WP-2016-014

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May 2016
http://www.igidr.ac.in/pdf/publication/WP-2016-014.pdf

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## Abstract

*There is a growing concern among policy makers about how electricity is generated and consumed in the context of energy security and global climate change. In such a scenario, renewable energy sources, especially solar and wind energy, are likely to play a significant role in providing reliable and sustainable electricity to consumers as they are locally available and their carbon foot print is small. The future share of power by renewables will greatly depend on the expected generation cost and the government's support to investments in the sector. Using levelised cost approach, capital cost, operating and fuel costs of major electricity generation technologies are compared. Then, a forecast is made for electricity generation in India, using non-linear Bass diffusion model over 15-year horizon, until 2030, for all major energy technologies, viz., coal, natural gas, hydro, solar, wind, and biomass. The results show how present trends and future forecasts of electricity-generating technologies change the electricity generation mix, and how solar and wind power may increase their share in the total generation. However, fossil fuels will continue to remain competitive relative to renewables due to their cost advantage. The main issue considered here is whether each energy technology has reached its maximum penetration level. This helps set out a path for renewable energy technology diffusion in the Indian power sector*

**Keywords: Cost, Diffusion, Power, Renewables, Technology,**

**JEL Code: P28, Q41, Q42, Q48**

**Acknowledgements:**

The author wishes to thank Mr. Anik Chakraborty, M. Tech. Student, Centre for Energy Engineering, Central University of Jharkhand, Ranchi, who was with us at IGIDR on an internship for helping me in developing the technology diffusion model.

# ECONOMIC DYNAMICS AND TECHNOLOGY DIFFUSION IN INDIAN POWER SECTOR

## 1. INTRODUCTION

Central to the development of power sector is the expected cost of electricity generation through alternative energy sources. There is an overwhelming consensus among policy makers that the best way to develop an energy-surplus economy, attracting investment and creating jobs while reducing carbon emissions and supplying power to rural and remote areas is to increase the share of renewables in power generation. As per International Energy Agency (IEA) estimates, the world energy-induced $CO_2$ emissions will increase by 57.4% during 2005–30, India accounting 14% of it (IEA, 2015), while its share in incremental world energy demand during the same period will be about 6%. India has higher share of emissions in power generation owing to heavy reliance on low-quality coal with high ash content and low share of zero-carbon fuels (TERI, 2012). As with other developing countries, the major dilemma India faces today is prioritising energy goals which need to follow the path of low-carbon economy with reduced dependence on coal and promotion of renewable technologies for power generation. A radical transformation of the power sector is required to decarbonise it.

Renewable energy sources such as biomass, solar and wind have beneficial effect on energy and environmental security. These resources are the most abundant in nature and easy to deploy. However, as of now, their share in total power generation is limited to about 10%. Coal has a dominant share (73%) followed by natural gas (10%). However, due to their non-renewable nature and environmental impact, there is a fledgling interest in renewable resources. In recent years, among non-hydro renewables, solar and wind power penetration (in terms of installed base) is increasing rapidly. This is mainly due to falling costs, new application areas, growing investor interest due to investment attractiveness and strong policy support. The introduction of renewables in power generation not only protects environment but also provides significant employment to the population. Thus power generation through renewables is not only an economic and environmental solution but also a social one too (Reddy, 2015).

It is generally believed that renewable energy is “poor man’s” energy as majority of the poor and rural households use biomass for cooking and heating purposes. In remote area and hilly regions electricity is as such being provided using renewable resources. To remove this misconception and provide the benefit to a large section of population, it is important to focus on connecting renewable electricity production to the national grid. At the same time, policy makers are finding it difficult to balance three must-haves for the power sector: affordability, reliability, and acceptability (based on environmental performance). Hence, the time is ripe to examine these issues to design enabling policies which require a thorough study of the economics of power generation and diffusion of renewable technologies in the future. This will help in not only meeting the rapid growth in electricity demand but also maintain affordable and reliable service to consumers.

The present study uses technology-specific innovation system approach under the assumption of the existence of technological systems in India and that they vary in their ability to develop and diffuse into the society (Jacobsson and Johnson, 2000). Here, the competition is between renewable energy technologies and incumbent fossil-fuel-based ones (along with the associated systems). We compare the costs of power generation through renewables vis-à-vis conventional technologies using levelised cost approach taking into consideration capital cost, fuel cost and other O&M costs[1]. Information on the technical performance and cost characteristics has been gathered for each of these technologies. Using the Bass model, we project the installed capacity of various technologies and their impacts on land and water by 2030. The future composition of energy mix will depend on the reliability and cost competitiveness of various technologies. This in turn help in designing an optimal investment strategy for capital stock turnover, technology costs, and projected demand growth.

## 2. INDIA’S ENERGY MARKET

### 2.1 Energy consumption by source

The primary energy consumption in India is from coal, oil, gas and other renewables. A look backwards reveals significant changes in the energy mix (Reddy, 2009). While oil’s contribution was negligible in 1950, its share went up to 23% in 2015. The share of coal and natural gas too increased. Natural gas also became popular in the secondary energy mix in power generation. These increases offset the decline in use of renewables, mainly biomass. Fuelwood was used over centuries for household cooking and its share decreased through substitution with LPG.

Table 1 provides information on the energy mix in 2015. The total primary energy consumption stood at 775 MTOE of which the contribution of coal was the highest at

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[1] The levelized cost is the ratio of the net present value of total life cycle costs of the power plant to the quantity of energy produced during the life of the plant (West , 2011).

46.5% followed by oil at 23.3%. Renewables (including biomass) accounted for 19% and the rest by natural gas, hydro electricity and nuclear energy. In the coming years, the demand for fossil fuels is expected to increase which will result in increased emissions that affect local, regional and global climate.

**Table 1: Energy consumption by source in India (2015)**

| **Source** | | MTOE | % |
|---|---|---|---|
| Coal | | 360 | 46.46 |
| Oil | | 180.7 | 23.32 |
| Gas | | 45.8 | 5.91 |
| Hydro | | 29.6 | 3.82 |
| Biomass | | 137 | 17.68 |
| Other renewables | | 13.9 | 1.79 |
| Nuclear | | 7.8 | 1.01 |
| Total | | 774.8 | 100.00 |

**Source:** MoP, 2015

## 2.2 Electricity generation

### *2.2.1 Performance of Power Plants*

Electricity is generated through various technologies and the choice of technology, fuel and unit rating depends on various factors. The range of unit ratings varies with the system. Coal and gas are the major sources used for electricity generation while hydro and other renewables like wind and solar contribute around one third of the total. By the end of 2015, the total no. of power plants were 851 (Anon, 2015a, Anon, 2015b,) of which were 132 coal-fired, 43 gas-fired, 7 nuclear, 66 hydro, 470 wind, 47 solar and 86 biomass-based plants. The total installed capacity stood at 245 GW. A comparison of the current installed capacity of coal-based plants (153 GW) and gas-based plants (23 GW) shows the dominant role of coal-fired plants in Indian power generation.

The power, produced by 851 power plants works out to an average of 288 MW/plant. The number of plants, their rated capacity and their power generation are given in Table 2. Typical Indian power plant capacities range from 1 to 800 MW and the average size of the power plant is about 391 MW. The two categories of technologies that produce major share of power are coal and hydro. Large plants have low operational costs and costs less too for grid connectivity.

Of the total 245 GW of installed capacity, 62.5% is coal-based, 9.5% is natural gas-based, 25% is from renewables and the rest is from nuclear and oil sources. From renewable energy sources, hydro-power has the largest installed capacity (12% of total) and 13.5% comes from other renewable sources such as solar, wind, and combustible waste. This shows that, in the current fuel mix fossil (coal, natural gas and oil) and nuclear fuels have a combined installed capacity of 74% of the total installed capacity.

The total electricity generation in 2015 was 1145 TW-h which, divided by 8760 hours/year, equals an average power of 132 GW**.** The contribution from coal is the highest at 73%, while its share in the total installed capacity is only 62%. The case is reversed in the case of renewables. Using normalised load factors to account for fluctuations in wind and solar power, the contribution of renewables to gross electricity consumption is only about 10%.

**Table 2: Characteristics of power plants**

| Technology | Rated Capacity (MW) | No. of Plants | Total (MW) | Average (MW/Plant) | % Share | PLF | Generation (TWh) | % Share | Generation (GWh/MW) |
|---|---|---|---|---|---|---|---|---|---|
| Coal Based | <200 | 7 | 758 | 108 | 0.31 | 0.43 | 2.85 | 0.25 | 3.77 |
| | 200-500 | 33 | 12475 | 378 | 5.09 | 0.69 | 75.4 | 6.58 | 6.04 |
| | 501-1000 | 29 | 21820 | 752 | 8.9 | 0.67 | 128.07 | 11.18 | 5.87 |
| | 1001-2000 | 45 | 62390 | 1386 | 25.45 | 0.62 | 338.85 | 29.58 | 5.43 |
| | >2000 | 18 | 55860 | 3103 | 22.78 | 0.6 | 293.6 | 25.63 | 5.26 |
| Gas Based | <100 | 13 | 558 | 43 | 0.23 | 0.13 | 0.64 | 0.06 | 1.14 |
| | 100-500 | 14 | 8568 | 612 | 3.49 | 0.17 | 11.26 | 0.98 | 1.31 |
| | >500 | 16 | 13970 | 873 | 5.7 | 0.22 | 28.15 | 2.46 | 2.01 |
| Nuclear | 440-1400 | 7 | 5780 | 826 | 2.36 | 0.83 | 36.1 | 3.15 | 6.25 |
| Hydro | <100 | 15 | 583 | 39 | 0.24 | 0.33 | 1.5 | 0.13 | 2.57 |
| | 100-500 | 31 | 8006 | 258 | 3.27 | 0.4 | 29.45 | 2.57 | 3.68 |
| | >500 | 20 | 21094 | 1055 | 8.6 | 0.47 | 88.7 | 7.74 | 4.2 |
| Wind | 0.2-1500 | 470 | 23439 | 50 | 9.56 | 0.32 | 65.7 | 5.74 | 2.8 |
| Solar | 1-221 | 47 | 3743 | 80 | 1.53 | 0.21 | 7.54 | 0.66 | 2.01 |
| Biomass | 0.01-1.5 | 86 | 6126 | 71 | 2.5 | 0.72 | 37.56 | 3.28 | 6.13 |
| Total Coal Based | | 132 | 153302 | 1161 | 62.53 | 0.6 | 838.773 | 73.23 | 5.47 |
| Total Gas Based | | 43 | 23096 | 537 | 9.42 | 0.17 | 40.04 | 3.5 | 1.73 |
| Total fossil-fuel-based | | 175 | 176398 | 1008 | 71.95 | | 878.81 | 76.73 | |
| Total hydro | | 66 | 29683 | 450 | 12.1 | 0.4 | 119.6 | 10.4 | 4.03 |
| Total other renewables | | 603 | 33308 | 55 | 13.59 | | 110.81 | 9.67 | |
| Grand total | | 851 | 245169 | 288 | 100 | | 1145 | 100 | |

Between 1975 and 2015, electricity generation in India increased 17 fold with an average increase of 10.1% per year reaching 1145 TWh by 2015. The power generation from renewable sources (excluding hydro) increased 10 times between 2000 and 2015, to reach 108 TWh. Generation from coal increased by 24 times and that from hydro sources by four times. Gas-based power generation reached peak at 100 TWh in 2010 but declined later due to the non-availability of gas. Solar photovoltaic power generation increased many fold, from 0.02 to 7.5 TWh (from 2010 to 2015) due to an increase in capacity and decline in capital costs. Electricity from onshore wind increased 20 times from 2000 and reached 65.7 TWh by 2015. An amount of 37.6 TWh of renewable electricity was added via biomass-based plants. Table 3 provides the electricity generation figures for 1975 to 2015.

**Table 3: Power generation (TWh) through various sources**

| Year | Coal | % | Gas | % | Hydro | % | Nuclear | Solar | Wind | Biomass | Total Renewables | % | Grand total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1975 | 34.85 | 52.6 | 0 | 0 | 28.97 | 43.8 | 2.4 | | | | | | 66.22 |
| 1985 | 96.96 | 62 | 1.38 | 0.89 | 53.95 | 34.5 | 4.08 | | | | | | 156.36 |
| 1995 | 289.38 | 73.4 | 26.99 | 6.84 | 68.9 | 17.5 | 9.07 | | | | | | 394.34 |
| 2000 | 370.88 | 71.8 | 47.1 | 9.12 | 73.58 | 14.3 | 19.48 | | 3.27 | 2.18 | 5.45 | 1.06 | 516.49 |
| 2005 | 461.79 | 68.2 | 64.16 | 9.48 | 113.5 | 16.8 | 18.8 | 0.005 | 12.42 | 6.27 | 18.69 | 2.76 | 676.95 |
| 2010 | 612.5 | 66.1 | 93.28 | 10.1 | 130.51 | 14.1 | 36.04 | 0.022 | 36.62 | 17.94 | 54.59 | 5.89 | 926.92 |
| 2015 | 838.7 | 73.2 | 40.04 | 3.5 | 119.6 | 10.4 | 36.1 | 7.54 | 65.7 | 37.56 | 110.8 | 9.7 | 1145.39 |

Source: MoP, 2015, Anon, 2015e, Indiastat.com.

### *2.2.2 Power plant efficiency*

Electric energy generation is basically of converting primary energy into electrical energy. However, in most cases, primary energy cannot be directly converted into electricity and it goes through several transformations. For example, coal is converted to steam and then to mechanical energy in the turbines which is connected to generators where electrical energy is produced because of which the efficiency of power generation[2] is generally low (Anon, 2003; Hussy, *et al.*, 2014).

Efficiency varies with the source and also with technology. In India, at present, coal is converted into electricity using sub-critical technology. The average efficiency of coal-based power plant is between 25 and 30%. This low value is due to the fact that Indian coal is a low-grade one and contains high ash content (30–50%). Advanced technologies like IGCC (Integrated Gasification Combined Cycle) can have higher efficiencies. In case of gas-based

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[2] The electric power plant efficiency η is defined as the ratio between useful electricity output from the generating unit in a specific time unit, and the energy value of the energy source supplied to the unit in the same time frame (Anon, 2003).

power generation, CCGT (Combined Cycle Gas Turbine processes) technology is more efficient than a simple gas turbine cycle. Gas-fired power plants in India are built mostly after 1990. At present, the efficiency of gas-fired power generation is in the range of 45–50%. Between 1990 and 2010, the efficiencies of gas-based power generation have increased significantly (from 20 to 50%) while that of coal remains almost stagnant at about 30% (Fig. 1)

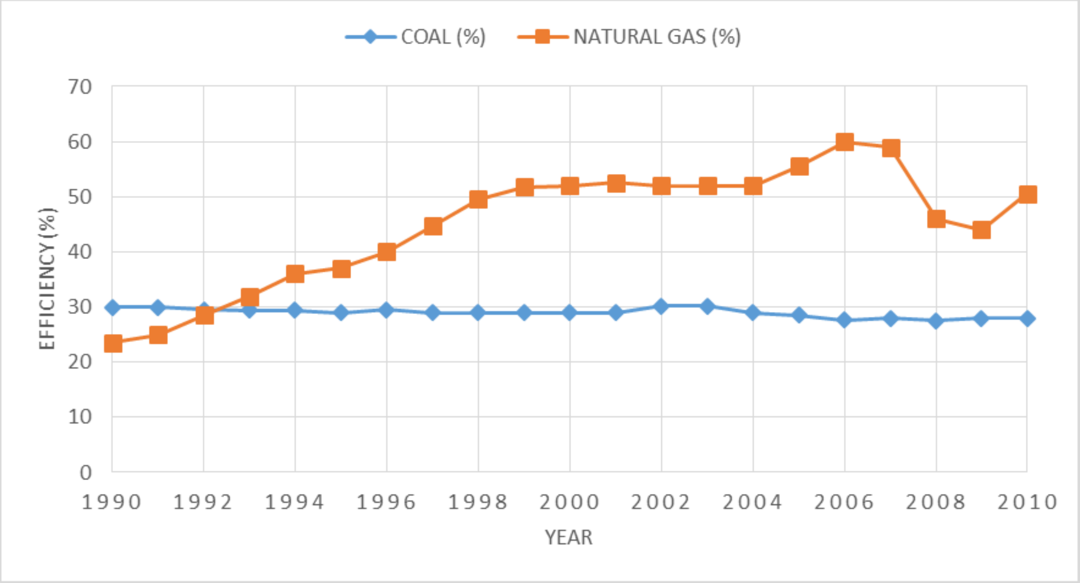

**Figure 1: Power Plant efficiency comparison between coal and natural gas based plants (1990-2010)**

Nuclear power stations in India have efficiencies of around 30%. The efficiency of a hydro-electric power station depends on the type of water turbine. In India, most of the power is generated through large hydroelectric power plants whose efficiencies are around 75%. In case of renewables, wind energy conversion efficiency[3] is about 30%, while that of solar PV[4] is about 15% and solar thermal, between 15 and 18%. Biomass power plant efficiency ranges between 30 and 40% depending on the material used (vegetal or animal origin) (Fig.2).

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[3] Wind turbine extracts power from the air (kinetic energy) and converts to electric power.

[4] The efficiency of solar photovoltaic cells is the ratio of electrical energy produced by the cells to the incident solar radiant energy.

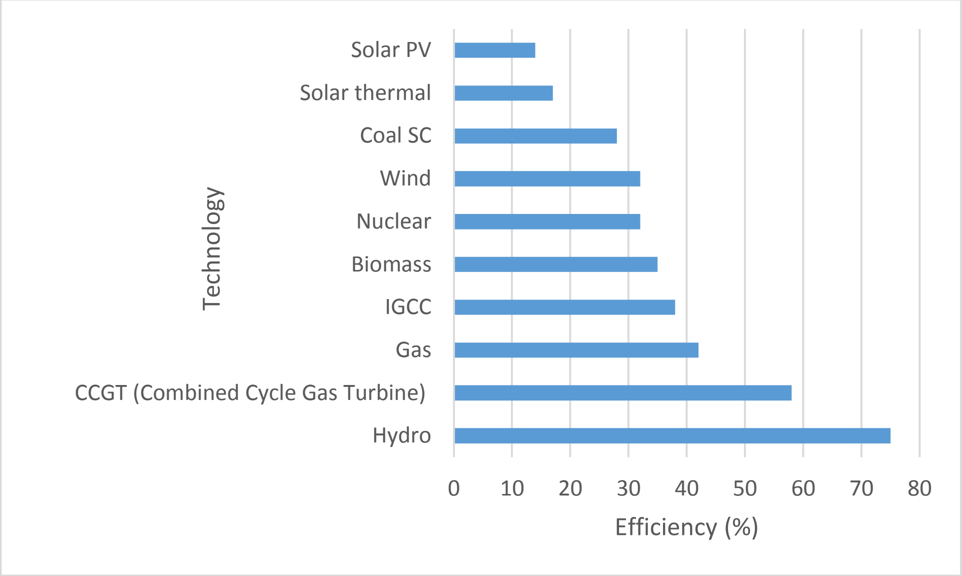

**Fig 2: Technological Efficiencies of Power Generation**

### 2.3 The Return on investment

The term net energy ratio (NER) is used to show how 'efficient' a technology is in terms of providing energy to society. NER is the most important parameter as it describes the overall life-cycle efficiency of a power supply technique. It is also known as the energy returned on energy invested (ERoEI) or energy return on investment (EROI) (Hall *et al*., 2014). It is calculated as the ratio between energy inputs and energy outputs for an energy generating technology. In general, technologies that require fuel have a lower ERoEI than those that can extract "free" energy from the environment (wind, sunlight, etc.). Along with EROI, the energy internal rate of return (EIRR) ) also plays a significant role in choosing a technology. EIRR is the percentage of the energy invested that is returned each year, analogous to IRR for financial investments (Bull, 2010).

**Table 4: Mean EROI values for Power generation systems**

| Source | ERoEI (Average) | EIRR (Average) (%) | Power plant life (years) |
|---|---|---|---|
| Coal | 5.5 | 17 | 30 |
| Gas | 3.5 | 11 | 32 |
| Nuclear | 10.9 | 36 | 30 |
| Hydro power | 22 | 40 | 60 |
| Wind | 25 | 125 | 20 |
| Biomass | 5 | 20 | 25 |
| Solar PV | 8.3 | 34 | 4 |
| Solar thermal | 9.9 | 40 | 25 |

Source: Bull, 2010, Anon, 2015c

Table 4 shows high values of ERoEI for wind, solar and nuclear power and low values for coal and gas. Coal is bracketed under low value category as the energy required to mine and transport it is high compared to the power it produces. Most of the energy that goes into mining coal is for digging and transporting it to the power plant. In a steady state of technological mix, knowing the ERoEI of a technology is important since new investments in power plants are made after the decommissioning of old ones. However, in a period of transition, from non-renewables to renewables, there is a need to have a quick return on energy investments to maintain the needs of the society. This means that, if we're going to keep the non-energy economy going while making the transition, we can't put too much energy today into the long-lived energy investments which we will use tomorrow (Bull, 2010). For this the timing of energy flows which interact with ERoEI is important. In such a scenario, renewable electricity generation technologies requires all energy to be invested up front while fossil fuel-based technologies spread out this investment over the lifetime of the plant. The concept of IRR has to be adapted to ERoEI analysis by substituting investment flows with energy flows. Once we know the life of a power plant and what percentage of the energy cost is fuel compared to the percentage of the energy embodied in the plant, we can estimate the EIRR. As shown in table 4, fossil fuel-based power generation technologies fared badly when compared with renewables (except biomass).

**Table 5: Energy Intensity of technologies**

| Technology | Energy Intensity (MJ/KWh) |
|---|---|
| Coal super critical | 1.05 |
| Coal sub critical | 1.28 |
| Gas | |
| Hydro | 0.04 |
| Nuclear | 0.16 |
| Wind | 0.15 |
| Solar PV | 0.9 |
| Solar thermal | 0.22 |

Along with ERoRI and ERIR, the energy intensity of a technology plays an important role in choosing the technology mix for power generation. A kilowatt-hour (kWh) of electric energy delivered to the final user has an energy equivalent to 3.6 MJ. To produce one kWh of electricity (i.e., the heat rate) energy is used by various categories of electricity generators. As shown in Table 5 coal-based power plants require an average of 1.05 MJ to generate a kWh of electricity to be delivered to the electric grid. In contrast, hydro power plants require only 0.04 MJ. The energy intensity figures reveal that, with the exception of solar PV, which is almost as energy intensive as coal power (0.9 MJ/kWh for PV against 1.2 MJ/kWh for coal), all the renewable energy technologies are not energy intensive. Hydropower is the least energy-intensive source, followed by nuclear and wind. Thermal solar generation is also a low energy-intensive technology (just above 0.20 MJ/kWh).

## 2.4 The dynamics of Renewable energy system evolution

The evolution of renewable energy system began in the 1990s, which contributed to increased share of renewables (other than hydro) in power generation. This is mainly due to policy shift from providing subsidies to consumers to encouragement to power producers through incentives. The Electricity Act of 2003 (MoP, 2003) provides a mandate to the State Electricity Regulatory Commissions to develop renewable energy projects and include the fixation of minimum quotas for the sourcing of renewable energy power (REP), known as renewable purchase obligations (RPOs) and the determination of preferential feed-in tariffs (FITs). This provided competitive field for renewables. Even though policy and fiscal measures were in place earlier too, the FITs and RPOs constitute the backbone of the policy to boost REPs. In the process, barriers have been overcome and a process of enthusiasm among promoters has started.

The availability of renewable energy (in GW) and the amount that can be exploited are shown in Table 6. Solar energy is the most abundant in India with a potential of 749 GW. However, as on 2015, only 0.67% of its potential has been exploited. The second-most abundant source of renewable energy is Wind, which is exploited to 24% of its full potential. Bio energy is exploited to about 4.65% of its full potential. Of the total potential of renewable energy (896 GW) only 4.3% (38 GW) is being exploited for power generation. The main deterrent for the limited exploitation for generation is its relative cost vis-à-vis fossil fuels.

**Table 6: Availability of renewable energy by source**

| Energy source | Availability (GW) | | Resource Exploited (in %) |
|---|---|---|---|
| | Total | Exploited | |
| Solar Energy | 749 | 5.01 | 0.67 |
| Wind | 102 | 24.75 | 24.26 |
| Bio Energy | 17.53 | 4.65 | 26.53 |
| Others | 27.4 | 4.06 | 14.82 |
| Total | 895.93 | 38.47 | 4.29 |

Source: MNRE, 2015

From the available data (Table 7), it can be seen that the cost of power generation (COG) through renewable energy technologies remains well above that of non-renewable-energy based technologies. However, over time, the cost is increasingly becoming competitive for supplying power to the national grid. As a result, in locations where the wind speed is high or excellent solar radiation exists, the power generation is often competitive with coal-based or natural gas-based electricity generation. Between 1995 and 2015, wind turbine prices have declined sharply and continued technology improvements resulted in increased capacity factors. The COG of wind power has therefore dropped significantly and wind energy is increasingly becoming the least-cost option for new grid supply. Between 2005 and 2015, the cost of solar PV systems has been on the decline leading to corresponding decline in the level of cost of power generation (Singh, 2015). In 2015, the COG was the highest for solar thermal technology at Rs. 10.08/KWh and the consumer price works out Rs. 12.05/unit. Power through Solar PV, however, is cheaper than solar thermal at Rs. 7.05/unit (Anon, 2015f). Energy from wind has the lowest cost of generation at Rs 3.6/unit and sold to the consumers at Rs.3.6–5.5/KWh (Anon, 2015d) depending on the state-level subsidies and government policies. Biomass for power generation is a mature technology and hence has lower potential for cost reduction. However, where untapped economic resources exist, this technology can further reduce its COG—cheaper than other renewables, fossil fuels and nuclear. The significant variation in COG among renewables is not surprising because the cost of renewable technologies depends mostly on local resource availability which varies significantly within the country.

**Table 7: Declining cost of power from renewables**

| Year | Solar (Grid Connected) | | Wind | | Biomass | |
|---|---|---|---|---|---|---|
| | Installations (MW) | Cost of power generation (Rs./KWh) | Installations (MW) | Cost of power generation (Rs./KWh) | Installations (MW) | Cost of power generation (Rs./KWh) |
| 1995 | 6.98 | | 320 | | 28 | |
| 2000 | 9.98 | | 1167 | 5.14 | 383 | 5.95 |
| 2005 | 12.68 | 21.5 | 4430 | 4.20 | 1104 | 5.0 |
| 2010 | 173.62 | 16.5 | 13065 | 3.85 | 3151 | 4.2 |
| 2015 | 4116.62 | 6.9 | 23439 | 3.60 | 5152 | 3.65 |

## 3. CHARACTERISTICS OF DIFFERENT POWER GENERATION TECHNOLOGIES

### 3.1 Performance data

Power generation technologies are broadly divided into fossil fuels and renewable energy related. The fossil fuel technologies consist of coal, natural gas and oil-based ones while the renewable energy-related technologies include hydro, wind, solar and biomass. Table 8 provides information on nine technologies that represent electricity generation options in India. As indicated in the table, a single energy source (e.g., coal) can be is used in various types of power-generating systems, which include steam cycles, integrated gas-combined cycle, etc. (converting coal into gas and is used to drive a steam turbine). Each combination of energy source and technology has advantages and disadvantages (technical, economic, and environmental). In order to identify a system that is better than others, one has to evaluate all the factors which are unique to that system.

Technologies are also categorised by load factor. Base load power plants typically have annual load factors that exceed 75 percent, mostly fossil-fuelled (coal or natural gas) and nuclear plants. Biomass plants can be placed in this category on the renewable resource side. Intermediate load plants have annual load factors ranging between 40 and 50%. Some gas-based plants, wind and solar PV fall into this category. Most of the hydroelectric and solar thermal plants operate as peak load plants whose load factors range between 30 and 40%. We cannot compare the cost per kWh to generate electricity from wind with that of coal as these two technologies satisfy two different customer needs, namely, one is a peaking technology, while the other is a base-load technology (Hynes, 2009).

### 3.2 Land and water requirements

In general, land use for power generation consists of land required for fuel production, processing and storage at the production site. Land is also required for power transmission and distribution lines. However, these requirements are not considered here and only land for power plant construction and fuel storage are considered. Similarly water is required for fuel production, extraction, transport, and processing. In the present study we consider only water demand that arises at power stations for cooling systems. Conventional power plants are not very large (~ 500 MW) which require about 0.5 ha/MW. Nuclear plants, however, have larger land requirement, about 1 ha/MW, due to security and used fuel storage needs. In case of renewables, the land requirement is much larger. This is because most of these technologies are driven by solar energy and the sun delivers only about 1 kW/m$^2$ of energy to the earth's surface. Solar PV requires about 8 ha per MW and solar thermal about 10 ha. Similarly it is so for wind generation. Biomass power generation has a larger land requirement since it has to store fuel. From a land-use perspective, viable renewables are wind and solar PV technologies.

Power production requires significant quantity of water which is used for steam generation and condensation. The water input required per kWh varies with the technology. Conventional power generation technologies are the most water-intensive with 25l/kWh for coal and 32l/kWh for nuclear (due to large water need for cooling systems). Hydro power is also very water intensive, due to evaporation from increased reservoir surface. However, when compared with other sources, hydropower does not have additional water requirements for fuel production. Among renewable energies, wind and Solar PV have no operating water requirement. In Solar Thermal power generation, water use can be eliminated if boiling oils are used. The location and the characteristics of the plant can significantly impact the choice of fuel and power-generating system. From these comparisons, one can select the energy source, the power-generating system and the appropriate criteria to be used while choosing a plant site (Table 8).

**Table 8: Characteristics of Power generating systems**

| Technology | Carbon neutral | State of technology | Location | Dispatch | Land area (ha./MW) | Water requirement (l/KWh) |
|---|---|---|---|---|---|---|
| Conventional | | | | | | |
| Coal | No | Mature | Central station | Base load | 0.6 | 25 |
| integrated gas-combined cycle (IGCC) | No | Emerging | Central station | Base load | 0.4 | 22 |
| Gas CC | No | Mature | Central station/ customer located | Base load | 0.35 | 10 |
| Nuclear | Yes | Emerging | Central station | Base load | 1.2 | 32 |
| Renewable | | | | | | |
| Hydro | Yes | Mature | Central station | Peak load | 6.6 | 20 |
| Wind (Onshore) | Yes | Mature | | Intermittent | 10 | 0.5 |
| Biomass | Yes | Mature | | Base load | 15 | 3 |
| Solar PV | Yes | Commercial | Customer located | Intermittent | 8 | 2 |
| Solar thermal | Yes | Commercial | | Peak load | 10 | 4 |

Source: Senger and Spataru, 2015, Bean, 2015

### 3.3 Levelised Cost of Electricity Generation

Electricity generation costs are a fundamental part of energy market analysis. To design policies, an understanding of power generation costs is essential. Comparing the cost to generate electricity from various renewable resources, like wind or solar with that to conventional sources like coal, nuclear or natural gas is not a proper way to assess the cost economics. In order to make a choice of the best technology, it is necessary to quantify and evaluate various factors. For example, in a comparison between coal and nuclear energy, nuclear energy has higher capital costs but its fuel costs are low. Similarly, the capacity factor (depends on the expected operation hours per year) of the plant plays an important role. Even though wind and solar are desirable and economically justified due to their low capacity factors, they are unable to compete with conventional technologies due to their low capacity factors. In the present study, the competitiveness comparison is carried out for electricity-producing technologies. The study includes both fossil-fuel based and renewable energy technologies.

One of the key parameters that is used to judge the financial viability of a technology is the Net Present Value (NPV), which is the value of the investment today considering both the capital cost as well as fuel and other O&M costs. The NPV is calculated by determining the annual cash flows from the investment and discounting them to the present time with certain discount rate. If the NPV is zero, then we can assume that the utility is just earning the cost of capital. By adjusting the constant real electricity price over the life of the facility to achieve NPV = 0, the price of electricity can be obtained to just make the technology economically viable. This is termed as the levelized Cost of Electricity (LCOE) (ATSE, 2011). The levelized cost of electricity generation can be defined as the ratio of the net present value of total capital and operating costs of a particular plant to the net present value of the net electricity generated by that plant over its operating life (Kost *et al*, 2013). The levelized cost represents a minimum break-even tariff expressed in Rs. /KWh for each type of technology, based on assumptions and the chosen discount rates (weighted average cost of capital). Thus, to compare the costs of generation technologies, first the total costs and the load factor for each technology are considered and then the net present value analysis is performed. This is the only logical way to evaluate power generation technologies. There are many studies on the estimation of levelized costs (Risto and Aija, 2008, West J, 2011, and Anon, 2015d). One of the most widely used studies is done by Lazard (2016), the latest version of which was released in 2015.

Determining the levelized cost of power generation is difficult due to uncertainties in fuel prices and variations in O&M costs. Forecasting the cost has even larger bands of uncertainty. For capital intensive technologies, such as nuclear and renewables, the largest uncertainty lies with the capital expenditure, the gestation period and the annual capacity factor. The levelized cost for technology *k* can be described as follows:

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{t,el}}{(1+i)^t}}$$

Where,

LCOE = Levelized cost of electricity (Rs. /kWh)

I = Investment expenditures (Rs.)

$A_t$ = Annual costs in year t (Rs.)

$M_t$ = Quantity of electricity produced in year t (kWh)

i = Discount rate (%)

n = Economic operational lifetime of the power plant (years)

t = Year of lifetime (1, 2, ...n)

The investment is the cost of capital while annual costs include fuel cost as well as O&M (fixed and variable) costs (Rs. Million/MW/year). The fixed costs include all costs, which include: administration, operational staff, planned and unplanned maintenance, payments for O&M service agreements, property tax, and insurance. The variable O&M costs (Rs. Million/MWh) include consumption of auxiliary materials (water, lubricants, fuel additives), treatment and disposal of residuals, output-related repair and maintenance, and spare parts. It should be noted that O&M costs change over time and are therefore the average costs of the entire lifetime of the power plant. Fuel costs includes the cost of main fuel as well auxiliary fuel. The O&M costs are calculated by dividing the total annual costs (fuel costs, fixed and variable O&M costs) with the net generating capacity and net annual generation, respectively. Capital costs are given in Rs./KW basis and to obtain them in a Rs. /kWh form, one has to annualize the total cost of the plant and then divide it by an estimate of the average annual kWh that the plant is expected to generate. This estimate depends on the average annual load factor.

Table 9 provides information on cost data for various power-generating technologies on KWh basis. The technologies include both non-renewable (fossil fuel thermal and nuclear power stations) and a range of renewable generation, including solar and wind. Since these costs are calculated at the plant level, they do not include transmission and distribution costs. The table consists of various types of technologies, their capital costs (Rs. Million/MW) and the capacity factor (%) for the production of electricity. Thus, from the table we can observe that coal IGCC has the highest capacity factor with about 70%. The cost to build a new 1,000

MW coal-based sub-critical plant ranges from Rs. 40 million per MW (or Rs.40,000/kW) to Rs.60 million/MW (Rs.60,000/kW) with the average working out to Rs.54,000/KW. This is an overnight construction cost and does not include costs to maintain it. By looking at the figures one can compare which technology is the most or least expensive to build. In general, base-load technologies are more expensive to build than intermediate-load technologies, while intermediate-load technologies are more expensive to build than peaking technologies.

**Table 9: Levelized cost of Power generation through various technologies in India**

| Details | Solar PV | Solar Thermal | Wind | Biomass | Nuclear | Gas | Hydro | Coal | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | SC | IGCC |
| Plant life (years) | 25 | 25 | 25 | 20 | 40 | 40 | 40 | 30 | 40 |
| Discount rate | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Capital Cost (Rs (mil.)/MW) | 62.00 | 137.70 | 61.90 | 49.21 | 150.00 | 42.00 | 72.00 | 54.00 | 85.00 |
| O&M Cost (Rs (mil.)/MW) | 1.30 | 1.77 | 1.06 | 4.47 | 15.00 | 1.94 | 2.33 | 1.20 | 1.00 |
| PV | 11.80 | 16.07 | 9.65 | 38.06 | 146.69 | 18.97 | 22.79 | 11.31 | 9.78 |
| Fuel Price (Rs/Kg) | 0.00 | 0.00 | 0.00 | 1.58 | 4147.00 | 5.71 | 0.00 | 3.30 | 3.30 |
| Fuel Consumption Norm (Kg/KWh) | 0.00 | 0.00 | 0.00 | 1.25 | 0.00025 | 0.46 | 0.00 | 0.75 | 0.50 |
| Fuel Cost (Rs. Mil/MW) | 0.00 | 0.00 | 0.00 | 12.11 | 6.36 | 6.90 | 0.00 | 13.01 | 10.12 |
| Present Value of fuel cost (Rs.million) | 0.00 | 0.00 | 0.00 | 103.11 | 62.17 | 67.50 | 0.00 | 122.63 | 98.94 |
| Life Cycle Cost (Rs.Million) | 73.80 | 153.77 | 71.55 | 190.37 | 358.85 | 128.47 | 94.79 | 187.94 | 193.72 |
| Annualised LCC (Rs.Million) | 8.13 | 16.94 | 7.88 | 22.36 | 36.70 | 13.14 | 9.69 | 19.94 | 19.81 |
| Capacity factor (%) | 18.00 | 22.00 | 25.00 | 70.00 | 70.00 | 30.00 | 35.00 | 60.00 | 70.00 |
| Annual Generation (KWh/KW) | 1577 | 1927 | 2190 | 6132 | 6132 | 2628 | 3066 | 5256 | 6132 |
| Generation Cost (Rs/KWh) | 5.16 | 8.79 | 3.60 | 3.65 | 5.98 | 5.00 | 3.16 | 3.79 | 3.23 |

Source: Anon 2015d, and Indiastat.com

Compared to fossil fuels, most renewable energy sources require large capital investments, as shown in Table 9. Fuel and other O&M costs spread out over a long period of time and hence their present value will be very small. For example, when burning a fossil fuel like natural gas to generate electricity, a large portion of the total cost goes to fuel purchases which spread over a 30-year lifetime. Another issue with the renewables is the transmission and distribution costs (which are not considered here). Power generation through renewables is more expensive because, unlike fossil fuels, which can be transported to the power plants, renewable sources like biomass, wind and solar are natural phenomena specific to a particular geographic location. Thus, getting the electric power to consumers involves not just the standard capital and operating costs, but also of transmission to connect to the grid (Palmer *et al*, 2010).

By looking at costs/kWh, we cannot arrive at with certainty that a particular technology is the best one. This is because for a utility the cost/kWh for a technology is not the only consideration to select a technology but also the risks associated with each type. In other words to perform a capital investment analysis on the technologies that have a reasonable chance of being cost competitive, one has to consider the respective load factor and the risks they possess (Hynes, 2009). For example, the risk the utility takes while choosing the wind plant is weather risk (if the wind does not blow coincident with the utility's peak demand). As the table shows the LOCE of gas-based technology is 1.5 times than that of wind. Thus, the utility pays a premium for gas-based technology because it can be operational for 24 hours a day.

Figure 2 summarises the cost components of various energy technologies. By dividing the costs among capital, fuel, and O&M, we can observe that, fossil-fuel-driven technologies have low capital cost share. As shown in the figure, solar thermal and hydro have the highest share of capital cost (about 90%) followed by wind and solar PV with 86.5% and 84% respectively. In comparison, the lowest cost conventional technologies are coal-fired ones at 32.7% and 44% and nuclear at 41.8%. This shows that renewable technologies, such as wind and solar are expensive to build but cheap to operate since they have no fuel costs and have generally lower O&M costs as well. The scene is reversed for conventional technologies.

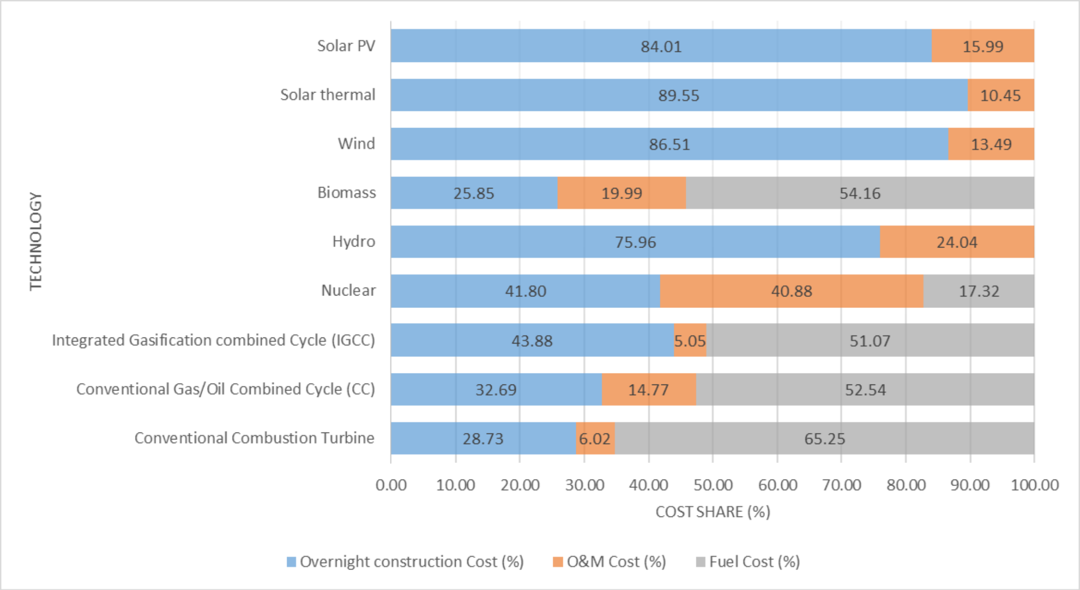

**Figure 2: Cost components of energy technologies**

It should be noted here that the amount of money spent to build and operate a power plant is not the only consideration while selecting a technology as it does not include environmental externalities such as the cost of air pollution impacts. If we include these costs, renewable energy technologies perform better than fossil fuel-driven ones. Also, the renewable energy sources are considered as intermittent because sun shine won't be available during night and rainy days and in many parts of the country wind speeds are not high. As a result, these technologies cannot replace the existing system of "conventional" technologies in the near future.

### 3.4 Carbon intensity of power generation technologies

While generating electricity, greenhouse gases are emitted and hence have a carbon footprint. Fossil-fuelled power generation has a high carbon footprint while renewables have a low carbon foot print. One reason why renewable electricity is costlier than that produced using fossil fuels is that the environmental costs associated with fossil fuel utilisation are not accounted while calculating levelized costs. Due to its low carbon foot print power generation from renewables avoids this cost. Imposing a policy that places a price on $CO_2$ emissions would help to close the gap in costs (Palmer, 2010). The carbon intensities ($CO_2$ emissions in g./KWh) of various technologies are shown in Table 10.

**Table 10: Carbon intensity of various technologies**

| Source | $CO_2$ emissions (gm/KWh) |
|---|---|
| Coal | 960-1300 |
| Natural gas | 460-1230 |
| Hydro | 2-410 |
| Nuclear | 9-100 |
| Biomass | 37-166 |
| Solar PV | 30-150 |
| Wind | 11-75.0 |

**Source:** I R Pillai, R Banerjee, 2009. , Anon 2016

Coal-fuelled electricity generation has the largest carbon footprint (>1,000g $CO_2$/kWh). Most emissions arise during plant operation. Emissions from renewables have low carbon foot print (<200g $CO_2$/kWh) and are emitted during non-operational phase. The emissions from hydro energy depend on plant size, location, capacity etc., and thus GHG emission varies from 2–410 $CO_2$ g/KWh. The GHG emission from biomass and solar PV are 37–166 $CO_2$ g./KWh and 30–150 $CO_2$ g/KWh, respectively.

Data presented until now present the benefits associated with the introduction of renewable energy technologies. They include environmental benefits such as reduction in carbon emissions which contribute to the objectives of reducing global warming. Another benefit pertains to energy security provided by localized energy sources that reduce the dependence on imports. Compared with fossil fuel technologies, which are typically mechanized and capital intensive, the renewable energy technologies are labor-intensive meaning that, on average, more jobs are created for each unit of electricity generated from renewable sources than from fossil fuels (Gkatsou, 2014). Thus, for a sustainable society, renewable energy plays an important role in power generation when introduced on a large scale in the coming years. In order to design appropriate policies, models should be developed to project potential generation through various renewable energy resources.

In the present study, an innovation diffusion model is used to forecast electricity generation using various renewable energy technologies. These diffusion models have been widely used to analyse the growth pattern of new technologies and to estimate their market potential. They have shown good representation of real market dynamics and their usefulness has been shown in several business and academic fields.

## 4. ANALYTICAL FRAMEWORK

### 4.1 Technology diffusion in the power sector

As argued in the broader literature on innovation systems, the innovation and diffusion process is both an individual and collective effort. The determinants of this process are not found only within individual firms; they are embedded in innovation systems that guide, aid and constrain the individual actors within them. In this manner, technological change becomes endogenous to the economic system. Due to the technology-specific features of the approach, it is particularly attractive when the focus of enquiry is competition between emerging and incumbent technologies (and between associated technological systems) (Jacobsson and Bergek, 2004).

There is a long-felt need to predict the diffusion of various technologies and the market for specific types of technologies. Various mathematical models have been used as forecasting tools (e.g., Gompertz, Fisher-Pry, Bass); learning models (e.g., Dirichlet, Artificial Neural Networks) and Regression models (e.g., trending or multivariate models based on historical data). Conventional forecasting tools do not effectively account for soft cost factors, such as government regulation or public opinion of power sources (Massiani and Gohs, 2015, Giovanis and Skiadas, 1999).

In the present study, we project the diffusion of various power plant technologies in India. Depending on the shape of function f (t), various models like external, internal and mixed- influence models can be used (Rao and Kishore, 2009). Several flexible models have also been developed to explain the diffusion behaviour. The Bass model developed by Frank Bass (1969) is by far the most common and accurate one to study diffusion as well as forecast the future of technologies. Therefore, we have used the Bass diffusion model to study the diffusion of renewable energy technologies in India.

The fundamental model can be explained as follows:

$$dN(t)/dt = f(t)\,[m - N(t)] \qquad (1)$$

where

$N(t)$ = cumulative number of adopters at time $t$, in the present case cumulative installed capacity (MW)

$m$ = market potential and

$f(t)$ = time dependent function.

The above equation according to the Bass diffusion model can also be written as follows:

$$dN(t)/dt = [p + (q/m)\,N(t)] \times [m - N(t)] \qquad (2)$$

where

p = coefficient of innovation

q = coefficient of imitation

$f(t) = p + (q/m)\,N(t)$

Now, Bass model in discrete form can be written as:

$$\begin{aligned} N(t-1) - N(t) &= pm - p*N(t) + q*N(t) + (-q/m)*N^2(t) \\ &= pm + (q-p)*N(t) + (-q/m)*N^2(t) \\ &= a + b*N(t) + c*N^2(t) \qquad (3) \end{aligned}$$

where

a = pm

b = (q-p)

c = (-q/m)

where, a, b and c can be obtained by regression analysis (NCSS Statistical Software is being used).

p, q, m can be obtained as follows:

p = a/m

q = −c/m

$$m = \frac{-b \pm \sqrt{b^2 - 4ac}}{2c}$$

The last equation is obtained for the asymptotic condition

$$dN(t)/dt \rightarrow 0; \text{ as } t \rightarrow \infty \text{ and } N(t) \rightarrow m. \tag{4}$$

Table 11 shows the value of p, q and m for conventional power-generation technologies.

**Table 11: Bass model parameters for conventional technologies**

| | **Coal** | **Gas** | **Hydro** | **Nuclear** |
|---|---|---|---|---|
| **P** | 0.00070 | 0.03 | 0.01 | 0.04 |
| **Q** | 0.48 | 0.72 | 0.40 | 0.66 |
| **M** | 328784.32 | 27664.12 | 48016.38 | 10356.23 |

The above model has been used to project the diffusion of different renewable energy technologies by the year 2030. Where availability of data is insufficient, we have used trend forecasting to assume values so that we obtain a better $R^2$ value. This gives us a more accurate fit.

### 4.2 Application of the model for power generation

Electrical power utilities generate power from various sources such as coal, natural gas, hydro power and renewable sources such as solar and wind. Each of these technologies has unique power-generation costs and capacity. The power that is generated through these technologies is connected to a common power grid that distributes electrical power to various end users.

A method for predicting an optimal mixture of power-generation technologies has been developed using a forecasting model. The inputs include: costs of a plurality of power-generation technology types and the probability distributions to the estimated costs. Based on this information, estimated costs are projected over a period of time for each type of power-generation technology. We have projected a mixture of future power plant technology based on a Bayesian combination analysis.

From the diffusion model results, it can be seen that the total number of installations for coal, gas, hydro and nuclear power plants by 2030 will be 2,72,408 MW, 27,535 MW, 46,396 MW and 8,389 MW respectively. It is seen that coal-based technology dominates the power-generating sector. However, its rate of growth is declining as the technology has matured and new and renewable energy technologies are already in place. Along with this general decrease of coal capacity, gas-fired power stations are likely to replace coal-based power generation. The total gas capacity increases by approximately 9.6 GW with an annual growth of about 5% by 2030. In the case of nuclear power, capacity will be maintained at around 6.6 GW until 2020. Between 2020 and 2030, an increase of 20% is seen which means that the additional nuclear capacity will be about 45% higher than that in 2015 (Fig. 3).

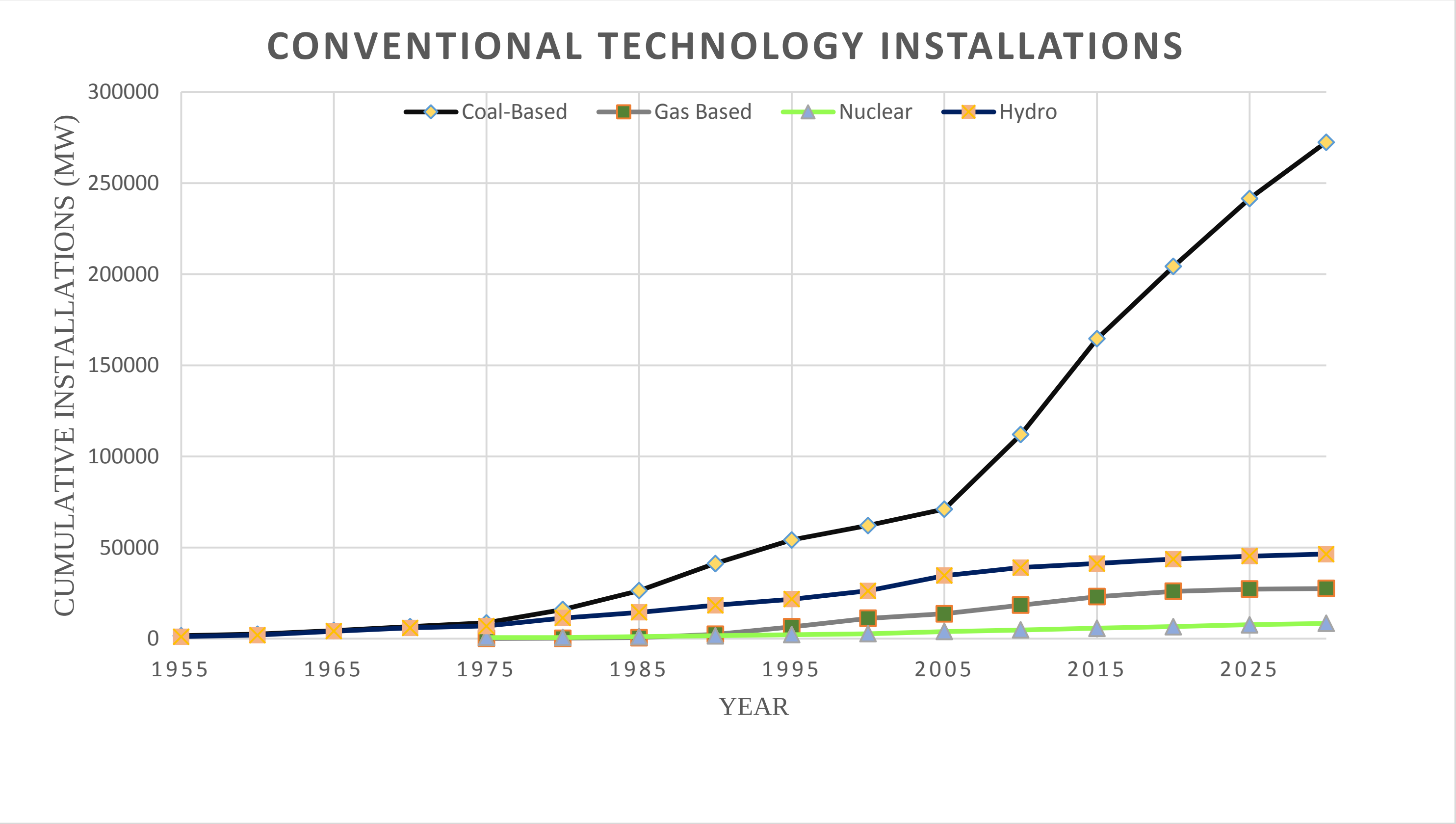

**Figure 3: Cumulative installations of conventional technology based power plants.**

By using the Bass diffusion model we have forecast renewable energy installed capacity until 2030. A higher value of p indicates a high response in the start-up period, which may be influenced by government policies. q measures the success of diffusion and a higher value indicates a high rate of diffusion (Table 12).

**Table 12: Bass model parameters for renewable technologies.**

| | **Wind Energy** | **Solar PV (Grid Connected)** | **Biomass Energy** | **Solar Water heater** |
|---|---|---|---|---|
| **p** | 0.0117 | 0.0129 | 0.009 | 0.0009 |
| **q** | 0.171 | 0.185 | 0.158 | 0.25 |
| **m** | 52132.95 | 49490.51 | 16038.94 | 152135566.1 |

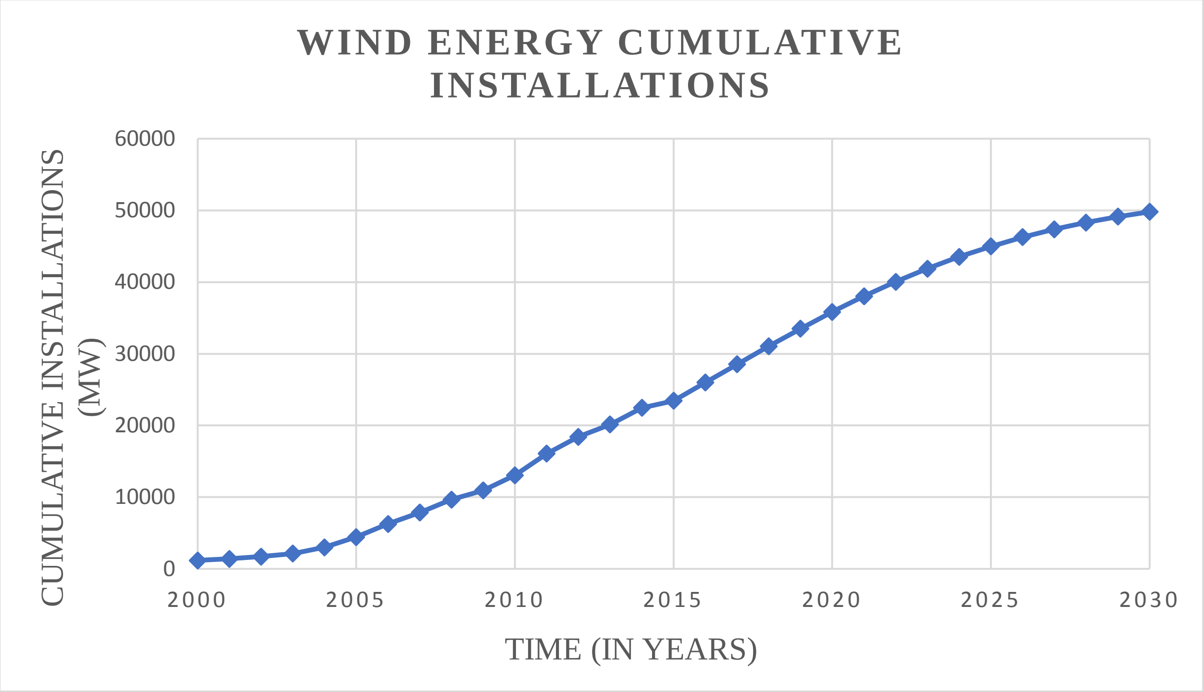

**Figure 4: Cumulative installations of wind energy technology based power plants.**

As shown in Fig. 4, the supply of wind energy will be the largest through 2030 in the Indian power sector. This is due to the fact that power can be generated on a relatively large scale and it has a higher capacity factor than other sources (Huh and Lee, 2014). Another unique feature of wind energy is that it has the smallest COG. As shown in Fig. 4, wind power reaches its peak in 2017 and will approach the maturity stage. The approximate installation of wind power plants by 2030 will be around 49.8 GW.

In comparison with other renewable sources, the diffusion pattern of solar PV and solar water heaters show a steady path of increase by 2030. These technologies will still be at their growth stage in the product life cycle (launch, growth, maturity, and decline). The ultimate supplies of solar PV in the electric power sector are expected to be about 36,000 MW in 2030. Fig. 5, shows a steep increase in installations from 2011 onwards. This is because of the implementation of The Jawaharlal Nehru National Solar Mission (JNSSM) in 2010. The mission is aimed at reducing the cost of solar power generation in the country through (i) long-term policy; (ii) large scale deployment goals; (iii) aggressive R&D; and, (iv) domestic production of critical raw materials, components and products. It can be seen that the total installation in 2030 will be around 36.1 GW.

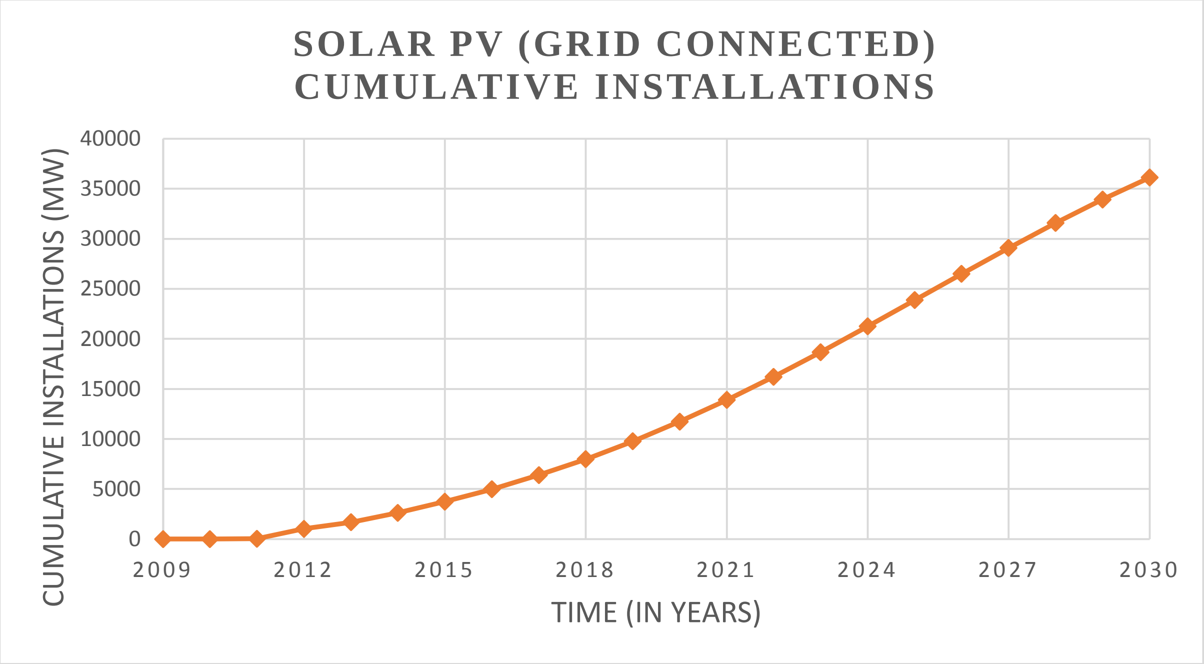

**Figure 5: Cumulative installations of SPV technology based power plants.**

The solar water installations in India (Fig. 6) have shown a steady and regular growth, especially after 2010. From the model we can see that the total installations will be around 113.8 million m$^2$ by 2030.

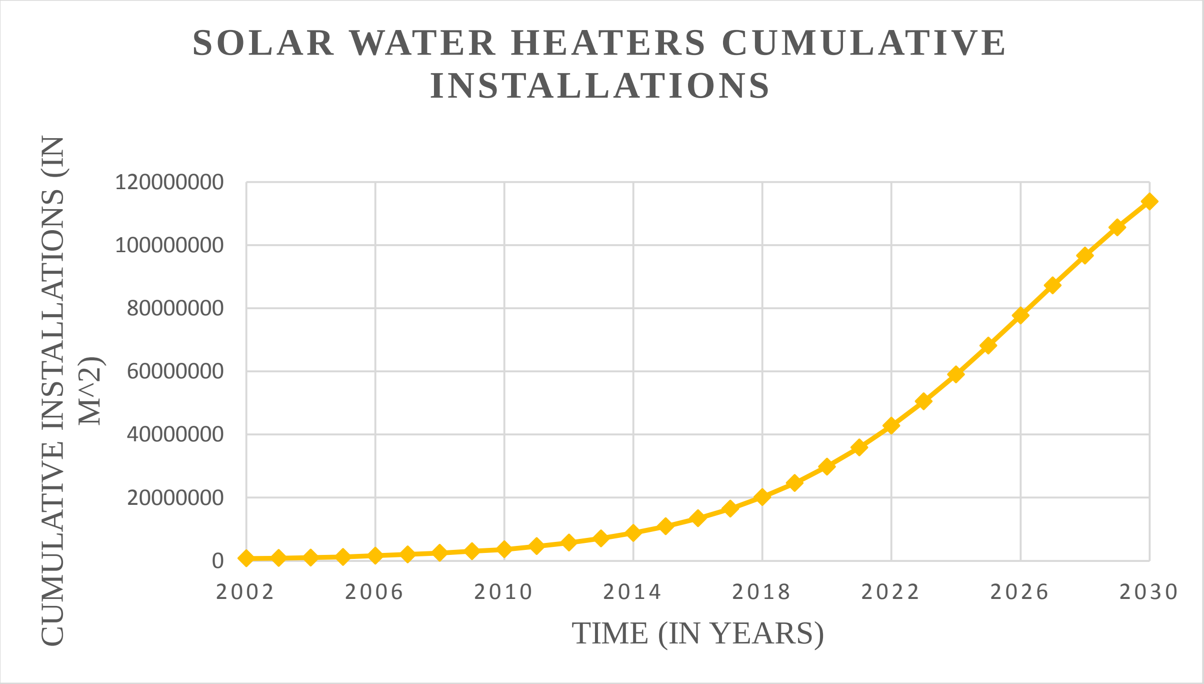

**Figure 6: Cumulative installations of Solar Water Heaters.**

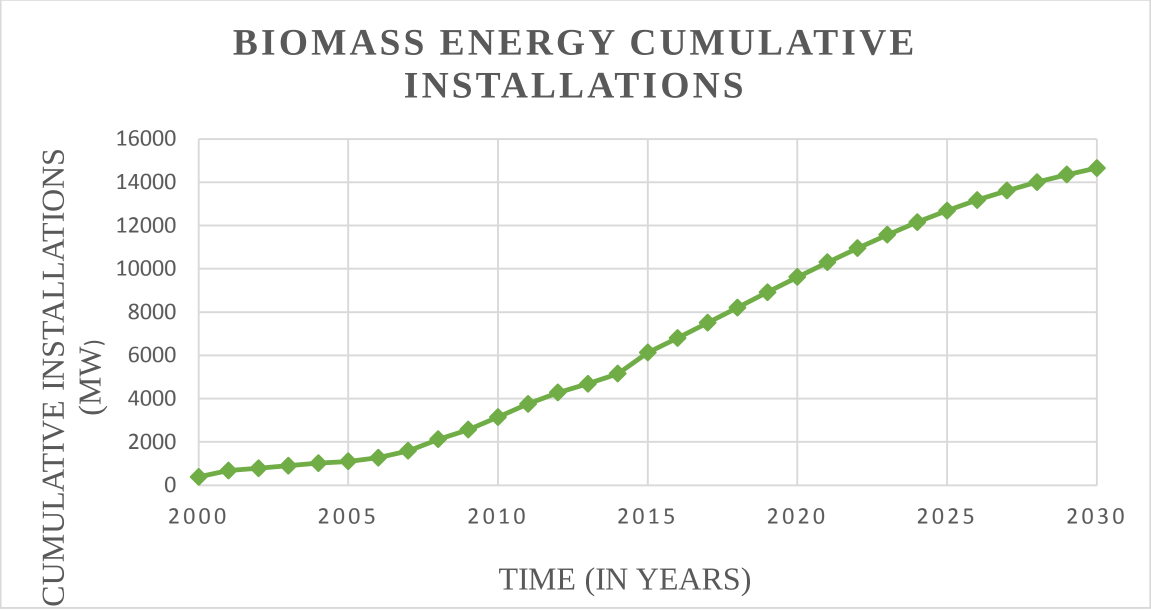

**Figure 7: Cumulative installations of Biomass based power plants**

The biomass-based power plants have shown a steady increase. Fig. 7 shows that the total installations will be around 14.65 GW by 2030.

The model predicts a future energy-mix using the Bass model. As the results show (Table 13) coal remains the key energy source even by 2030 because it is the cheapest source of energy and the technology is mature. Unless externalities are included in the cost of energy, there is little reason to believe that the attractiveness of coal will decrease (Narbel and Hansen, 2014). Though natural gas is expected to remain an important fuel for power generation, due to limited proven reserves, its share will eventually decline. Overall, the share of non-renewables is expected to decrease from 72% in 2015 to 67% in 2030. Renewables will play an increasingly important role as to account for 22% in 2030. Solar alone would contribute 8 and wind 11% of the 2030 power generation. Large hydro Power Plants are expected to remain stable.

**Table 13: Projection of installed capacity of various technologies by 2030.**

| Year | Share of various technologies in total installed capacity (%) | | | | | | | | Total Installed capacity(MW) |
|---|---|---|---|---|---|---|---|---|---|
| | Coal | Gas | Nuclear | Hydro | Solar | Wind | Biomass | Total renewables (*) | |
| 2015 | 61.4 | 8.6 | 2.2 | 15.4 | 1.4 | 8.7 | 2.3 | 12.4 | 268062 |
| 2020 | 61.0 | 7.0 | 2.0 | 13.0 | 3.5 | 10.6 | 2.8 | 16.9 | 331129 |
| 2025 | 59.9 | 6.7 | 1.9 | 11.3 | 5.9 | 11.2 | 3.2 | 20.2 | 403258 |
| 2030 | 59.8 | 6.1 | 1.9 | 10.2 | 7.9 | 10.9 | 3.2 | 22.1 | 455312 |

(*) excluding Hydro

## 5. Discussion

### 5.1 The Energy Mix-2030

India’s energy mix, even in 2030 will be dominated by fossil fuels. The Bass model forecast of the installed capacity of power plants shows that coal and gas will make up around 70% of the total in 2015 which is forecast to be about 66% by 2030. This means that no significant shift away from fossil fuels to renewables is seen until 2030.

### 5.2 Cost of Electricity Generation

Of the total power-generation costs, fuel costs constitute a significant portion. Plants that rely on domestic sources of fuel will have a significantly lower cost associated with fuel than those that rely on imported fuels. Since India’s power plants depend on domestic coal, the future power-generation costs do not increase significantly as in the case of gas-based plants which depend on imported fuel. Similarly, the efficiency of fuel conversion plays an important role in determining the cost of power generation for conventional technologies like coal and gas. Also, plant utilisation factor plays a major role in the quantity of power generated. In the power-generation cost, factors that play an important role are costs for transmission and distribution networks. Since we are unable to obtain or predict future prices for various fuels, efficiencies and power factors of technologies and T&D costs, we could not project the costs of power generation in 2030.

### 5.3 Technology diffusion until 2030

While projecting diffusion, we have excluded a number of variables. Exogenous impacts such as the value of R&D expenditure and external pollution costs are not included. Similarly, the model excludes the values of investments in a particular technology, effect of plant size, scale, plant lifetime, regulatory changes and subsidies. The impact of these combinations of factors will affect diffusion significantly. However, since estimating the probability of such impacts would be difficult and hence they are excluded for the analysis.

We believe that large variations in projected generation capacity are unlikely. However, the production mix is sensitive to the imported prices of coal and natural gas. Even if there are emission charges, it will have a limited impact on the power mix in 2030 due to the high share of coal-based capacity that is under development.

The share of renewable energy technology will continue to grow in future. However, as seen from the projections, they are unlikely to alter the energy mix significantly. The costs of power generation through renewables is falling continuously. The potential for significant cost reductions over time is high as the scale of manufacturing along the entire production value chain increases. The potential of cost reduction for fossil-fuel-based technologies is not high since the technological improvements for these mature technologies are incremental in nature. This will provide a growing market for renewable energy technologies even without government subsidies.

### 5.4 Impact of future power-generation mix on land and water

Wind-based power generation has the highest land requirements, as 498,071 ha are projected to be impacted by electricity generation by 2030, compared to 306,207 ha for wind and 289, 000 ha for solar PV. For the conventional power generation, coal power plants require 163, 445 ha. With regards to water requirement, coal-based power plants rely heavily on water for cooling. Wind power has the lowest water requirements with 0.85 million l. At present wet-cooling systems are in operation in India which are less efficient than dry-cooling systems which reduce water consumption by over 90 per cent. However, due to their high cost, the dry cooling systems are not preferred. To reduce water consumption, either the power system have to implement more dry-cooling systems or shift generation to renewables (Table 14).

**Table 14: Land and water impacts for power generation**

| Technology | Land Required (ha) in 2030 | Water Required (Ml l.) in 2030 |
|---|---|---|
| Coal | 163445 | 4963.5 |
| Gas | 9637 | 198 |
| Nuclear | 9205 | 281 |
| Hydro | 306207 | 3007 |
| Wind | 498071 | 0.85 |
| Biomass | 219825 | 270 |
| Solar PV | 289000 | 1.45 |

## 6. CONCLUSIONS

The present study provides the technology characteristics of various power generating systems including the levelised costs of electricity-generation technologies (LOCE) which play a significant role in the future prospects of these technologies. To arrive at the costs we have considered capital costs and the present value of fuel and other O&M costs. The results confirm that coal, gas, and wind remain competitive over the long term. At present, solar power remains expensive, even though the tariffs have come down significantly in the recent past. The costs for newer coal-based technologies such as integrated gasification combined cycle (IGCC) are calculated here which seems to be promising. Biomass power generation seems to have lower levelised costs than many other technologies due to lower fuel prices. These levelised costs of electricity are estimated using data at a particular point of time and with particular assumptions. These costs are likely to change over time and in some cases may change significantly as in the case of solar power. However, there is a possibility of falling construction costs for most technologies and especially the newer technologies. The levelised costs are sensitive to the discount rate, capacity factor and fuel prices.

The study applied the Bass model framework to generate energy production forecasts for a 15-year-ahead horizon (2030) through various energy technologies from the Indian context. The share of renewable energy generation in the total will increase from the existing 12.43% to about 22% by 2030, thus becoming a focal point of discussion for the future energy policy. It is observed that the diffusion of some of the renewable energy technologies will reach its peak in the near future. Several factors influence the future diffusion including available resource potential, electricity generation costs, etc. Constraints on the land and water availability are also expected to affect electricity generation through renewables.

With increasing installations of renewable power plants and therewith associated higher shares of power supply, there will be a fundamental change in the electricity supply system. In such a scenario, other than LCOE, many factors play a role in the analysis and evaluation of a technology. For example, the "value" of electricity will become more important, i.e., its availability at times of high demand and the ability to provide services. So it is essential that the power system should be regarded in its entirety since there are many interactions and interfaces among different sectors (power, heat, transportation, etc.) and the prices that are charged should depend on the services that are provided (Kost et al, 2013).

In order to achieve that goal, it is important that we should find out the nature of direction and the quantum of speed with which the power system is experiencing. Various factors influence that change; they include: policy stimulus, efficiency of technologies and the role of actors. The future mix of power generation capacity depends on these factors. The technology diffusion trends indicate that the Indian power system is moving in the right direction. This shows that long-term structural changes which include technological and policy changes are taking place. Even though such changes are difficult to anticipate, historically, these structural changes enabled us to improve quality and quantity of energy services (Grubler and Enovic, 1996). This suggests that, while evaluating the power system, such driving forces are important factors and should be captured in the diffusion models.

**Acknowledgements**

The author wishes to thank Mr. Anik Chakraborty, M. Tech. Student, Centre for Energy Engineering, Central University of Jharkhand, Ranchi, who was with us at IGIDR on an internship for helping me in developing the technology diffusion model.

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