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Estimation and Comparision of Cost of Coal Power Generation with External Costs and Cost of Solar Power Generation with Grid Integration Costs

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ABSTRACT:

This paper aims to present that however coal electricity tariff are lowest one among all sources of electricity generation but true cost of coal electricity is highest among all sources of power generation. Each stage in the life cycle of coal—extraction, transport, processing, and combustion—generates a waste stream and carries multiple hazards for the public health and the environment. These costs are external to the coal industry and paid by whole society and environment, thus often considered "externalities. Many of these so-called externalities are, moreover, cumulative. Accounting for the damages conservatively doubles to triples the price of electricity from coal per KWh generated. This paper aims to present the fact that large scale solar power installation in India require huge investment in transmission system and grid upgradation lead to increase in cost of solar power but even after adding the grid integration cost with government target of 100 GW solar installed capacity by 2022, solar power is still far cheaper than true cost of coal power.

Keywords: *coal power cost; externalities, solar cost, grid integration cost*

INTRODUCTION

Coal has been a cheap source of power and electricity since the beginning of the industrial revolution. Cheap and plentiful, coal has problems of environmental and social impacts that were often overlooked because of its very low price. Coal-fired power stations contribute to widespread indirect costs, referred to as externalities. These externalities include the contribution to climate change, the effect of emissions, such as particulate matter (PM), sulphur dioxide (SO2) and oxides of nitrogen (NOX) on the health of peoples, and the effect of coal mining and power generation on water consumption and available water supplies. Furthermore, coal mining and related activities are associated with many forms of environmental degradation, such as habitat loss. It also has a negative impact on the transportation network, and that further contribute to climate change, as well as transportation network maintenance and other problems.

For the electricity generation section, there are a number of researchers focusing on electricity external costs. In summary, the main reasons for studying the external cost of power generation include: (a) to provide and diversify multiple technologies; (b) to propose future policy implication; (c) to emphasize the social and environmental impact of external cost. Lingling et al (2015) estimated the external costs of a coal-fired plant as 0.072 US $/kWh for China. They also estimated the cost component wise in dollar per Mwh for CO2- 27.410$, CH4- 931.94$, SO2- 4842.7$, NOx- 4459.4$, CO- 165.99$, PM2.5- 19,471$, Fly ash - 23$, Furnace residue -16.5$, Gangue- 1.2$, Contaminated water- 3.32$ respectively for

China. Mahapatra et al (2012) estimated external cost of coal based electricity generation for Ahmedabad.

The majority of these additional costs are indirectly paid by society at large. Markets generally fail to account these costs, since these costs are borne by individuals within society rather than the decision makers or the entity responsible for the pollution and environmental degradation.

However, as a fuel, solar energy is free and clean but for generating power have problem of high initial investments requirement (module and balance of system costs), uncertainty and variability as power generation dependent on sunlight, geographical constraints (location specific), efficiency etc. These problems needs large investments in transmission strengthening, storage technologies, balancing reserves, ancillary market, setting REMC's and grid upgradation. As a result, solar power is believed as costly source of power and there is doubt for investment in solar and its dominance as main source of power in future. But solar is a newer technology, with problems that likely will be solved overtime in future with increase in demand, technology improvement and R & D efforts which make it reliable, clean and cheaper main source of future power generation.

This study estimates the cost of coal power that includes its external costs and cost of solar power that include costs due to uncertainty and variability, geographical constraints. Based on these estimates, comparison is made between the two i.e. cost of coal power and solar power. In this study relatively conservative estimates of the externality cost of coal-fired power generation are provided, because some impacts are excluded due to data availability, quantization and monetization constraints. Despite its conservativeness, the results of the analysis point to rather large externality costs. This study estimates cost of grid integration taking into account the cost of building required transmission capacity, integrating RE with the grid while ensuring grid stability. These estimates are primarily collected from existing literature – both domestic and international.

COAL POWER GENERATION

Coal remains dominant in electricity generation in India. India is the third largest producer and second largest consumer of coal in the world. Major reason of coal's domination of India's production and consumption is its low market price. Coal-fired power plants accounts for 62% (165 GW) of total power generation installed capacity and generate 74% (850 billion units) of India's electricity in 2014-15. India's greenhouse gases emission is 3.05 billion tonne of CO2 equivalent that is about 7% of global greenhouse emissions. Electricity production is the single largest source of greenhouse gas emissions. India generates 74% of its electricity through coal and coal power generation accounts for 90% GHG emissions from Electricity sector.

Coal is touted as a cheap source of energy and in fact in most places it is cheaper per kilowatt hour than other competing sources of energy sources. However, this "market price" fails to take into account a variety of other factors that make up the true cost of coal. These additional costs are borne not by coal companies but by other industries, the taxpayer, and future generations. Worldwide these additional costs were estimated to exceed far greater than the worldwide economic value of coal.

This apparently cheap fuel has grave repercussions, as reliance on coal comes with heavy environmental and social costs. Every step in the process of coal-fired power generation from mining to combustion causes severe damage to environment and society. The low price of electricity generated by coal accounts for just fraction of its Full Cost. This larger part of total cost that society pays known as External costs.

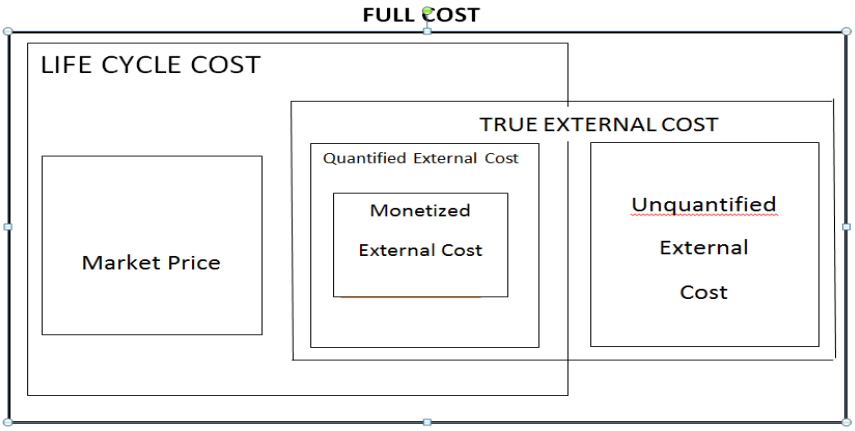

Figure 1: Full cost components in Life Cycle approach

In addition, the transportation of coal for power plants constitutes 80 per cent of the coal traffic of Indian railway and that also associated with pollution, accidents and deaths. Coal transportation by the railways is, therefore, closely linked to the demand from the power sector. If coal use were to be expanded, land and transport infrastructure would be further stressed.

SOLAR POWER GENERATION

Solar power price declines have beaten expectations of most analysts. In the ongoing NTPC solar park tender, solar prices have breached the INR 5/Kwh (INR 4.34/Kwh by Fortum Finnsurya Energy in January 2016). Today, in India solar prices are within 15-20 percent of coal power prices on a levelized basis. While this may not fully capture the costs such as grid integration costs for solar. But according to estimate and analysis even after considering the same solar prices would be competitive with coal and could be lower than coal power prices by 2022. The disruption which we are yet to see may come from the solar rooftop business that require support by rise & evolution in storage technologies and net metering support. Solar roof top power today already competitive compared to grid power. In this paper we remain restricted to utility scale solar power. Decrease in solar power cost attributed to the fall in the price of solar panels and other equipment's, increase in efficiency, government subsidies and policies. Increase in conventional power cost attributed to increase in imported as well as domestic fuel prices, increase in taxes and decrease in government incentives and subsidies.

LITERATURE REVIEW

External costs of coal power generation

Based on an extensive review of literature discussed below, it is evident that the external costs of life cycle of coal based power generation are significant. According to the National Research Council report (National Research Council, 2010) the total annual external damages from sulphur dioxide, nitrogen oxides, and particulate matter created by burning coal in more than 400 coal-fired power plants (which produce 95 percent of the US coal-generated electricity), was about US $62 billion. Jonathan Levy's (2009), study on coal pollution identifies the impact on health as one of the largest externality costs. The study presents arrange of health-related damages of US $30,000 to US $500,000 for every tonne of PM2.5emission. For each tonne of sulphur dioxide pollution, or SOX, the health damage ranges from $6,000 to $50,000 per tonne, while for NOX, the per-tonne rate ranges from $500 to$15,000.

Epstein (2011) finds that the best estimate for the total economically quantifiable costs, based on a conservative weighting, amount to US $345.3 billion, or US cents 17.8/kWh of electricity generated from coal. The low estimate is US $175 billion, or over US 9 cents/kWh, while the upper limit would be US $523.3 billion, approximately US cents 27/kWh. Rafaj and Kypreos (2007) adjusted the Extern results to create a global estimate, resulting in an external cost estimate for pulverized coal combustion of US $ 58/MWh (in 2010 prices). In 2007, researchers at the Paul Scherrer Institute in Switzerland reported that the external costs of coal combustion was in the range of US cents 5.7 - 11.7/kWh (excluding CO2). However, the estimates are in the range of US cents 7.5 - 13.6/ kWh if CO2 emission is factored in. A study conducted in 2009 by the Australian Academy of Technological Sciences and Engineering (ATSE) valued the external costs from the combustion of brown coal at A$ 52/MWh and those from the combustion of black coal at A$A42/MWh.

Grid integration costs of solar power generation

A limited number of solar integration studies exist, largely as a result of the recent cost declines, to the point where systems are now considering much larger levels of solar energy than they were four or five years ago. Synapse summarizes the results of five studies. Integration costs are similar to or lower than costs using similar metrics for wind energy, perhaps contributed by the relatively low penetration values assumed and/or the additional capacity value associated with solar capacity.

Interesting anecdotes from these studies include:

- Two groups conducted integration studies for Arizona Public Service (APS), with different primary challenges for integration. The Black & Veatch (B&V) study found that integration costs where driven by increased operating (spinning) reserves and minor increases in incremental energy costs. The Argonne study found the inflexible nature of the existing coal and nuclear generation fleet to be a driving factor. Integration costs were more than halved by assuming an increasing amount of ramping from nuclear power plants, decreasing from $3.88 per MWh to $1.74 per MWh.

- Tucson Electric Power (TEP) looked at concentrated solar power (CSP), PV, and wind resources in 100 MW increments, and found that wind was substantially less expensive than both solar resources, and CSP was much easier to integrate then PV, as a result. These costs

were based on inter-hour fuel costs to make the renewable profiles comparable to a flat-block purchase, and did not incorporate additional system regulation costs.

• Xcel Energy, which operates in Colorado, looked exclusively at distributed PV and focused on increasing utilization of gas resources to balance intermittency. As a result, the cost values were sensitive to gas prices, similar to its wind integration study.

In order to estimate the true cost of solar power we consider the costs of grid integration. It is difficult to estimate the grid integration costs however, we made the estimates based on the range of values observed from different studied conducted in the world.

EXTERNALITIES IN COAL BASED POWER GENERATION

There are various externalities linked to different stages in the life cycle of electricity generation from coal fired thermal stations. However it is evident and stated earlier that in most cases data related to the externalities is unavailable as well as difficult to obtain, a substantial part of the analysis had to depend on estimates from secondary literature. However, effort has been put in to ensure that such estimates are current and relevant to the Indian context. External cost estimation of coal based power generation through the life cycle approach contain the elements/stages outlined in Table 1.

Table 1: Externalities in Coal Power Generation

Environmental	Social
Coal Mining & Processing	
Deforestation	Occupational Injuries/disease/deaths & accidents
Emission	Health Impacts & Mortalities in nearby Communities
Contamination & decline of UG & Surface Water Sources	
Land Degradation	
Coal Transportation	
Emission by Diesel Engines	Death & Injuries in Accidents linked to Coal Transportation
Coal Combustion	
Emission	Health Impacts & Mortalities in nearby Communities
Water Consumption & Degradation	
Waste Disposal (Ash)	

Costs of Coal Power Generation With External Costs

Based on the secondary literature available from (i) – (viii) & (xi), the calculation has been done and results are obtained for each head of external costs in various stages of coal fired power generation and expressed in cost rupees/paise per KWh as summarized in Table 2. The

summarized result and its graphical representation in Figure 1 illustrates that external cost are almost equal to the LCOE of coal power generation and increase coal power cost by twice. The result in Table 2 clearly illustrates that coal combustion contributes to majority of external costs.

Table 2 : External Cost of Coal Power Generation		
Costs Heads	**Cost (Paise per KWh**	**%**
Cost of GHG Emission due to Deforestation	0.137	0.02
Cost of Water Contamination	132.862	16.11
Cost of Land Degradation	0.264	0.03
Damage Cost of Methane Emission by mines	22.489	2.73
Cost of Fatalities, Morbidity & Injuries in Coal Miners	1.054	0.13
Damage Cost by Coal Transportation	5.127	0.62
Total Damage cost by Gaseous emission	581.140	70.48
Cost of water consumption	17.000	2.06
Cost of Mortality and Morbidity	64.457	7.82
External Cost of Coal Power Generation	**824.529**	**100.00**
These cost are calculated from secondary literature that give costs in World Context		
World External Cost of Coal Power Generation is Rs. 8.24 per KWh		
World Levelized Cost of Coal Power Generation is Rs. 6.70 per KWh		
Estimated Total Cost of Coal Power Generation in world context is Rs. 14.94 per KWh		
External costs In Indian Context		
Estimated External Cost of Coal Power Generation is Rs. 3.73 per KWh		
Levelized Cost of Coal Power Generation is Rs. 3.05 per KWh		
Estimated Total Cost of Coal Power Generation in Indian context is Rs. 6.78 per KWh		

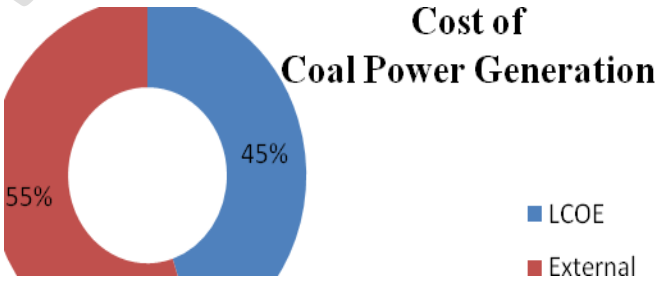

Figure 2 1: World Share of external costs and LCOE in total costs Coal power

COST OF GRID INTEGRATION OF SOLAR

Cost of Integration the solar power into the Grid can be broadly categorized into two parts:-

i) Transmission cost (Grid strengthening Cost) which comprise of cost of building transmission lines and cost of building transmission (Transformation) capacity.

It is estimated that during 13th Plan Period, about 62,800 circuit kilometers (c-km) of transmission lines, 15,000 MW of High Voltage Direct Current (HVDC) terminal capacity and 128,000 MVA of transformation capacity of the 400 kV and above voltage level transmission systems would be required.

Accordingly, the plan estimates that total fund requirement for 13th Plan would be of the order of Rs. 260,000 crore as against Rs. 234,000 crore required in 12th plan period. This would consist of Rs. 160,000 crore for 400kV and above transmission system and about 100,000 crores for 220 kV and below systems most of which would be for state transmission systems. These cost estimates for overall added installed capacity by thermal, renewable, nuclear, hydro, etc. From above estimates, the cost of transmission system strengthening can be assumed rupees one crore per megawatt

ii) Grid integration costs which comprise of balancing, forecasting, stabilization, communication system, storage. Setting REMC and other costs.

There are no domestic studies carried out in this respect. In 2013, a partial analysis of the additional costs of integrating significant levels of solar PV generation in Europe, taking into account capacity adequacy and reserves, upgrading of the main European Union (EU) transmission network, the cost of reinforcing the distribution network and the impact of solar PV on network losses (beneficial atlow penetration rates), indicated average integration costs of around USD 0.02/kWh for 10% of EU's generation from solar PV, rising to around USD 0.025/kWh for 18% of EU generation coming from solar PV. Taking a more holistic approach to integrating solar PV by including demand response as an additional source of flexibility would reduce these costs by an average of 20%.

In Indian Context

IESS (Indian Energy Security Scenerio), 2047 envisages that RE will constitute approximately 15% of India electricity generation mix by 2022 (The heroic effort scenario of the IESS 2047 estimates 460 TWh RE in a total electricity supply of 3026 TWh). International literature states that this will not exert any significant pressure on generation costs provided the grid planning and operation protocols are appropriately designed. Based on the empirical assessments in other countries, it can be assumed that grid integration will constitute approximately 10% of the levelized cost of RE in the present context. This cost share can be possibly made to reduce to 6% by 2021-22 as planning and operations related interventions are adopted. It may be noted that this is a ballpark estimate and detailed studies need to be carried out to determine costs of integration (according must-run status to RE plants). Hence from above analysis it can be concluded that estimated grid integration costs are 10% of LCOE (Levelized Cost of Electricity) for 15% Solar penetration.

Table 3: Estimated Cost of Solar Power with Grid Integration costs

Transmission Cost	
Solar Installed Capacity addition	100 GW
Cost transmission Strengthning	1 Crore / MW
Total Cost transmission Strengthning	100000 Crore
Life of Transmission line	35 year
Electricity Transmitted by these lines in 35 Year (GWh)	5825400
Cost per Gwh (Rs.)	171662.0318
Cost per Kwh	0.171662032
Hence Transmission Cost is 17.17 Paise Per KWh	
Costs of Integration	
Cost of Integration solar to Grid in percent of LCOE	10% of LCOE for Solar
Levelized cost of Electricity for solar	Rs 7.04 / KWh
Cost of Integration solar to Grid	Rs 0.704 / KWh
Total Cost of Grid Integration (Crore)	292934.4
Hence Cost of Integrating Solar at 15% penetration level is 70.4 paise / KWh	
Estimated total Cost of Grid Integration of 100 GW Solar is 87.57 Paise Per KWh	
Estimated total Cost of Solar Power Generation is (7.04 + 0.8757) Rs. 7.92 Per KWh	

Source:- CERC, Petition No. 17/SM/2015, Report on Green Energy Corridor (Transmission plan for envisaged renewable capacity) by PGCIL, "Report of the expert group on 175 GW renewable energy by 2022" by NITI Aayog

RESULTS & DISCUSSION

Externalities in Coal Power Generation are Coal Mining & Processing, Coal Transportation, Coal Combustion and are further categorized into two parts ie. Environmental and Social. The environmental factors taken into account for coal power generation external costing are Deforestation, Emission, Contamination & decline of UG & Surface Water Sources, Land Degradation, Emission by Diesel Engines, Emission. The social factors taken into account for coal power generation external costing are Occupational Injuries/disease/ deaths & accidents, Health Impacts & Mortalities in nearby Communities, Death & Injuries in Accidents linked to Coal Transportation, Health Impacts & Mortalities in nearby Communities. The cost heads for calculating the External Cost of Coal Power Generation are taken as: Cost of GHG Emission due to Deforestation, Cost of Water Contamination, Cost of Land Degradation, Damage Cost of Methane Emission by mines, Cost of Fatalities - Morbidity & Injuries in Coal Miners, Damage Cost by Coal Transportation, Total Damage cost by Gaseous emission, Cost of water consumption and Cost of Mortality and Morbidity. These cost are calculated from secondary literature that give costs in World Context. Finally the External Cost of Coal

Power Generation for world average is Rs. 8.24 per KWh. Levelized Cost of Coal Power Generation is Rs. World average is Rs. 6.70 per KWh. Estimated Total Cost of Coal Power Generation in world context is Rs. 14.94 per KWh. Here from the figure1 for world trend of share of external costs and LCOE it is seen that if LCOE is 45% then external costs is 55%. For Indian context Levelized Cost of Coal Power Generation (LCOE) is Rs. 3.05 per KWh (Source: Central Electricity Authority). From the LCOE cost, external Cost of Coal Power Generation has been extrapolated and is Rs. 3.73 per KWh. Estimated Total Cost of Coal Power Generation in Indian context is Rs. 6.78 per KWh. However from Estimated total Cost of Grid Integration of 100 GW Solar is 87.57 Paise Per KWh. Estimated total Cost of Solar Power Generation is (7.04 + 0.8757) Rs. 7.92 Per KWh

CONCLUSIONS

Coal has been a cheap source of power and electricity since the beginning of the industrial revolution. Cheap and plentiful, coal has problems of environmental and social impacts that were often overlooked because of its very low price. Coal-fired power stations contribute to widespread indirect costs, referred to as externalities. The results of the analysis provide evidence of the need to invest in alternative (renewable) energy sources, and for government to support those investment initiatives for sustainable development. Cost of coal power with the externalities cost is almost double of what we pay for. This study shows that with its external costs coal power is comparable to solar power. Over time with technology, environmental awareness for sustainable development, power market advancement and further decrease in costs, solar photovoltaic source of electricity will eventually overtake coal as our main source of electricity.

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