Energy Policy 120 (2018) 425–435

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Economic dynamics and technology diffusion in indian power sector

B. Sudhakara Reddy

Indira Gandhi Institute of Development Research, Mumbai, India

ARTICLE INFO

Keywords:
Diffusion
Electricity
Levelised cost
Renewables
Technology

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

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. 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, 2016).

It is generally believed that renewable energy (firewood, cattle-dung, etc) 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 so 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

E-mail address: sreddy@igidr.ac.in.

https://doi.org/10.1016/j.enpol.2018.05.044
Received 9 February 2018; Received in revised form 27 April 2018; Accepted 16 May 2018
0301-4215/

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 Bergek, 2004). 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.

In the light of the current debate on the sustainable development and climate change it is necessary to address the question of the adoption of renewable energy technologies in energy production. The attempts to answer this question using econometrics models have not given satisfactory answers since they do not capture the mechanics of underlying diffusion process. Widely verified model like Bass diffusion model might be more suitable for that purpose. Using the Bass model (West, 2011), 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 sector

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 and Srinivas, 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.

During 2015–16, India's total primary energy consumption stood at 775 MTOE of which the contribution of coal was the highest at 46.5% followed by oil at 23.3%. Renewables (including biomass) accounted for 19.5% and the rest by natural gas, hydro-electricity and nuclear energy (MoP, 2015). 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.

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, 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 plant capacity (of 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 1. 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 h/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 generation is only about 10%.

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 electricity from renewable was added via biomass-based plants. Table 2 provides the electricity generation figures for 1975–2015 (Anon, 2015c).

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, 2012; Hussy et al., 2014; EURELECTRIC, 2003).

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 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).

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

[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 [4].

[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, 2012).