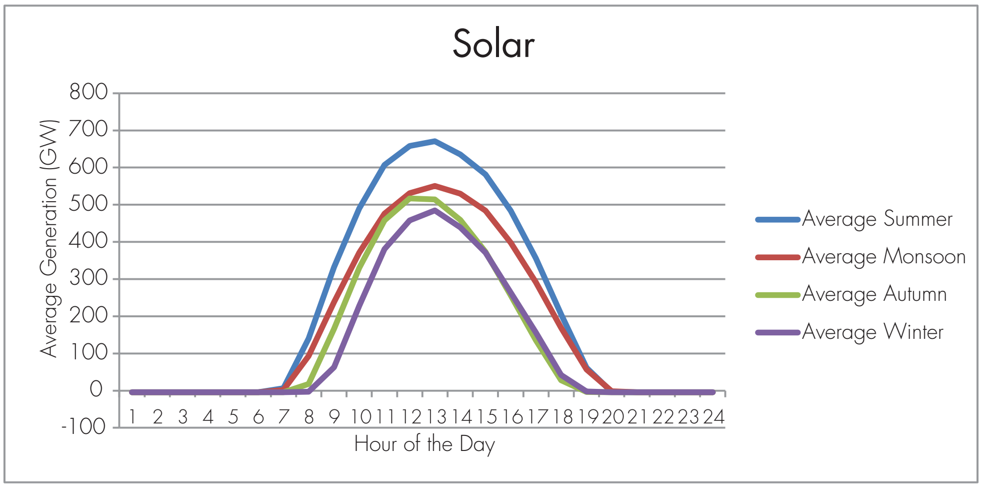

Figure 4 - Generation through solar across different seasons

Basic characteristic of solar and wind energy sources is that they are dependent on season, weather conditions, making their output generation variable in nature. Solar power output is dependent on the irradiation and temperature of the location which vary on hourly, daily, seasonal and annual basis. Generally, solar generation peaks in the summer and its diurnal profile does not change much across seasons.Wind generation in India peaks in the Monsoon (June-September) and is significant for all 24 hours, which is not the case in winter and therefore has a major impact on the integration costs/strategies. In summer, solar generation peaks while overall wind generation is low; in monsoon, wind generation peaks while solar generation drops. Both solar and wind generation drop significantly in winter; thus, for aggressive renewable energy penetration pathways, most of the grid balancing support (storage, gas CT etc) is required in the winter.

2.1.4. RE Assumptions for Various Pathways

The following charts illustrate the key assumptions for wind and solar for three different pathways, viz, High RE, Medium RE and Low RE assumed for the study.

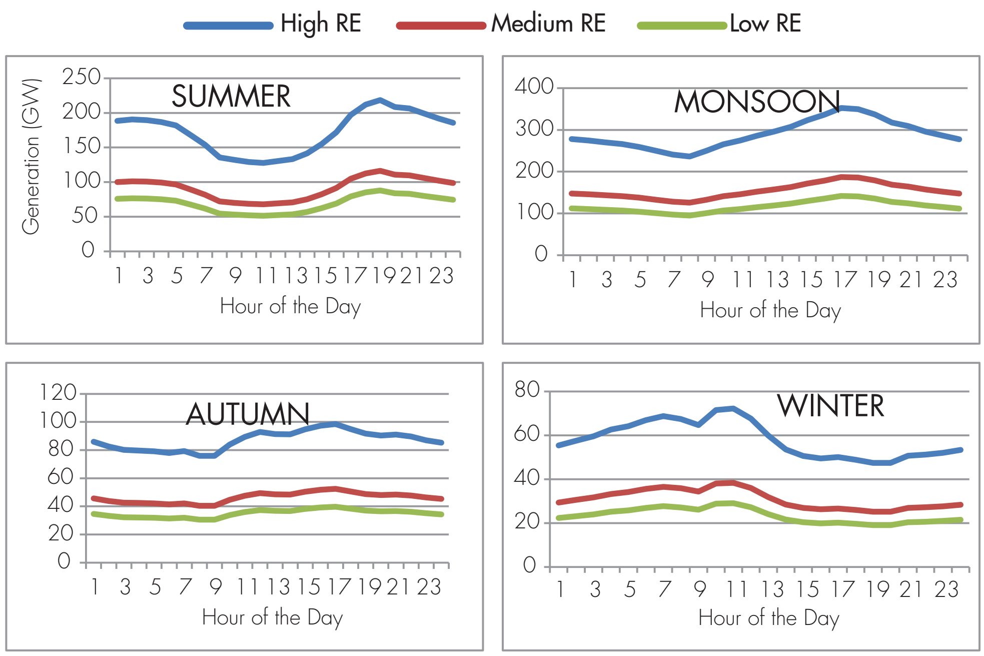

Figure – 5 - Wind energy generation profiles

It can be seen that there is significant variation in wind generation in all seasons. Wind generation peaks in the monsoon and is the lowest in the winter. In monsoon and summer, the wind generation peaks late afternoon/early evening which matches with the overall demand patterns in these seasons. In winter, the sudden drop of wind generation in the evening is responsible for sudden ramping requirement to cater the evening demand.

2.1.4. RE Assumptions for Various Pathways

The following charts illustrate the key assumptions for wind and solar for three different pathways, viz, High RE, Medium RE and Low RE assumed for the study.

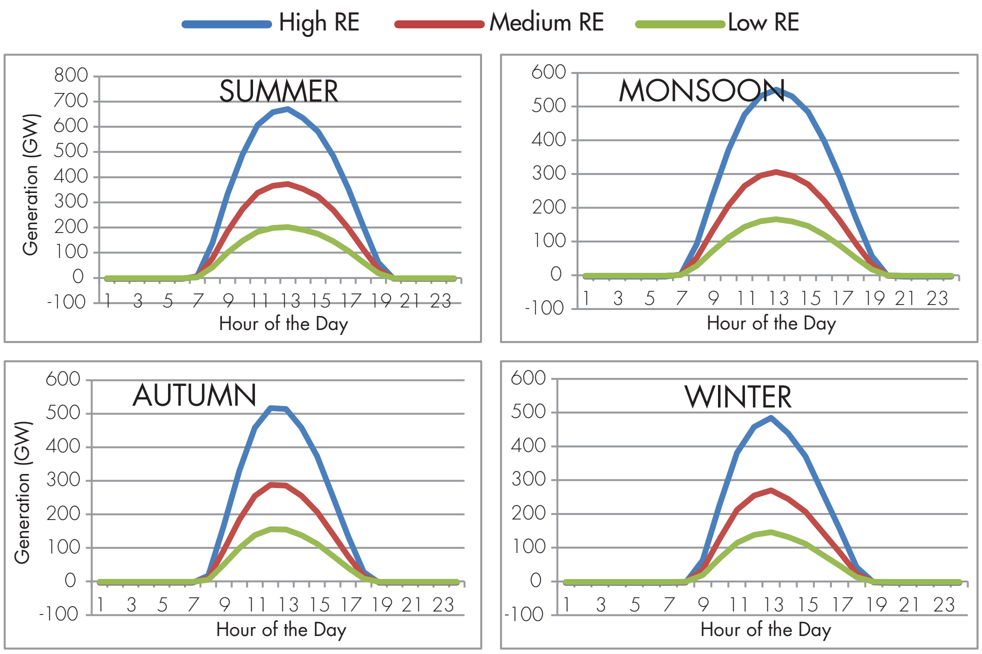

Figure – 6- Solar energy generation profiles

The average generation profiles for each season under different scenarios are shown in the charts above.

As evident from the charts, solar peaks in the summers and drops significantly in the winter. However, solar profile follows the same pattern in all the seasons.

3. RESULTS

3.1. Impact on Net Load to be Met by Conventional Generators

Net load (or the residual load) is estimated by subtracting the variable RE generation from load. It is the load to be met by the conventional capacity. The following charts show the national net load curves for an average day in each season.

Summer, 2046

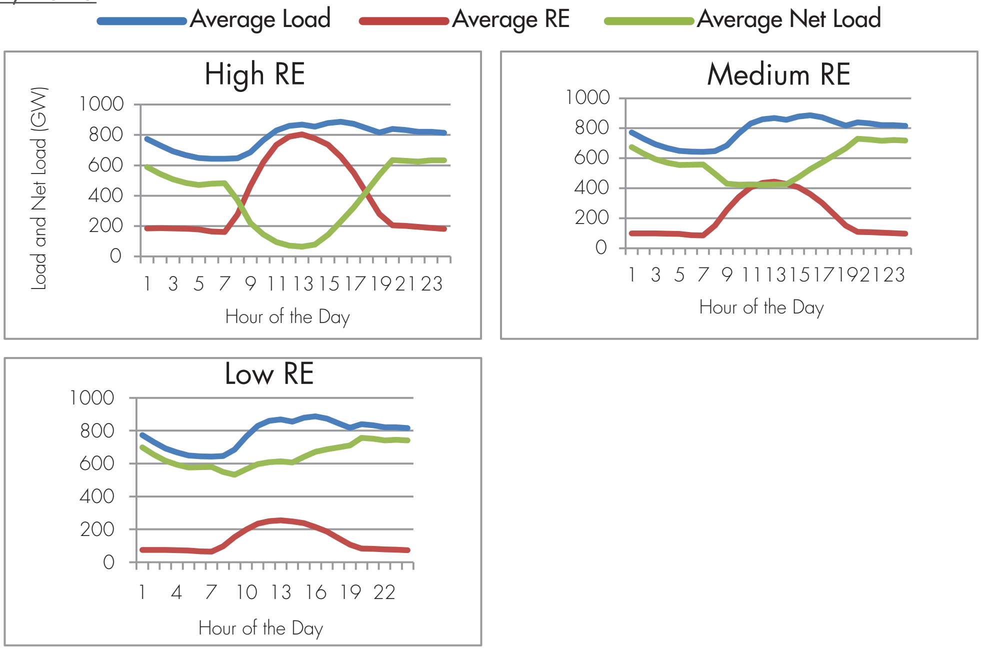

Figure – 7a

As evident in the charts, the load peaks up in the afternoon and remains high in the evening and night mainly because of the space cooling load in the summers. Solar also peaks up in the afternoon and correlates well with the load curve until early afternoon. In the high RE scenario, net load dips very significantly in the afternoon and causes conventional capacity to back down to the minimum. At the same time, it also introduces significant ramping in the evening when generation from solar drops significantly.

In case of medium RE scenario too, we can observe drop in Net Load during the afternoon and ramping up is needed in the evening.

In low RE scenario, low RE generation makes the net load curve look much flatter.

Monsoon, 2046

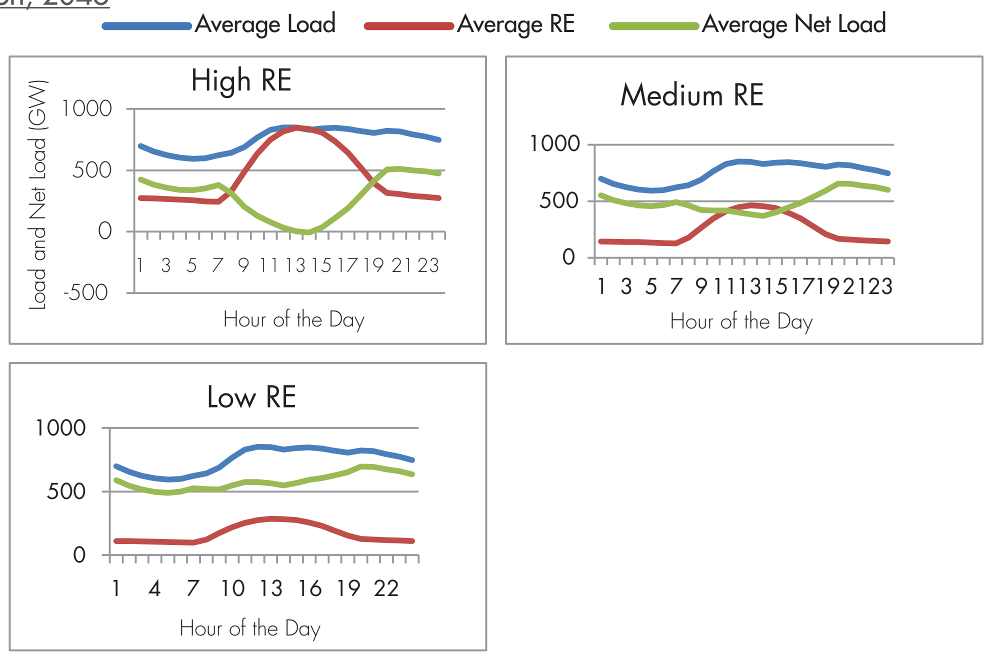

Figure – 7b

In the monsoon, load curve shows somewhat similar pattern like summer months with peak in the afternoon and significant load in the evening and night, again because of the space cooling demand in the humid weather. Wind is significantly high in the monsoon than rest of the months. RE penetration in the afternoon in case of high RE scenario is so high that it calls for curtailment of RE. The net load curves for other two scenarios follows somewhat similar pattern as in the summer.

Autumn, 2046

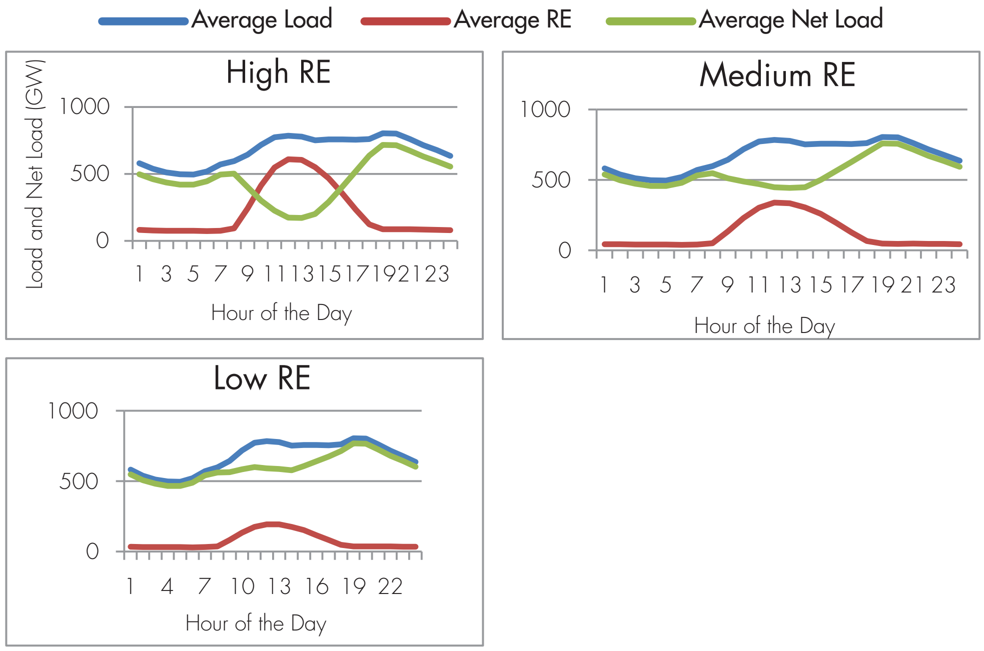

Figure – 7c

Autumn load shows different pattern with two distinct peaks – one in the afternoon and other in the evening, mainly because of heating requirements. Overall demand is much lower than summer and monsoon. Net load curve shows a drop in the afternoon when renewable energy is at peak. Also, one can notice that the ramping requirement in the evening is much higher than summer and monsoon due to rapid drop in renewable energy generation and increase in the evening load.In case of medium and low RE scenario, net load curve coincides the load curve in evening and early morning due to negligible generation from wind and no generation from solar.

Winter, 2047

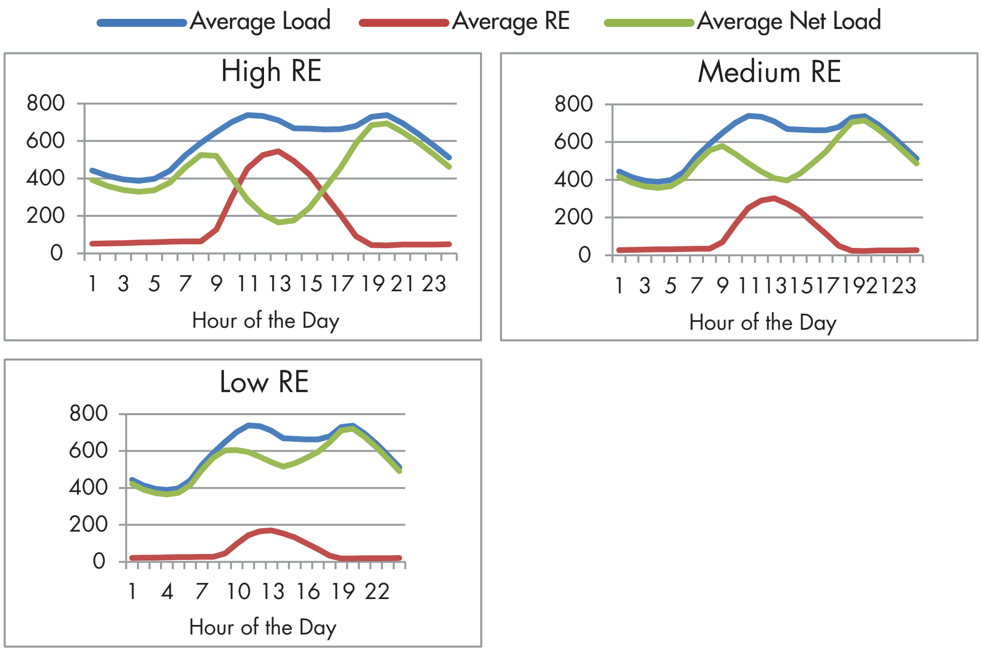

Figure – 7d

The load curve in case of winter is very prominent with two distinct peaks – one in the morning due to heating demand and other one in the evening mainly because of lighting and heating requirements. Overall demand in the winter is much lower than all the seasons, so as the generation from wind and solar. This drop in RE generation has a major bearing on the energy support that may be needed in winter. The ramping requirement in the evening is much higher to meet the sudden evening demand coupled with sudden drop in the generation from wind and solar. Net load curve overlaps the load curve in evening and early morning again because of sudden drop in the renewable energy generation.

3.2. Installed Capacities and Capacity Factors of each Technology

Table below shows the total (national) installed capacities, and capacity factors (i.e. Plant Load Factors) of each technology for each energy scenario.

Technology	**High RE Scenario**		**Medium RE Scenario**		**Low RE Scenario**	
	Installed Capacity	Factors (PLF) Capacity	Installed Capacity	Factors (PLF) Capacity	Installed Capacity	Factors (PLF) Capacity
Coal	539	54%	539	78%	539	87%
Gas	83	1%	83	8%	83	32%
Nuclear	45	90%	45	90%	45	90%
Hydro	105	30%	105	30%	105	30%
Biomass +Cogen	20	3%	23	7%	11	19%
Small Hydro	30	35%	30	35%	15	35%
Wind	551	27%	293	29%	222	29%
Solar	807	21%	449	23%	243	22%
Waste to Electricity	4	4%	4	7%	4	19%

Table 3: Total (national) installed capacities, and capacity factors (i.e. Plant Load Factors) of each technology for each energy scenario

It is interesting to note that as we move towards aggressive renewable energy penetration, the PLF of coal based thermal power plants is decreasing, which could imply that either the growth of coal based plants has to curb or the system would not be feasible. As we move towards high RE, we could see that the gas plants operate with annual capacity factor of 8% in medium RE case to even 1% in case of high RE scenario, implying that there is so much RE in the system already that no energy support from gas is required. Gas only operates for ramping support and hence very low PLF.

3.3. Load and Net Load Variability

The following table reveals the max load variability and max net load variability or system ramp (SR) for various RE penetration scenarios.

It can be noted that the load is significantly variable as well. For example, the maximum variability in national load in FY 2046-47 is projected to be 129.688 GW/hr (2.16 GW/min).The incremental variability added due to renewable energy generation is important from the perspective of system balancing and security.

Scenario	Max Load Variability (GW/hr)	Max Net Load Variability (GW/hr)
High RE	129.688	237.18
Med RE	129.688	137.997
Low RE	129.688	133.276

Table 4: Max load variability and max net load variability or system ramp (SR) for various RE penetration scenarios

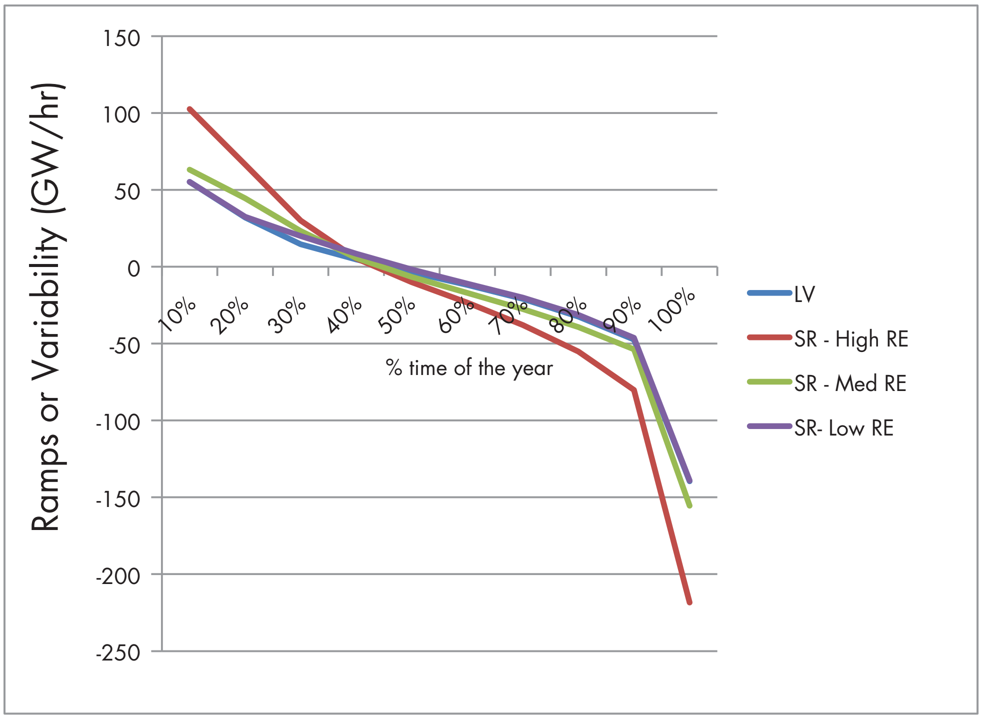

Figure 8 - Load and Net Load Variability in 2047

As shown, the maximum net load ramps in case of medium and low RE scenarios are almost close to load ramps, implying the maximum additional variability introduced due to the RE generation is relatively less. However, the net load variability in case of high RE scenario is very high than the load variability implying high variability introduced due to RE.

3.4. Average Hourly Dispatch in Each Season

The following charts show how the average hourly dispatch in each season for the national grid. They show how each generation technology contributes towards meeting the load. For example, nuclear and coal power is used as the base load. Solar energy does contribute in the peak demand hours (afternoon cooling peak), while nationally wind energy contributes equally in peak as well as intermediate demand hours.

3.4.1. Average Hourly Daily National Dispatch during Summer 2046 (April-May)

Insight: In all the three scenarios, nuclear and coal are dispatched as base loads. The solar output is highest insummer, however, the generation is limited to afternoon peak load hours. Gas and hydro based capacity are crucial for evening ramp up and energy support. Solar CSP (with storage) helps in meeting the evening peak demand in all seasons. Given the large conventional capacity, significant increase in RE capacity requires conventional plants to back down to the minimum. RE curtailment is also necessary in the afternoon in case of high RE. In medium and low RE scenario, there is enough conventional capacity in the grid to integrate the RE and no curtailment of RE is needed.

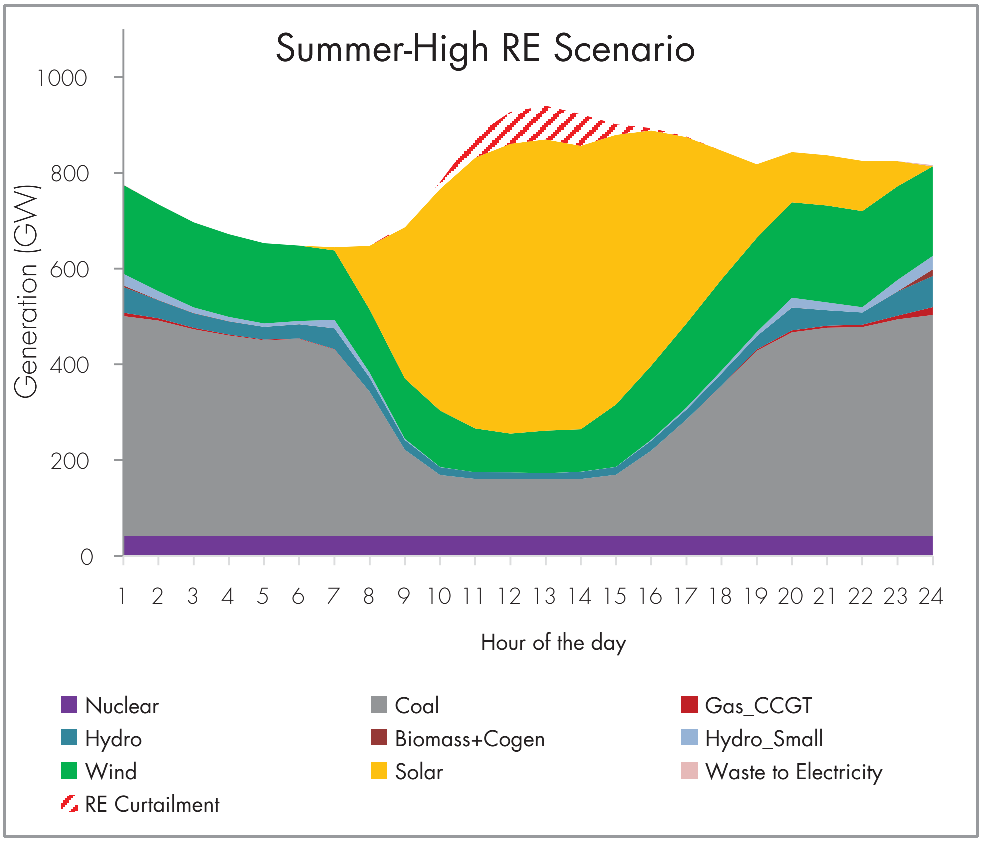

Figure 9

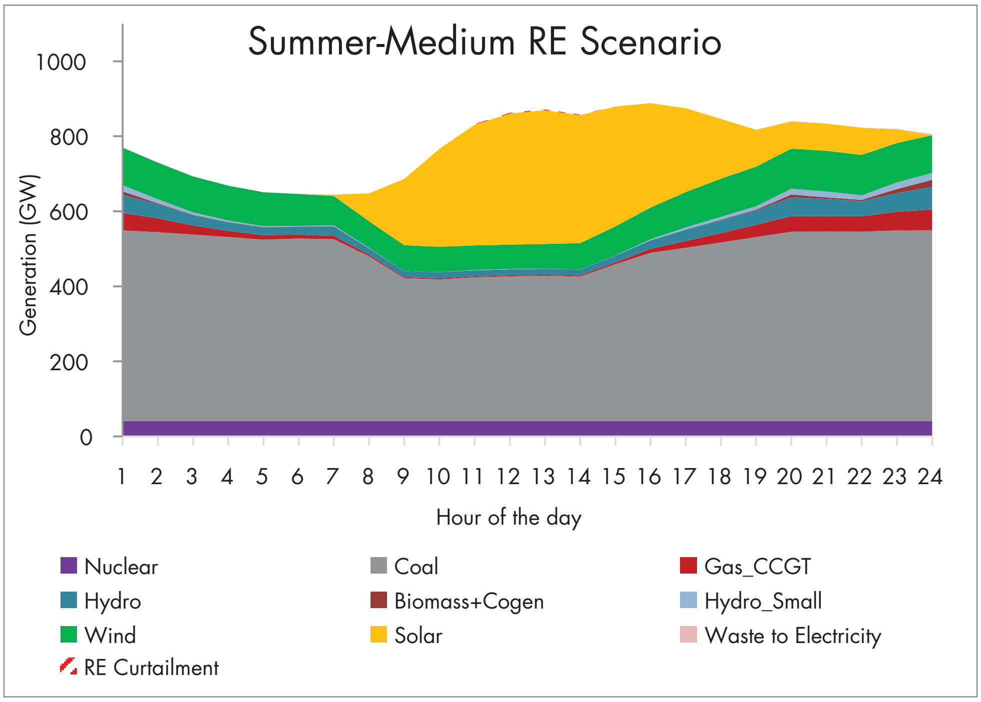

Figure 9

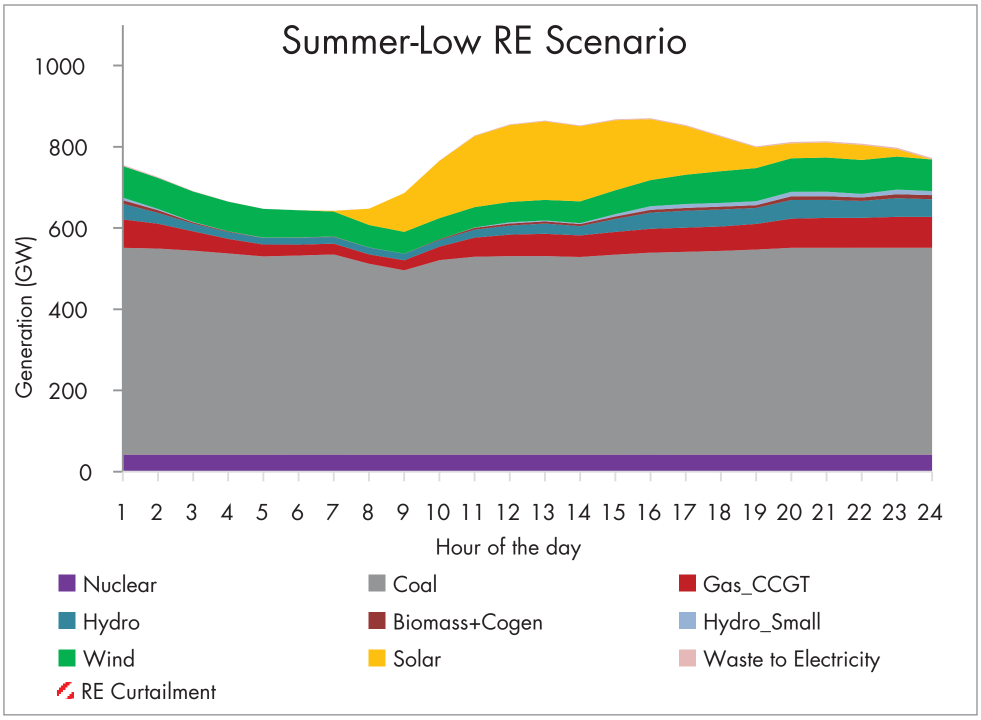

Figure 9

3.4.2. Average Hourly Daily National Dispatch during Monsoon 2046 (June-September)

Insight: Monsoon demand shows somewhat similar pattern as summer.In monsoon, renewable energy, especially wind generation peaks and provides major support during the afternoon and evening demand peak. Hydro and gas based generation provides ramping up support during the evening when RE generation drops, though it is lower than in the summer. In case of high RE penetration, some curtailment of RE is also needed because of the limited ability of the conventional system to back down generation. No curtailment of RE is however needed in case of low RE penetration and the ramping up requirement is also less.

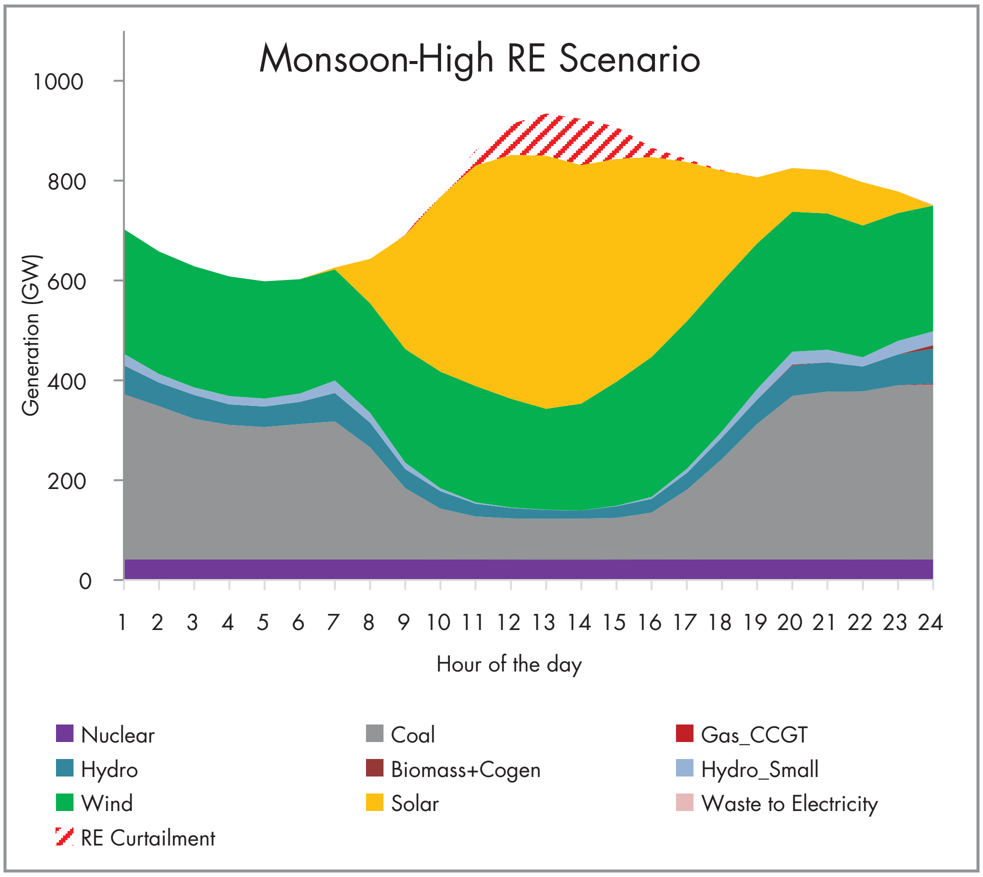

Figure 10

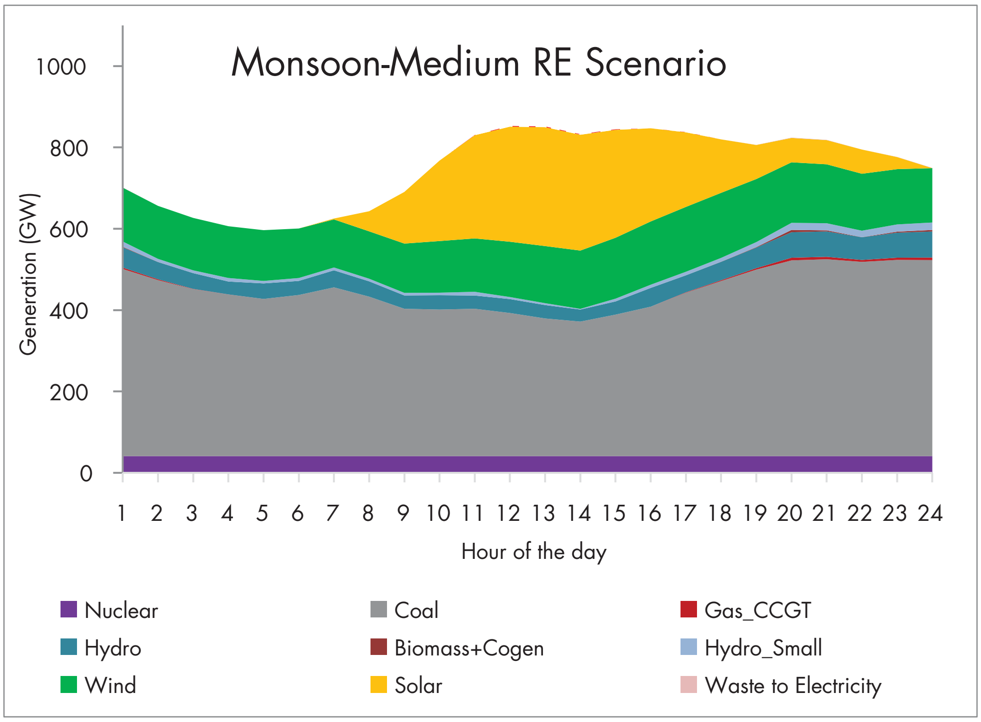

Figure 10

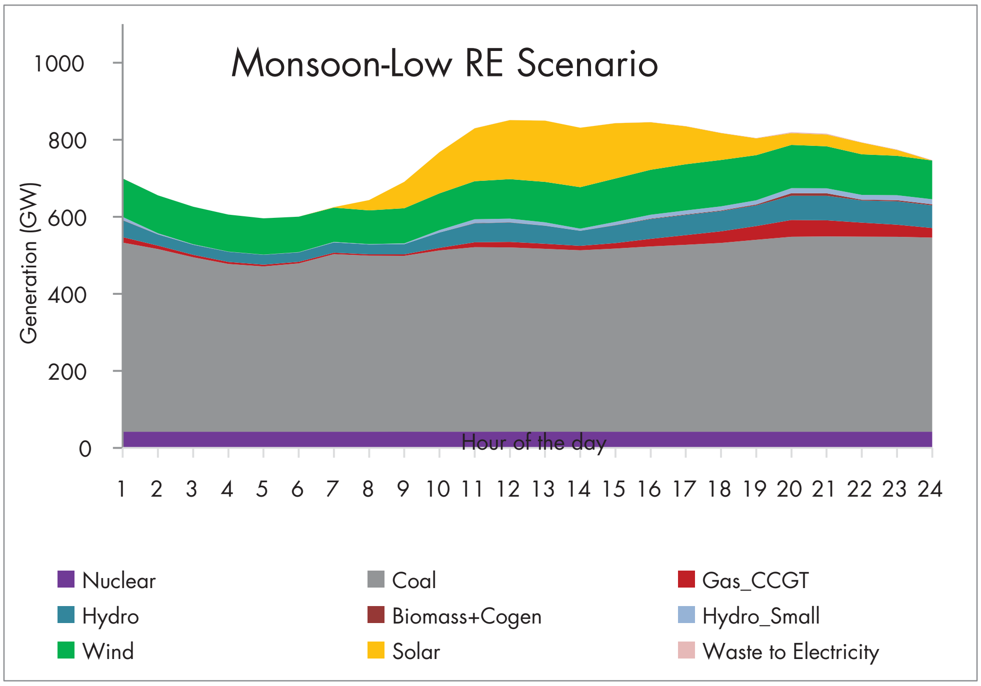

Figure 10

3.4.3. Average Hourly Daily National Dispatch during Autumn 2046 (Oct-November)

Insight: Two demand peaks can be seen: one in afternoon and other in the evening. The evening peak support from gas and hydro becomes crucial, especially in case of low and medium RE.Curtailment of RE is necessary in case of high RE scenario.

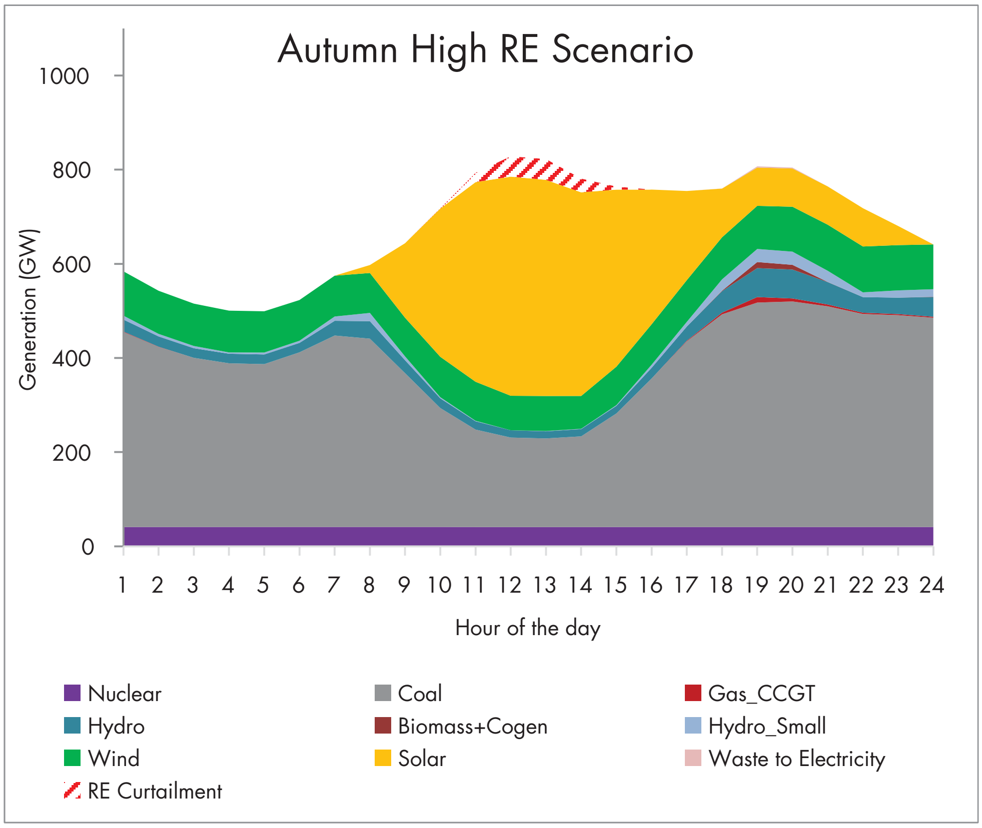

Figure 11

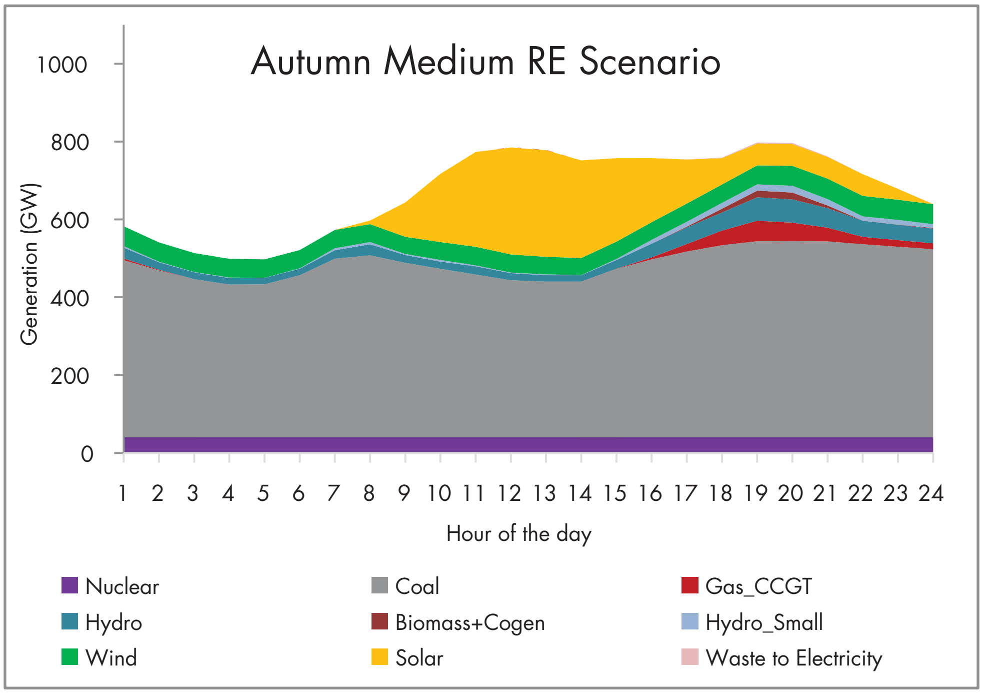

Figure 11

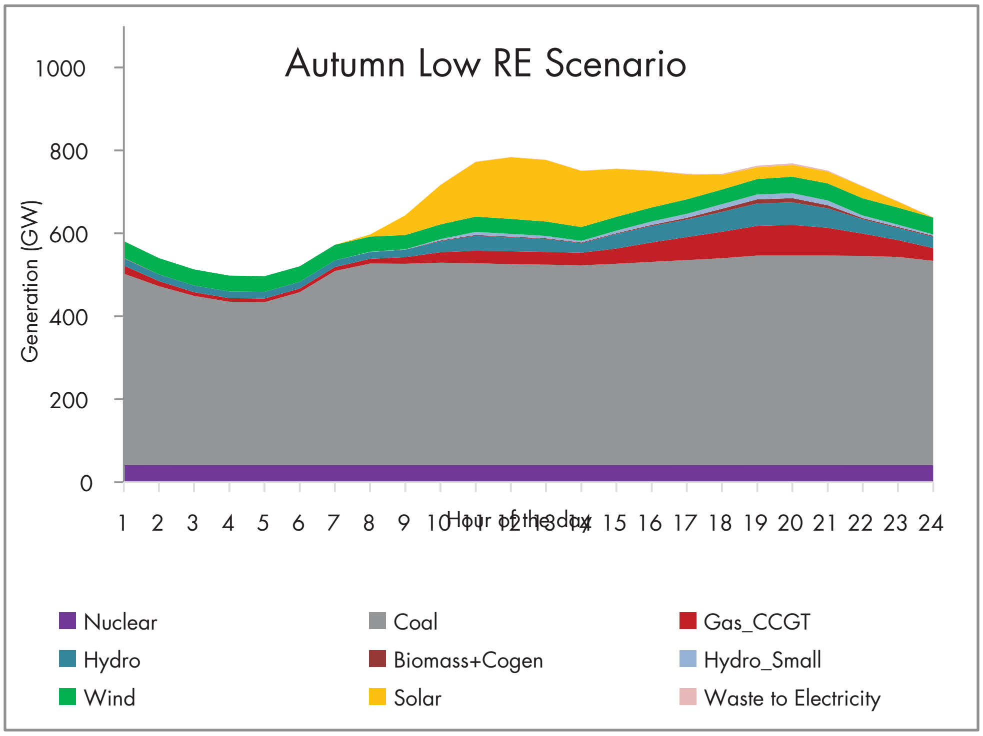

Figure 11

3.4.4. Average Hourly Daily National Dispatch during Winter 2046-47 (Dec-February)

Insight: The overall demand is relatively lower in the winter than other seasons with two distinct demand peaks – one in morning and other in the evening. In case of high RE penetration in winter, we can see some curtailment of RE is needed in the afternoon either because the total RE generation is more than the demand or the conventional plants cannot back down anymore because of the system security constraints. However, significant energy support is needed in the evening to meet the demand in case of low and medium RE.

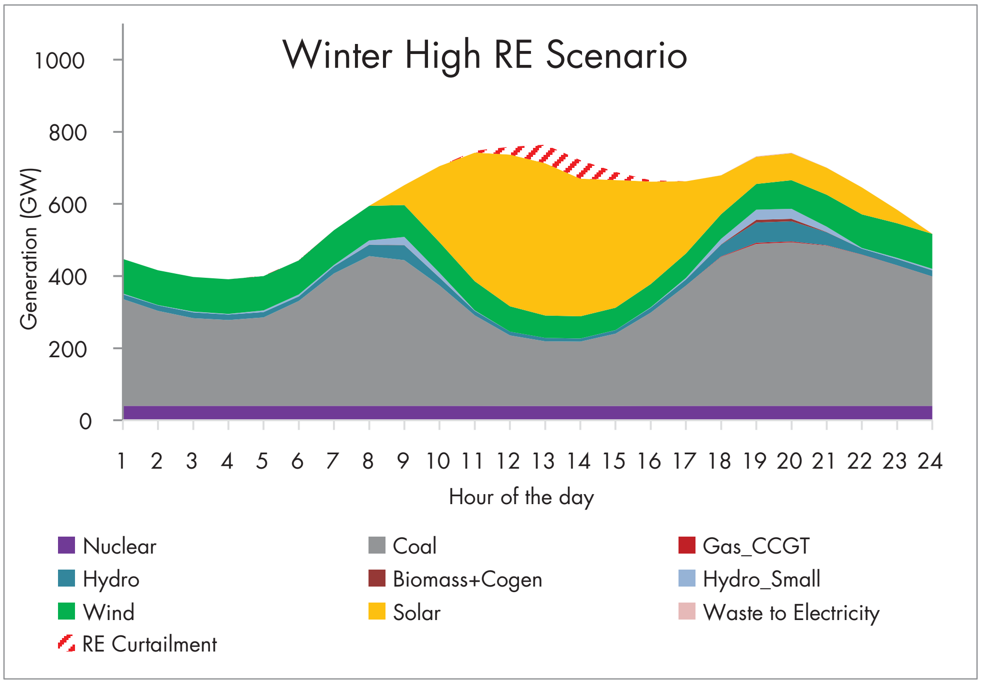

Figure 12

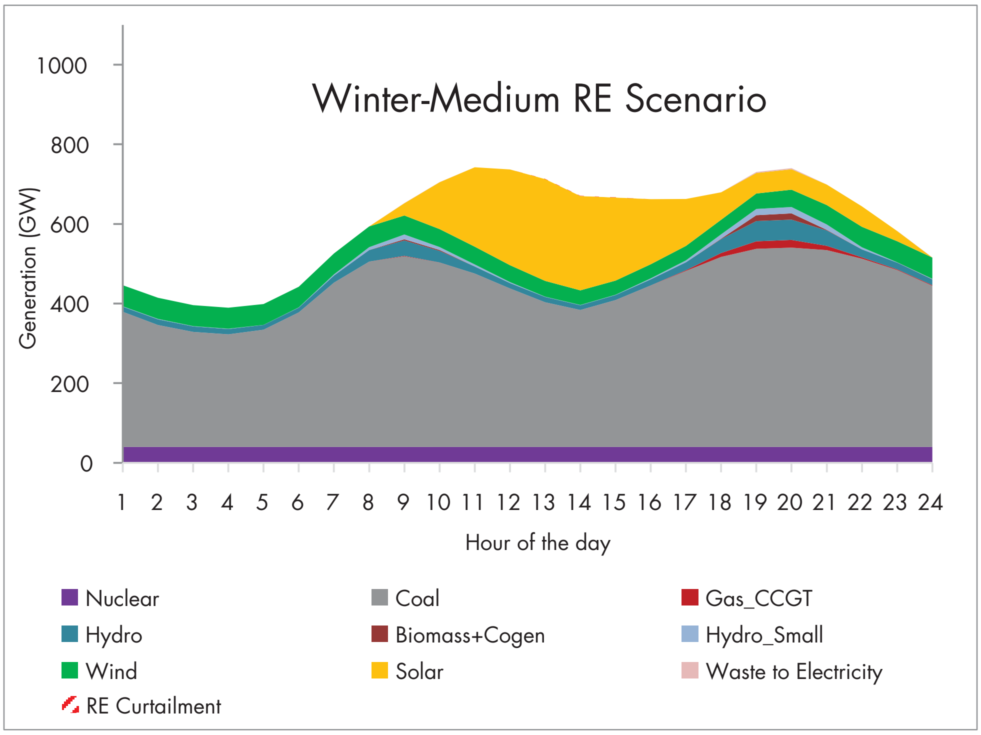

Figure 12

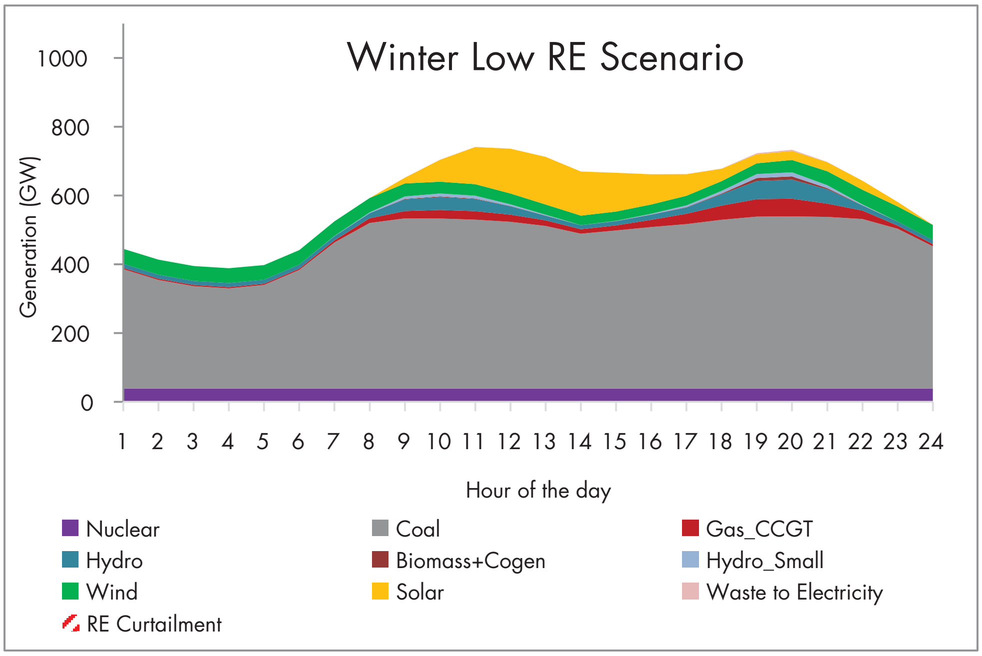

Figure 12

3.5. System Operation on Extreme Days

It is very important to see that how the system would be operated in case of extreme events/days such as very high load day, high renewable energy generation day, or sudden variability in renewable energy generation etc. The following sub sections show how the system would be operated on such extreme days.

3.5.1. Maximum RE Day

Insight: The following charts show the national dispatch for the maximum RE day which is 17th June, 2046 in each scenario. Maximum penetration of RE in case of high RE scenario may call for complete shut down of conventional plants along with curtailment of RE. Once the conventional plants are shut, they take lot of time to start up and become operational. In such situations, energy storage solutions such as batteries can provide support by storing excess renewable energy during the day and helping in shaving off ramping requirement in the evening. Good RE forecasting practices are crucial to handle such extreme events.

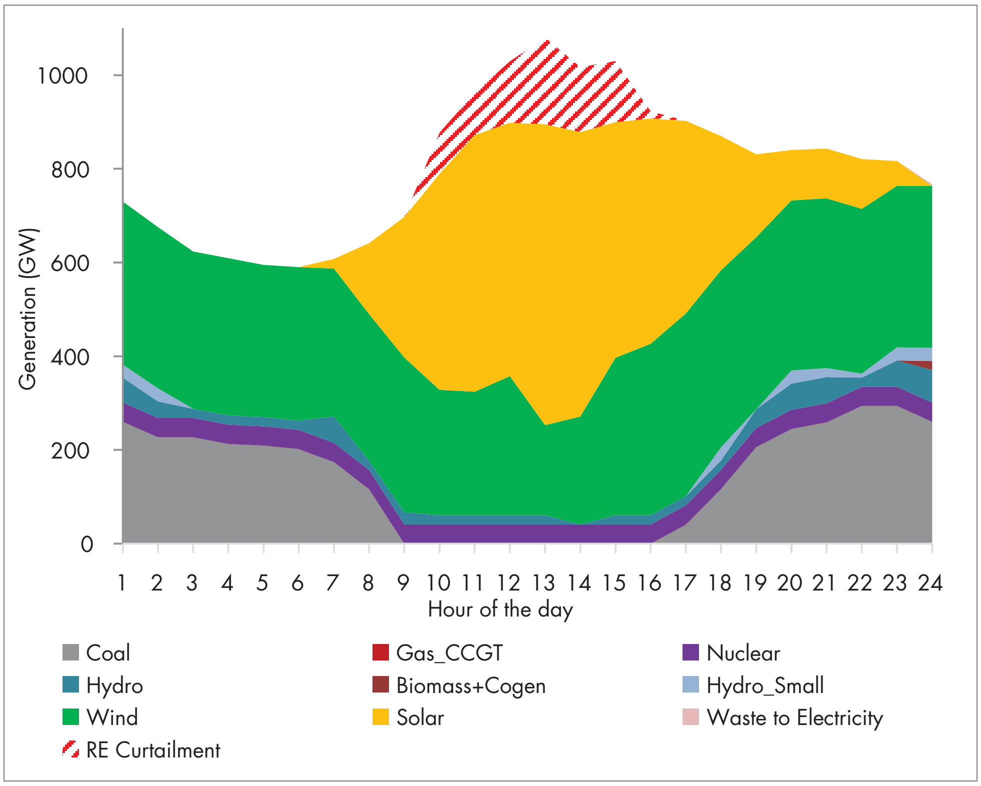

Figure 13a. Hourly National Dispatch for Maximum RE Day (June 17th) – High RE Scenario

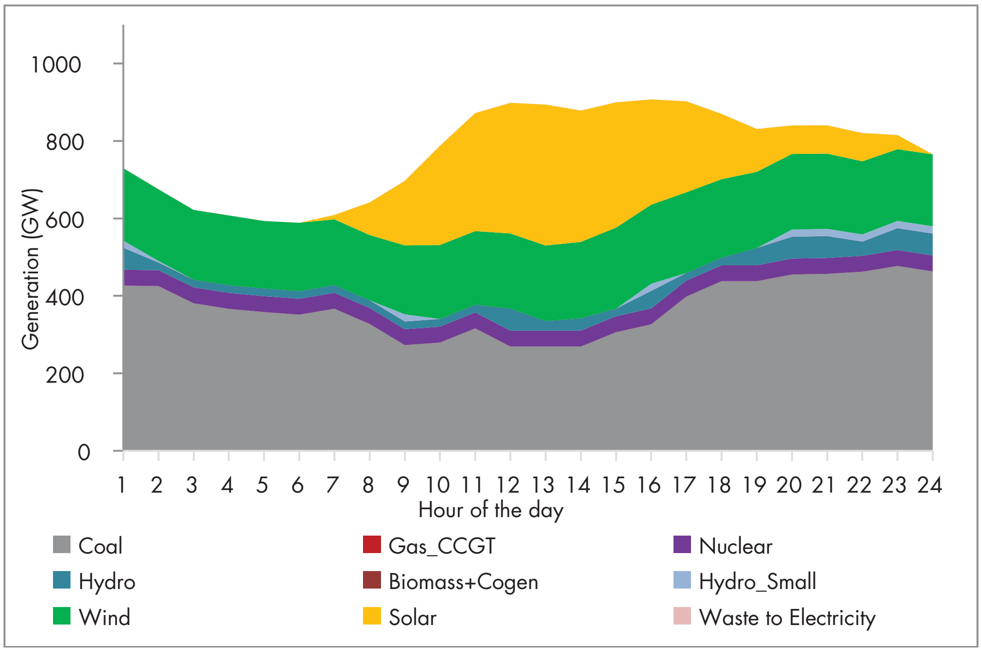

Figure 13a. Hourly National Dispatch for Maximum RE Day (June 17th) – Medium RE Scenario

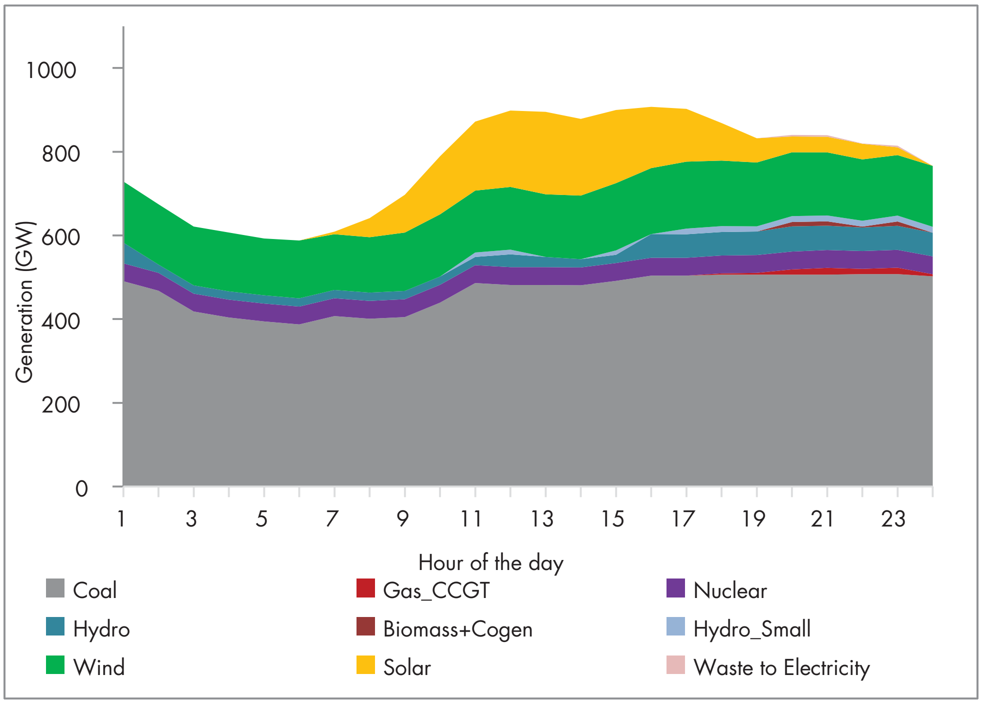

Figure 13a. Hourly National Dispatch for Maximum RE Day (June 17th) – Low RE Scenario

3.5.2. High Variability in RE Generation

Insight: A basic characteristic of the renewable energy sources (wind and solar) is that they are variable in nature. The following charts show the national dispatch in each scenario on 18th May, 2046 with maximum variability (i.e. maximum hour to hour variation) in RE generation.It can be seen, both solar and wind are showing maximum variability from 0900 hrs till 1400 hrs. Significantly high capacity of RE inspite of variability in case of high RE scenario requires the conventional plants to back down to minimum in the afternoon with substantial RE curtailment. In case of medium and low RE, there is enough conventional capacity in the grid and no curtailment of RE is needed.

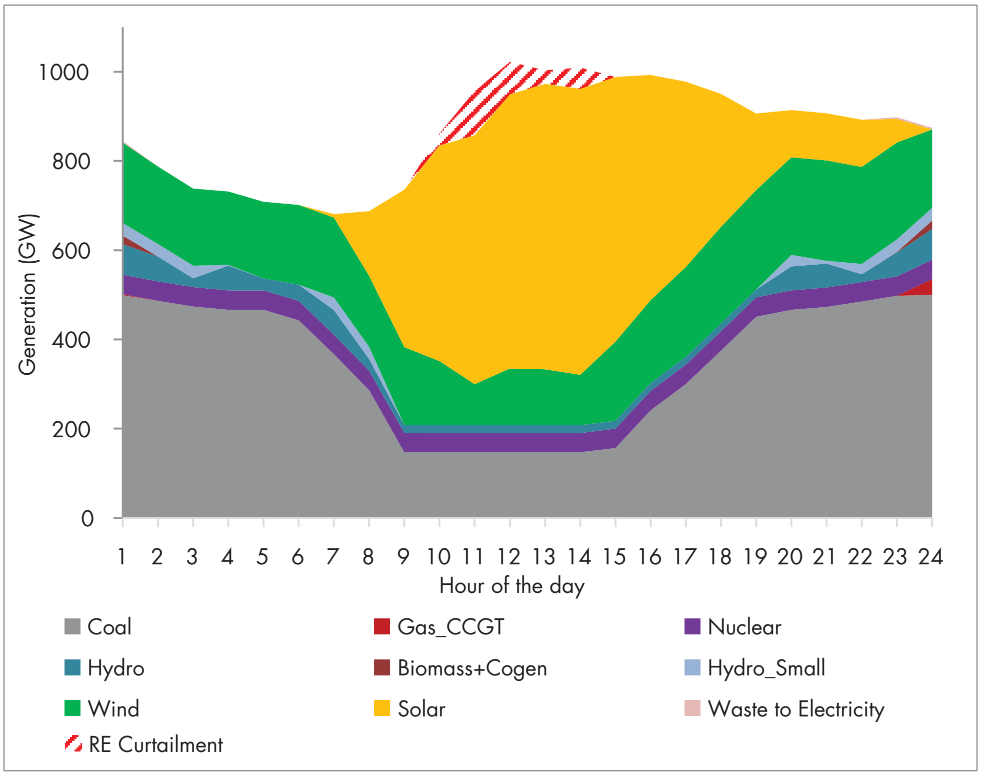

Figure 13b. Hourly National Dispatch for Max RE Variability Day (May 18th) – High RE Scenario

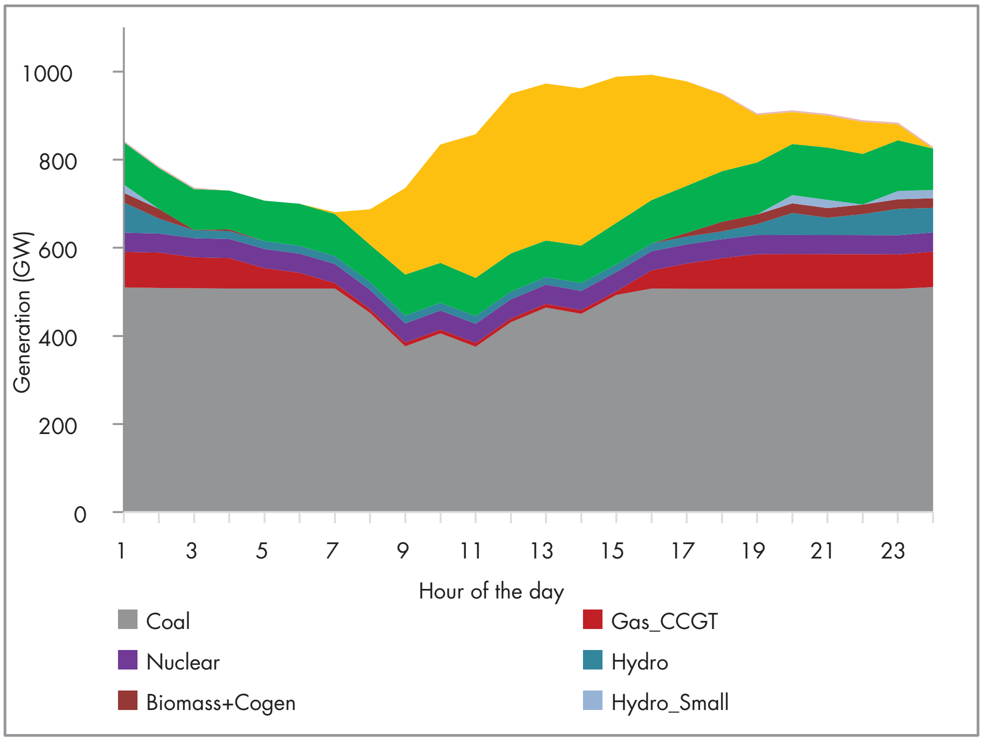

Figure 13b. Hourly National Dispatch for Max RE Variability Day (May 18th) – Medium RE Scenario

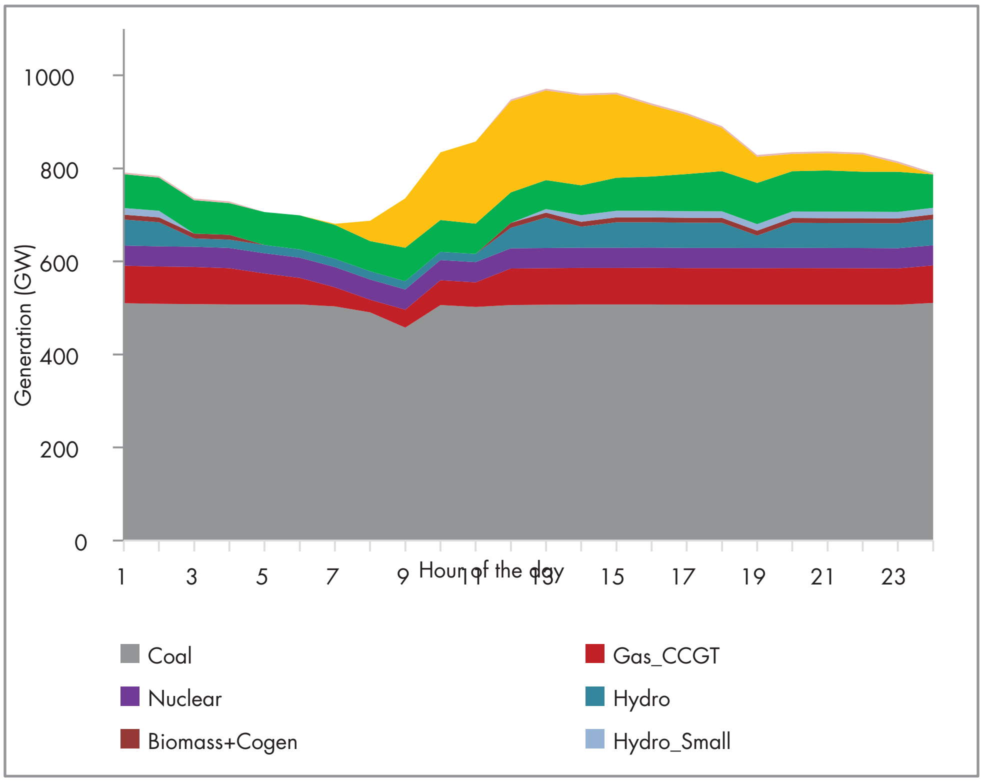

Figure 13b. Hourly National Dispatch for Max RE Variability Day (May 18th) – Low RE Scenario

3.5.3. Maximum Load Day

Insight: The following charts show the national dispatch for the maximum load day which is 3rd June, 2046 in each scenario.In case of High RE scenario, even in case of high load, we can still see some curtailment of RE because of the limited ability of the conventional system to back down completely. Since the max load day is on 3th June, 2046, both solar and wind are high.

In case of Low RE scenario, maximum load is met through coal, gas and nuclear

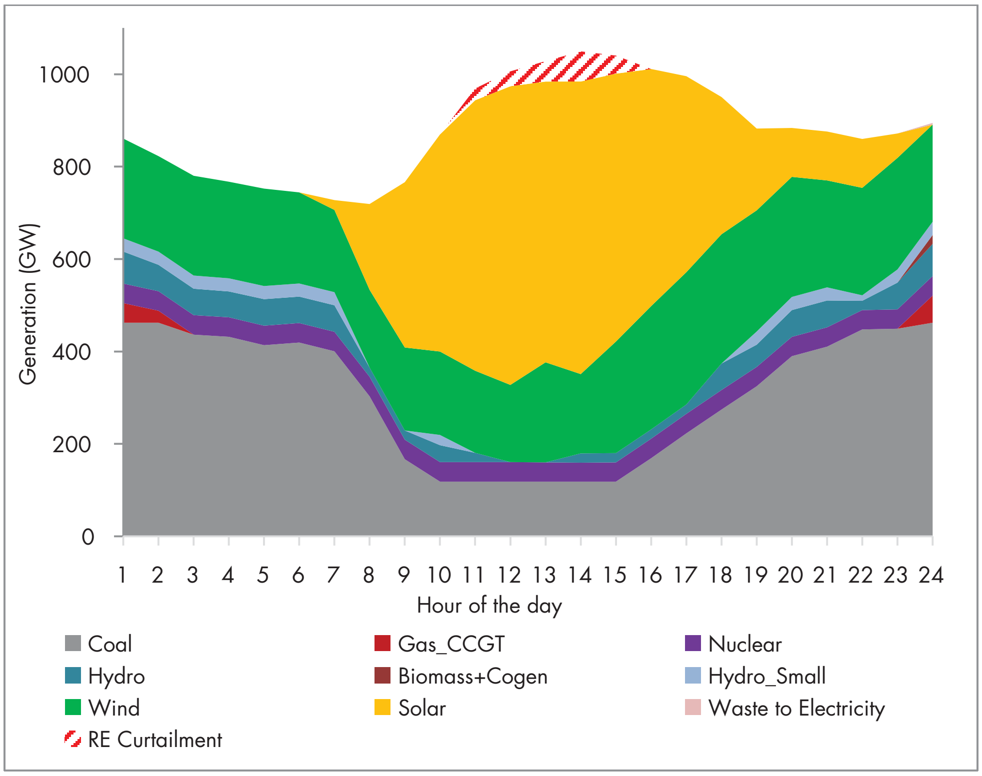

Figure 13c. Hourly National Dispatch for Max Load Day (June 3rd) – High RE Scenario

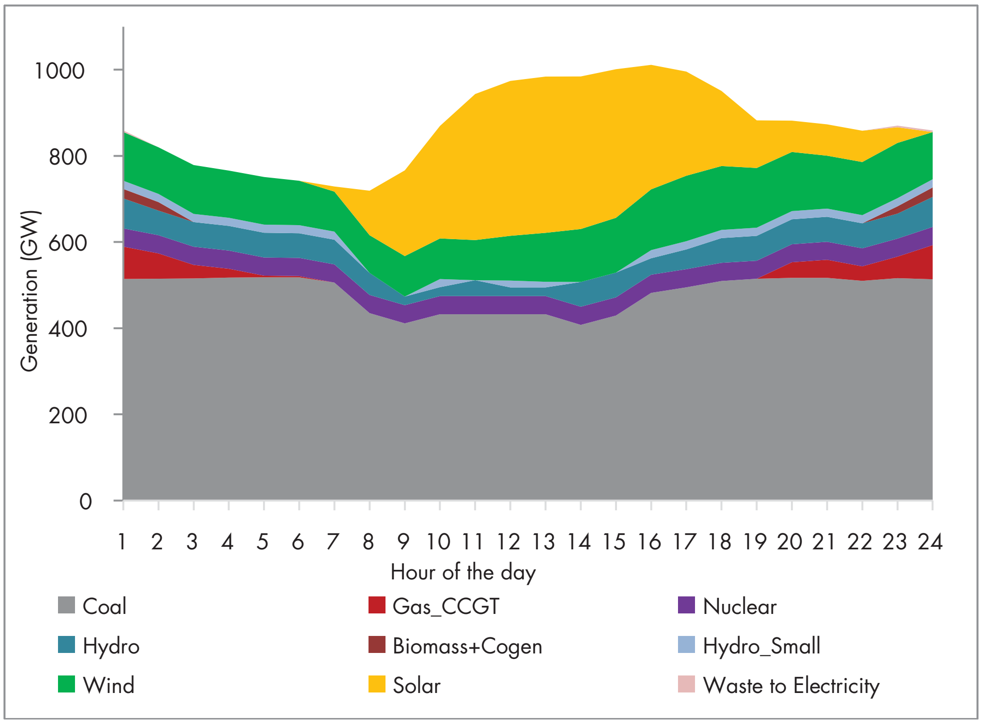

Figure 13c. Hourly National Dispatch for Max Load Day (June 3rd) – Medium RE Scenario

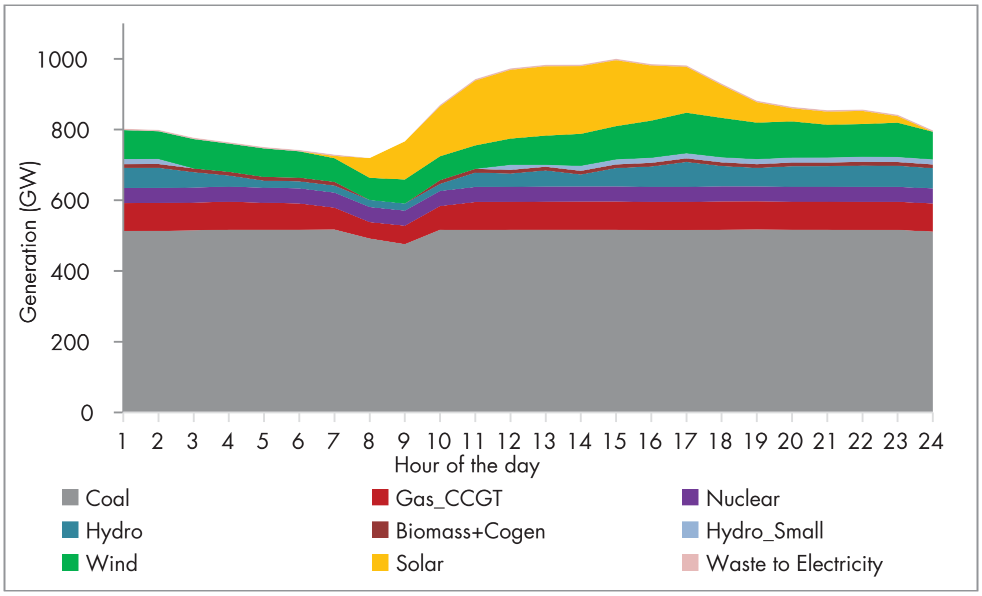

Figure 13c. Hourly National Dispatch for Max Load Day (June 3rd) – Low RE Scenario

3.5.4. Minimum Load Day

Insight: The following charts show the national dispatch for the minimum demand day which is 13th Dec, 2046 in each scenario. In case of low demand day, we can see potential renewable energy over-generation and some curtailment is needed in case of high RE scenario.

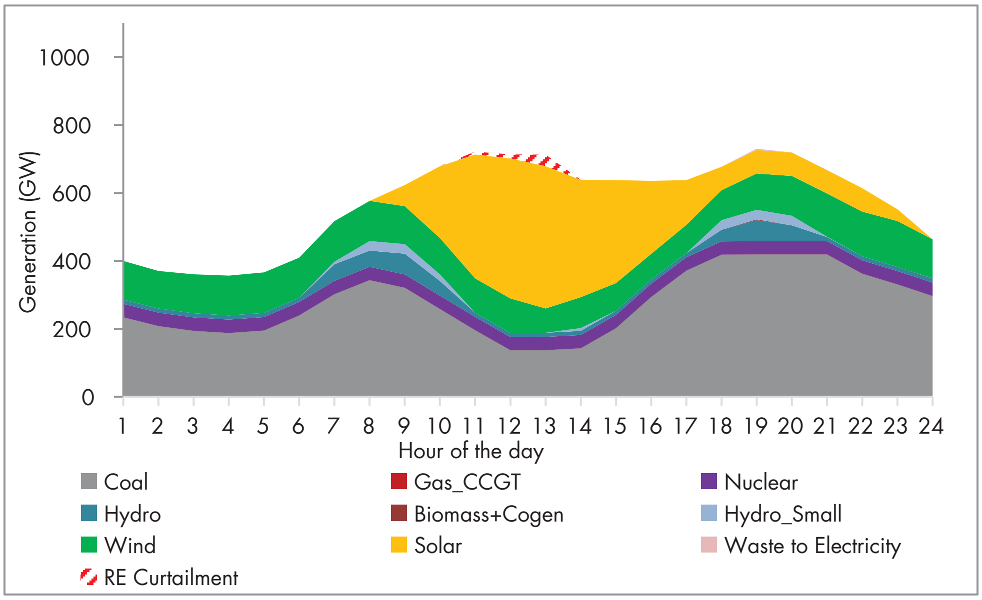

Figure 13d. Hourly National Dispatch for Minimum Load Day (Dec 13th) – High RE Scenario

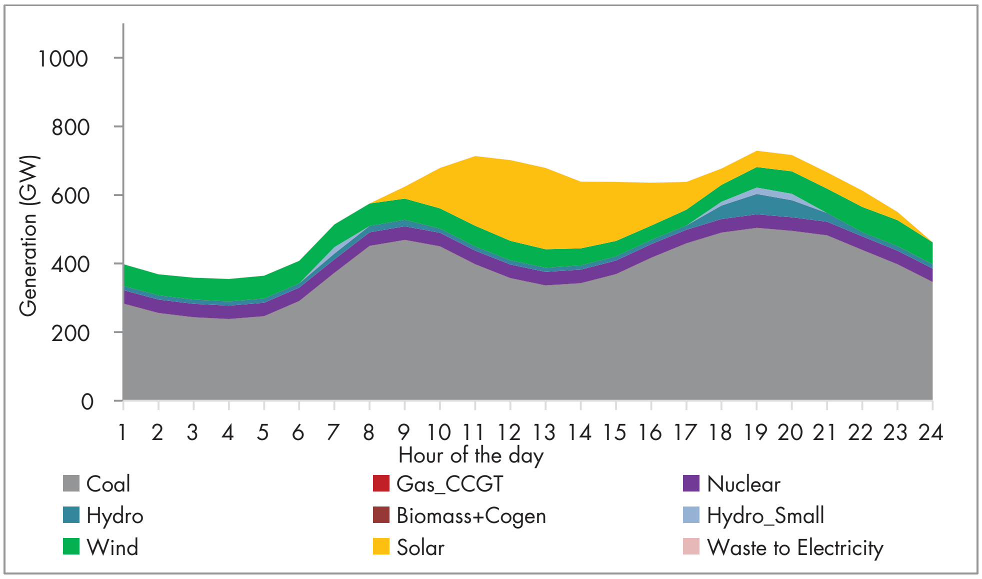

Figure 13d. Hourly National Dispatch for Minimum Load Day (Dec 13th) – Medium RE Scenario

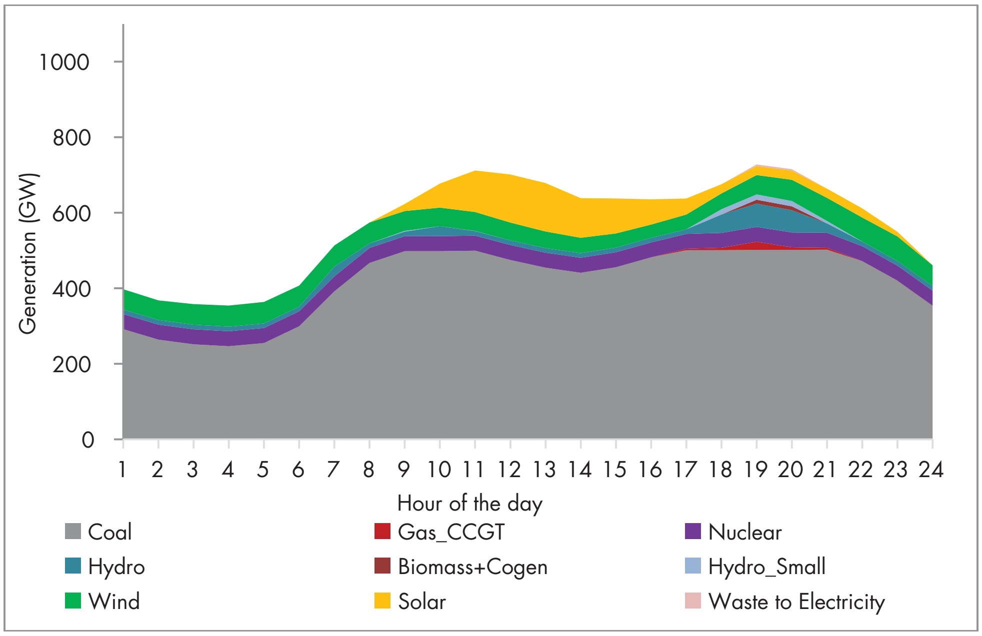

Figure 13d. Hourly National Dispatch for Minimum Load Day (Dec 13th) – Low RE Scenario

4. CONCLUSION

Aggressive RE capacity targets set by India calls for discussion on the policy and regulatory strategies to integrate RE in the Indian power system.

As evident from the research carried out for year 2046-47, the PLF of coal based power plants decreases from 87% in case of low RE scenario, 78% in medium RE to 54% in case of high RE scenario. Lower PLF of the coal based capacity in case of high RE scenario could imply that either the growth of coal based power plants has to curb or the system would not be feasible. On the other hand, given the amount of conventional capacity at Level 3 of IESS, there is a need for RE curtailment in case of high RE and medium RE scenarios implying energy loss. This means that we need significantly less coal capacity than required as per level III (aggressive pathway) of IESS to minimize the total cost and avoid lowering of capacity factors of coal power plants. But we would still need this conventional capacity irrespective of the level of RE capacity for meeting the evening peaks, especially winter peak in case we don't have any other economical or feasible option/s.

Level of curtailment can be avoided by integrating demand response as well as storage along with energy efficiency. The curtailed RE could then be stored and used as a flexible resource to ramp up and ramp down the system. The power system needs flexibility and peak support for reliable RE integration, and it need not be technology specific. Therefore, by year 2047, if any other economical sources start providing such services (for example, more flexible hydro dispatch with lesser constraints on discharge, demand response, batteries, other advance storage technologies etc.), the need for conventional based capacity addition would reduce significantly.

It is also important to note that RE forecasting is absolutely crucial for handling extreme events for reliable grid integration. With newer state-of-the-art forecasting techniques, forecast errors have been reducing rapidly especially with the use of the real-time generation data. With establishment of Renewable Energy Management Centers and the new forecasting regulations for the interstate RE generators, India has already started creating a robust framework for RE forecasting.

Integration of RE in the system also calls for discussion on the cost/commercial strategies. In the present research, we could not carry out the cost assessment of integrating various levels of RE on the grid, mainly because of uncertainty in assumptions related to cost and technology options in the year 2047, which leaves significant scope for future work.

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ANALYZING THE IMPACT OF CLEAN COAL TECHNOLOGY (CCT) ON THE OVERALL ENERGY SCENARIO

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Disclaimer: This research report is intended to inform decision-makers in the public, private and third sectors. Shri Manoj Kumar Upadhyay is Senior Research Officer in Energy, Climate Change and Overseas Engagement, NITI Aayog, Government of India. The views of writers is personal and it does not represent the views of either the Government of India or NITI Aayog. They are intended to stimulate healthy debate and deliberation in power sector. For any query please contact us on E-mail: energy-niti@ismger.nic.in and Telephone no.: 011-23042422

OBJECTIVES OF THE REPORT

The objective of the study was to analyse Clean Coal Technology scenario in India. While creating scenarios for clean coal technology, the objective was also to analyse Clean Coal Technology Share, Fund Requirement for Clean Coal Technology, Land Requirement, Coal Consumption and Import Dependence, Emission Reduction due to clean coal technology intervention in the medium term.

ACKNOWLEDGEMENTS

I would like to acknowledge NITI Aayog's Knowledge Partner, University of Petroleum and Energy Studies, Dehradun for providing critical inputs to this report. I also acknowledge suggestions and critical inputs given by delegates during NITI - IEEJ conference of Joint Study Project. Further, I would like to thank our Energy team colleagues and Shri Surinder Singh Sur, Joint Adviser (Energy), NITI Aayog for constructive guidance and discussions. I convey my special thanks to Shri Anil Kumar Jain, IAS, Additional Secretary (Energy), NITI Aayog for providing valuable oppurtunity to participate and lead clean coal technology in India as a part of the joint study project with IEEJ. I would like to acknwoledge Shri Harendra Kumar, Joint Advisor, who has initiated this study & provided able leadership to this project.

ABSTRACT

Clean Coal Technologies (CCTs) have been developed and deployed to reduce environmental impact of coal utilisation. Initially, the focus was on reducing emissions of particulates, SO2, NOX and mercury. The coal sector – producers, consumers and equipment suppliers for power plants - as well as governments and agencies in countries where coal is essential, have a long experience of clean coal technology deployment. Experience continues to grow as the technologies are introduced and spread in developing countries. The CCT focus in India has moved to the development and operation of low and near-zero GHG emission technologies like carbon dioxide capture and storage (CCS). IEA has identified four groups of CCTs (coal upgrading, efficiency improvements at existing power plants, advanced technologies and near-zero emission technologies) that can dramatically reduce GHG emissions. In the spirit of such an exercise, this report analyses what is possible share of CCT for India using India Energy Security Scenarios-2047 tool developed by the erstwhile Planning Commission and later refined by its successor NITI Aayog. The above Calculator allows us to adopt the more ambitious targets deemed feasible and consider the outcomes in terms of reduction in carbon emissions reduction, GHG Emission and Emission Intensity of GDP. This Report elaborates the multiple options of the share of Clean Coal Technology in power sector and policy interventions in this context. Interestingly, it is found that although most of the public attention is devoted to green sources of energy, about 86% of the mitigation potential in India comes from interventions focussing on energy efficiency measures, building better cities and encouraging behaviour changes among consumers. The remaining 14% comes from deploying low carbon technologies in the electricity and the fuels sector.

However, to see, the impact of low carbon technologies in the electricity sector, two scenarios of IESS, 2047, namely Business-As-Usual (i.e. Deterministic Effort) and Clean Coal Technology (i.e. Aggressive Effort) have been considered. Under CCT scenario, the share of electricity generation through coal based power plant will be around 55% in 2032. Therefore, it seems that coal will be major source for electricity even in coming years. Moreover, the share of Ultra-Super Critical technology is slowly being replaced by IGCC under this scenario. The Sub-Critical technology in coal based power plant is projected to retire by 2032. IGCC & Ultra-Super Critical technology will increase nearly 10 percentage point efficiency of the power plants in comparison to Sub-Critical & Super Critical technology. The IGCC & Ultra Super-Critical technology will reduce nearly 30% coal requirement and around 30-50% NOx, Sox, CO, Particulate Matter emissions.

Moreover, under CCT scenario, the land requirement may reduce by around 30-35% for the Ultra Super-Critical technology and coal import for coal power generation may fall by one-third. The capex per GW for Ultra Super-Critical technology will be nearly 1.2 time higher than Sub-Critical technology & Super-Critical technology by 2032.

Further, the outcome of this study indicates that electrostatic precipitators and fabric filters can

remove 99% of the fly ash from the flue gases and flue gas de-sulfurization reduces the output of sulphur dioxide to the atmosphere by up to 97%. Low-NOx burners allow coal-fired plants to reduce nitrogen oxide emissions up to 40%, further, if it is coupled with re-burning techniques, NOx can be reduced 70% and selective catalytic reduction can clean up 90% of NOx emissions. These mitigation measures & intervention of clean coal technologies will help to reduce overall emission intensity including power sector by 38% in 2032 & 52% in 2047 (at the base level of 2005 emission intensity).

1. INTRODUCTION

India is the world's third largest coal producing country and second largest coal importer. The country continues to significantly rely on coal for electricity generation, and this abundant and affordable fossil fuel accounts for 61 percent of the country's electricity output (FY16). As coal will continue to power a large – and possibly even increasing – share of the Indian economy in the foreseeable future, managing the negative side effects of the power industry due to environmental degradation should be seen as a continued priority. Over the past several decades, advancements in clean coal technology (CCT) have managed to reduce the power industry's negative environmental and health impacts across the globe but lot more needs to be done.

This report makes an attempt to explore the impact of Clean Coal Technologies in the Indian coal based power value chain, with the goal of reducing its environmental footprints. To address the said issue, an attempt has been made, both by examining existing literature on the subject and using modelling tool - 'Indian Energy Security Scenario, 2047 (IESS, 2047)'. The concept of CCT itself can be seen as an umbrella term, encompassing a wide array of technologies and innovations that can help reduce emissions – of fly ash, particles and gasses such as carbon dioxide (CO2), carbon monoxide (CO) and nitrous oxides (NOX). International Energy Agency (IEA) has "identified four groups of CCTs (coal upgrading, efficiency improvements at existing power plants, advanced technologies and near-zero emission technologies) which can dramatically reduce GHG [greenhouse gas] emissions".

This report attempts to explore the options India has by comparing the implications of two alternative scenarios (created by using IESS, 2047 tool) for clean coal technologies penetration and impact of CCT on GHG emissions that are consistent with achieving a high growth rate of GDP. One is a business-as-usual (BAU) scenario, which projects energy requirements, CCT penetration and its impact on GHG emissions if no special efforts are made. The other is an alternative Clean Coal Technology Scenario (CCT) scenario, based on strong action to increase penetration of CCT in coal based power generation, mitigate GHG emissions, promote greater energy efficiency and shift to cleaner energy sources.

2. CLEAN COAL TECHNOLOGIES

2.1. Subcritical technology

The most commonly used in coal-fired plants in India wherein powder coal is injected into the boiler and burned to raise the steam for subsequent expansion in a steam-turbine generator. Water flows through tube within the body of the combustor is heated toproduce steam at a pressure below the critical pressure of water (22.1 MPa[18]). Subcritical units are designed to achieve thermal efficiency typically up to 38 percent (Lower and Higher Heating Value, net) and not meet the performance of other CCT technologies. The cost of a subcritical unit is estimated to be from USD 600/kW to USD 1980/kW, approximately 10 percent to 20 percent lower than for a supercritical unit (IEA, 2007, 2012b).

2.2. Supercritical technology

Steam is generated at a pressure above the critical point of water, so no water-steam separation is required. Supercritical plants typically reach efficiency of 42 percent to 43 percent. The higher costs may be partially or wholly offset by fuel savings. The cost of a supercritical unit is estimated to be from USD 700/kW to USD 2 310/kW (IEA, 2011b).

2.3. Ultra-supercritical technology (USC)

This is similar to supercritical generation, but operates at even higher temperatures and pressures. Thermal efficiencies may reach 45 percent. Current Ultra Super Critical plants operate at up to 620°C, with steam pressures from 25MPa to 29MPa. The overnight cost of ultra-supercritical units may be ranging from USD 800/kW to USD 2530/ kW (IEA, 2007; IEA, 2011b).

2.4. Advanced Ultra-Supercritical (A-USC) technology

Using the same basic principles as USC, development of A-USC aims to achieve efficiencies in excess of 50 percent, which will require materials capable of withstanding steam conditions of 700°C to 760°C and pressures of 30MPa to 35MPa. Developing super-alloys and reducing their cost are the main challenges to commercialization of A-USC technology.

2.5. Integrated Gasification Combined Cycle (IGCC)

Coal is partially oxidised in air or oxygen at high pressure to produce fuel gas. Electricity is then produced via a combined cycle. In the first phase, the fuel gas is burnt in a combustion chamber before expanding the hot pressurised gases through a gas turbine. The hot exhaust gases are then used to raise steam in a heat recovery steam generator before expanding it

[18]Megapascal is a pressure measurement unit. 1 Megapascal = 9.86923267 atmosphere

through a steam turbine. IGCC incorporating gas turbines with 1500°C turbine inlet temperatures are currently under development, which may achieve thermal efficiency approaching 50 percent. IGCC plants require appreciably less water than Pulverised Coal combustion technologies. The overnight cost of current IGCC units ranges from USD 1100/kW to USD 2860/kW (IEA, 2011b). In OECD countries, the cost is estimated at about USD 2600/kW, but this number can vary by around 40 percent (IEA, 2011a).

3. METHODOLOGY OF PROJECTION

India Energy Security Scenario (IESS), 2047, an energy projection tool developed by NITI Aayog has been used for projecting clean coal technology scenario in India. The Business-As-Usual Scenario of Level 2 (Deterministic Effort) and Clean Coal Technology Scenario of Level 3 (Aggressive Effort) have been considered for projection. These scenarios have been created by assuming:

- GDP: 8.5% (CAGR) Growth 2012-2047,
- Population: 1.2 Billion (2012) - 1.7 Billion (2047),
- Urbanization: 31% (2012) - 51% (2047)
- Share of Manufacturing: 16% (2012) – 34% (2047).

The other national targets such as 175 GW of Renewable Energy by 2022, Housing for All by 2022, 100 Smart Cities by 2022 & INDC target have been taken into account for projecting aforesaid scenarios.

Business-As-Usual Scenario (BAU)

Under BAU scenario of IESS, 2047, the demand side and supply side has been kept on Level 2 i.e. Deterministic Effort or present policy level. Meanwhile, the renewable energy target of 175GW by 2022, housing for all by 2022, 100 smart cities by 2022 and meeting INDCs target by 2030 has been taken into consideration while selection of the scenarios. Further, to meet the aforesaid target the supply side has been adjusted with level 3 & 4 i.e. Aggressive Effort and Heroic Effort.

Clean Coal Technology Scenario (CCT)

Under CCT scenario, the demand side and supply side has been kept on Level 3 i.e. Aggressive Effort. In both scenarios, the total installed capacity and coal based installed capacity are different. Meanwhile, the efficiency of the coal based power plant has been set at level 3 to see the penetration and efficiency impact of clean coal technology in the power plant. Further, the second generation fuel has also been set on higher side then business-as-usual scenario.

4. CURRENT POLICY SCENARIO

4.1. Status of Power Sector

As on 31.3.2017, the installed capacity of Power Plants (Utilities) was about 3,19,606.30 MW. The electricity generation was 903 BU (including imports) in the year 2016-17. The per capita consumption of electricity in the country was about 1,010 kWh in the year 2014-15 and 1075 kWh (provisional) in the year 2015-16. Further, out of 5,97,464 census villages, 5,93,225 villages (99.2%) have been electrified as on 31.03.2017. Moreover, Regional grids have been integrated into a single national grid with effect from 31.12.2012, thereby providing free flow of power from one corner of the country to another through strong inter regional AC and HVDC links. The All India peak demand (MW) as well as energy (MU) shortage have registered steady decline. The peak shortage and energy shortage was 1.6 % and 0.7 % respectively during the year 2016-17.

4.2. Generation Plan[19]

As on 31.3.2017, 12th Plan (2012-17) capacity addition from conventional sources was 99,209.47 MW (Thermal – 91,73.45 MW, Hydro – 5,479.02 MW, Nuclear – 2,000 MW) against a target of 88,537 MW. This was about 112% of the target. Further, during 12th Plan, capacity addition from supercritical technology based coal power plants was around 39% of the total capacity addition from coal based plants. Further, as on 31.03.2017, India has achieved a total installed capacity of 50,018 MW from Renewable Energy Sources. The country has revised its Renewable Energy capacity target to 175 GW installed capacity by the year 2021-2022.

Moreover, a capacity addition of about 22,470 MW (Coal & lignite – 0 MW, Gas – 4,340 MW, Hydro 15,330 MW, Nuclear -2800 MW) will be required from conventional energy sources in the country during the years 2017-22 against 99,209.47 MW capacity during the 12th Plan. Although, the capacity addition from coal based power plants is estimated to be zero, a total capacity of 50,025 MW coal based power projects are currently under different stages of construction and are likely to yield benefits during the period 2017-22.

Further, an additional capacity of about 60,885 MW (Coal - 44,085 MW, Nuclear -4,800 MW, Hydro-12,000 MW) will required from conventional energy sources in the

[19]As per CEA, National Electricity Plan Report

country during the years 2022-27. Considering 22,470 MW capacity addition from conventional energy sources during 2017-22 and target capacity addition of 1,00,000 MW from Renewable Energy Sources during 2022-27, it is expected that the share of non-fossil based installed capacity (Nuclear + Hydro + Renewable Sources) will increase to 52 % by the end of 2021-22 and will further increase to 57 % by the end of 2026-27. The Renewable Energy Generation will contribute about 20.3 % and 24.2 % of the total energy requirement in 2021-22 and 2026-27 respectively.

Incremental energy savings due to implementation of various energy saving measures, during the year 2016-17, 2021-22 and 2026-27 would be 26 BU, 137 BU and 204 BU respectively. The projected Peak Demand will be 235 GW and Energy requirement will be 1,611 BU (after considering DSM measures) at the end of 2021-22 which is around 17% and 15.4 % lower than the corresponding projections made by 18th EPS report. The projected Peak Demand will be 317 GW and Energy requirement will be 2132 BU at the end of 2026-27 which is around 20.7% and 21.3 % lower than the corresponding projections made by 18th Electric Power Survey (EPS) report.

4.3. Coal Requirement[20]

The total coal requirement in the year 2021-22 and 2026-27 has been estimated as 727 MT (Scenario – I with 175 GW installed capacity from RES by 2021-22) and 901 MT respectively including imported coal of 50 MT. The coal requirement for the year 2021-22 and 2026-27 have been worked out considering 30% reduction in Hydro generation due to failure of monsoon and being supplemented by coal based generation.

4.4. Gas Requirement[21]

It has been stated that, against a total domestic natural gas allocated to power projects of 87.46 MMSCMD, the average gas supplied to these gas based power plants during the year 2015-16 was only 28.26 MMSCMD. It has been estimated that the gas based stations shall need 53.56 MMSCMD of gas to meet the balancing requirement of the grid arising due to RES integration.

4.5. Fund Requirement for generation capacity addition[22]

The total fund requirement for generation capacity addition is estimated to be Rs.10, 33,375 crore during the period 2017-2022 which includes the funds required for RES capacity addition, as well as the expenditure done during this period for the projects coming up in the year 2022-27. The total fund requirement for the period 2022-27 is estimated to be Rs. 6,05,965 crore which does not include advance action for projects coming up during the period 2027-2032.

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[20]As per CEA, National Electricity Plan Report

4.6. CO2 emissions reduction[23]

The total CO2 emissions for the year 2021-22 and 2026-27 is estimated at 983 million tonnes and 1165 Million tons respectively. The current (2015-16) average CO2 emission factor is estimated at 0.732 kg CO2/kWh (Including renewables). It is expected that this average CO2 emission factor may reduce to 0.581 kg CO2/kWh in the year 2021-22 and to 0.522kg CO2/kWh by the end of 2026-27.

Emission intensity kgCO2/GDP (Rs) from grid connected power stations is likely to reduce by 43 % by the end of 2021-22 and 53.96 % by the end of 2026-27 from the year 2005 level. It is estimated that 6.073 Million tonnes of CO2 emissions has been avoided during 2015-16 due to commissioning of Super-critical technology based coal power plants. The estimate is based on the assumption of commissioning of sub critical technology based units under BAU scenario. It is estimated that about 268 Million tonnes of CO2 emission will be avoided annually by the end of the year 2021-22 from renewable energy sources.

5. OUTCOMES OF THE SCENARIO

5.1. Clean Coal Technology Share

BAU scenario shows that based on projected yearly growth basis, share of Ultra Super-Critical technology (USC) in total generation capacity of 848 GW in 2032 &1566 GW in 2047 be 35% in 2032 & 60% in 2047. However, share of IGCC technology is projected to be lower at 10% in 2032 & 40% in 2047. CCT scenario shows that the USC will increase to 45% in 2032 & 40% in 2047 and share of IGCC technology will be 15% in 2032 & 60% in 2047. The share of USC is slowly being

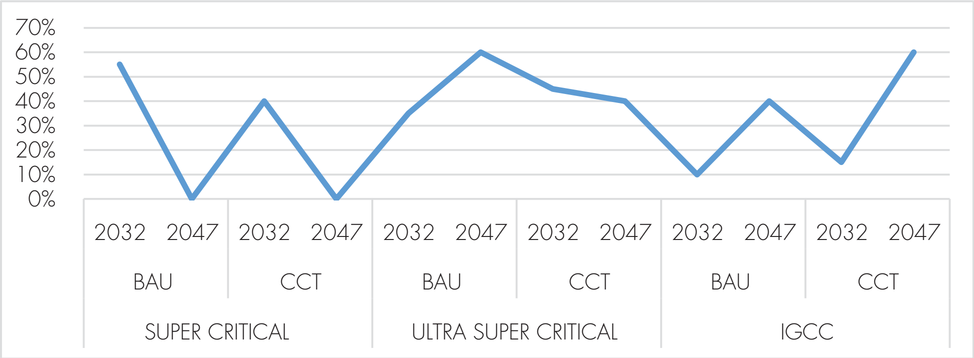


Figure 1: % Share of Clean Coal Technologies (year on year basis)

[21]As per CEA, National Electricity Plan Report
[22]As per CEA, National Electricity Plan Report
[23]As per CEA, National Electricity Plan Report

replaced by IGCC under CCT scenario. The Sub-Critical technology in coal based power plant is projected to retire by 2032.

5.2 Fund Requirement for Clean Coal Technology

The capex requirement per GW, under IGCC technology will be nearly twice over Sub-Critical technology & Super-Critical technology by 2047 in CCT scenario. The capex per GW, under Ultra Super-Critical technology will be nearly 1.2 time higher than Sub-Critical technology & Super-Critical technology by 2032.

Moreover, IGCC & Ultra-Super Critical technology will increase nearly 10 percentage point's efficiency of the power plant in comparison to Sub-Critical & Super Critical technology. The IGCC & Ultra Super-Critical technology will reduce nearly 30% coal requirement emissions by around 30-50% across NOx, SOx, CO, Particulate Matter and Raw Water Usage.

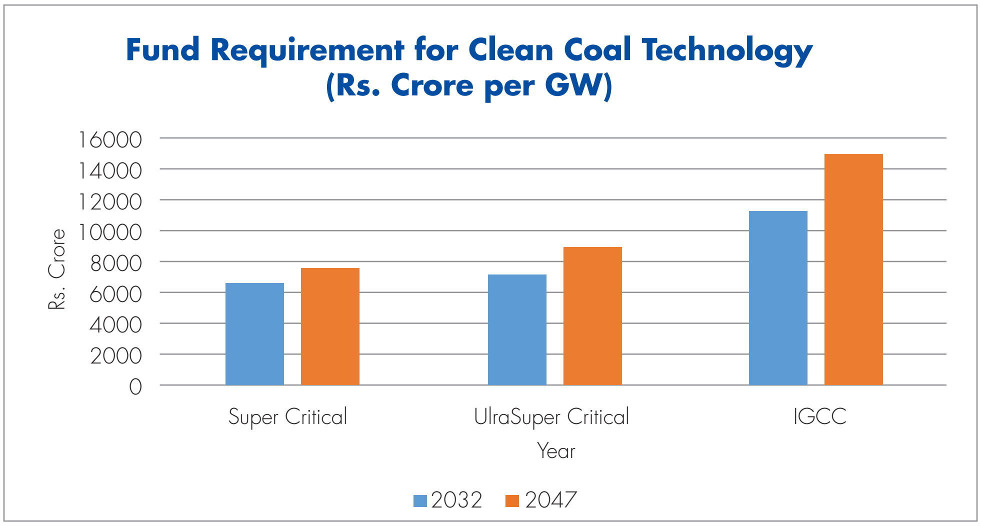


Figure 2

5.3 Land Requirement

The land requirement for clean coal technologies will depend upon the designing of power plant. For example, if vertical/tower type boiler is taken into design (like ISOGO Power Plant, Japan) then land requirement may reduce by around 30-35% for the Ultra Super-Critical technology.

5.4 Coal Consumption and Import Dependence

The above mentioned CCT share in CCT scenario will reduce 33% coal import for coal power generation. The hydro carbon fuel requirement by power sector will also reduce by nearly 30% in 2032 & 39% in 2047 at 2012 base level.

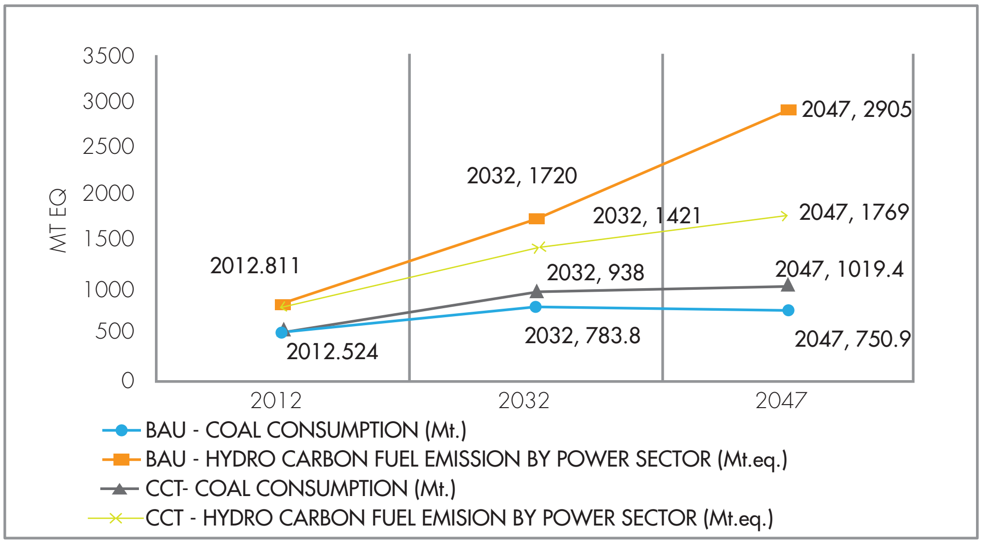


Figure 3: Coal Consumption

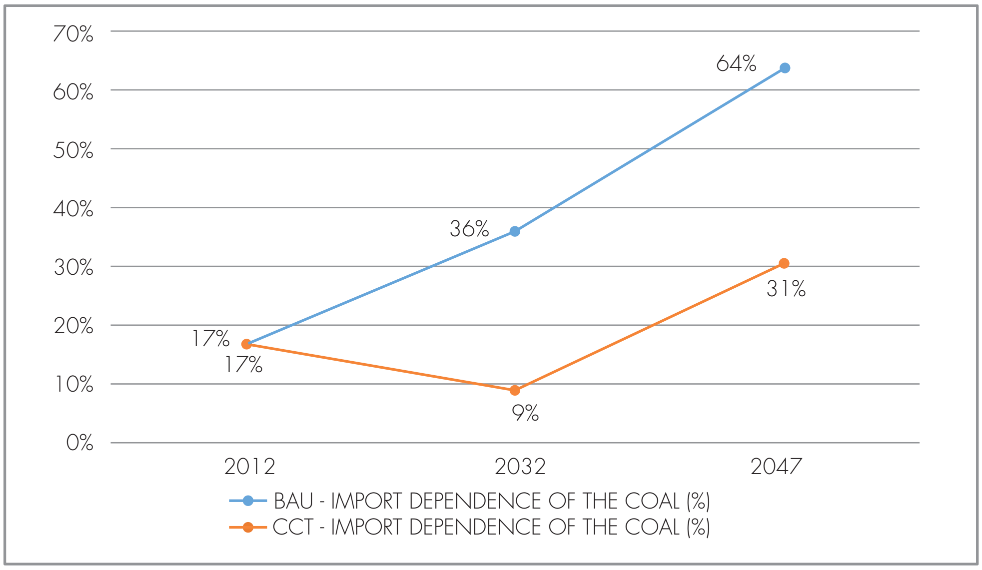
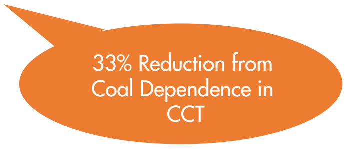


Figure 4: Import Dependence



5.5 Emission Reduction

Due to intervention of clean coal technologies, emission intensity will reduce by 38% in 2032 & 52% in 2047 at the base level of 2005 emission intensity under CCT scenario. If the above projected scenario is implemented by Ministry of Power, India will easily meet the INDC target and even surpass these targets.

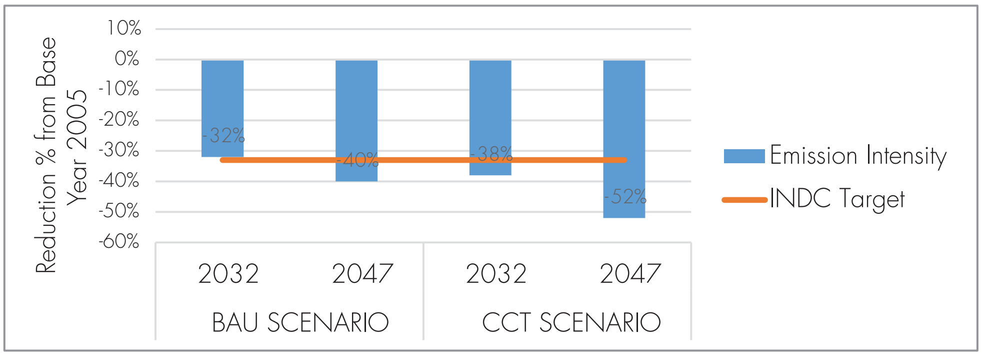


Figure 5: Emission Intensity

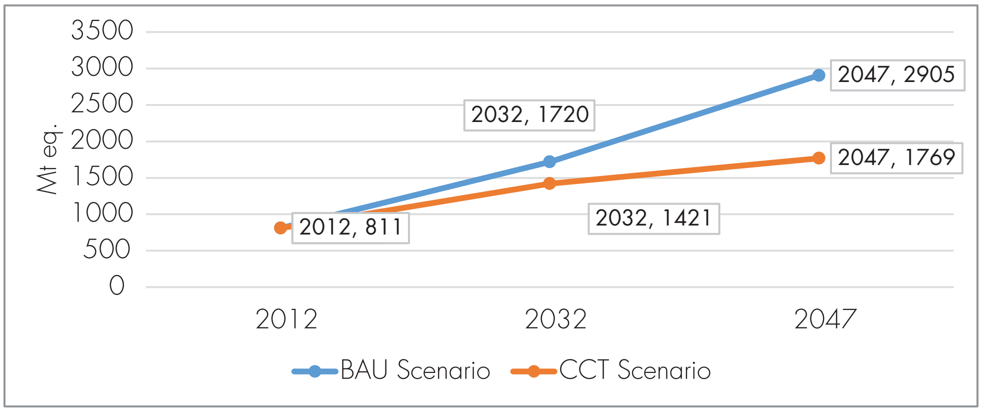


Figure 6: Hydro Carbon Fuel Emission by Power Sector

5.6 Electricity Generation Mix

The share of electricity generation through coal based power plant will almost be around 55% in 2032 under BAU scenario and 50% in 2032 under CCT scenario. Therefore, it seems that coal will be major source for electricity even in coming years.

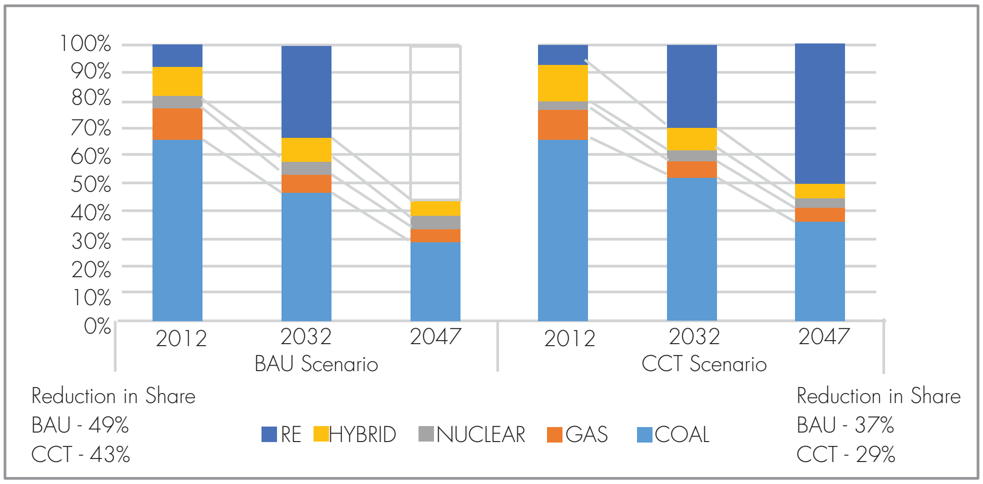


Figure 7: Electricity Generation Mix

6. CONCLUSIONS

The main conclusions from this report can be summarised below:

1. As on 30th June, 2015, India had 11.35% share of supercritical technology based power plant in the total coal based power plant capacity. Further, during 12th Plan, capacity addition from supercritical technology based coal power plants is likely to contribute around 39% of the total capacity addition from coal based plants. Moreover, to achieve NDC target and Paris Agreement, India needs to increase its share of clean coal technology from 11.35% to 50% by 2047 under BAU scenario and 80% under CCT scenario by 2047.

2. The CCT scenario explored that India can reduce the trajectory of GHG emissions substantially. This requires a dedicated and persistent action to reduce the energy intensity of GDP in many sectors, especially in industries and also to shift the composition of energy supply towards green sources. Although, this scenario still leaves per capita emissions level in 2047 at a high level in the context of global carbon constraints, it does demonstrate that India could peak GHG emissions before the mid-century if there is a concerted global effort to achieve ambitious goals.

3. Under CCT scenario, the social and environmental costs of the power generation will reduce as Clean Coal Technology will reduce CO2, SOX, NOX and particles in the air, water contamination and uses carbon as material for co-production.

4. Although, public attention focuses heavily on green energy sources, almost 86 % of the reduction in emissions in our low-carbon scenario comes from action on the demand side to improve energy efficiency and only 14% from the supply side. This is partly because the technologies in use, and the systems we have, are far less energy efficient than is now possible. This highlights the importance of supporting the development and deployment of energy-saving technologies, encouraging behavioural change amongst consumers, supporting and creating the systems for sustainability in grid networks, public transport, urban areas and many others.

5. Although, no single policy intervention will address the structural changes needed to move to the CCT scenario path, energy pricing is critical. Prices of fossil fuels should be set at levels which not only avoid subsidies, but ideally, also reflect social costs associated with fossil fuels. This will incentivise savings in the use of these fuels and encourage shift to greener energy. The revenues earned from taxes that penalize fossil fuels could be used to encourage energy-saving technologies, foster R&D on clean energy, or support the building of sustainable infrastructure programmes and also protect the poor.

6. Rational energy pricing can be supported by regulatory measures that can help to push towards more energy-efficient technologies and less polluting systems. Well-designed regula-

tion, with clarity about policy in the longer term, supported by a rational approach to energy pricing and policy can make a big difference. It will create an environment which develops confidence and encourages investment.

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