Lappeenranta University of Technology
Faculty of Technology
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Mitigation possibilities to Greenhouse gas emissions from power production in India

Lappeenranta, 26 Nov 2013

Examiners: Professor Risto Soukka
Professor Lassi Linnanen

ABSTRACT

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Global warming is assertively the greatest environmental challenge for humans of 21st century. It is primarily caused by the anthropogenic greenhouse gas (GHG) that trap heat in the atmosphere. Because of which, the GHG emission mitigation, globally, is a critical issue in the political agenda of all high-profile nations.

India, like other developing countries, is facing this threat of climate change while dealing with the challenge of sustaining its rapid economic growth. India's economy is closely connected to its natural resource base and climate sensitive sectors like water, agriculture and forestry. Due to Climate change the quality and distribution of India's natural resources may transform and lead to adverse effects on livelihood of its people. Therefore, India is expected to face a major threat due to the projected climate change.

This study proposes possible solutions for GHG emission mitigation that are specific to the power sector of India. The methods discussed here will take Indian power sector from present coal dominant ideology to a system, centered with renewable energy sources. The study further proposes a future scenario for 2050, based on the present Indian government policies and global energy technologies advancements.

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Sridhar Sekar

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LIST OF ACRONYMS AND ABBREVIATIONS

AHWR	Advanced Heavy Water Reactors
BCM	Billion cubic meters of natural gas
BIPV	Building Integrated Photovoltaic
CCGT	Combined Cycle Gas Turbine
CCI	Clinton Climate Initiative
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CEA	Central Electricity Authority
CSLF	Carbon Sequestration Leadership Forum
CSP	Concentrated Solar Power
C-WET	Center for Wind Energy Technology
EIA	Energy Information Administration
EOR	Enhanced Oil Recovery
GBI	Generation Based Incentives
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GWEC	Global Wind Energy Council
ICOSAR	Indian CO_2 Sequestration Applied Research
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producers
ISGTF	India Smart Grid Task Force
JNNSM	Jawaharlal Nehru National Solar Mission
LCOF	Low Carbon Optimistic Future Scenario
MNRE	Ministry of New and Renewable Energy
Mtpa	Million metric tons per annum
NAPCC	National Action Plan on Climate Change
NERP	National Rural Electrification Policies
OECD	Organization for Economic Co-operation and Development
REC	Renewable Energy Certificate
RPO	Renewable Purchase Obligation
RPS	Renewable Purchase Specification
SHP	Small Hydropower
WEO	World Energy Outlook
WNA	World Nuclear Association

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1 INTRODUCTION

Global warming is the most important topic discussed worldwide, which has the menacing potential to mark the ultimate end of man's existence. Former U.S. Vice President, Al Gore describes it as the greatest environmental challenge for humans in the 21st century. Global warming is chiefly attributed to anthropogenic greenhouse gas emissions that trap sun's heat in the earth atmosphere. Based on the method of causation, Global warming is divided into natural and anthropogenic types. While the former is desirable for existence of life in earth, the latter should be abated.

Naturally, part of the solar energy coming to earth is absorbed by the planet and remaining is radiated back to space. However the GHGs present in the atmosphere absorbs a larger portion of this radiated energy and again radiate back to earth, creating natural global warming. On the other hand, substantial amount of GHGs are pumped into atmosphere via human activities, which is called the anthropogenic global warming. Statistics says that, since the industrial revolution, there has been a steady increase in the concentration of various greenhouse gases in the atmosphere.

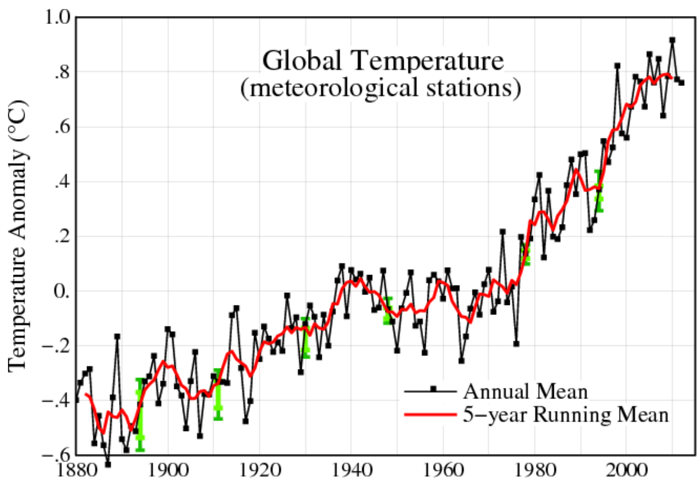


Figure 1: Global mean surface temperature between 1880 and 2007 (NASA, 2013)

The Intergovernmental Panel on Climate Change (IPCC) indicates through its climate change model projections that there will be further rise in average global temperature between 1.1 and 6.4°C comparing to the period 1980-1999.The most prominent emitters of GHGs are the conventional power plants producing electricity from fossil fuel combustion. In the effort to mitigate this problem, various nations are taking multidimensional initiatives.

1.1 India's Background

India is the seventh largest country in the world with a population of 1.2 billion, accounting over 17% of world's population and is stepping towards unquenchable thirst for energy. It is the fifth largest consumer of energy in the world, accounting for 3.7% of the total consumption of world and its total electricity demand is expected to grow by six fold in 2050, compared to 2010.

India faces a challenge of sustaining its rapid economic growth while maintaining its carbon emission level to alleviate climate change. India, with its economy linked closely to its natural resources and climate sensitive sectors like agriculture, water and forestry, climate change will pose a major threat to the livelihood of its people.

The country, geographically, is well-endowed with both renewable and exhaustible resources. In addition, unlike few other nations, India has wider spectrum of choices to develop a pathway for ecologically sustainable growth, because it is at an early stage of development. On the other hand, moving away from coal till 2030 is not a possible solution given the time taken for developing new technologies for power production and the aspirations of India's GDP growth. This will lead to inevitable growth in CO_2 emissions in the future.

This study assesses how a scenario made by a range of low carbon technologies could help India in attaining healthy energy growth while remaining relatively at low level of CO_2 emissions over the next four decades, in spite of significant economic growth and development.

The study is an attempt to find the available emission mitigation options on energy sources specific to India's greenhouse gas emission. Although, in global perspective, there are several options available for emission control and green power production, this study comprehends only five non-conventional technologies, namely Solar, Hydropower, Wind, Nuclear and Biomass and two methods for conventional technologies, namely Carbon capture and storage and Energy efficiency improvement.

The mitigation options discussed in this report are chosen based on two criteria. First is that the methods are given adequate interest by the Indian government's future policies. Solutions like Solar power, Wind and Nuclear power are seen occupying significant share in the energy policy. The second criterion is the technical feasibility of the specific option. Even though solar power is not widely spread in the country, the potential of the technology is immense in India and therefore is seen as a viable option for future.

In the last section of the study, three scenarios for power generation are discussed. These three scenarios are developed using GaBi 6.0 – product life cycle analysis software, using the available energy options in India. Two of the three scenarios are projections for the year 2050.

1.2 Energy Outlook of India

Since 2000, the economy of India grew at an annual rate of approximately 7 percent. In 2011, India stands fourth in world as the largest energy consumer after the United States, China and Russia. According to International Energy Outlook (EIA, 2013) by EIA, India and China will be the biggest driving force for Asian energy demand growth through 2035.

India's energy policy primarily focuses on energy security for its growing energy demand. Between 1990 and 2011, the primary energy demand of India has more than doubled. However, the per capita energy consumption of India remains still lower than the global level. India is very dependent on imported crude oil, despite having large coal reserves and recording healthy growth in natural gas production in the past two decades. (EIA, 2013)

The major energy sources of India are Coal, petroleum and traditional biomass. According to IEA, the industry is mostly fueled by traditional biomass, representing over 40 percent of India's total primary energy demand. The fastest growing area of energy demand is power sector, recording growth from 23 percent to 38 percent in total energy consumption between 1990 and 2009. (EIA, 2013)

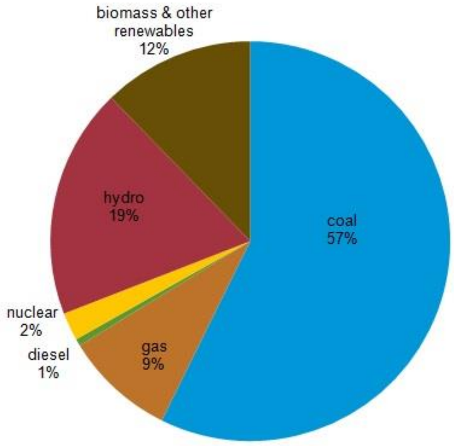


Figure 2: Installed power capacity of India, 2011 (EIA, 2013)

The total installed electricity geenrating capacity of India is 211 GW, as of September 2012. As shoẃn in Figure 2, themajority share is from coal-fired power plants. Next to it, hydropower takes the position with about 20% share in installed capacity.

India's Five-Year Plans

Indian government economic policies are implemented through five-year plans that are developed , executed and monitored by the Planning Commission. After India becoming a republic, the first five-year plan was introduced in 1951. In the beginning period of development, the main objective of the five-year plan was the GDP growth. However, in the recent plans, there are also other dimensions of economic growth like reversing the decelaration trend of agricultural growth and providing health services and education to all nationals. In addition, the role of state government in meeting the goal has been expanded in recent years. The state governments will receive substantial assisstance from central government to meet the targets. (IEA, 2007)

Coal

After China and USA, India is the third largest coal producer with 557.6 million tons, which represents 6.2 % of world's total coal production. Coal being the most abundant natural resource, it continues to be the predominant source to meet domestic energy needs. It accounts for 69% of the electricity sector supply and 55% of the total energy supply. One estimate indicates that the coal reserves up to 1200 m in India are 276.8 billion tons, contained in a coal bearing area of 22400 sq. km (Kumar, et al., 2012). However, owing to the inferior quality of domestic coal, they are not suitable for modern thermal power plants.

In the recent years, the demand for coal has rapidly grown in accordance with country's growth in coal-fired power plants and coal based industries. The demand is projected to grow by 11% a year, reaching 135 million tons in 2011-12, among which, up to 20% is imported. India exports coal to its neighboring countries, even though it is insignificant compared to its import figures.

Oil and Natural Gas

According to latest estimate in 2010, India has around 0.4% of the world's proven reserves of crude oil, 1201 MMT of crude oil and 1437 BCM of natural gas. Even though the domestic production of crude oil has increased significantly, the import of oil has increased by almost 15 folds between 1970-71 and 2009-10. In the recent years, natural gas consumption of India has risen faster than any other fuel. The demand of it has been growing at a rate of 6.5% per year during the last decade. (Kumar, et al., 2012)

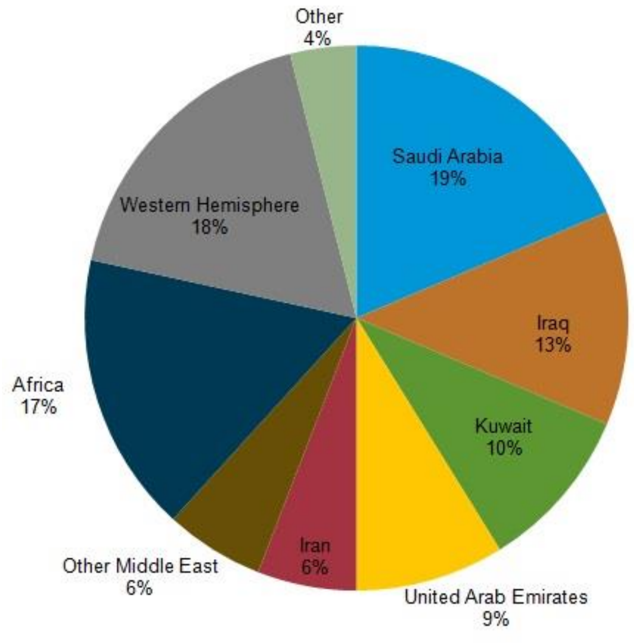


Figure 3: India crude oil imports by source, 2012 (EIA, 2013)

India has increased its oil imports from 40 percent of demand in 1990 to more than 70 percent of the demand in 2011. The largest supplier is Saudi Arabia with about 19 percent of oil imports (Refer to Figure 3). The second largest is Africa (17 percent), with majority of that share coming from Nigeria. (EIA, 2013)

Nuclear

As of 2010, India generates 4780 MW of power through 20 nuclear reactors. The nuclear sector of India is undergoing rapid expansion with plans to increase the total output to 64,000 MW by 2032. Recent estimate shows that India's known commercially viable reserves are from 80,000 to 112,000 tons of uranium. Even if India's nuclear output quadruple to 20 GW by 2020, it would only consume 2000 metric tons of uranium per annum, leading to 40 to 50 years of sufficient fuel supply for nuclear power. (Kumar, et al., 2012)

1.3 Existing Scenario for 2050

The scenario taken as a reference for 2050 in this study is developed by AVOID program. The 'Avoiding Dangerous Climate Change (AVOID)' program was formed in 2009 by UK government to seek advice to avoid GHG emissions that cause potentially dangerous climate change (Met Office, 2013). In the study conducted by AVOID program on India's emissions, two low-carbon scenarios are considered. The first scenario is with no specific technology limitations and the other with a number of limitations like no CCS to be deployed in future.

1. Reference Scenario

The reference scenario is in which India would deploy all the cost effective technologies in power sector without any specific policy constraints and with no CO_2 constraints. As a part of this pathway, India would prefer energy efficiency options that are cost saving over the long run. It is obvious that the reference scenario is unrealistic, as the political decisions and international obligations would prevent to adopt these options. (Gambhir, et al., 2012)

2. Low Carbon Scenarios

Two low carbon scenarios are developed by Avoid. They both operate under the constraint that the per capita CO_2 emissions of India will reach 1.3 tCO_2 per person per year by 2050. This constraint is fixed based on the projection of global per capita CO_2 emissions, which is converging to this level to reach the global CO_2 emissions of 12 $GtCO_2$ in 2050 (Gambhir, et al., 2012). Assuming that the low carbon emission policies are followed post 2050, this pathway provides us a 50% chance to contain the global warming to 2 °C rise.

LC1 – First Low Carbon Scenario

LC1 was formed by TIAM-UCL model. Providing with the CO_2 constraint, the model is allowed to choose the technologies for India without placing any additional constraints. The thus formed result is consulted with reviewers for feasibility of each technology within India.

LC2 – Second Low Carbon Scenario

Based on the comments from the reviewers on the first low-carbon scenario, the LC2 is designed. The comments and their respective constraints are listed below.

Table 1: Comments and conditions of low carbon scenarios

Comments on LC1	**Conditions for LC2**
Biomass availability for power generation is uncertain due to agricultural needs.	Biomass in power generation is restricted to 35 GW.
CCS technology is uncertain in India.	No CCS implementation
India's emission would not peak until after 2020 because of large amounts of unabated coal power plant emissions.	The emissions are allowed to grow as per the reference scenario until 2030 and then reduction is achieved.
Less wind than expected, given likelihood of good resource potential	Wind increases as a result of the restriction of biomass and CCS

India faces a big challenge of developing a power generation system that comprises the future demand while keeping the CO_2 emissions under control. India is in a favorable position to choose the low carbon methods because most of its power generating technologies in 2050 will be a new build. India's energy demand is in rapid increase in recent years. The electricity demand growth-rate between 1995 and 2008 is 5.3% per annum.

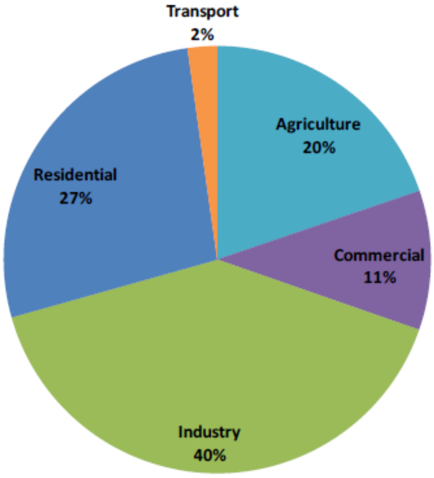


Figure 4: Share of Electricity Consumption by end user demand in 2010 (Gambhir, et al., 2012)

The above figure shows the share of electricity consumption by 2010. It is clear from the figure that Industry and Residential sectors are the major areas of power consumption. Although the plant load factor of India is improved from 52% in 1980s to now around 79%, it is still inefficient compared to international standards. Almost all the running coal plants are sub critical technology and operate with an average efficiency of around 33 percent. One reason for this low efficiency is due to the high-energy consumption, low maintenance of auxiliary power plant equipment.

In addition, India has high transmission and distribution losses of about 25 % compared to 10 % in developed countries. Because of these difficulties in power generation and distribution, India faces electricity supply shortages and high emissions factor. In NAPCC, India aims to support and deploy energy efficient technologies to power plants, including market based mechanisms, innovation and fiscal instruments.

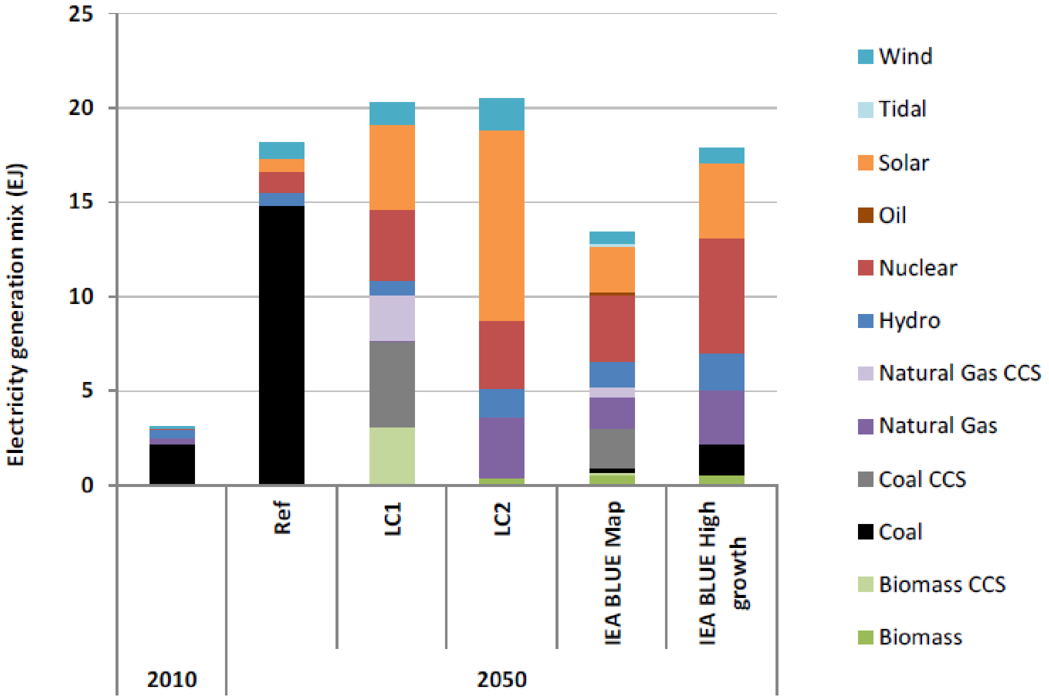


Figure 5: Electricity Generation mix for different scenarios (Gambhir, et al., 2012)

In 2010, the total installed capacity is 183 GW wit electricity generation around 3.1 EJ. Indian electricity generation is dominated by fossil fuel technologies, with more than 80% of electricity generation from them. Nearly 50% of electricity generation is from coal-fired power plants and an additional 16% is from gas and oil power plants. On the other hand, the share of renewable in the generation mix is on rapid increase. Among the current renewable capacity, Hydropower contributes a bulk share with an installed capacity of 40 GW. Presently, nuclear power shares only a small percentage in the generation mix. However, the GOI has an active indigenous nuclear power program and aiming for 25% of power generation from nuclear by 2050. (Gambhir, et al., 2012)

In the reference scenario, the electricity demand is projected to increase by six fold, reaching 18.2 EJ by 2050. As there are no constraints placed, coal is the dominant fuel for power generation with an installed capacity of 563 *GW*. Both gas and oil are completely replaced by wind, solar and nuclear, proving that these technologies will be cost effective over time.

Coming to low-carbon scenarios, decarbonizing the power sector is the important role in emission reduction. The electricity generation is higher compared to reference scenario. In the first low-carbon scenario, CCS is extensively implemented to decarbonize the power sector. By 2050, almost all the non-CCS coal plants are phased out, whereas CCS installed power plants would reach 158 GW for coal, 98 GW for gas and 111 GW for biomass. It is uncertain that CCS is feasible to this extent in India. Due to the prevalent problem of low efficiency of power plants, an additional load of CCS would be severely opposed. In order to deploy CCS successfully, a significant penetration of super- and ultra-super-critical (SC and USC) technologies is required. (Gambhir, et al., 2012)

In the second low-carbon scenario, CCS is completely excluded, switching coal to renewable and unabated gas. It will contribute de-carbonization to most of the power sector. The non-fossil fuel power contributes to more than 80% of the total installed capacity, mainly comprising solar (800 GW) and wind power (229 GW). The projection for solar power is higher than the IEA's estimates. This projection is based on the technical potential and it is a key renewable energy for India. According to JNNSM, by 2022, the GOI has set a target of 22 GW of solar PV modules with appropriate initiatives to improve the manufacturing capabilities.

Emissions

Indian coal power plants are carbon intensive with emission at about 980 gCO2/kWh in 2010. It is due to ageing, poor maintenance and low efficiency of the power plants. Considering the national action plan for energy efficiency improvements, the emission intensity of electricity is projected to around 500 gCO2/kWh in 2050 in the reference scenario. The position of coal in electricity generation mix is not significantly changing and it will make up 70% of total power generation. This leads to an average emission intensity of electricity as 700 gCO2/kWh in 2050. (Gambhir, et al., 2012)

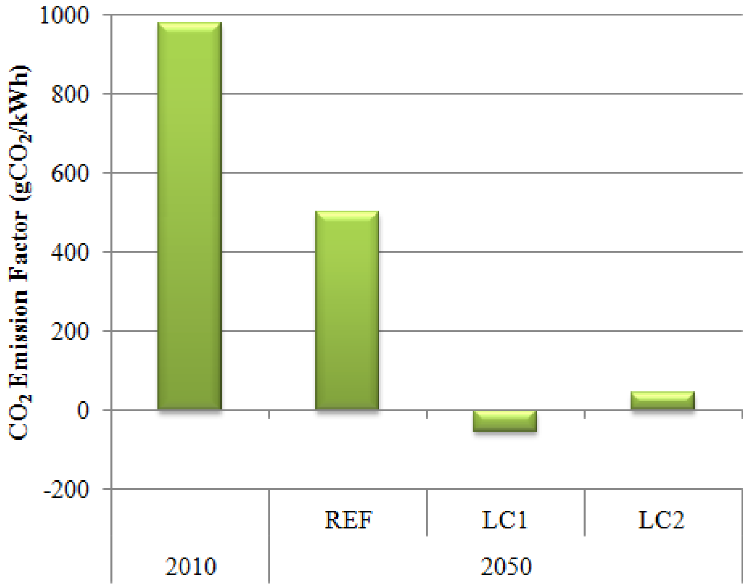


Figure 6: CO_2 Emission Factor for different scenarios

Interestingly, the first low-carbon scenario results in a net negative electricity emission factor of -55 gCO2/kWh by 2050. It is due to the application of CCS to biomass plants and electricity generation from other sources with zero or near-zero carbon emission. Even though the scenario is technically feasible, the achievement of the result remains highly uncertain because the technology to combine CCS with biomass power plants is not yet commercially implemented. The second low-carbon scenario (LC2) is having an average emissions factor of 45 gCO2/kWh. For India, this target is highly ambitious owing to the present high emission factor 980 gCO2/kWh. However, the target is in line with the aspirations of other developed regions. For instance, the climate change committee of UK has indicated that this target is achievable by 2030 in the UK.

1. Solar

Scenarios and their targets in 2050

REF	LC1	LC2
63 GW	360 GW	800 GW

Present status of Solar Technology:

- Solar PV has made some impact in rural applications of India

- Concentrated Solar Power (CSP) is a mature technology worldwide. However, in India, it is yet to be implemented and the government has planned many such projects around the country.

Challenges to scale-up in future:

- In future, there could be material resource constraints for developing solar PV.
- To achieve the required level of solar PV installation, India needs to improve its manufacturing capability of silicon wafers.

2. Wind

Scenarios and their targets in 2050

REF	LC1	LC2
112 GW	140 GW	229 GW

Present status of Wind Technology:

- India stands 5^{th} in world in wind power capacity with installed capacity of 15 GW
- India has over 7500 km of coastline with high potential for offshore wind plants. However, offshore wind is yet to be explored in India, even it has experience of such projects internationally.

Challenges to scale-up in future:

- In the areas of high wind power capacity, increasing the capacity of the grid will enable effective integration and utilization of wind power.
- Until assessing the India's resources, it is unlikely that the potential of offshore wind will be exploited.

3. Hydro

Scenarios and their targets in 2050

REF	LC1	LC2
61 GW	65 GW	142 GW

Present status of Hydro Technology:

- India's total installed capacity of large hydroelectric projects is 39 GW and SHP projects is 3 GW

- India has a large manufacturing base for components of small projects. On the other hand, for large scale projects, there is lack of skilled labors.

Challenges to scale-up in future:

- Grid integration of large hydro projects to the center of power demand is the key area for improvement in future.
- Due to high capital cost of large hydro projects, it will receive lower priority among other options to increase power capacity in India.

4. Nuclear

Scenarios and their targets in 2050

REF	LC1	LC2
43 GW	142 GW	156 GW

Present status of Nuclear Technology:

- India has indigenous nuclear program with present installed capacity of 4.8 GW
- Owing to its rich thorium resources, India plans to utilize them in thorium based reactors.

Challenges to scale-up in future:

- India will rely on foreign supplies for uranium, as it has very limited uranium resources.
- Due to the necessity of water resources for advanced large capacity reactors, many of the future plants will be located in the coastal areas. This in turn will require robust and high capacity grid infrastructure.

5. Carbon Capture and Storage (CCS)

Scenarios and their targets in 2050

REF	LC1	LC2
0 GW	367 GW	0 GW

Present status of CCS Technology:

- Although on demonstration level, large scale CCS is implemented in many places around the world, it is still expensive and has limited commercial development in India.

Challenges to scale-up in future:

- As the indigenous coal has high ash content, most of the pre-combustion carbon capture technologies are not suitable for India.
- Presently, there is no political will for CCS development in India, as it an expensive technology. The government expects international community to take lead in this issue.

2 MITIGATION METHODS

2.1 Carbon Capture and Storage technology

Carbon capture and storage (CCS) is relatively new concept in carbon mitigation. The process is to capture carbon from the point of origin and store safely in storage sites beneath land. The carbon emission sources, which in our study is thermal power plant, is retrofit with proper arrangements to capture CO_2 and transport to storage sites usually deep oceans, depleted oil and gas field, saline aquifers and un-minable coal seams. The method is a promising option to significantly reduce CO_2 emission in a huge scale.

Technology

The process of CCS involves three components, namely capture, transportation and storage. (Akorede, et al., 2012)

Capture

Capture is the first process in CCS technology and is located in the emission source sites. This process is physical removal of CO_2 from a mixture of flue gases in the power plant and preparing it for transportation. It involves separation of flue gases, containment and pressurization of CO_2. It is accomplished by three methods,

1. Post-combustion capture
2. Pre-combustion capture
3. Oxy-combustion process

Post-combustion capture

The method is separation of CO_2 from flue gas of the power plant. Separation technologies for this process are absorption, adsorption and membrane processes. It promises to cut about 85% of CO_2 emissions from the plant and thus ensuring their viability in long term.

Pre-combustion capture

The process is to capture CO_2 from the fuel (coal) by gasification before actual combustion.

Oxy-combustion process

It is similar to post combustion technique, except that the actual combustion here takes place in oxygen rich environment. The inlet air is separated to produce high concentrated oxygen for combustion. By doing so, the flue gas is CO_2 rich, which is easy for capturing.

Transportation

The second step in CCS is to transport the captured CO_2 to nearby storage site. For the amount of CO_2 generated in power plants, pipelines are the most likely mode of transport for the captured gas to geologic storage sites.

Storage

Long-term storage requires stringent conditions for sequestration sites to prevent the captured emissions from escaping into the atmosphere. The storage site can handle large amounts of CO_2 depending on its characteristics like depth, thickness and permeability. At present, for long-term storage, deep saline aquifers and depleted oil and gas fields are the most preferable sites.

2.1.1 Significance of CCS technology

Without CCS technology, mitigating carbon emissions will require significant curtailment in the use of global coal, which is presently not feasible, as it remains the world's most available fossil fuel. The IPCC predicts that CCS could contribute between 10 to 55 percent of cumulative worldwide carbon mitigation effort over the next 90 years. It states "the most important single new technology for CO_2 savings" in power and industry sectors.

CCS could potentially capture 90 percent of all carbon emitted by a given plant, compared to a conventional coal plant without it (Akorede, et al., 2012). Nevertheless, it requires 40 percent additional energy to run a CCS coal plant relative to a conventional coal plant.

Table 2: Mean value of life-cycle GHG emissions for selected technologies (Akorede, et al., 2012)

Option	Total emissions avoided in 2030 ($GtCO_2$-eq)
Fuel switching & plant efficiency	1.07
CCS	0.81
Wind	0.93
Nuclear	1.88
Hydro	0.87
Bio energy	1.22
Geothermal	0.43
PV and CSP	0.25

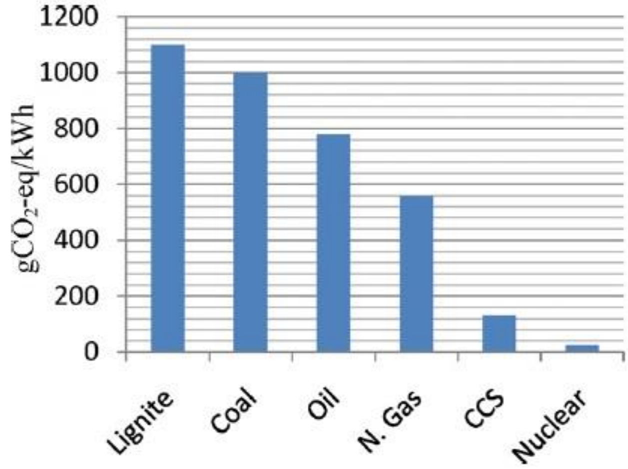


Figure 7: Life cycle GHG emissions (Mean Value) of selected power plants (Akorede, et al., 2012)

The graph Figure 7 shows the mean value of life cycle GHG emissions for selected power plants. It is clear that plants operating with Lignite and coal are the highest carbon emitters with values 1100 and 1000 gCO_2-eq/kWh respectively (Akorede, et al., 2012). On the other hand, CCS produces only less emission in its entire life cycle i.e.130 gCO_2-eq/kWh. As a result of which, the CCS is projected to reduce 0.81 $GtCO_2$-ea of emissions by 2030, as shown in Table 2.

2.1.2 Issues surrounding CCS

Despite the great advantages of implementing CCS, a major concern is leakage of sequestrated CO_2 through the injection pipe. The injection pipes are usually fitted with non-return valves, which prevent leakage during power outage. However, there is possibility that the pipe itself could tear and leak CO_2 due to high operating pressure. Few other issues that could act as barriers for widespread deployment of CCS technology are,

- Uncertainty about ultimate cost and feasibility of the technology
- Identifying the responsible authority for sequestrated CO_2
- Establishing clear jurisdiction for pipeline construction
- Overcoming public opposition

Considering the above problems and the fact that CCS is expensive to implement, the private investors are likely of the opinion that CCS is risky and an expensive option.

2.1.3 CCS in India

India is the second largest populated country and ranks sixth in the world in terms of CO_2 emissions from fossil fuels. A large portion of the country's power plants is inefficient and old and it is expected that India in coming years will need to upgrade its power plants significantly.

In addition to higher initial investment cost in implementing CCS, about 20-30% of additional fuel is compromised in capturing and compressing CO_2 before its transportation to sinks (Hetland, et al., 2009). Even though CCS is a costly and energy consuming option, India to its CO_2 mitigation obligations, it is necessary to implement CCS in the required scale or to withdraw parts of its generating capacity.

Unlike European countries, where issue of GHG emissions is high on political agenda, India is more focused on energy supply, cost and local pollution. Presently coal is the prevalent fuel in Indian power sector and is likely to be so in the near future. This means that the time is due for India to step into research and development of CCS technology and make way for cleaner energy policy. The first step in this direction is to gain knowledge in CCS from major projects and storage sites.

Recent predictions show that the global demand for power will rise by a factor of 3 to 7 in this century. In this situation, the primary energy demand of the non-OECD countries is expected to grow 9 times faster than the OECD countries in absolute terms over the next 20-30 years. Despite the effect of carbon emissions, coal will continue to dominate and serve as the main fuel during the aforementioned period. (Hetland, et al., 2009)

IEA projects that coal generation will double between 2000 and 2030. During this period, the new plants will produce total life cycle CO_2 emission of 500 billion tons. Interestingly, this amount is half the cumulative global carbon emissions from all modes of fossil fuels over the past 250 years. This peaking growth of carbon emissions calls for immediate action for mitigation in global scale. Therefore, over the coming years, significant transition towards sustainable fossil fuel technologies, like CCS is needed.

India's CO_2 emission accounts for 5% of the world's emission level and clearly grows at a rapid rate. Carbon emissions have almost tripled in 2010 compared to 1990 level. The carbon emission on India increases by 3.5% annually from 2010 to 2035, according to WEO 2012 New policy scenario (IEA, 2012). In addition to that, by 2035 the contribution of India in the global CO_2 emission level will be 10%. A major portion of emissions is produced from electricity and heat sector, representing 54% in 2010, which was 40% in 1990. Transportation sector is contributing only 10% share in the total. However, the growth rate of emissions in transportation sector is one of the fastest.

Owing to population strength of India, the carbon footprint per capita is only 1.6 ton per annum, which is lower than the world's level of 4.8 tons per annum in 2010 (Hetland, et al., 2009). Nevertheless, India is expected to upgrade its power plants with CCS technology in next 10-15 years or to withdraw a substantial part of its power generating capacity. This is due to the old age and low efficiency of its power plants. Therefore, the potential to invest and develop large clean development mechanism projects (CDM) is high in India.

India is a developing nation and it is probably not in a position to take severe mitigation commitments as industrialized countries are doing. In addition, India cannot be blamed for much of the global carbon emissions from the past.

Clean development mechanism

Clean development mechanism or CDM is an initiative to promote organizations to opt for projects that offer emission reductions with highest cost-effective options. In such case, India is a destination that offers lower investment cost, quicker permits and high improvement potential owing to low efficiency of Indian power plants. Since carbon mitigation is a global concern, industrialized countries have options through CDM to invest in clean projects in developing nations to achieve their mitigation obligations. Furthermore, India is in the need of institutional and industrial investors to upgrade its ageing power plants. In that aspect, it is in the interest of the developing countries to pursue suitable policies for risk sharing with the industrialized countries to CDM like projects. In addition, it will also increase job opportunities and prosper the developing countries.

2.1.4 Geological Site

The stored CO_2 will be in super critical pressure and hence will be in liquid state. The density of CO_2 will be less than water. Because of this, there will be a buoyancy force acting upwards, which should be counteracted by a sedimentary layer called cap lock. For this reason, characterization of the storage site in the beginning phase of CCS implementation is critical. To maintain the super critical pressure of CO_2 in the storage site, a depth of more than 800m is required for the deep hole.

There are four main CCS plants operating in industrial scale around the world. The Statoil hydro operated Sleipner West Field in Norway is in the continental shelf of North Sea. The plant capacity is 1 Mtpa CO_2. The second is Weyburn project in Saskatchewan, Canada. It is an enhanced oil recovery (EOR) project operating from October 2000. The plant is capacity is 0.8 Mtpa CO_2. (Hetland, et al., 2009)

The In Salah gas project in Algeria is an onshore project operated by BP since 2004. The plant capacity is 1.2 Mtpa CO_2 (Hetland, et al., 2009).The fourth main project is Snøhvit in coast of Hammerfest, Norway. It is operated by Statoil Hydro with a capacity of 0.7 Mtpa CO_2.

In India, CCS is relatively in early stage as the India government is not seeing it as a major contributor for emission mitigation and not included in the national energy and climate policy. Presently the government is concerned in modernization and efficiency improvement of Indian thermal power plants.

As implementing CCS will significantly reduce the plant efficiency, it is not an option. In 2008 'National Action Plan on Climate Change' CCS is not mentioned. Instead, focus is on renewable energies like solar and plant efficiency improvement. In spite of the wary position towards CCS, the government is funding to research and development units involved in CCS technologies.

The department of science and technology has formed a network called 'Indian CO_2 Sequestration Applied Research' (ICOSAR) in 2007 to facilitate research in CCS (Viebahn, et al., 2011).Research on all three main techniques of CO_2 capture is being conducted in the labs of India. In the post combustion capture, the research is concentrated on the development of cost-effective solvents, adsorbents and membrane materials.

In the pre-combustion capture process, high temperature combustion is given priority. In addition, it is also concentrating on to accept high ash content coal for coal gasification processes. Presently there are no demonstration plants for CO_2 capture in power sector and merely a small number of planned projects. However, since 1988, there is a plant operated by Indo gulf Corp. where CO_2 is captured in commercial scale for urea production. In 2008, from October to December, the plant captured 7,659 tons of CO_2 for its production. (Viebahn, et al., 2011)

The Oil and Natural Gas Corp. (ONGC) – India's major oil and gas supplier is planning to use the captured CO_2 for Enhanced Oil Recovery (EOR) operations in Ankleswar oil field. In the effort of carbon mitigation, India government is involved in several international networks like Carbon Sequestration Leadership Forum (CSLF)

<u>CO_2 Sinks</u>

The carbon sequestration in India is insecure because there are only few studies made on the geological potential of storage. The studies are also done in vague manner and there is no certain figure for total storage capacity of India. The potential sinks in India are saline aquifers, depleted oil and gas reservoirs, basalt formations and un-minable coal seams.

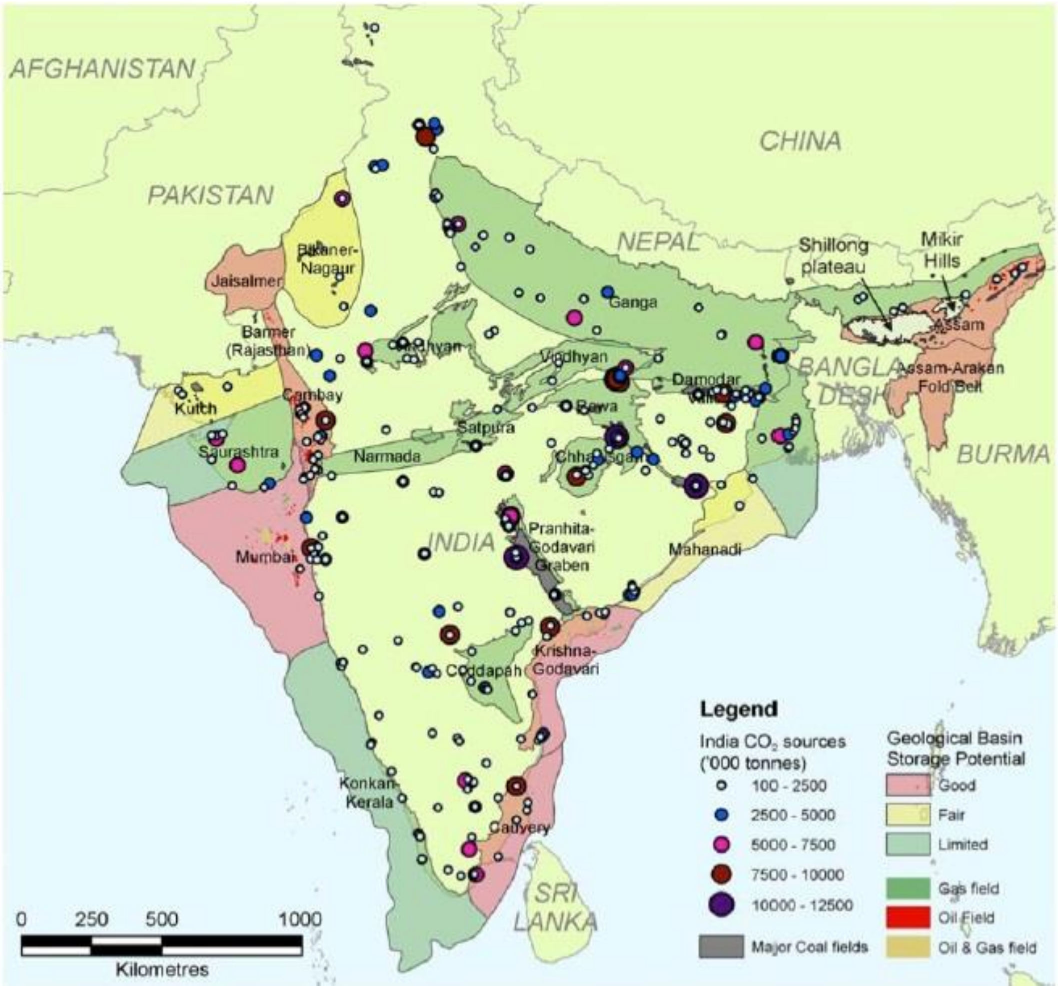


Figure 8: Potential basins, CO_2 sources and Oil and Gas fields of India (Viebahn, et al., 2011)

Saline aquifers are located in India in the borders of the peninsula, in the states of Rajasthan and Gujarat, as shown in Figure 8. The storage potential is strong in the Krishna-Godavari and Cauvery basins situated in the Southeastern coastal zones, the Mumbai basin area in the west and the Assam area in the far east of India. Fair storage potential areas are in Mahanadi basin, Kutch and Bikaner Nagaur. In addition to that, there is enormous Deccan basalt province in the central western India.

IEA Greenhouse Gas Program has released a comprehensive report on CO_2 storage potential of India in 2008. The estimate is 68 Gt CO_2. It is the sum of 5 Gt CO_2 (from depleted oil and gas fields and un-minable coal seams) and 63 Gt CO_2 from saline aquifers. Two other estimates in 2005 and 2006 says that the total capacity of India as 105 Gt CO_2 and 572 Gt CO_2 respectively. (Viebahn, et al., 2011)

If India grows at a rate of 8-9% then the energy consumption will grow by 6-7% annually. For this reason, India needs to concentrate on clean coal technology, emission mitigation measures and better investment decisions. Clean coal technologies refers to wide range of measures like, efficiency improvement, co-firing biomass with conventional coal to reduce coal consumption per unit of power.

Even though there are many measures to promote clean coal utilization, the potential to emission reduction is limited, even if collectively implemented in power plants. Therefore, the need for CO_2 sequestration arises to mitigate emissions from fossil-fuel fired plants significantly. Technically, CCS technology is feasible in India. However, because of non-technical reasons, it is not an appropriate option for emission mitigation in India.

CCS involves permanent storage of CO_2 by injection into suitable formations. Therefore, it is required to perform an extensive assessment of storage sites like depleted oil and gas fields, deep saline aquifers and coal seams. If storage site is not available in the optimal position with respective to the sources, then transportation of CO_2 is to be arranged. Depending on the quantity of $CO_{2,}$ the mode of transportation is decided. (Viebahn, et al., 2011)

One option for India is to transport CO_2 by ship containers to its oil importing countries like Qatar for their EOR operations. The compressed CO_2 can be sent in the returning empty containers.

2.2 Energy Efficiency Improvement

Significance

Indian government has prepared a national modernization program to overhaul and modernize all conventional power plants. The program is based on the Five-year plan of Government of India. The program has identified a large existing capacity i.e. 129 units of total capacity 26 *GW* and 95 units of total capacity 21 GW for Renovation and Modernization (R&M) and Life Extension (LE). (Oberst, 2013)

The program functions during the 11th plan and 12th plan periods. Modernization of conventional power plants is equally prioritized to construction of new plants by Indian government. As per the program, 50 identified conventional power plants will be modernized by the end of 2016 (Oberst, 2013).The demand for power plant modernization is high because of raising energy demand in the country and national emission reduction obligations.

India with the aim of providing power to all citizens, its power sector was opened for Independent Power Producers (IPP) in 1991.Since its implementation a series of regulations and structural reforms are developed to reduce losses and expand total capacity.

A thermal power plant produces nearly 71% of total commercial electricity in India. This figure is expected to increase to 78% by 2031 according to Indian planning commission (Bhattacharya, et al., 2010). Therefore, energy efficiency in power sector is critical and will have significant impact in CO_2 emissions. Presently the literatures written on Indian power plants approach the energy efficiency problem in two perspectives.

One approach is to examine the existing efficiencies of Indian power plants, comparing them with the standards of different countries and explaining the causes of variation. Another approach is to focus on the possibilities of energy efficient investments in future plants. Coal-fired Indian power plant's average thermal efficiency is 29 percent in 1998. This is 10 percentage points lower than the value of Japan, which is the most efficient country. (Bhattacharya, et al., 2010)

Most of the coal-fired generating units (approx. 90%) are subcritical type with a maximum thermal efficiency between 35 and 38 percent. The average efficiency of these units will be around 30%. The reason for such low figure is due to two factors. Technical factors like high ash content or low heat content of Indian coal. The other reason is the inefficiencies in management.

The low heat content or high ash content coal requires more heat to produce electricity. In other words, it consumes more coal to produce electricity. The average heat content of coal used in Indian power plants is 4 000 Kcal/Kg in 1990 down from 6 000 Kcal/Kg in 1960, with ash content between 25 and 45 percent (Bhattacharya, et al., 2010).This is the case of domestic coal. However, India also imports coal for its power requirements. The problem with imported coal is high tariff and transportation cost.

One study finds that energy efficiency increases from 25.66 to 26.93 percent by improving the management practices of power plants (Bhattacharya, et al., 2010). Furthermore, use of high-quality coal could increase the efficiency to 29.2 percent. The plan of Indian government is to increase the capacity by six fold in electricity production by the year 2030. As previously stated, a major percentage (78%) of this capacity will come from thermal power plant and so the energy efficiency initiatives are crucial in future investments.

For thermal power plants the energy efficient options available at the moment are supercritical coal-fired plants and combined cycle gas turbine (CCGT) plants. CCGT plants produce low carbon emissions compared to coal-fired plants. This provides an advantage to opt CCGT plants over the conventional plants for carbon mitigation. However, the total cost per KWh for CCGT plants is 5.48 cents versus 3.10 cents per KWh for coal plants. (Bhattacharya, et al., 2010)

This means that even though the CCGT plants are more efficient, it would require a significant boost in the form of carbon premium to compete economically with coal-fired plants.

A proposal for Incentive-based Efficiency Improvement

India is standing fourth in world in carbon emissions worldwide and is growing at a rapid rate of 5.5% p.a. comparing to 3.2% for China, 1.6% for US and 1.1 for the world. Most of the contemporary discussions on mitigation of CO_2 emissions lie in Carbon Capture and Storage (CCS) technology, which is an option highly suitable and driven by industrialized countries. However, for a developing country like India, where there is high scope for improving power plant efficiencies, this option deserves preference and imminent attention. According to (Chikkatur, et al., 2007), improving the coal-conversion efficiency in power plants still remains the most cost-effective option for CO_2 mitigation in Indian power sector environment.

In addition, the coal reserves in India may not be large. A recent estimate indicates that the total coal reserves of India would be about 44 billion tons. If the estimate is accurate, then the coal era of India might only last till 2050, according to a scenario in (Chikkatur, et al., 2007). This challenges us with the reason that the coal is invaluable and needs to be utilized to maximum efficiency in power conversion. It will also help to enhance energy security of the country and therefore, improving power plant efficiency of India remains an important aspect of its energy policy.

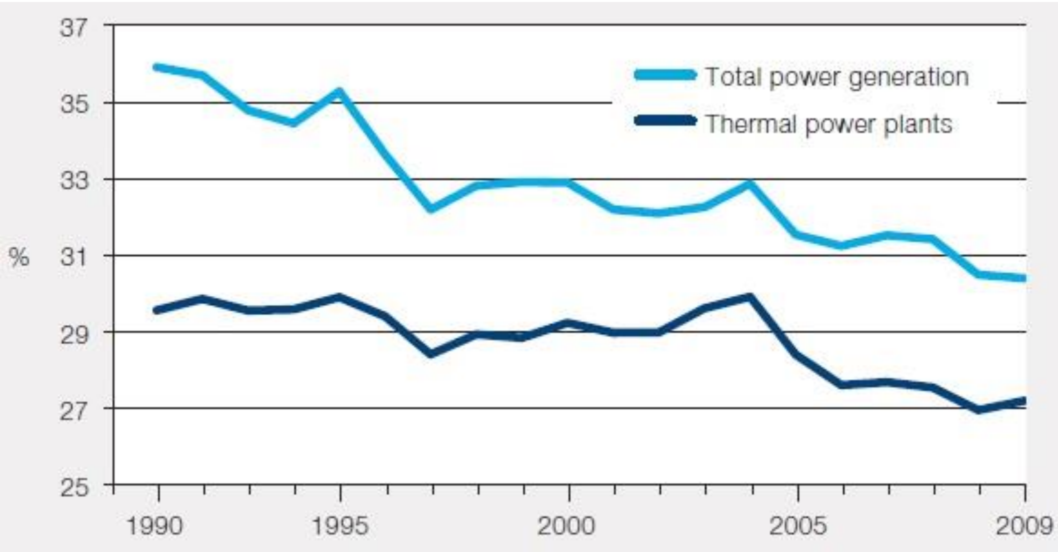


Figure 9: Efficiency of Power generation and Thermal power plants (ABB, 2011)

In (Chikkatur, et al., 2007), it is indicated that a minimum of 1-2 percentage points can be improved in the efficiency of Indian power plants. Interestingly, a 1% improvement in the efficiency of coal power plants will yield 0.4% gain in the cost (Figure 10) and 3% gain in coal use and its respective carbon emissions (Sharma, 2004).

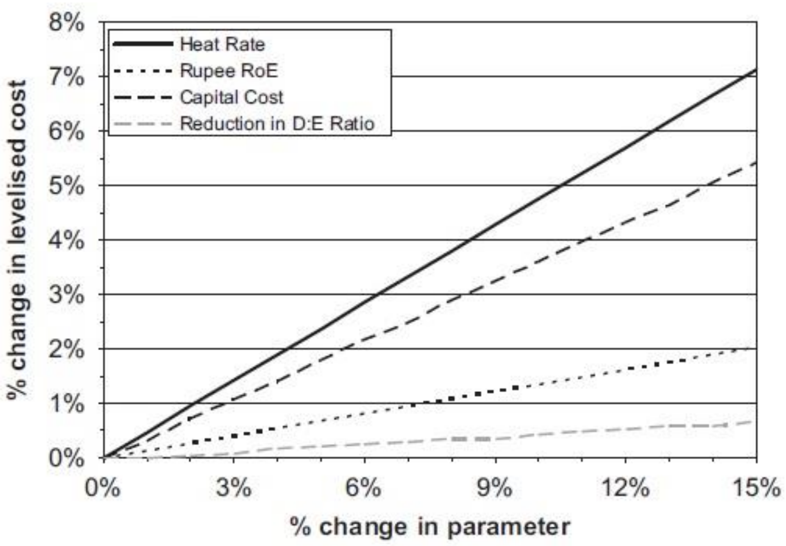


Figure 10: Cost sensitivity to various parameters (Chikkatur, et al., 2007)

The low generation efficiency is usually attributed to the following technical and institutional factors,

- Poor grid conditions
- Low PLF
- Degradation due to age
- Poor quality of coal
- Lack of required operation and maintenance
- Ownership patterns
- Regulatory framework, and
- Tariff structure and incentives

Regardless of these reasons, it is clear that a significant improvement in the power-plants can only be achieved either by mandates or by appropriate incentives. In (Chikkatur, et al., 2007), the authors propose a three-pronged scheme to promote efficiency improvement in regulated power plants. The cumulative benefit of the proposal will be increase in efficiency and customer benefit. The schemes are briefed below and they are applicable to only the existing power plants of India, particularly to plants operating in sub-critical technology.

1. Revised performance benchmark

According to this scheme, the basic tariff is determined based on a benchmark defined by the median, which is calculated using data from all existing units in the country, regardless of the ownership. This Median Heat Rate (MHR) determines the tariff for any period based on the preceding time period. The advantage of such an approach is that current tariff is automatically adjusted over time.

2. Relative Performance Incentive (RPI)

This scheme provides additional motivation for power plants to improve their efficiency relative to other plants. It is an optimistic mechanism that provides positive incentive for plants performing well rather than a penalty for poor performing plants. The plants that are performing more than the median will receive incentives that escalate with increasing deviation from the median level. (Chikkatur, et al., 2007)

3. Self-Improvement Incentive (SII)

An SII provides incentives to power plants based on their present performance in comparison to their own past performance. The greater the positive deviation in efficiency from the previous time period, the higher will be the incentives. In addition to that, poorer performing plants are given higher incentives than a better performing one. This idea is to provide motivation for poor performers.

2.3 Solar Power

India is ideal for solar power because of its high solar irradiation. It is also densely populated which drives enormous demand for energy. A major initiative proposed by Government of India to promote sustainable growth and energy security is National Solar Mission (JNNSM).

The Prime minister of India launched national Solar Mission on January 2010. Under this mission, the plan is to 20 GW of grid connected solar power by the year 2022 (MNRE, 2010). JNNSM is planning to create conditions through rapid scale-up of capacities and technological innovations to drive down costs towards grid parity.

In the India's land area, about 5 000 trillion kWh per year energy is incident with most parts receiving 4-7 kWh per sq. m per day. With this resource potential, both technologies, solar thermal and solar photovoltaic will provide huge scalability for solar in India. In the rural electrification perspective, off-grid decentralized and low temperature application will be advantageous. It will also meet heating and cooling demands in the rural and urban areas.

Nevertheless, the constraint on scalability will be availability of space, since all solar applications are space intensive. In addition, without proper storage, solar energy is subject to high degree of variability because of the monsoon season in India. Environmentally, solar power has zero impact while generating heat and electricity. (MNRE, 2010)

From India's energy security perspective, solar power is the most secured, since it is abundantly available. Theoretically, if only small fraction of the entire incident solar energy is effectively captured, then it will meet the entire country's energy demand. On the other hand, considering the present situation on large proportion of poor and energy un-served population, the need to exploit the abundantly available energy source is imminent. Even though today the cheapest method of power production is by coal combustion, this scenario will change in the near future.

In 2012, the country's total demand-supply gap is about 98 MT and out of which India imported about 85 MT. It is projected that the coal demand will increase to 980.5 MT annually in 2016-17 at a CAGR of 7.1% (MNRE, 2010)

As the country will shift to import more coal in the future, the price of power will depend on the coal availability on the international market. In this situation of energy shortage, the country is increase the use of diesel for energy production, which is costlier than coal. Therefore, harnessing solar energy in large scale is both urgent and feasible to meet the country's future energy demands.

JNNSM will adopt a 3-phase approach. These three phases are based on India's five-year plans up to 2022.

Table 3: Targets of three phases in JNNSM (MNRE, 2010)

Application	Phase I Target (2010-13)	Phase II Target (2013-17)	Phase III Target (2017-22)
Solar Collectors	7 million Sq. m	15 million Sq. m	20 million Sq. m
Off-grid solar applications	200 MW	1 000 MW	2 000 MW
Utility grid power, including root tops	1 000-2 000 MW	4 000-10 000 MW	20 000 MW

At the end and midterm of 12th and 13th plans, there will be evaluation of progress, review of capacity and targets for subsequent phases. In the first phase, the aim of the mission is to enable environment for solar technology to penetrate into the country both at centralized and decentralized level.

The targets specified in the table are entirely dependent on the availability of international finance and technology. The plan promotes off-grid applications, which is set to increase reaching 1 000 MW by 2017 and 3 000 MW by 2022.It is also planned to deploy 20 million solar lighting systems in rural areas by 2022. (MNRE, 2010)

2.3.1 Mission Strategies

The policy will create necessary environment to attract investments (domestic and foreign) in research, domestic manufacturing and development of solar power generation. The key driver for enhancement of solar power is Renewable Purchase Obligation (RPO), which is mandated for power utilities. This will promote utility scale power generation, whether solar PV or solar thermal plants.

The mission also targets to solarize all applications, domestic or industrial, below 80 °C (MNRE, 2010).In remote areas of India, where grid connection is neither feasible nor cost intensive, off-grid solar applications are cost effective. The mission will provide solar lighting system to rural areas under rural electrification program of MNRE to cover about 10 000 villages and hamlets.

2.3.2 Solar energy potential in India

India has huge scope for generating power and thermal applications using solar energy. As it lies in the sunny belt of the world, most regions of India receives 300 days of sunlight a year, which is a promising condition for solar energy utilization (Sharma, 2011). Depending on location, the daily average solar energy incident ranges over India from 4 to 7 kWh/m^2 and sunshine hours per year is between 2 300 and 3 200. This is enormous amount energy, from which we can generate more than 500 000 TWh per year of electricity with PV modules of 10% conversion efficiency. This number is equal to three orders of magnitude greater than the projected power demand of India by 2015.

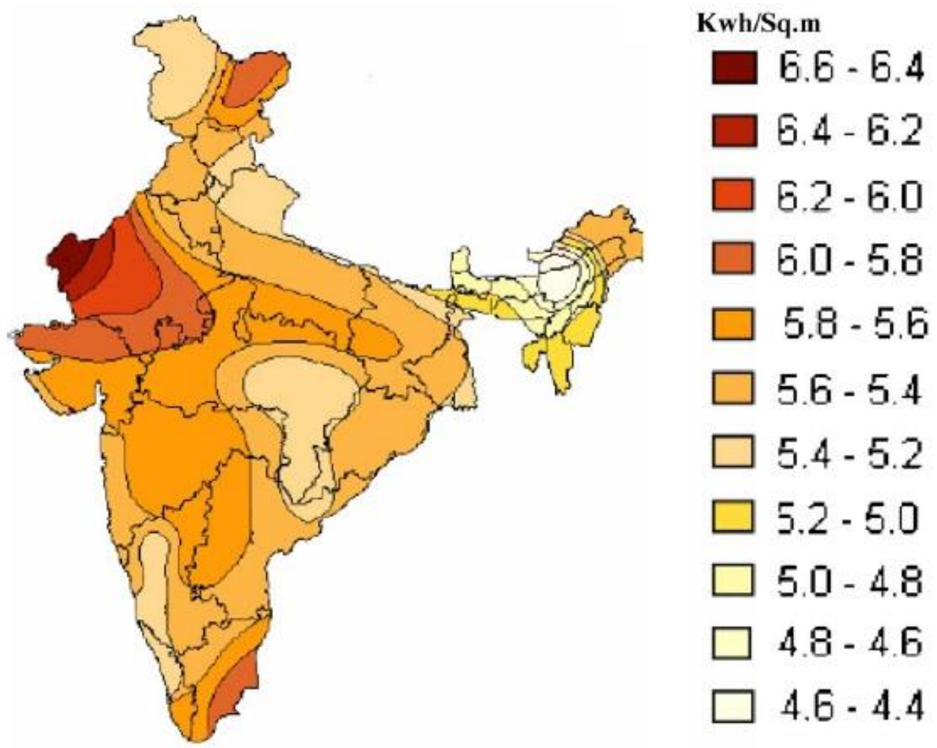


Figure 11: Solar radiation in India (Sharma, 2011)

The Figure 11 shows the region wise solar radiation levels of India. The maximum radiation lies in the regions of Rajasthan, northern Gujarat and parts of Ladakh.

Solar PV module is one of the highest capital cost technology of all renewable energy methods. However, owing to very low maintenance cost and repair needs, its operational cost is the lowest. For solar PV to have deeper penetration in Indian market, it is imperative that the capital cost is reduced significantly. The approximate capital cost per MW for solar power plant is INR 170 million, including the cost of land, balance of systems, cost of panels and other additional infrastructures. (Sharma, 2011)

Future Solar power projects

The government of India has received several solar power plant proposals from major companies like, Reliance Industries, Titan Energy Systems, Signet Solar, KSK Energy Ventures, Tata BP Solar India and so on. Tata BP Solar is providing design, manufacturing and installing solar solutions for the past 15 years and is significantly expanding its manufacturing capacity to 300 MW. The company has installed India's largest Building Integrated Photovoltaic (BIPV) plant at the Samudra Institute in Pune.

The Moser Baer Photo Voltaic Limited (MBPV) is planning to build two grid-integrated solar farms in the states of Rajasthan and Punjab with each 5 MW capacity. Bharat Heavy Electricals Limited (BHEL) has taken several initiatives in the Lakshadweep, where hazardous diesel generators are affecting the fragile ecology of the coral islands. In total, BHEL has commissioned 11 solar power plants, adding over 1 MW to the island's generating capacity (Sharma, 2011). These solar plants cater about 15% of the union territory's energy demand.

The first megawatt size grid connected solar power plant in India has been constructed in the state of West Bengal. Two more plants have been set in Karnataka with 2 MW capacities each. In addition, Renewable energy Ministry has cleared proposals in 2010 to set up another 28 MW capacity solar plant in India. Gujarat, a state of India, with an average solar radiation of 6 kWh/m^2 is eager to adopt alternative sources of energy in the state. Initially, the state government's target was only 500 MW by 2014 (Sharma, 2011). However, the target is now increased to nearly six folds because of the financial support from foreign countries. The proposed projects will receive fund from William J Clinton Foundation, which is a result of Clinton Climate Initiative (CCI). The project will take 10 000 ha of land across three locations within an area of 150 Km^2 in Gujarat.

The Indian state of Rajasthan is estimated to have the highest solar radiation in the country. The desert state is attracting lot of investments towards solar energy sector. Rajasthan Renewable Energy Corporation (REEC) says that 72 power companies are registered for generation of 2 500 MW in solar energy sector. The proposals are from different companies and REEC will develop these projects as per the guidelines of the National Solar Mission. In addition to that, RIL is constructing a 5 MW solar plant in Nagaur with a power purchase agreement from three power distribution companies of Rajasthan. Even though the government takes several initiatives, the cost per megawatt of solar power is still expensive. (Sharma, 2011)

2.3.3 Ultra Mega Solar Power Plant

In September 2013, the government of India has unveiled plans to build an Ultra Mega 4 GW solar power plant in the northwestern part of the Rajasthan state. A solar plant of this scale is the first in world and is expected to set a trend for large scale solar power development in the world. The project is expected to complete its first phase of 1 GW by the end of 2016 and to be implemented through a joint venture of five state-owned companies of India, namely, BHEL, Solar Energy Corporation of India, Power Grid Corporation, Satluj Jal Vidyut Nigam and Rajasthan Electronics and Instruments Ltd. From the experience gained through the construction of the first phase, the remaining capacity will be implemented through a variety of models. (Bayar, 2013)

Rajasthan is the India’s largest in solar insolation and possesses a strong grid and state-owned land banks for grid-connected solar projects. The government has outlined plans to build large amounts of solar projects in the desert regions of the states Rajasthan and Gujarat. According to MNRE, the total electricity demand of India in 2012 could be met if mega solar projects are built on just 5% of the nation’s unused desert land (Bayar, 2013). Presently India has a total of 1761 MW of grid-connected solar capacity and is expected to add 2.8 GW in 2014 from the solar power auctions in 2012 and early 2013.

2.4 Nuclear power

2.4.1 Background

The primary energy consumption of India has more than doubled between 1990 and 2011. In this high rate of rising energy demand, the challenges faced by the government are its dependence on imported energy resources and the inconsistent reform in energy sector. India has indigenous nuclear program and is planning to produce 14 600 MWe by 2020 (WNA, 2013). By 2050, it aims to supply accomplish 25% share in the total electricity generation.

For 34 years, India was largely excluded from trade in nuclear plant or materials because of its weapon program. This gesture has hampered the development of civil nuclear energy until 2009. During that period of trade ban, India was exclusively developing a nuclear fuel cycle to exploit its domestic thorium reserves. Presently, it is expected that foreign technology and fuel will considerably boost India's nuclear power plans. (WNA, 2013)

By the end of 2011, nuclear power has supplied 20 billion kWh (3.7%) of India's electricity and achieved 350 reactor years of operation. Present fuel situation of India, with shortage of fossil fuels, is driving investments in nuclear power. The government is planning to achieve 25% nuclear power contribution in the power sector.

In 2004, the future target set for nuclear power is 20 GWe by 2020. However, in 2007, the prime minister of India referred this target as modest and capable of being doubled by foreign investments. Later there have been a few other targets set by NPCIL. In December 2011, the parliament told that targets that are more realistic are 14 600 MWe by 2020-21 and 25,500 MWe by 2032. (WNA, 2013)

The Atomic energy commission of India envisages a long-term plan of 500 GWe nuclear on line by 2060. It has speculated that this amount might be still higher as 600-700 GWe by 2050, contributing to half of all electricity.

India was excluded from the 1970 Nuclear Non-Proliferation Treaty (NPT) because of its acquiring nuclear weapons after 1970. As a result, the nuclear power program's growth of India has proceeded largely without support from other countries. In the mid-1990s India possessed some of the world's lowest capacity factors. However, the factor impressively rose from 60% in 1995 to 85% in 2001-02. (WNA, 2013)

The nuclear self-sufficiency of India is on raise extending from uranium exploration and mining, heavy water production, reactor design and construction, to reprocessing and waste management. It is also researching on technologies to utilize its abundant resources of thorium for power production.

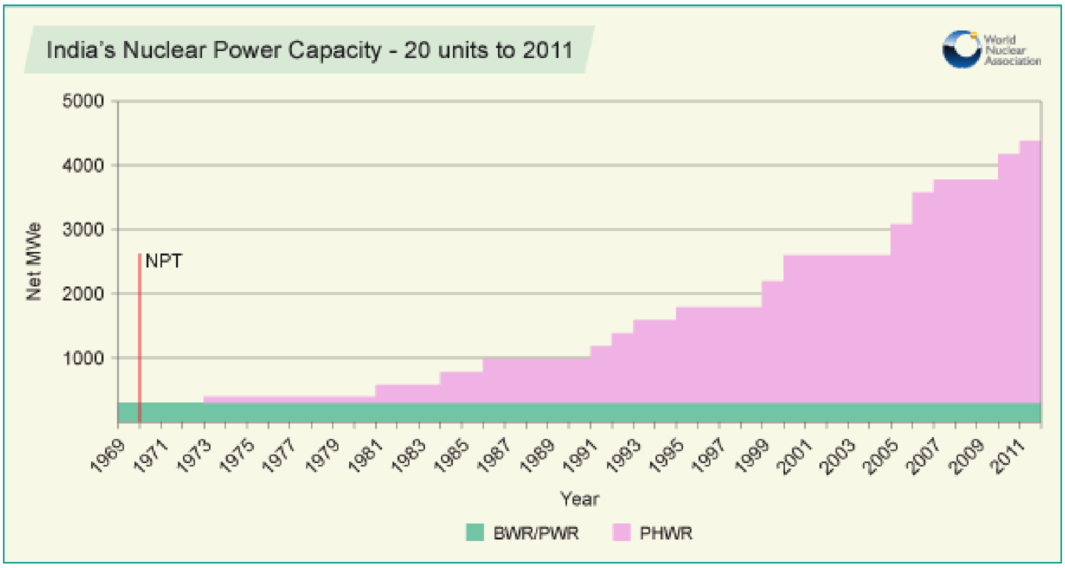


Figure 12: Nuclear power capacity of India up to 2011 (WNA, 2013)

The Indian Atomic Energy Commission (AEC) is the main policy building body, whereas, the Nuclear Power Corporation of India Limited (NPCIL) is responsible for design, construction, commissioning and operation of thermal nuclear power plants. Even though NPCIL is having enough funds for nuclear power expansion, it is aiming to include public and private corporations in the expansion plan, notably, National Thermal Power Corporation (NTPC – A government owned entity). The 1962 Atomic Energy Act prohibits private corporations into nuclear power generation and as of 2010, the government is of no intention to change that.

Table 4: India's operating nuclear power reactors (WNA, 2013)

Reactor	State	Type	MWe net, each	Commercial operation
Tarapur 1 & 2	Maharashtra	BWR	150	1969
Kaiga 1 & 2	Karnataka	PHWR	202	1999-2000
Kaiga 3 & 4	Karnataka	PHWR	202	2007 (due 2012)
Kakrapar 1 & 2	Gujarat	PHWR	202	1993-95
Madras 1 & 2	Tamil Nadu	PHWR	202	1984-86
Narora 1 & 2	Uttar Pradesh	PHWR	202	1991-92
Rajasthan 1	Rajasthan	PHWR	90	1973
Rajasthan 2	Rajasthan	PHWR	187	1981
Rajasthan 3 & 4	Rajasthan	PHWR	202	1999-2000
Rajasthan 5 & 6	Rajasthan	PHWR	202	Feb & Apr 2010
Tarapur 3 & 4	Maharashtra	PHWR	490	2006, 05
Total (20)			**4385 MWe**	

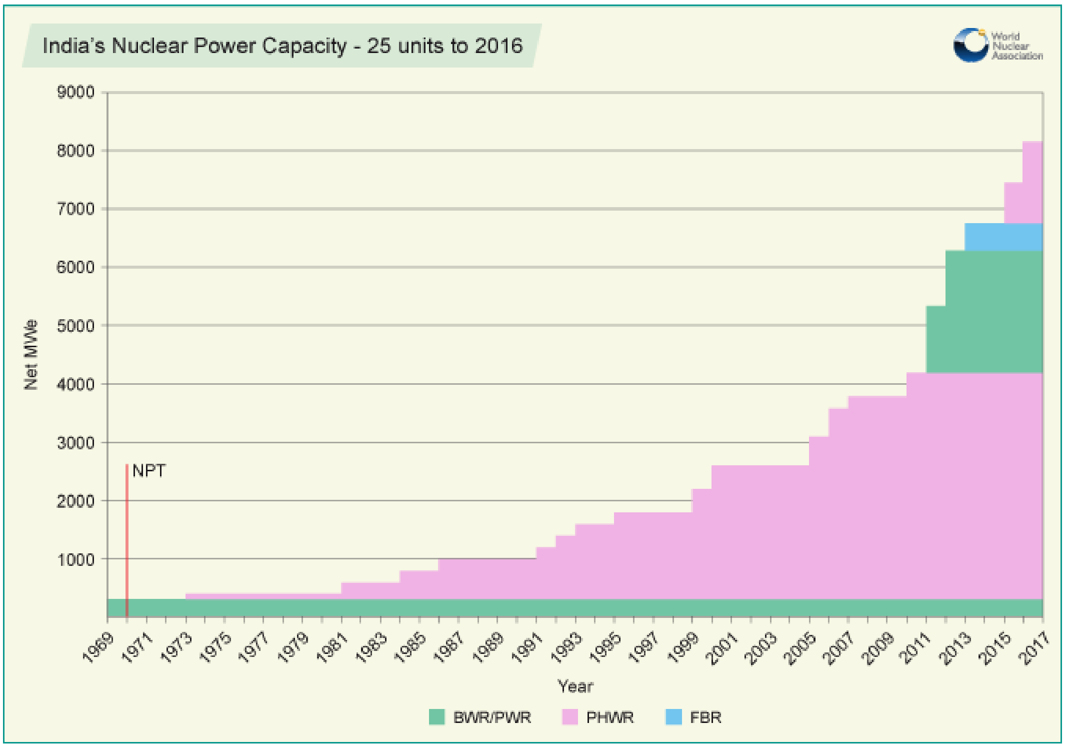


Figure 13: Nuclear power capacity of India - 25 units to 2016 (WNA, 2013)

Table 5: India's nuclear power reactors under construction (WNA, 2013)

Reactor	Type	MWe net, each	Project control	Commercial operation due
Kudankulam 1	PWR	950	NPCIL	7/2013
Kudankulam 2	PWR	950	NPCIL	3/2014
Kalpakkam	FBR	470	Bhavini	2014
Kakrapar 3	PHWR	630	NPCIL	June 2015
Kakrapar 4	PHWR	630	NPCIL	Dec 2015
Rajasthan 7	PHWR	630	NPCIL	June 2016
Rajasthan 8	PHWR	630	NPCIL	Dec 2016
Total (7)		**4890 MWe**		

There was chronic shortage of nuclear fuel in the mid-2008 and the plants went to run at half capacity. Expectation was that this situation would persist for several years; however, there was some easing in 2008 due to new mill coming on line in Jharkhand state.

2.4.2 Nuclear Energy Parks

In addition to the existing eight-unit Rajasthan nuclear plant, the NPCIL is planning to setup five new “Nuclear Energy Parks”. The capacity of each park will be in the combination of eight new-generation reactors of 1 000 MWe, six reactors of 1 600 MWe or simply a single 10 000 MWe plant. According to this plan, by 2032, between 45-45 GWe would be generated from these five parks. (WNA, 2013)

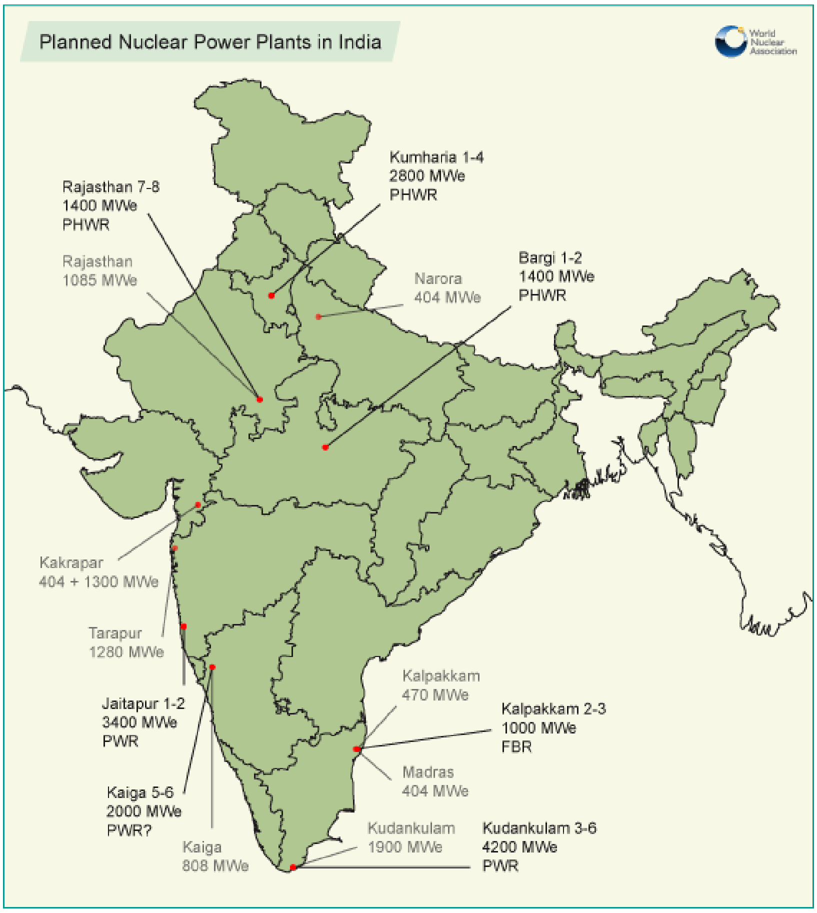


Figure 14: Planned nuclear power plants in India (WNA, 2013)

The new energy parks are planned in the following locations,

1. Kudankulam in Tamil Nadu – 9 200 MWe
2. Jaitapur in Maharashtra – 9 600 MWe
3. MithiVirdi in Gujarat
4. Kovvada in Andhra Pradesh
5. Haripur in West Bengal – 4 800 MWe
6. Kumharia or Gorakhpur in Haryana – 2 800 MWe
7. Bargi or Chuttka in Madhya Pradesh – 1 400 MWe

2.4.3 Uranium resources in India

India's uranium resources are classified as modest. The reasonably assured resource (RAR) is 102 600 tons of U in January 2011. However, DAE claims the value to be 152 000 tU in February 2012. India expects to import the increasing proportion of its demand. In 2013, the import is about 40% of the requirements. Exploration works are performed by the Atomic Minerals Directorate for

Exploration and Research (AMD). Mining and processing of fuel is by Uranium Corporation of India Ltd (UCIL), a subsidiary of DAE.

2.4.4 Thorium fuel-cycle development

India's long-term goal in nuclear program is to develop an advanced heavy-water thorium cycle. It involves three stages. The first stage employs the PHWRs fuelled by natural uranium and light water reactors to produce plutonium. The second stage uses the burning plutonium in fast neutron reactors to breed U-233 from thorium. At this stage, the blanket around the core will contain both uranium and thorium, so that more plutonium is produced along with U-233. In the third stage, the Advanced Heavy Water Reactors (AHWRs) burns the U-233 from stage 2 and some of this plutonium with thorium, producing nearly two-thirds of power from thorium. (WNA, 2013)

In 2002, the regulatory authority has approved to construct a 500 MWe prototype fast-breeder reactor in Kalpakkam and it is expected to be operating in 2012. The reactor is fuelled by uranium-plutonium oxide. It will have a blanket of uranium and thorium to breed fissile U-233 and plutonium respectively. This action will take India's ambitious thorium to stage 2 and eventually to full utilization of its resources.

2.5 Wind Energy

2.5.1 Background

India provides huge business opportunities in wind power sector for domestic and foreign investors with the status of third largest annual wind power market. In 2011, by adding 3 GW of new installations, the Indian wind power sector has made a record annual growth (GWEC, 2012). Throughout India, the wind power is now widely recognized as a complementary energy source for securing its sustainable energy future.

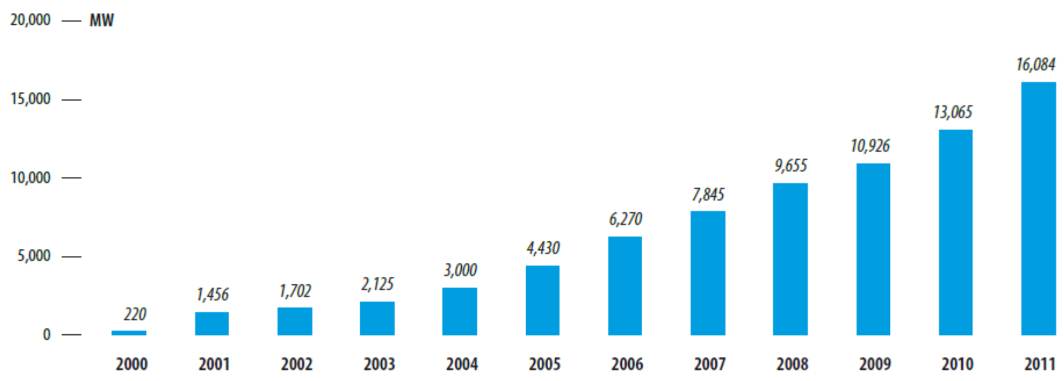


Figure 15: Cumulative wind power installation in MW (GWEC, 2012)

In 2012, renewable energy accounted for 12.2 percent of the total installed capacity and wind power accounts for about 70 percent of this capacity. By August 2013, the total installed capacity of wind power in India is GW.

According to the New Policies Scenario of the World Energy Outlook (2011), India's total wind power capacity would reach 779 GW by the year 2035. For India to reach this level, the growth rate (CAGR) must be 5.9 percent. In other words, the capacity addition must be 20 GW per year from 2009 through 2035. However, the largest capacity addition till now is 18 GW during fiscal year 2011-2012. Therefore, the required scale of addition requires significant effort from government and different institutions. (GWEC, 2012)

Table 6 Wind energy targets in Five-Year plan periods (GWEC, 2012)

Plan	Period	Target in MW	Actual in MW
10th Five-Year plan	2002-2007	1 500	5 427
11th Five-Year plan	2007-2012	9 000	10 260
12th Five-Year plan	2012-2017	15 000 (Reference) 25 000 (Ambitious)	--

Historically, wind power sector has often exceeded the target set for it under 10th and 11th Five-Year plans. For the 12th plan period (April 2012 to March 2017), the Ministry of New and Renewable Energy (MNRE) has fixed a reference target of 15 000 MW and an ambitious target of 25 000 MW (GWEC, 2012). In addition, the MNRE has prioritized the issue of transmission, which is significantly low in the whole power system. A joint committee comprising of the MNRE, the

Ministry of Power, the Central Electricity Authority and the Power Grid Corporation of India is working on to mitigate transmission losses.

The state-run Centre for Wind Energy Technology (C-WET) has assessed India's wind power potential as about 102 GW at 80 meters height at 2% land availability. It is estimated that even if the full potential of 102 GW is harnessed for power production, it would contribute only 8% of the electricity demand in 2022 and 5% of the demand in 2032. (GWEC, 2012)

However, there was also another assessment conducted by Lawrence Berkeley National Laboratory (LBNL) with assumption of turbine density as 9 MW/Km^2. According to this study, the total wind capacity of India ranges from 2 006 GW (80m hub height) to 3 121 GW (120m hub height). The difference in value between C-WET and LBNL is due to the adoption of different mapping models for estimating the wind potential.

These research studies have significant impact in India's renewable energy strategy. The MNRE has signed a Memorandum of Understanding (MoU) with LBNL to collaborate on mapping models and other issues in estimating the wind potential. (GWEC, 2012)

Nearly 95 percent of India's wind energy development to date is five states in southern and western India, owing to high potential in these regions. The states are Tamil Nadu, Andhra Pradesh, Karnataka, Maharashtra and Gujarat, and they account for 85% of total installed capacity by 2012.

2.5.2 Offshore Wind Power Development

India has over 7500 Km of Coastline. In 2012, a Wind Energy Steering Committee was formed by MNRE to develop offshore wind power. The government is planning to develop offshore wind energy in coastal states of Andhra Pradesh, Gujarat, Maharashtra, Odisha, Kerala, Karnataka, West Bengal and Tamil Nadu. The state of Tamil Nadu has taken a lead in this plan and by installing a 100 m wind measurement mast in Dhanushkodi (GWEC, 2012). According to a preliminary assessment conducted by Scottish Development International (SCI), Tamil Nadu has a potential of 2 GW in the southern regions.

In a recent study by WISE, the offshore wind potential of Tamil Nadu is estimated to be 127 GW at 80 m height.

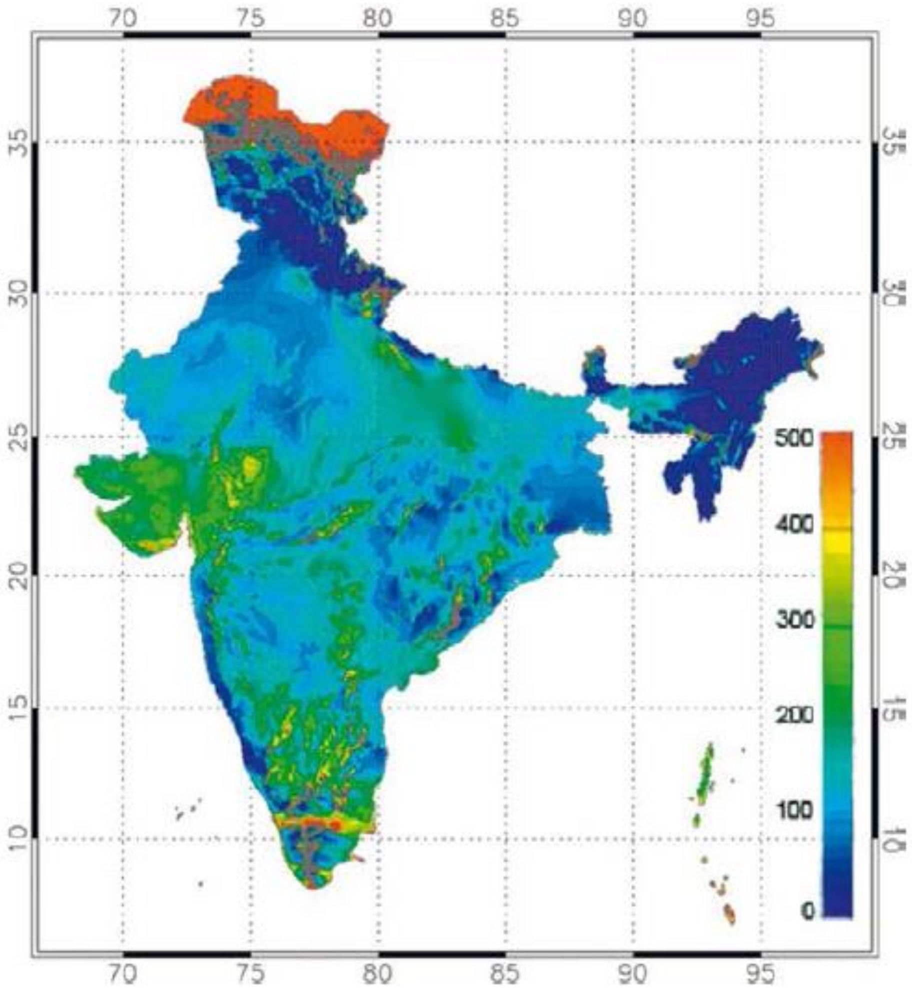


Figure 16: Wind power density map at 80 m (W/Sq. m) (GWEC, 2012)

2.5.3 Barriers to high growth

Presently India's annual manufacturing capacity is over 9.5 GW of wind turbines and the country is envisaging 3 GW of annual installation during 12^{th} plan period. The utilization of country's wind power manufacturing and resource potential is in a modest pace, owing to several factors like,

1. Lack of regulatory framework to facilitate purchase of renewable energy from outside the host state
2. Inadequate grid connectivity
3. High wheeling charges in some states, and
4. Delay in acquiring land and obtaining statutory clearances.

Besides these factors, there are other potential barriers to achieving higher growth rates in both short and medium terms. Since the last decade, the government was providing three types of key incentives for wind power, namely, Accelerated Depreciation (AD), Generation Based Incentive (GBI) and Renewable Energy Certificates (REC) mechanism. (GWEC, 2012)

Accelerated depreciation (AD) is seen as the main reason for growth of wind power in India. However, by reducing this benefit in the current plan (12^{th} period), the GBI has become a crucial incentive for the wind power sector. The GBI has not attracted many power producers as envisaged in its beginning years of operation. This is because the benefit provided in GBI is less and not in par with the Accelerated depreciation scheme.

The Renewable Purchase Specification (RPS) and tradable Renewable Energy Certificates (REC) are the two additional supports for the sector from the government. However, presently there are no incentives in the existing framework for RPS, especially in wind-energy rich states of India. (GWEC, 2012)

Another important barrier for wind energy development is inadequate grid infrastructure in India. In most of the wind energy potential states, there is no significant spare capacity in the grid and as a result, the state governments prefer thermal power plants to windmills. Therefore, there is imminent need for augmentation of grid capacity.

Renewable energy law

Today, most countries in advanced levels of wind power development have an integrated energy framework with long-term vision and time-bound plans. India lacks this kind framework. Such a framework is mandatory for India's wind power growth and it will not only address the concerns of investors related to volatile environment policy but also indigenous power supply free from oil price fluctuations. (GWEC, 2012)

Recently the energy coordination committee of India has decided to support the enactment of the renewable energy law. The MNRE has constituted a working committee for R.E. Law. However, the outcomes and discussions of the committee are unknown. The World Institute of Sustainable Energy (WISE) is conducting major public campaigns to implement R.E. Law in the country.

As part of its UNFCCC obligations, India has framed a National Action Plan on Climate Change (NAPCC) in June 2008, stating government's vision for sustainable and clean energy future. According to that plan, by 2020, India is expected to procure 15% of its power from renewable energy sources. (GWEC, 2012)

Generation based incentive (GBI)

GBI is an incentive initiated by government to promote wind power projects. The scheme includes captive wind power projects but not the third party projects like merchant power plants. The benefits of GBI and AD are mutually exclusive. The incentive is disbursed on a half-yearly basis through the Indian Renewable Energy Development Agency (IREDA). The scheme was applicable initially to wind power projects commissioned before 31st March 2012. Later, MNRE recommended running the scheme over the 12th plan period (2012-2017) (GWEC, 2012). In August 2013, the government has cleared this approval and the GBI will function in the 12th plan period.

The GBI will provide an incentive of INR 0.5 per kWh (~ 1 US$ cent) of electricity generated with a cap of INR 10 million per MW (~ $ 162 000) of capacity. In its original scheme, the GBI is not attractive enough for developers to leave AD. Industry experts in India suggest that by doubling the incentive to INR 1.0 per kWh and removing the cap will help boost the appeal of GBI among developers.

Renewable Energy Certificate (REC) Scheme

The Renewable Energy Certificate (REC) scheme was introduced in 2010 for states to procure RECs to fulfill their RPS targets. The electricity act 2003 mandates Renewable Purchase Specification (RPS) for all the states. Most of the states have specified targets for its consumption of electricity from renewable energy sources. A single REC means that a renewable energy plant has produced one MWh of electricity. The RECs are tradable certificates and under present framework, the renewable energy generators can trade RECs through a power exchange platform. (GWEC, 2012)

The price of REC would be determined at the power exchange on momentary supply and demand situation, within the price band determined by the Central Electricity Regulatory Commission. The prices are calculated separately for solar and non-solar sources like wind, biomass and small hydro. In the price band, the upper and lower prices are called forbearance and floor price respectively.

The REC trading in Indian market began recently in February 2011 and it requires registration of project developers in National Load Dispatch Centre. The issued RECs are traded in the recognized power exchanges within the price boundary set by CERC. As of April 2012, the price range for wind power generation is between INR 1 400 and INR 3 480 per MWh. (GWEC, 2012)

By October 2012, wind energy projects contributed about 56% of the total accredited project capacity listed by the national REC registry. It suggests that more developers are entering the REC market and the mechanism is inviting interest. On the other hand, due to weak enforcement of RPSs at the state level, there is rising numbers of unsold RECs in the market. The RPS is applicable uniformly on the Distribution Companies (DISCOMs), captive power users and open access consumers. However, in September 2012, no state-owned DISCOMs bought certificates even though it is an obligation for them. It is due to lack of obligation enforcement at the state level.

Initiatives are taken to address the implementation issues of REC mechanism and there is continuous learning in this new field. Some states have stepped forward to impose penalty to generators for their non-compliance of RPO targets. However, it is still a challenge for India to make REC a widely acceptable instrument and create a revenue stream for the project financing community. Furthermore, to meet its 15 percent renewable energy NAPCC target by 2020, India needs a dynamic RPS scheme with frequent revisions. (GWEC, 2012)

Grid Integration

Often inadequate grids are a barrier for smooth integration of power generation from renewable. India’s transmission network is two-tiered.

1. Power Grid Corporation of India – Manages inter-state grids
2. State Transmission utilities – Manages local grids

India yet needs to develop a unified grid system through integration of the local, regional and national grids. India has five regional grids; Northern, North eastern, Western, Eastern, Southern regions. Among the five, except the southern region, all the four are connected. By 2014, the fifth region is also planned to be integrated to attain one national grid. (GWEC, 2012)

Wind power is variable in nature, which could cause problems in maintaining balance in power supply and demand. Most of the wind stations are located in remote areas of India that are far away from load distribution centers. Because of weak transmission and distribution network, often it is difficult to connect these remote wind farms with the network.

Grid Stability

Grid stability is the main factor of consideration when interconnecting a new system to an existing grid. The conventional networks are tuned for conventional mode of power flow. Whereas, the wind power, on interconnection, faces new challenges like safety, reliability and efficiency of the system. Due to the variable nature of wind power, an interconnection standard is developed to sustain the variability of the wind power. (GWEC, 2012)

Smart Grid Task Force

Modernization of grids, both regional and national, should be one of the primary areas of investment for development of wind energy in India. Especially after the introduction of IEGC, the grids across the country now have to take on power from renewable energy sources under different schemes and distribute them.

Taking the idea to next step, in 2010, the Ministry of Power (MOP) has framed ‘India Smart Grid Task Force (ISGTF). The vision of MOP in framing the task force is to bring the fields, IT, Communication and Power sector to form a comprehensive power grid infrastructure. In addition, in May 2011, India’s Bureau of Energy Efficiency has teamed with the IT firm IBM to develop the country’s first smart grid project. The analysis will determine the readiness of

India for deploying smart grid technologies and will calculate the investment return for a planned smart grid projects across India. (GWEC, 2012)

Based on the recommendations from Indian Smart Grid Forum, the MOP is supporting 14 pilot projects proposals across various locations of India worth approximately US$ 72 million. For the proposals to be successful, all the concerned government entities like, the Ministry of Power, the Ministry of New and Renewable Energy, the Ministry of Communications and Information Technology and the Ministry of Environment and Forests must work together to develop a common action plan.

2.5.4 Wind Power Scenarios

IEA – New Policies Scenario

The New Policies Scenario by International Energy Agency is based on the present intentions and directions in national and international energy policies. Even though the directions have not been implemented completely in formal decisions and enacted into law, they are considered for the scenario. Although the difference between the New policies Scenario and Reference Scenario is marginal for wind power, it is still positioned in the center of the World Energy Outlook (WEO) analysis.

According to this scenario, up to 2015, the annual wind energy markets will stay flat out and then will shrink to about 10% comparing to 2011 market for up to 2020. It projects a gradual slowdown in the annual market to 2030 and remains flat for the rest of the period. Even though the market sees a slowdown, the cumulative installed capacity would still reach 586 GW by 2020 and 917 GW by 2030. (GWEC, 2012)

GWEO – Moderate Scenario

The GWEO ‘Moderate Scenario’ follows almost the same path as the IEA New Policies Scenario. It takes into account the policy measures that are already enacted in the planning stages and assuming that the commitments by governments at Cancun will be implemented. At the same time, the scenario assumes that the existing and planned national and regional renewable energy targets are met.

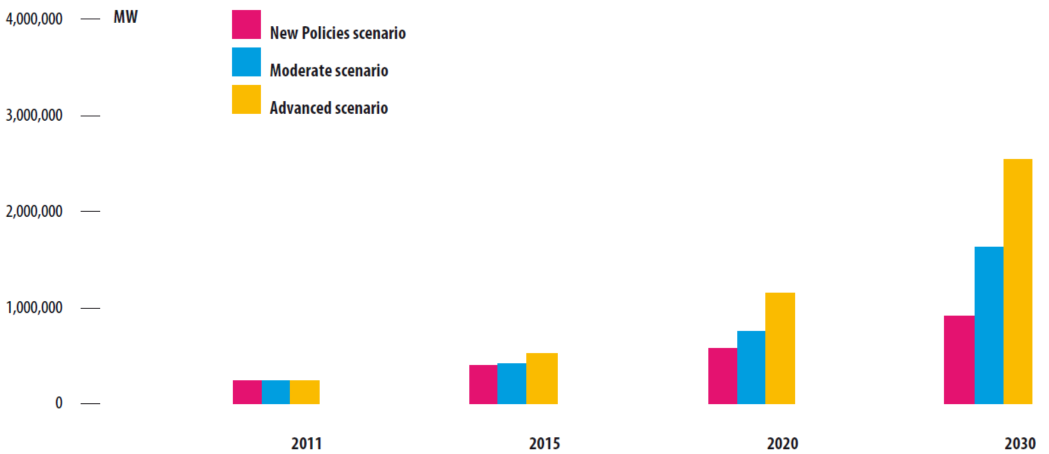
The projection by Moderate Scenario is by 2020, the total cumulative installed capacity will be 760 GW with annual market size topping 70 GW. The Scenario is optimistic in 2020s and the growth would continue like in the past two years. The annual market size in 2020s will approach 100 GW per year and a total installed capacity of about 1 600 GW by 2030. (GWEC, 2012)

GWEO – Advanced Scenario

The Advanced Scenario is an ambitious scenario with projection of best growth possible, but still well within the capacity of the industry as of today and in the future. It assumes the following.

1. Unambiguous target for renewable energy
2. Strong political will to create appropriate policies
3. The stamina to stick with the policies
4. Government will enact clear and effective policies for carbon mitigation in line with the universally agreed target of maintaining global mean temperature below 2 °C above pre-industrial temperatures.

In the Advanced Scenario, the projection shows the potential of wind power to cater 20% or more of the global electricity supply in the world (GWEC, 2012). Throughout this decade, the scenario maintains ambitious growth rate with assumptions of overcoming the present problems in the near future. The annual market size is projected to reach up to 130 GW by 2020 with a total cumulative installed capacity reaching 1 149 GW and more than 2 500 GW by 2030.



		2011	2015	2020	2030
New Policies scenario					
	[MW]	237,699	397,859	586,729	917,798
	[TWh/a]	583	976	1,439	2,412
Moderate scenario					
	[MW]	237,699	425,155	759,349	1,617,444
	[TWh/a]	583	1,043	1,863	4,251
Advanced scenario					
	[MW]	237,699	530,945	1,149,919	2,541,135
	[TWh/a]	583	1,302	2,821	6,678

Figure 17: India: Cumulative Wind Power Capacity in MW (GWEC, 2012)

2.6 Hydropower

Hydropower is a crucial contributor for Indian power sector. Owing to growing energy demand in the country, hydropower is increasing significantly with minimum environmental impacts. It has the potential to provide sustainable energy services using the indigenous resources and solve the longstanding energy crisis in the country.

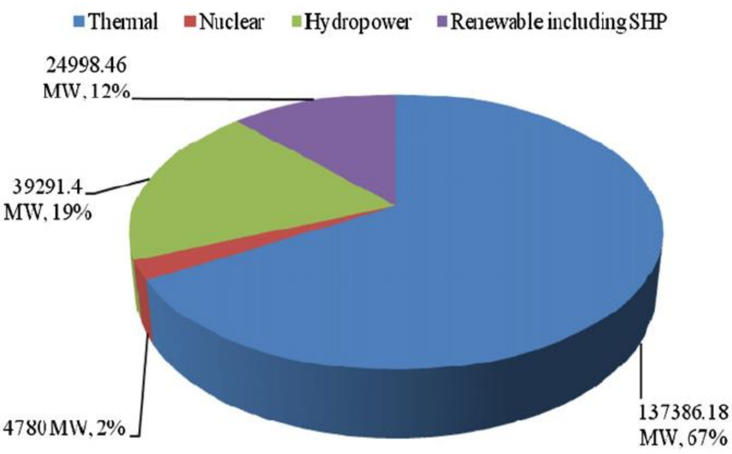


Figure 18: Aggregate installed power capacities in India in 2012 (Sharma, et al., 2013)

As inferred from the figure, hydropower is the second highest contributor of the Indian energy consumption, with 19% of electricity generation. One important property and an advantage of hydropower is that it can respond to fluctuations in electricity demand, both base-load and peak-load demands and therefore it helps in stabilizing the power grid. The Indian Hydropower and Small Hydropower (SHP) ranks sixth in world for total hydro capacity with more than 40 GW of existing capacity.

2.6.1 Potential in India

India is rich in hydro-electric potential and ranks 5th in world in terms of exploitable hydro-potential. The basin wise assessment of hydro-potential of India is shown in Table 7. This assessment made by CEA, says that the economically exploitable hydro-power potential of India is around 148 700 MW.

Table 7: Basin wise Hydro-potential (EAI, 2012)

Basin/River	Probable Installed Capacity (MW)
Indus Basin	33 832
Ganga Basin	20 711
Central Indian River System	4 152
Western flowing rivers of southern India	9 430
Eastern flowing rivers of southern India	14 511
Brahmaputra Basin	66 065
Total	1 48 701

In addition to large hydro plants, there are also pumped storage projects and hydropower from small, mini and micro schemes. The potential of them are estimated to be 94 000 MW and 6 782 MW respectively. Therefore, the total hydro-potential of India is about 250 000 MW. (EAI, 2012)

Cooperation with Neighbors for Hydropower

India imports large amount of energy from Bhutan. Due to its geographic location, Bhutan has many fast flowing rivers with an estimated hydropower potential of around 30 000 MW. Presently, the captured power is 1 488 MW and among which approx. 5.3 billion units energy, nearly 75%, is exported to India (Sharma, et al., 2013). There exists a long association from India in providing technical and financial assistance to Bhutan for the development of hydropower resources.

India also assists Nepal for the development of its hydropower potential. At present, the bilateral power exchange at the borders between Nepal and India is 50 MW. By 2017, Nepal plans to produce 2230 MW of hydropower and out of which, about 400 MW is planned to export to India. In future, for high capacity hydro projects to be developed in Nepal, the mutual understanding between the two countries is crucial to meet both the financial and technical requirements. (Sharma, et al., 2013)

2.6.2 Hydropower Projects Categories

Generally, the hydropower projects are categorized into two segments i.e. small and large hydro. There is no international standard to define SHP by power output. Different countries adopt different standards keeping the maximum limit ranging from 5 to 50 MW. In India, the hydro plants of capacity up to 25 MW is belong to SHP category (Sharma, et al., 2013). It is further sub divided into mini hydro plants of capacities between 100 KW to 2 MW and micro hydro plants of capacities less than 100 KW. The large hydro plants are under the control of Ministry of Power (MOP) and the SHPs are in control by Ministry of New and Renewable Energy (MNRE).

Developing renewable energy has been part of India’s energy supply strategy for long time. The strategy also needs to meet decentralized energy needs of the rural sector and in turn the energy security of the nation.

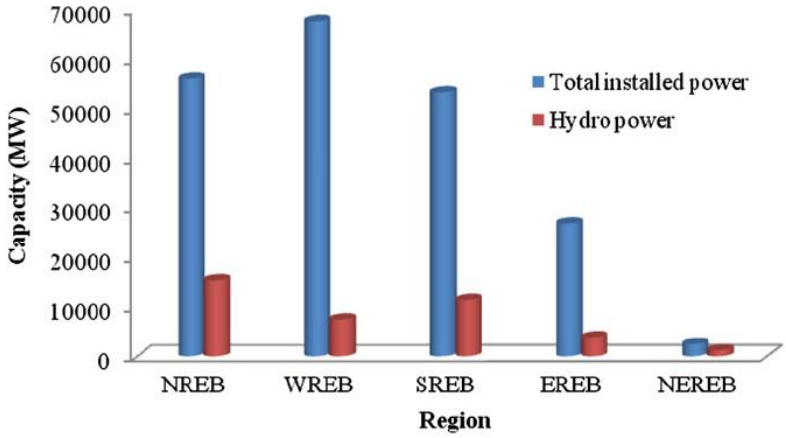


Figure 19: Installed Hydropower - Region wise (Sharma, et al., 2013)

Indian power sector is organized into five regional electricity boards. They are Northern, North Eastern, Western, Eastern and Southern Regional Electricity Board. The Figure 19 shows the region wise hydropower installed capacity along with its total installed capacity, as on August 2012. From Figure 20 it is clear that more than 60 % of total hydropower generated in India belongs to state sector.

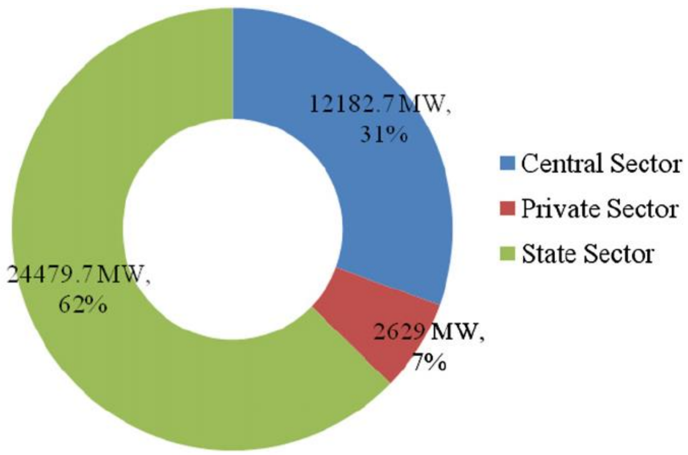


Figure 20: Installed Hydropower - Sector wise (Sharma, et al., 2013)

2.6.3 SHP in India

The total installed capacity of SHP is 3 434 MW by August 2012. The MNRE has estimated the India's total SHP potential as 15 384 MW by identifying 5718 prospective plant sites. In this potential, about 42% (6592 MW) comes from four northern mountainous states of India, namely, Himachal Pradesh, Uttarakhand, Jammu and Kashmir and Arunachal Pradesh. The GOI is planning to develop half of the identified projects in the next 10 years by supporting SHP through capital subsidies and preferential tariffs. (Sharma, et al., 2013)

The Government of India has initiated many electricity policies to promote SHP and other renewable energy sources in the country in the last few years. Foremost amongst them are briefly discussed here.

1. **Electricity Act, 2003**

- Suitable measures shall be provided to SERCs to promote cogeneration and generation of electricity from RES
- The Appropriate commission shall specify the terms and commissions for tariff determination

2. **National Electricity Policy, 2005**

- It stipulates progressively that the share of electricity from RES need to be increased
- Purchase of electricity from RES by the distribution companies shall be through competitive bidding

3. **The National Tariff Policy, 2006**

- It mandates each SERC to specify a Renewable energy Purchase Obligation (RPO/RPS) in a time-bound manner
- The percentage for purchase of energy should be made applicable for the tariffs to be determined by the SERCs.

4. **National Rural Electrification Policies (NERP), 2006**

- It provides guidelines to set up stand-alone RES systems for off-grid systems in rural areas of the country
- It specifies tariff forbearance for electricity supply to consumers in these areas.

5. **State level initiatives**

   In India, there are several states promoting SHP as renewable power generation source through their own state level policies that are different from national level policies. Some of the notable state level policies are enumerated below.

- Feed-in tariff policy for SHP
- Bay back for SHP: If one can generate power for his own home through renewable energy sources, he can sell the excess electricity, if any, back to synergy.

6. Financial assistance schemes

- MNRE has provided financial support/subsidy for activities like, new SHP projects in state, private, joint sectors and renovation and modernization of old SHP projects in public sector

SHP is the most promising solution to India, comparing to other renewable energy methods with an economic cost of approx. Rs. 3.90 per kWh (Sharma, et al., 2013). It can provide clean and economical solution to energy problems in off-grid, remote, rural and hilly areas of India, where regional grid extension is uneconomical. In addition, SHP has the lowest capital cost among renewable energy technologies in India, which is about 60-70 million rupees per MW (FY 2012-2013).

SHPs have high efficiency of between 70 and 90% and high capacity factor of about 50%, compared with 10% for solar and 30% for wind. It is also the reliable, clean, largely carbon-free and a flexible peak-load technology way to generate electricity. It promises an attractive energy payback ratio even for developing countries with a lifespan up to 100 years. (Sharma, et al., 2013)

Water quality issues of SHP

Water quality is a challenge to operate SHP plants due to the presence of silt contents, particularly during peak snowmelt and high flows. The SHP plants may also change water temperatures and lower the levels of dissolved oxygen. Poor quality of water leads to erosion of hydro turbine components, which will affect the efficiency of the plant. Such hydro turbine problem includes cavitation, sand erosion, material defects and fatigue. As the silt content of water increases, studies show that the efficiency of the turbine is decreased.

The environmental problems of hydropower plants are based on the encroachment of land due to damming or lowering of water level. The reservoirs have harmful effects on the downstream water quality of the rivers of India. One such problem is the formation of blue-green algae blooms in the downstream. Owing to high silt content from heavy rainfall in catchment areas, several SHP plants are shutdown in India. (Sharma, et al., 2013)

The GOI is taking major initiatives to mitigate the water quality problems. However, it is still a challenge to maintain water quality in the reservoir, as it constitutes a focal point for the river basin catchment. There are several factors of the reservoir contributing to water quality such as, reservoir morphology and depth, water retention time in the reservoir, climate, water quality of tributaries, quantity and composition of the inundated soil and vegetation and rapidity of impounding.

The barriers for development of hydropower are listed below. (EAI, 2012)

1. The land that is flooded by the construction of dam would have been available for use for the local community. The dam alters the landscape, character of the river and prevents the free movement of fishes.
2. Because of variations in flow, the partial or complete blockage of the river for energy conversion is affected.
3. Due to change in the course of waterways, the agriculture and ecosystems downstream are affected. Constructing a large-scale hydropower plant will pollute and damage the surrounding ecosystem significantly.
4. The reliability of hydro projects is also questionable due to prolonged droughts and dry seasons.

2.6.4 Environmental Benefits

The important environmental benefit of SHP is that no CO_2 is produced during power generation. It is a clean and renewable source of energy emitting only very low amount of GHGs compared to fossil fuels. On average, a 1 GW of additional renewable energy capacity achieves CO_2 emission reduction of 3.3 million tons per year. This proves that there is tremendous scope for SHP in Indian power sector towards meeting its future energy needs and its carbon emission mitigation obligations.

2.7 Biomass

2.7.1 Background

Over centuries, biomass is the major fuel for various energy needs. Until 19th century, global energy consumption is dominated by biomass and with rapid increase in use of fossil fuels; the share of biomass in total energy is in decline.

Yet, biomass still contributes to 38% of energy in developing countries (Shukla, 2011). Programs for biomass based power generation have recent origin in India. It is accelerated when MNRE appointed a task force in 1993 to probe on possibilities for bagasse based cogeneration.

‘Biomass power developers have initiated various steps to collect agro-residues from villages, its storage and proper transportation to biomass power plants’ said Dr. Farooq Abdullah, the Minister of New and Renewable Energy (Panchabuta, 2012). The MNRE encourages the use of biomass for power generation through different technological means like gasification, combustion and cogeneration. MNRE, in the twelfth five-year plan, has proposed to continue its support for various fiscal and financial incentives, which are being provided for setting up biomass-based power plants.

The incentives includes, accelerated depreciation on major components, excise duty exemption, capital subsidy linked with capital and relief from taxes. MNRE has also stepped forward to promote biomass based power production by arranging business meet, seminars and workshops. For the twelfth five-year plan, the target for renewable energy capacity addition is 29 800 MW, among which 2000 MW is from biomass energy. (Panchabuta, 2012)

Up to 2010, about 980 MW of biomass power has been commissioned and about 380 MW is in construction. (Panchabuta, 2010)

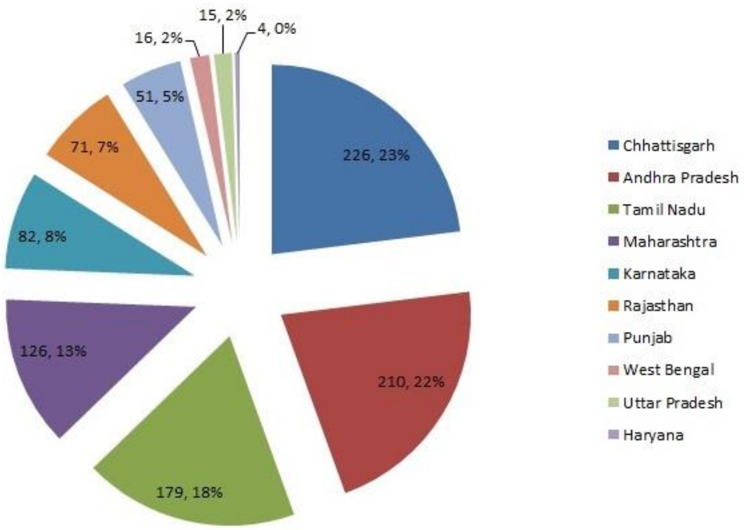


Figure 21: The state wise capacity of commissioned biomass power projects (Panchabuta, 2010)

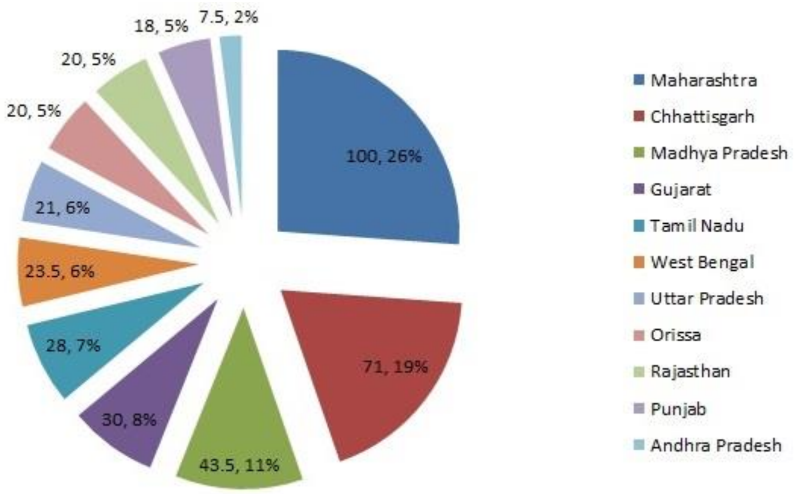


Figure 22: Projects under implementation (as of 2010) (Panchabuta, 2010)

Recently there are also technological advancements in the area of fuels to be used in biomass boilers resulting to include rice husk, sorghum among other residues. As India is one of the world's largest rice producers, MNRE is promoting to utilize the abundant rice husk for biomass power production. The important factor for development of biomass power projects is availability of feedstock. Due to this, the scope of biomass power in India is limited. The states that are well established in biomass power like Tamil Nadu, Andhra Pradesh and Karnataka have limited room for future advancements. While states like Maharashtra, Punjab and Madhya Pradesh have significant potential for capacity addition.

Biomass combustion-based power generation is of recent origin in India. In the late 1994, the program was started with two pilot plants of capacity 5 MW each. It aims to utilize the agricultural and agro-industrial residues, which is about 350 million tons annually in India. The program also received subsidy from government since 1995. The cost of power produced by this method is also expected to be competitive in the market. (Shukla, 2007)

The advancement of the biomass power program is increase the scale of production and to grid-connect the power production from variety of biomass materials like rice husk, bagasse, rice straw, wood, wood waste, wild bushes and paper mill waste. The estimated potential for power production by biomass gasification is 17 000 MW. In addition to that, power from sugarcane residues is estimated to about 3 500 MW (Shukla, 2007).

Extensive research in the combustion characteristics of biomass fuels is being carried out major boiler manufacturers of India, including Bharat Heavy Electricals Limited (BHEL) – World’s seventh largest power equipment manufacturer. Until 2007, nearly 55 MW of grid-connected biomass combustion plants are commissioned and about 90 MW of new plants are in construction (Shukla, 2007). The initiative to improve biomass power generation to grid-connected system has enhanced the economics and technology of the plants. Notably, Indian companies are entering into joint ventures with leading international manufacturers to exchange the technologies.

Raw biomass fuels have to be pre-treated according to the mode of transportation and then combustion. Drying the fuel will reduce transportation load. Moreover, it is an important step if the feedstock is carbonized or gasified. Pre-treatment also includes sorting, sizing and homogenizing for it to be properly combusted. While all these pre-treatment processes are mechanized in industrialized countries, it is still economical in India to manually pre-treat the fuel. (Shukla, 2007)

2.7.2 Competitiveness of biomass electricity

Biomass based electricity generation is economically successful in application like supplying electricity in decentralized locations and industries like sugar mills that generates biomass waste. Large-scale biomass power plants will be economic to run if its delivery cost is competitive with the cost of conventional electricity sources in centralized electricity supply. The primary competing source for electricity supply in India is coal-based power.

The electricity cost of biomass power plants will highly variable depending on the factors like source availability, location etc., and the standard size of grid-based biomass plants vary from 1 MW to 50 MW (Shukla, 2010). Whereas, the cost of coal power plant’s electricity is dependent on coal extraction cost and logistic costs. The standard size of coal power plants will be 500 MW.

According to (Shukla, 2010), the delivery cost of a 50 MW biomass plant is 15 percent higher than a coal power plant. However, this gap is expected to reduce in future due to following reasons,

1. Scale difference between coal and biomass plants will minimize

2. Cost of raw biomass material will reduce because of improvement in plantation practices
3. Coal price will increase in future

2.7.3 Future of biomass energy in India

Use of biomass in India is still confined to traditional cooking uses, despite the modern advancements in biomass energy technologies. Modern technologies in biomass energy utilization include transformation of biomass into synthetic gases and liquid fuels (Such as Methanol) and electricity for grid connectivity. In India, owing to the small biomass energy market, the penetration is difficult for modern biomass technologies.

The future of biomass energy in India is determined by providing energy services at competitive cost. The main factor for cost is sustained supply of raw biomass waste, which requires production of energy crops and wood plantations for meeting growing non-energy needs. Factors like land supply, enhanced biomass productivity, logistic infrastructure and economic activities of plantations will determine the future of biomass power in India. (Shukla, 2010)

In recent years, the knowledge in operating biomass plantations and energy conversion technologies is escalating. Even though the present penetration of modern biomass energy services is limited, proposals for policy reforms to eliminate energy subsidies will be advantageous to biomass energy growth. Developing nations have to smoothly transit from present inefficient biomass use in traditional sectors to a competitive and efficient use in the future. To attain this, realization of biomass potential in energy sector is crucial.

Climate change policies of India will have significant impact in advancement of biomass energy in the country. Governments, committed to sustainable development, prefer biomass due to its significant social and environmental benefits. However, a key issue for Indian policy makers is to develop a market for biomass energy services. (Shukla, 2010)

2.7.4 National program on Bagasse based Co-generation

The program launched in 1994 provided subsidies for specific demonstration projects, supported R&D activities and publicity. An important ground for capital subsidy is that the cogeneration plant cost if too high, almost equivalent to a new sugar mill. The program was later modified in 1995 and subsequently in 1996 to attract sugar mills into public sector (Shukla, 2011). Notable features of the program includes,

1. Significant subsidy for Demonstration scheme
2. Interest subsidy scheme
3. Support to R&D projects
4. Indirect programs like seminars, business meets in sugar producing sectors and interaction meetings among various stakeholders.
5. International support

According to (ITALIA, 2009), the potential of biomass power is as follows,

1. Power generation from surplus biomass is 18 000 MW
2. Additional power generation through optimum bagasse cogeneration is 5000 MW

The national biomass program has following components,

1. Biomass based power generation in grid connected mode
2. Cogeneration from bagasse in sugar industries for export of surplus power to grid
3. Off-grid biomass gasification systems for thermal and electrical applications for industry and village electrification

Biomass conversion technologies deployed in India as on 2009 (ITALIA, 2009),

<u>Grid Power</u>

- Combustion
- Gasification

<u>Off-grid/Distributed Power</u>

- Gasification

<u>Cogeneration</u>

- Bagasse cogeneration in Sugar mills
- Non-bagasse cogeneration in other industries

Table 8: Status of Biomass conversion technologies (ITALIA, 2009)

Program	**Commissioned projects (MW)**	**Projects under implementation (as on 2009) (MW)**
Bagasse Cogeneration	1048	1591
Biomass power	704	578
Total	1752	2169

3 SCENARIOS

3.1 LCA Study on Scenarios

Goal and Scope of the study

The goal of the study is

- To assess the given three scenarios and find the environmentally best performing scenario among them
- To find the amount of emission saving from replacing coal in future

The study is a cradle to grave analysis and covers the entire life cycle of power production, starting from fuel procurement to construction of power plants and production of electricity.

Functional Unit

Functional unit for our system is the amount of electricity generation from different power production methods, measured in TWh. The purpose of the system is to minimize the total GHG emission. Even though the GHG emissions are placed in the center of our analysis, the system also emits other emissions like particles, radiations and so on. However, all the other emissions are omitted in this analysis in order to make the system more comparable with in the unit processes.

System Boundary

In our study, there are 12 different unit processes, as shown in Figure 23. The system boundary contains all the 12 processes. Each unit process, except the process 'Total Electricity Demand', represents electricity production from different method and it includes sub processes like procurement or production of fuel, transportation, plant construction, power generation and plant End of Life (EoL).

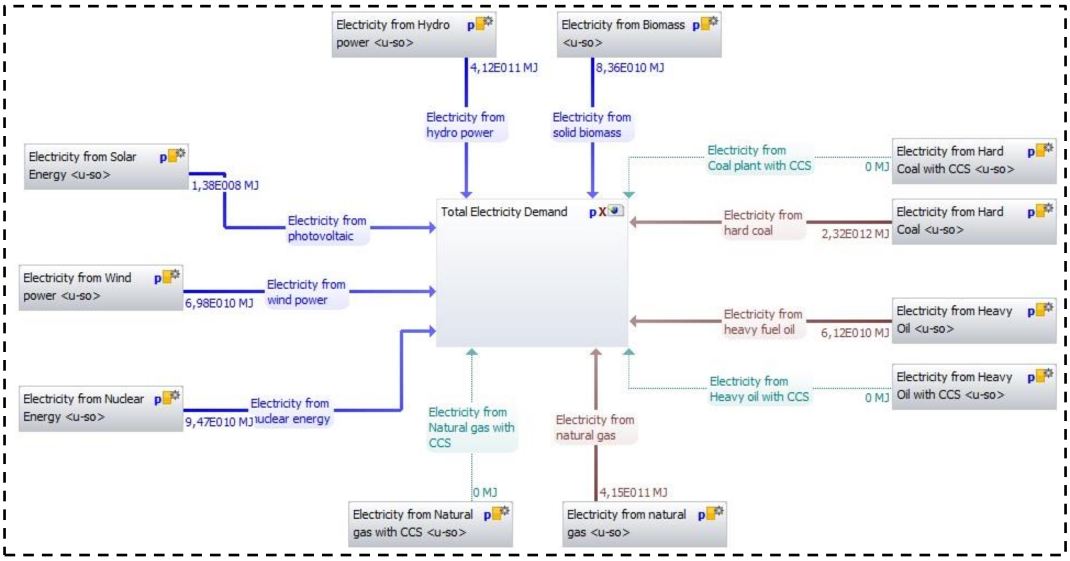


Figure 23: LCA – Mitigation Model

Life Cycle Inventory Analysis (LCI)

In our system, the total production of electricity for a particular year is kept fixed. This means, in 2010, the total unit produced in India is around 3.5 EJ and this value is contributed from different power producing sources. All the past data are obtained from IEA website (IEA, 2010). For the year 2050, the total electricity demand is projected to be 18.2 EJ, which is taken from the reference scenario of AVOID study (discussed in 1.3 Existing Scenario for 2050).

Sample Calculation for solar power,

$$Total\ Electricity\ demand\ in\ 2050 = 18.2\ EJ$$

$$Share\ of\ Solar\ PV = 35\%$$

$$Share\ of\ Solar\ technology = 0.35 \times 18.2 \times 277.8 = 1770\ TWh$$

$$Emission\ Factor\ for\ Solar\ technology = 80\ Kg\ CO_2e/MWh$$

Therefore,

$$Total\ emissionfrom\ solar\ technology\ for\ 2050 = 80 \times 1770 \times 10^6$$
$$= 0.14\ Gt\ CO_2$$

<u>Unit Processes</u>

There are eleven unit processes representing the eleven methods of power production and one fixed unit process for controlling the demand. The 11 unit processes are,

1. Electricity from Hard Coal
2. Electricity from Hard Coal with CCS
3. Electricity from Heavy Oil
4. Electricity from Heavy Oil with CCS
5. Electricity from Natural gas with CCS
6. Electricity from Natural gas with CCS
7. Electricity from Solar Energy
8. Electricity from Wind Power
9. Electricity from Nuclear Energy
10. Electricity from Hydropower
11. Electricity from Biomass

The description and flow diagram of each unit process is explained in Appendix 1.

3.2 Scenario 2010

In 2010, the total electricity demand of the Indian power sector was 3.46 EJ and was dominated by fuel coal. Nearly 80% of power has come from the fossil fuels (Refer Figure 25 for technologies mix). The contribution from solar PV is negligible and CCS has still not penetrated into the system. Next to fossil fuels, hydropower takes about 12% share.

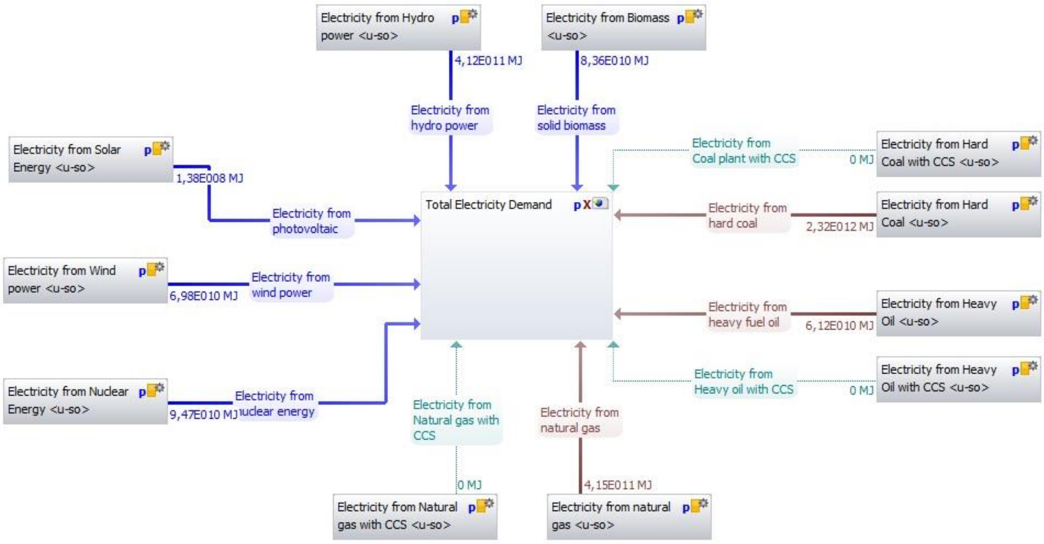


Figure 24: Flow Diagram of Scenario 2010

In this scenario, none of the unit processes concerning CCS technology is in the flow of the system (Flow diagram shown in Figure 24). The total demand is fulfilled by all other methods of power production, predominantly by fossil fuel technologies.

Emission Factor

Emission factor is defines as the amount of emissions (in CO_2e) produced per unit of power generation. The factor is specific to different technologies. From (IEA, 2013), the emission factors for fossil fuel technologies are obtained. For renewables, due to data insufficiency, the emission factors of North America are assumed for the study (Steinhurst, et al., 2012), except for biomass power. Calculation of emission factor for biomass power follows,

From (Environment, 2013), the GHG emissions from industrial boiler with wood pellets are fuel is 0.84 Kg CO_2/Kg fuel. The net calorific value of wood pellets is 17.17 MJ/Kg fuel.

Therefore,

$$Emission\ Factor = \frac{0.84}{17.7} \times 3600 = 176\ Kg\ CO_2/MWh$$

3.3 Reference Scenario 2050 (REF 2050)

This scenario will be the result in 2050 if there are no changes implemented to the existing scenario in 2010. The total power demand is 18.2 EJ, which is derived from the projection of AVOID study (discussed in 1.3 Existing Scenario for 2050). The power share from different technologies remains same as in 2010 and there are no carbon mitigation obligations from the Indian government. This scenario is kept as a reference to compare with scenario LCOF, which implements all necessary changes to reduce CO_2 mitigation.

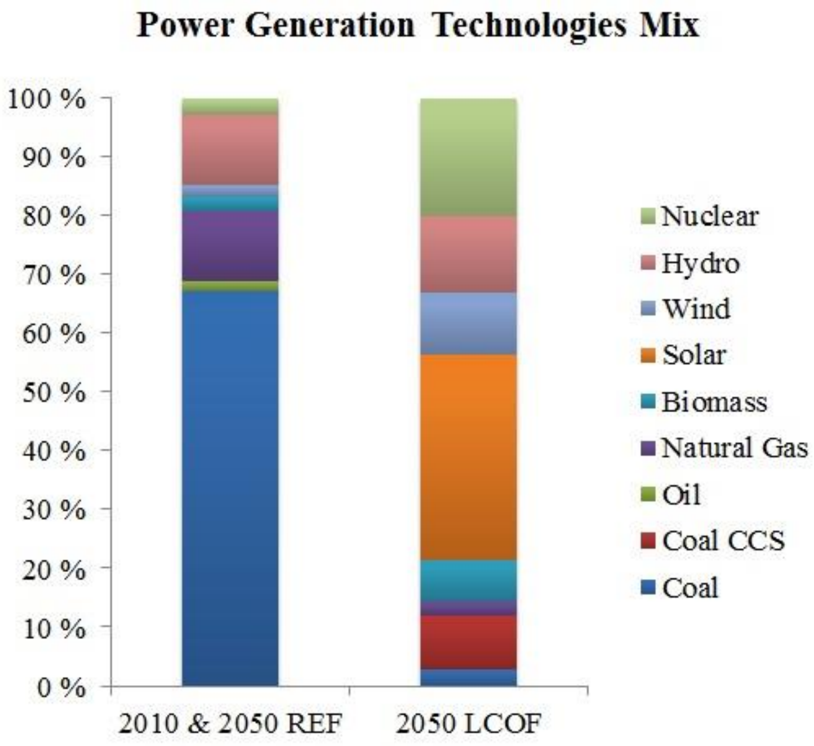


Figure 25: Power generation technologies mix for three scenarios

Similar to scenario 2010, there are no CCS technologies developed in this scenario. Even though, this scenario is less likely to happen, it provides an insight of where the present trend in Indian power sector is leading.

3.4 Scenario LCOF 2050

Scenario Low Carbon Optimistic Future (or LCOF) 2050 operates with the obligation of national carbon mitigation. In addition to the existing technologies in 2010, CCS is implemented with the fossil-fuel power production methods. The total power demand is same as that of the reference scenario 2050. The power share of different technology is determined based on the following factors,

1. Present interest shown towards the specific technology by the GOI
2. Penetration capacity of the specific technology based on its technical feasibility

For the fossil fuel based power production technologies, the power share envisaged is only 14.5% of the total demand, compared with 80% in 2010. It is due to two main reasons, one is the availability of coal and the other is the nation's carbon mitigation obligation. Even though India has abundant coal reserves to meet its future demands, it is highly uncertain that it will last until 2050. According to (Chikkatur, et al., 2007), the coal reserves of India may not be as high as traditionally thought to be. A recent estimate predicts that the total coal reserve of India is about 44 billion tons, meaning that it might only last for the first half of the 21^{st} century. Assuming that this estimate is accurate, it provides us a reason to see coal as a highly valuable source and needs to be utilized with maximum efficiency.

This scenario assumes that India has successfully implemented CCS technology to all coal based power plants. However, owing to India's present and foreseeable interest towards CCS technology and other economic factors, it is uncertain that India will implement CCS to its oil and natural gas power plants in future.

For non-fossil fuel technologies, the power share figures are arrived based on the government's interest and future action plans. Notable points that have influenced the electricity share projections for 2050 are listed below.

- 'National Solar Mission' that plans up to 20 GW of grid-connected power generation by 2022
- Solar energy is a key renewable energy source for India
- Indigenous nuclear power program, which plans to take over nearly 25 % of electricity share by 2050
- For wind power, GWEO-Moderate scenario projects a total installed capacity of 1 600 GW by 2030

Table 9: LCOF 2050 Overview

Method	Elec. Share %	Power Generation (TWh)	Emission Factor (KgCO2e/ MWh)	Total emission (Gt CO2e)	Emission %
Coal	3.0	151.7	1195	0.18	29
Coal CCS	9.0	455.0	110	0.05	8
Oil	0.0	0.0	1312	0.00	0
Oil CCS	0.0	0.0	110	0.00	0
Gas	2.5	126.4	517	0.07	11
N. Gas CCS	0.0	0.0	110	0.00	0
Biomass	7.0	353.9	176	0.06	10
Solar	35.0	1769.6	80	0.14	23
Wind	10.5	530.9	12	0.01	1
Hydro	13.0	657.3	152	0.10	16
Nuclear	20.0	1011.2	10	0.01	2
Total	**100%**	**5056.0**	**--**	**0.62**	**100%**

The share of solar energy in LCOF 2050 is the highest, equals to 35% of total (Shown in Table 9). In order to achieve this level, there must be radical improvement in solar power expansion in the decade 2040. Unlike other energy sources, solar energy is a key renewable source for India in future. Therefore, it is projected that it will dominate the power sector of India in 2050.

Life Cycle Impact Assessment (LCIA)

This phase of LCA is aimed at evaluating the significance of potential environmental impacts based on the LCI flow results.

Impact category, Category indicators and Characterization models

The impact category for our system is “CML 2001, Global Warming Potential (GWP 100 Years)”. The impact assessment is performed by scenario wise.

Table 10: LCIA Terms

Term	Selection
Impact Category	Climate change
LCI results	Amount of GHG per functional unit
Characterization model	Baseline model of 100 years of the Intergovernmental panel on Climate change
Characterization factor	Global Warming Potential (GWP 100 years) for each greenhouse gas (KgCO_2eq/Kg gas)
Category indicator result	Kg of CO_2eq per functional unit

Scenario 2010 and REF 2050

Both the scenarios operate in the same technology mix. However, they differ in total emission generation, owing to the power demand in two periods. The total emission in 2050 escalates to 4.6 billion tons of CO_2e, compared to 2010 level. This means that if the present trend in power sector is maintained until 2050 with no improvements in emission mitigation, then the total emission is projected to multiply by more than five folds i.e. 4.6 billion tons of CO_2e.

Table 11: Scenario 2010 and REF 2050 - Overview

Method	Elec. Share %	2010		REF 2050	
		Power Generation (TWh)	Total emission (Gt CO2e)	Power Generation (TWh)	Total emission (Gt CO2e)
Coal	67.1	644.4	0.77	3393.4	4.05
Coal CCS	0.0	0.0	0.00	0.0	0.00
Oil	1.8	17.0	0.02	89.5	0.12
Oil CCS	0.0	0.0	0.00	0.0	0.00
N. Gas	12.0	115.3	0.06	607.2	0.31
N. Gas CCS	0.0	0.0	0.00	0.0	0.00
Biomass	2.4	23.2	4.1E-03	122.4	0.02
Solar	0.0	0.0	3.1E-06	0.2	1.6E-05
Wind	2.0	19.4	2.3E-04	102.1	1.2E-03
Hydro	11.9	114.4	1.7E-02	602.7	9.2E-02
Nuclear	2.7	26.3	2.6E-04	138.5	1.4E-03

Total	**100.0%**	**960.1**	**0.87**	**5056.0**	**4.60**

The main emission contributing technology in both scenarios is the coal based power generation, as shown in Table 11. However, this trend is less likely to happen, considering the rising global warming tensions and coal availability to India.

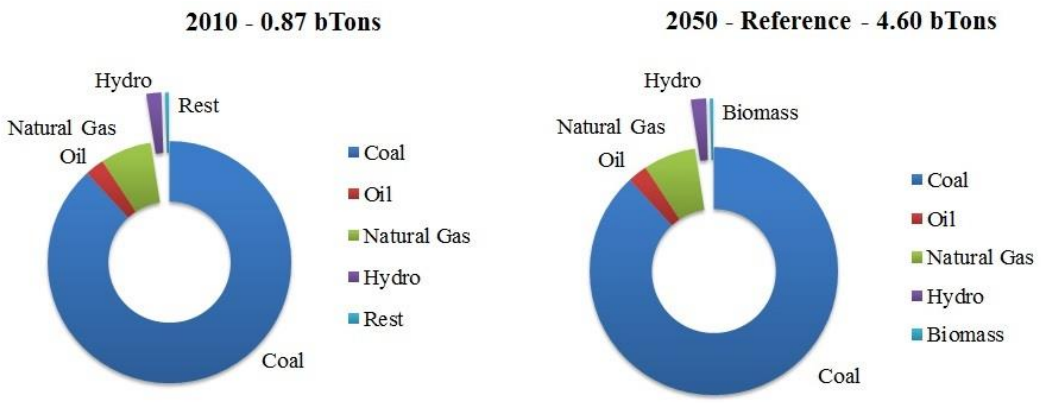


Figure 26: Emission mix from different technologies in Scenario 2010 and REF 2050[1]

<u>Scenario LCOF 2050</u>

The scenario LCOF 2050 utilizes all the technologies concerning emission mitigation in India, especially, carbon capture and storage in power plants operating with fossil fuels. The total emission in this scenario is 0.62 billion tons of CO_2e in 2050. The major contributors are coal (29%) and solar power (23%) technologies (Refer to Table 9).

[1] In REF 2050, the emission contribution from rest of the technologies are negligible and therefore not shown in the graph

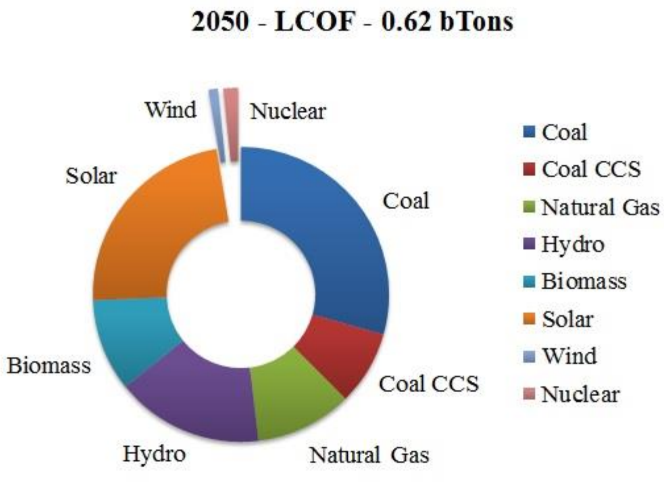


Figure 27: Emission mix from different technologies in Scenario LCOF 2050

3.5 Interpretation of results

Between the two scenarios of 2050, it clear from the results that LCOF 2050 will help India to meet its global emission mitigation obligations. It promotes the renewable energy technologies to a great extent, chiefly solar power. It is projected that to attain this level of expansion in solar power, India must see immense growth in solar power sector in the decade 2040.

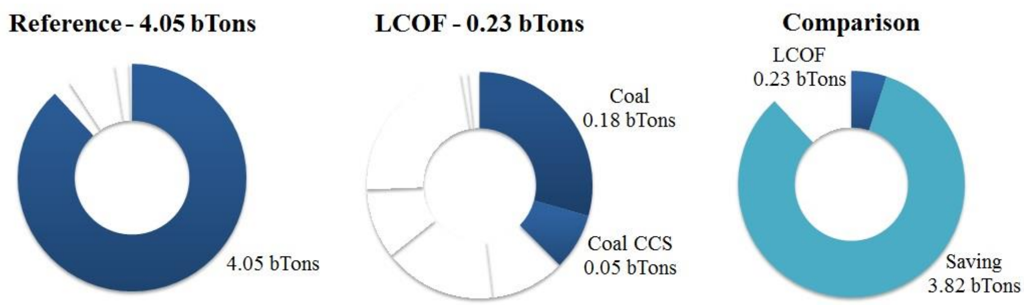


Figure 28: Coal emissions comparison in 2050

Figure 28 compares the emissions from coal based power generation between two scenarios. Coal is contributing to 4.05 billion tons CO_2e in reference scenario and 0.23 billion tons CO_2e in LCOF. Nearly about 3.8 billion tons CO_2e emissions is a saving from coal by shifting to renewable energy technologies[2].

[2] Emissions from renewable technologies are less, compared to coal power plants and therefore they are neglected in this graph for simplicity

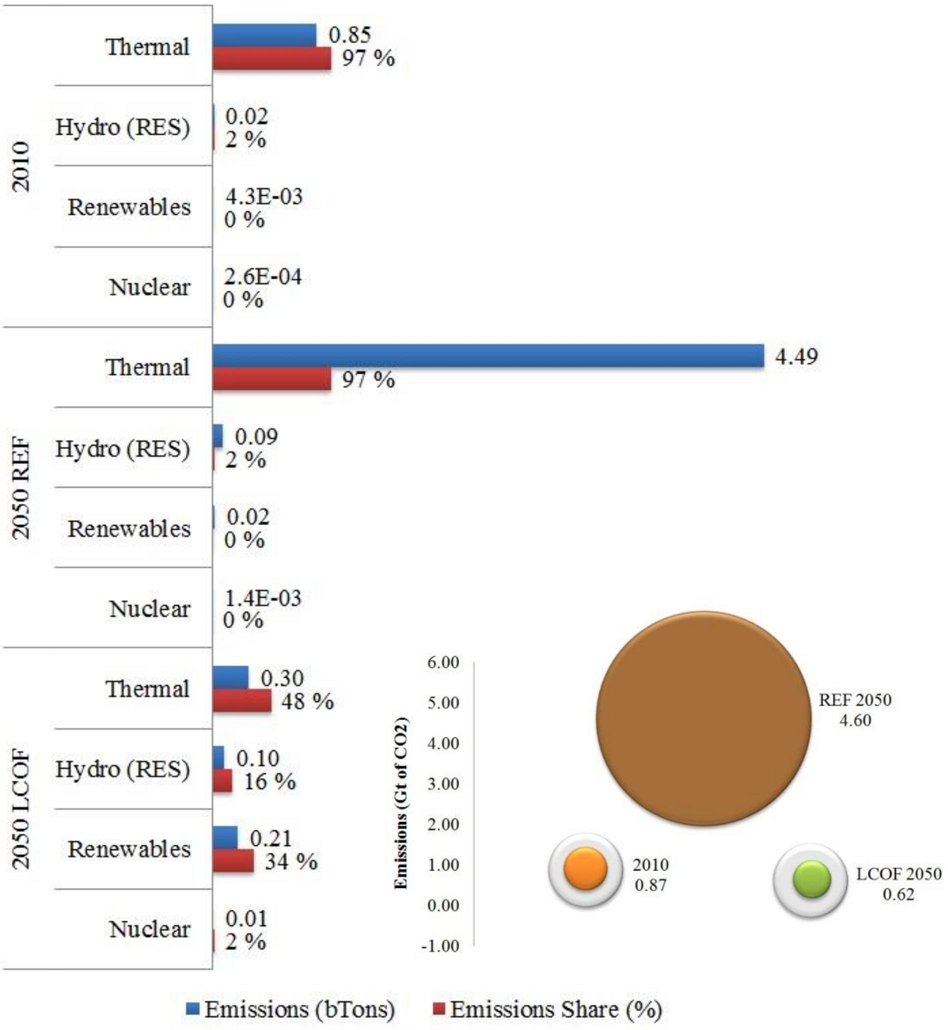


Figure 29: Sector wise emission and their comparison of all three scenarios

The Figure 29 shows the sector wise emissions data and share percentage in three scenarios. In all the three scenarios, thermal sector is dominant in emissions. As it seen in LCOF, renewable technologies are growing in rapid pace, contributing to 34% of the total. Also, the biggest balloon in the second graph represents the total emission of the scenario Reference 2050 and the smaller green balloon for LCOF 2050.

4 CONCLUSION

Indian power sector is diversified and dominated by fossil fuel technologies. The technologies that require huge scale of development for delivering low emission power for the future are CCS and Solar power. The renewable energy solutions like CCS and solar power are in beginning stage of penetration in the Indian power sector. Among them, the potential of solar energy is abundant in India and has huge scope for expansion to meet the energy demands. At the time when this paper is written, Indian government has unveiled a proposal to build a 4GW ultra mega solar power plant, first of its kind in the world. This marks the beginning of expansion and development of solar technology in India.

Presently, India is more focused on energy supply, cost and local pollution than the issues of GHG emissions. However, considering the prevalent use of coal in present and in foreseeable future, time is due for India to step into research and development of CCS technology and make way for cleaner energy policy, despite the prevalent obstacles. The main barriers for CCS penetration in the country are additional cost and energy consumption and safety issues like leakage of CO_2.

It is expected in next 10-15 years that India will upgrade its power plants with CCS technology or will withdraw a substantial part of its power generating capacity, due to old age and low efficiency of its power plants. On the other hand, the renewables methods like Wind, Hydro and Nuclear are already in steady growth. However, they still need rapid expansion in installation to cater power for the escalating electricity demand.

At present, only about 25% of the total hydro power potential is utilized for electricity. There is more space for expansion of hydro power in the country. Coming to nuclear energy, India has exclusive plans to utilize its abundant thorium reserves for power production through extensive research in the field. By 2050, the nuclear power program of India aims to supply 25% of the demand through nuclear power.

For wind energy, two different studies have been performed to assess the potential in India. Both the figures suggest that the India's potential is high. In addition, India also needs to enter the offshore wind power technology, as it has about 7500 Km of potential coastal line.

Life cycle analysis of three different scenarios of power generation is analyzed using the software GaBi 6.0. The results of the analysis suggest that the scenario LCOF 2050 employs more shares to renewable energy methods and saves about a tremendous 4 billion tons of CO_2 equivalent of emissions compared to reference scenario in 2050. It is clear that Indian power sector has to find its total emission level in the range close to the emissions of LCOF 2050, for it to meet the global carbon mitigation obligations in future.

REFERENCES

ABB India Energy efficiency report [Report]. - [s.l.] : ABB, 2011.

Akorede M.F [et al.] Mitigating the anthropogenic global warming in the electric power industry [Journal] // Renewable and Sustainable Energy Reviews. - [s.l.] : Elsevier, 2012. - Vol. 16. - pp. 2747-2761.

Bayar Tildy India to Build "Ultra Mega" Solar Power Plant [Online] // Renewable Energy World. - September 25, 2013. - November 10, 2013. - http://www.renewableenergyworld.com/rea/news/article/2013/09/india-to-build-ultra-mega-solar-power-plant.

Bhattacharya Soma and Cropper Maureen L Options for Energy Efficiency in India and Barriers to their Adoption [Report]. - Washington : Resources, 2010.

Chikkatur Ananth P [et al.] Tariff-based incentives for improving coal power plant efficiencies in India [Journal] // Energy Policy. - [s.l.] : Elsevier, 2007. - Vol. 35. - pp. 3744-3758.

EAI India Hydro Energy [Online] // Energy Alternatives India (EAI). - 2012. - November 2013, 15. - http://www.eai.in/ref/ae/hyd/hyd.html.

EIA U.S. India Energy Outlook [Online] // U.S. Energy Information Administration. - March 18, 2013. - November 10, 2013. - http://www.eia.gov/countries/cab.cfm?fips=IN.

EIA U.S. International Energy Outlook 2013 with projections to 2040 [Report]. - [s.l.] : U.S. Energy Information Administration, 2013.

Environment Canada Biomass Combustion [Online] // Environment Canada. - June 21, 2013. - November 15, 2013. - http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=8688E3C4-1.

GaBi 6 P.E Technical reference manual for GaBi 6 [Software Manual]. - Stuttgart : PE International AG, 2013.

Gambhir A [et al.] India's CO2 emissions pathway to 2050 [Report]. - London : Met Office Hadley Centre, 2012.

GWEC India Wind Energy Outlook [Report]. - [s.l.] : Global Wind Energy Council, 2012.

Hetland Jens and Anantharaman Rahul Carbon capture and storage (CCS) options for co-production of electricity and synthetic fuels from indigenous coal in an Indian context [Journal] // Energy for Sustainable Development. - [s.l.] : Elsevier, 2009. - Vol. 13. - pp. 56-63.

IEA CO2 Emissions from fuel combustion Highlights [Report]. - Warsaw : International Energy Agency, 2013.

IEA CO2 Emissions from Fuel Combustion Highlights [Report]. - [s.l.] : International Energy Agency, 2012.

IEA India: Electricity and Heat for 2010 [Online] // International Energy Agency. - 2010. - November 10, 2013. - http://www.iea.org/statistics/statisticssearch/report/?country=INDIA&product=electricityandheat&year=2010.

IEA World Energy Outlook 2007, China and India Insights [Book]. - [s.l.] : International Energy Agency, 2007.

ITALIA Indian wind and biomass power programme - An overview [Report]. - [s.l.] : Italian Trade Commission, 2009.

Kumar Tarun and Mohan Shyam Energy Security of India: An overview in present context [Conference]. - Hyderabad : E&D Directorate, ONGC, 2012.

Met Office Introduction to the AVOID research programme [Online] // Met Office. - September 30, 2013. - November 18, 2013. - http://www.metoffice.gov.uk/research/news/avoid.

MNRE National Solar Mission Document [Report]. - New Delhi : MNRE, 2010.

NASA GISS Surface Temperature Analysis [Online] // National Aeronautics and Space Administration. - November 12, 2013. - November 17, 2013. - http://data.giss.nasa.gov/gistemp/graphs_v3/.

Oberst Thomas TÜV SÜD to contribute to the Modernisation and Efficiency Improvement roadmap for Indian power plants [Online] // TÜV SÜD. - July 4, 2013. - November 10, 2013. - http://www.tuv-sud.com/news-media/news-archive/tuev-sued-to-contribute-to-the-modernisation-and-efficiency-improvement-roadmap-for-indian-power-plants.

Panchabuta India close to 1 GW of commissioned biomass projects; Likely to surpass target of 500 MW in the eleventh plan [Online] // Panchabuta. - November 22, 2010. - November 10, 2013. - http://panchabuta.com/india-close-to-1-gw-of-commissioned-biomass-projects-close-to-target-of-500mw-currently-at-460mw-in-the-eleventh-plan/.

Panchabuta India encouraging power generation projects from biomass [Online] // Panchabuta. - December 18, 2012. - November 10, 2013. - http://panchabuta.com/2012/12/18/india-encouraging-power-generation-projects-from-biomass/.

Sharma Atul A comprehensive study of solar power in India and World [Journal] // Renewable and Sustainable Energy Reviews. - [s.l.] : Elsevier, 2011. - Vol. 15. - pp. 1767-1776.

Sharma Naveen Kumar, Tiwari Prashant Kumar and Sood Yog Raj A comprehensive analysis of strategies, policies and development of hydropower in India: Special emphasis on small hydropower [Journal] // Renewable and Sustainable Energy Reviews. - [s.l.] : Elsevier, 2013. - Vol. 18. - pp. 460-470.

Sharma S.C. Deo Coal fired power plant Heat Rate and Efficiency Improvement in India [Conference] // APEC workshop on options to reduce CO2 emissions. - [s.l.] : CenPEEP, 2004.

Shukla P.R Biomass Energy in India: Policies and Prospects [Conference] // Biomass Energy: Key Issues and Priority Needs. - Paris : International Energy Agency, 2011.

Shukla P.R Biomass Energy in India: Transition from traditional to modern [Report]. - [s.l.] : The Social Engineer, 2010.

Shukla P.R Biomass energy strategies for aligning development and climate goals in India [Report]. - [s.l.] : Indian Institute of Management, Ahmedabad and Netherlands Environmental Assessment Agency, 2007.

Steinhurst William, Knight Patrick and Schultz Melissa Hydropower Greenhouse Gas Emissions [Report]. - Cambridge : Synapse Energy Economics Inc, 2012.

Viebahn Peter [et al.] Future CCS implementation in India: a systemic and long-term analysis [Journal] // Energy Procedia. - [s.l.] : Science Direct, 2011. - Vol. 4. - pp. 2708-2715.

WNA Nuclear Power in India [Online] // World Nuclear Association. - November 2013. - November 10, 2013. - http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/India/.

APPENDICES

Appendix 1: Description of unit processes in GaBi Models

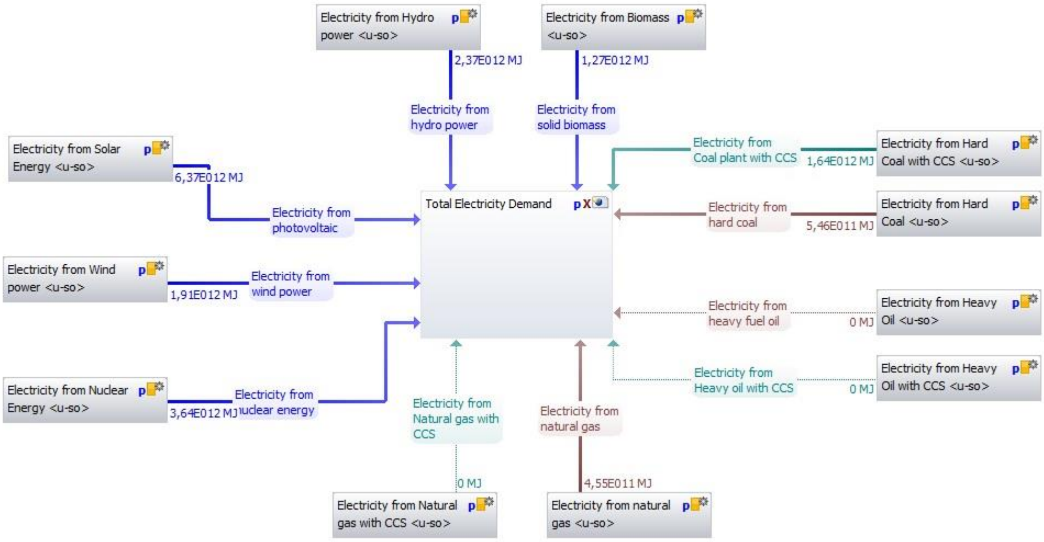


Figure 30: Flow diagram of scenario LCOF 2050

There are 12 unit processes in the future scenario models with the unit process ‘Total electricity demand’ as the control in the center. All the other eleven unit processes represent power generation from different technologies. Most of these methods are described below with process flow diagram.

<u>Electricity from Hard coal with CCS</u>

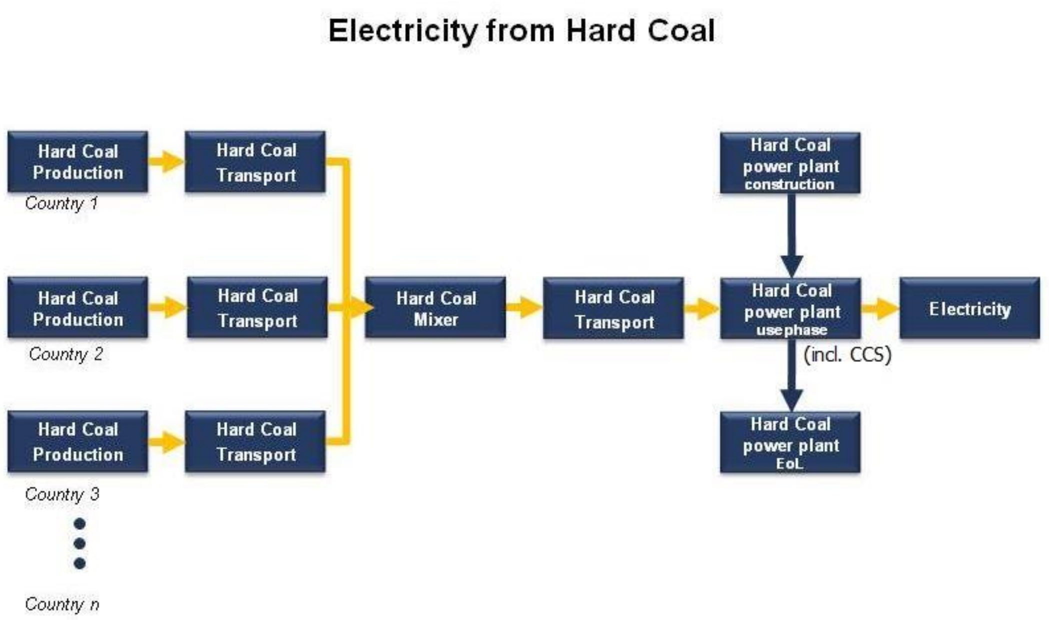


Figure 31: Process flow of Electricity from Hard coal (GaBi 6, 2013)

The Figure 31 shows the flow diagram of the unit process ‘Electricity from hard coal’. The first process is production of coal in different countries. It is then transported to the mixer of home country and to the specific power plant. Power plant section includes construction, use phase and End of Life (EoL). The additional technology of CCS is contained in the use phase of power plant. This flow diagram and description is same for other unit processes like Electricity from heavy fuel oil, natural gas and biomass.

Theory

The power plant model combines literature data plus calculated values for not measured emissions of e.g. organics or heavy metals. For the emissions CO_2, SO_2, NO_X, CO, CH_4, N_2O NMVOC and particulate matter measured or calculated data is used, taken from e.g. national inventory reports, emission inventory data bases, utility companies and other sources. The calculation of other emission within the models is based on energy carrier composition, transfer coefficients and power plant physics representing the applied flue gas treatment technologies and standards (flue gas de-sulphurization, dust filter etc.). (GaBi 6, 2013)

The electricity is either produced in a fuel specific power plant and / or fuel specific heat and power plants (CHP) according to the country / region specific situation. The country / region-specific fuel supply (by import and / or domestic supply) including the country / region-specific energy carrier properties (e.g. element and energy contents) is accounted for. Furthermore country / region specific technology standards of power plants regarding efficiency, firing technology, flue-gas desulphurization, NO_X removal and de-dusting are considered.

The own use of the energy producers is considered, the power import and distribution losses are not considered. Furthermore the data set comprises the infrastructure as well as the end-of-life of the power plant. The data set considers the whole supply chain of lignite/ hard coal / crude oil / natural gas exploration over mining and preparation to transport to the power plants.

Electricity from Nuclear Power

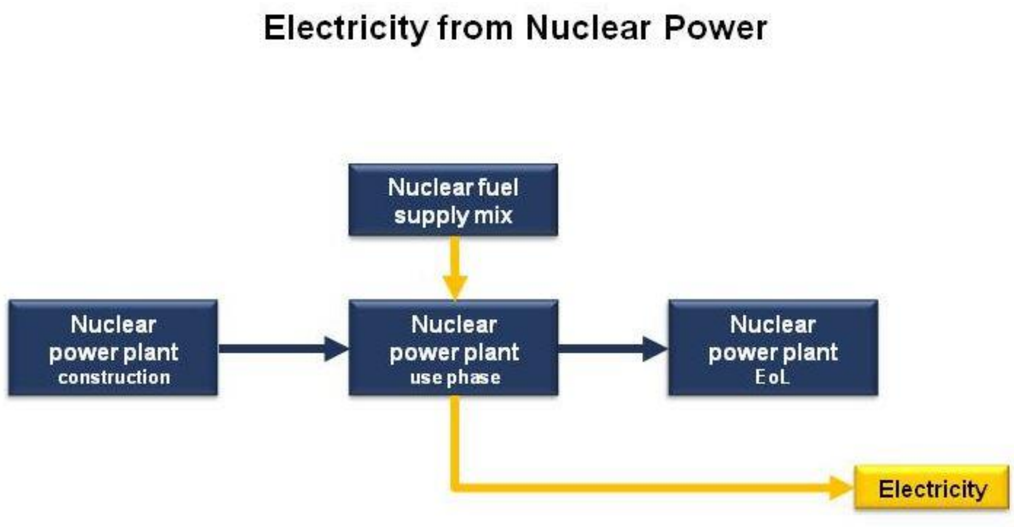


Figure 32: Process flow of Electricity from Nuclear power (GaBi 6, 2013)

The data set comprises the production of electricity from a mix of pressure and boiling water reactors. The power plants are parameterized and the mix is country specific. Furthermore the data set includes the infrastructure of the power plant as well as the end-of-life of the auxiliary buildings, e.g. cooling tower. The model is structured considering the main phases of the fuel cycle. In that perspective, the following main steps are considered: (GaBi 6, 2013)

a) Mining - extraction of the uranium from the mine using the processes of open pit mining and/or underground mining;
b) Milling - extraction of the uranium from the rock and production of a highly concentrated uranium oxide - "yellow cake";
c) Conversion - conversion of the "yellow cake" into uranium hexafluoride through dry process or wet process;
d) Enrichment - increase of the proportion of isotopes U235 in the uranium hexafluoride through one of the technologies: diffusion or centrifuge;
e) Fuel fabrication - production of the fuel assemblies that will be used in the reactors;
f) Use of the uranium in reactor - As mentioned before, two types of reactor is represented: pressure and boiling water reactors.
g) End of life of the spent fuel - After using the uranium in the rector, there are different possibilities for the uranium end of life: no reprocessing

(direct storage); reprocessing according to UK technology; reprocessing according to FR technology;

h) End of life of the LLW/MLW generated - According to the type of wastes, these are directly disposed or have a treatment (typically incineration, fusion and/or vitrification).

Electricity from Wind Power

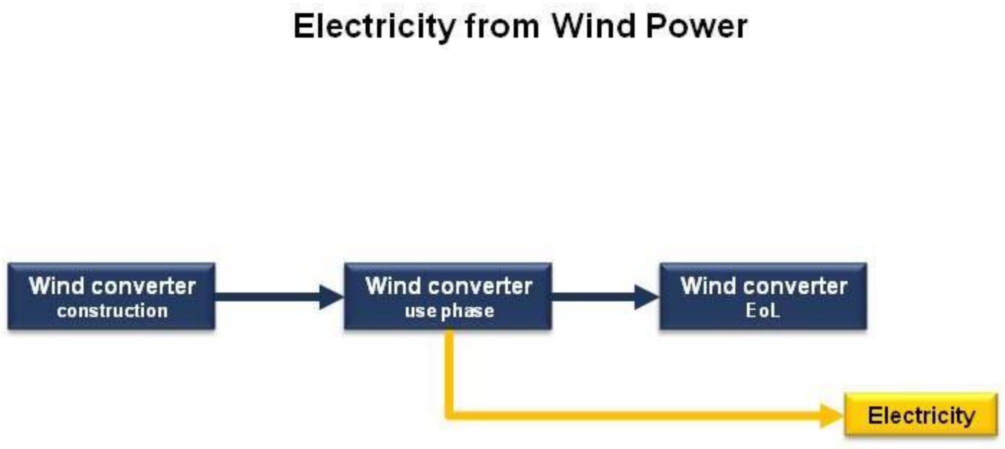


Figure 33: Process flow of Electricity from Wind power (GaBi 6, 2013)

The dataset is based on the model For a 300 MW wind power plant, which consists of 182 wind turbines and the required electrical gear such as cables and transformer. (GaBi 6, 2013)

1.65 MW wind turbines consist of the following main elements:

1. Rotor (spinner + three blades)
2. Nacelle
3. Tower
4. Foundation for the turbines

The system also includes:

- Transformer station
- Internal cables which connect the turbines to the transformer station
- External cables which connect the power plant to the existing power grid

The following stages phases are considered: Production, transportation, erection, operation, dismantling and removal of the wind turbines including electrical gear. Operational life of the wind turbines and cables is 20 years. Maintenance is included as well as the change of service material like oil for the generator. Full load hours are considered for the actual region using statistical information.

The modeled turbines are typical onshore site wind turbines so this LCA is representative for onshore wind power plants. Electricity production and plant configuration data was delivered from project models from wind power plant manufacturers. Full load hours are region specific. For the functional unit 1 kWh of generated electricity at the wind power plant is selected. This makes the LCA comparable with other electricity production technologies.

Electricity from Solar Power

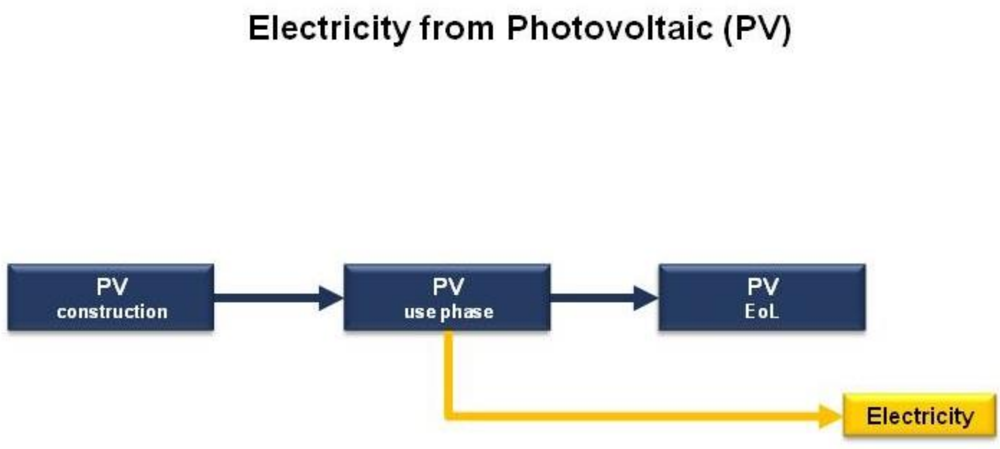


Figure 34: Process flow of Electricity from Solar power (GaBi 6, 2013)

The mix is based on the share of different Photovoltaic technologies installed in Europe. Regarding the module efficiencies, the following average efficiencies were used: Mono-silicon 14%, Multi-silicon 13.2%, Cadmium-telluride 9.0%, Amorphous-silicon 5.5%, Ribbon-silicon 11.2% and Copper-indium-gallium-diselenide 11%.

The efficiency of the Balance of System is 75% for slanted roof installation and 80 % for ground mounted. The share of slanted roof installation is 90%.

<u>Electricity from Hydropower</u>

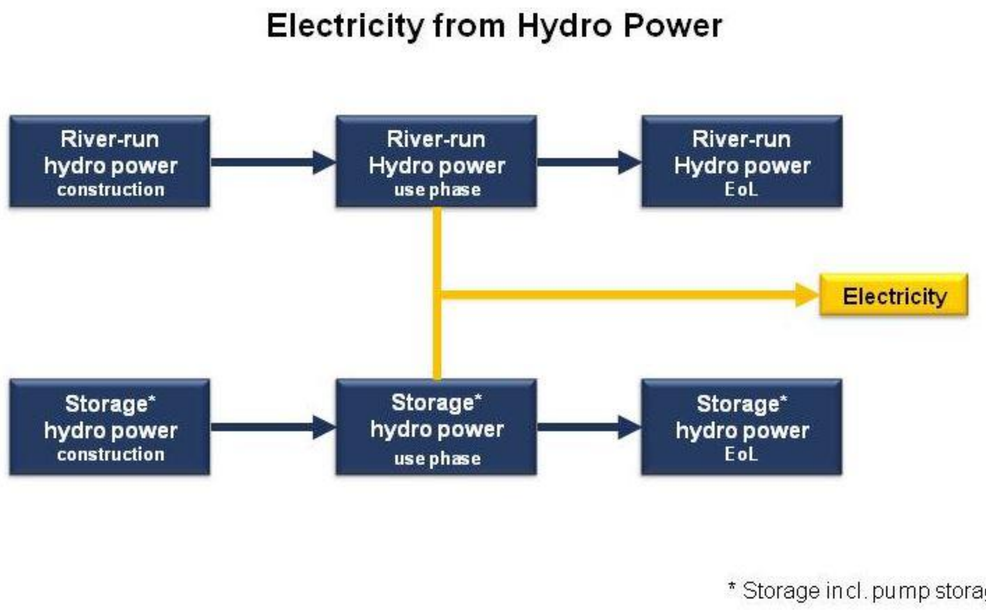
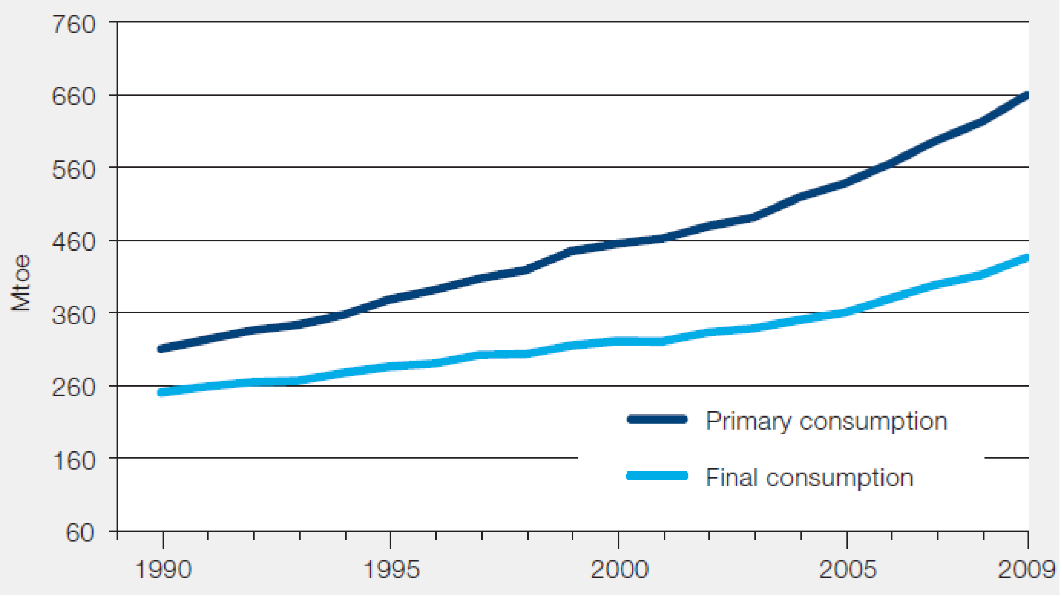


Figure 35: Process flow of Electricity from Hydropower (GaBi 6, 2013)

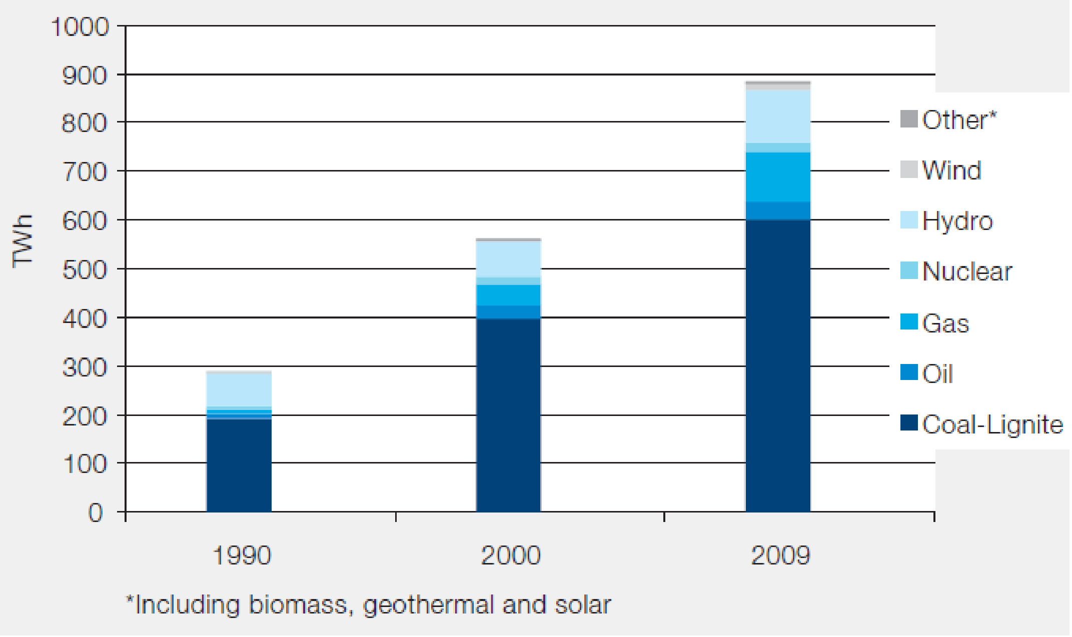
Electricity from water is generated in hydroelectric power plants like river power plants or storage power stations (dam or cavern). The data set comprises the infrastructure as well as end-of-life of the hydroelectric power plant with a general life time of 60 years. Greenhouse gas emissions from biomass decay in reservoir (region specific) and SF6 leakage from switches are included.

Appendix 2: Important graphs on Indian Power Sector

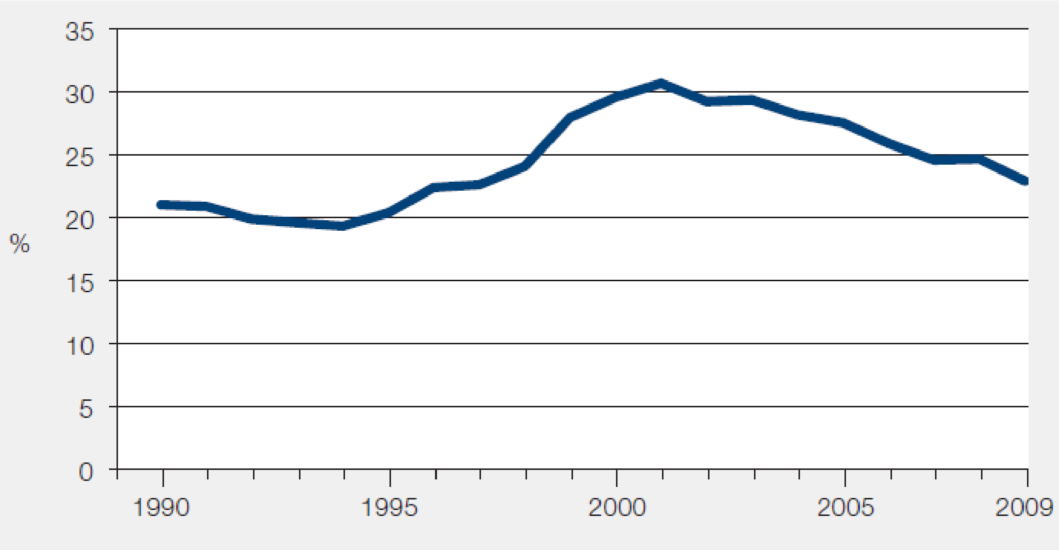
India: Primary and final energy consumption trend (ABB, 2011)



India: Power generation by source (ABB, 2011)



India: Electric transmission and distribution losses (ABB, 2011)



India: Average CO2 emission factor for power sector (ABB, 2011)