Analyzing Trade Offs in Short Term Power Sector Operations Under Minimum Offtake Guarantee Constraints in India

Pankaj Kumar
Interdisciplinary Programme in Climate Studies,
Indian Institute of Technology Bombay, Powai,
Mumbai, India
Email: pankaj.k@iitb.ac.in

Trupti Mishra
Shailesh J Mehta School of Management
Indian Institute of Technology Bombay, Powai,
Mumbai, India
Email: truptimishra@iitb.ac.in

Rangan Banerjee
Department of Energy Science and Engineering
Indian Institute of Technology Bombay, Powai,
Mumbai, India
Email: rangan@iitb.ac.in

Abstract— The Indian power sector is dominated by coal which accounts for 74 percent of the electricity generated. Due to the must-run nature of renewables, the plant load factor of thermal plants is currently low at 56 percent. In this study, we analyze the trade-offs and synergies in cost and emission minimizing power sector operating strategies for the Indian power sector in 2022.
An optimization model is created in TIMES framework with 2018 power sector inventory which includes 620 coal, 239 gas, 22 nuclear and 686 hydro units and capacity addition targets for 2022. We find that total emissions can be reduced by 16-23 percent in emission minimizing operating strategy. The carbon price for this scenario is in the range of 222-229 USD/tonne.

Keywords: Indian power sector, climate change mitigation, emissions

I. INTRODUCTION

The Indian power sector is dominated by coal which accounts for 57 percent of the electricity generated. Coal is the primary fuel used in the power sector and contributing majority of greenhouse gas emissions in the power sector. The greenhouse gases mainly carbon dioxide are responsible for climate change and hence there is an urgent need to mitigate energy-related emissions. Low average efficiency is a major factor for higher emission factor of Indian coal thermal power plants (Ecofys, 2018)[1].

India is also one of the largest economies in the world and poised for rapid growth in the coming decades. According to NITI Aayog’s National Energy Policy (NITI Aayog, 2017)[2] Indian electricity consumption will increase by more than 300 percent from 2012-2040. India also pledged 100GW of solar and 60 GW of wind capacity as a part of Paris Agreement targets to decarbonize Indian power sector. A set of stricter norms were issued by MOEFCC in (MOEF, 2019)[3] to reduce SOx, NOx, mercury and particulate matter emissions from Indian coal thermal plants. Thus the Indian government has prioritized emission reductions in its power sector policy agendas.

Several studies have been conducted in the past targeting decarbonization of India’s power sector. Mishra et al. (2015)[4] created a simulation model with a system dynamics framework. The model had a capacity expansion module along with a coal demand and import module. Shukla et al. (2008)[5] analyzed India’s capacity and energy mix in business as usual and sustainability scenario for 2050 in line with mitigation targets. The authors used a combination of models in a soft linked framework. Massetti (2011)[6] analyzed the implications of a range of carbon prices and their implications on emission reductions for the Indian energy sector.

Apart from these, some studies have also analyzed capacity expansion plans and power sector interventions in unit commitment and dispatch modeling frameworks. The study explored market penetration scenarios for clean coal technology for the year 2050. De la Rue du Can et al. (2019)[7] used a combination of LEAP and India DREAM model to assess the feasibility of India’s Nationally determined contributions under currently planned policies. Phadke et al. (2016)[8] used the PLEXOS framework to analyze dispatch in India’s variable renewable capacity targets for 2022 in different planned scenarios. None of the past studies have studied potential emission reductions from different dispatch strategies. In this study, we analyze potential emission reductions from existing coal thermal inventory in two contrasting strategies – cost minimization and emission minimization. The study is an attempt to provide insights on the future cost of low carbon transition.

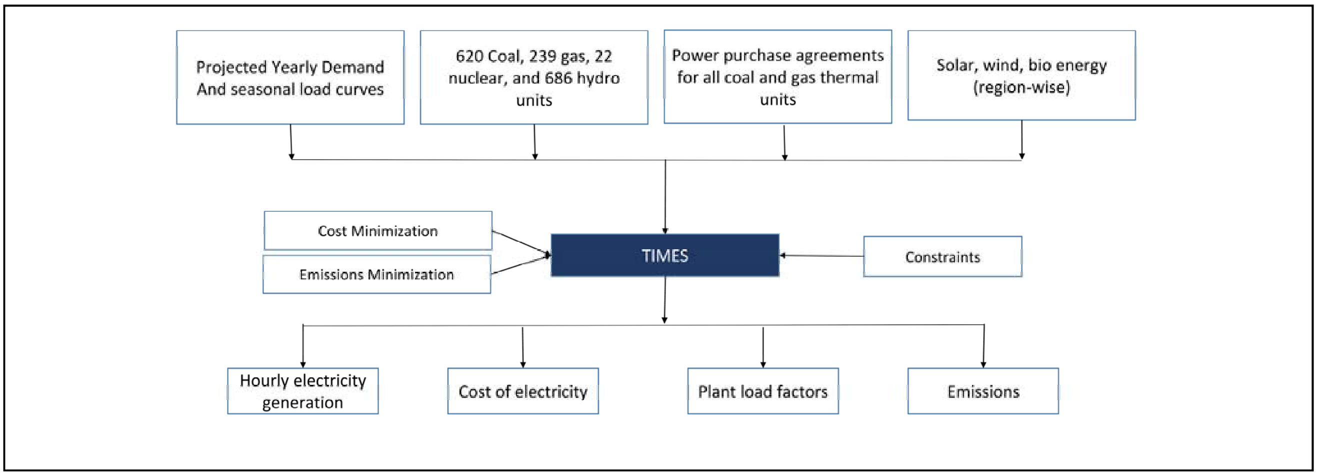

Figure 1 Research framework

Here, we use TIMES integrated assessment model to perform the analysis due to its technology explicit bottom-up framework. The sections ahead discuss the methodology and results.

II. MATERIALS AND METHODS

This study uses an Indian power sector model in TIMES framework for analyzing two dispatch strategies for the year 2022. TIMES has a bottom-up partial equilibrium framework which minimizes total system cost.

An optimization model is created in TIMES framework with March 2018 power sector inventory which includes 620 Coal, 239 Gas, 22 Nuclear and 686 Hydro units along with capacity addition targets for 2022 (inclusive of Paris agreement renewable targets). The power plant units are represented with techno-economic and operational characteristics like availability factors, heat rates, emission factors, ramp rates, minimum generation levels, and part-load efficiency. The solar and wind capacity is modeled region-wise while thermal power plants have unit-wise representation. Fig. 1 illustrates research framework of the study.

The model also represents the minimum guaranteed offtake for each power plant unit towards Discoms. The model is bottom-up, linear programming with unit commitment and dispatch features and minimizes the total cost of electricity production for 2022. We analyze the demand scenario with 7 percent GDP growth rate from 2015 till 2022.We assume the electricity intensity of GDP to remain same as 2017 in 2022. The cost and emission minimizing operating strategies are compared in terms of emissions, power plant operations, regional distribution, cost of carbon abatement and stranded assets.

Scenario details

As a part of this study two scenarios are analyzed for 2022 capacity mix.

a. Cost minimization

This scenario minimizes the total cost of electricity generation under operational and minimum offtake guarantee constraints. Here, the most economical power plants are prioritized for electricity dispatch.

b. Emission minimization

This scenario minimizes overall emissions from the power sector. Here, the most cleaner plants with the least emission factors are prioritized for electricity dispatch.

To perform this analysis, two different variants of TIMES objective function are created. The fixed cost component of allocated capacity under power purchase agreements is assumed as sunk.

Objective function

The objective function minimizes total cost of power generation. For this study, two different objective functions are used for 2022 target capacity.

Cost minimization

$$\text{ProdCost}(t,c) = \sum_{k}\sum_{s} FIXCOSTPP(t,k,s) + Min\sum_{k}[VARCOSTPP(t,k) * \sum_{s} ACTPP(t,c,k,s) + (FIXCOSTNPP(t,k) + VARCOSTNPP(t,k)) * \sum_{s} ACTNPP(t,c,k,s)]$$

Where ProdCost(t,c) is the total cost of production of electricity which is to be minimized in year t and season c. FIXCOSTPP (t,k,s) is the fixed cost component of electricity tariff from power plants covered in power purchase agreements in year t, from technology k and timeslice s. VARCOSTPP(t,k) implies the variable cost of electricity production from PPA covered plants with technology k in timeslice s. ACTPP(t,c,k,s) is the activity of power plant with technology k which is covered under PPA in year t, season c and timeslice s. FIXCOSTNPP(t,k), VARCOSTNPP(t,k) and ACTNPP(t,c,k,s) are defined in the same way for non-PPA plants as like FIXCOSTPP(t,k,s), VARCOSTPP(t,k) and ACTPP(t,c,k,s).

Emission minimization

The emission minimization objective function minimizes the total carbon emissions. This objective function ignores fixed and variable costs and only accounts for carbon tax on cardi oxide emissions.

$$\text{Prodcost}(t,c) = Min\sum_{s}[CTAX\,(t,c,p) * ENV(k,s,p)]$$

Here, CTAX (t,c,p) is the carbon tax in year t, on season c and pollutant p. ENV(k,s,p) is the

Here a carbon tax of 1$/tonne is levied on carbon dioxide emissions.

The typical Indian 24-hour load curve has two peaks, one in the morning and one in the evening. The data for the load curve for different months were taken from POSOCO (2016)[11]. The load curves for the year 2022 are projected from load curves of 2015. In order to project the demand profile, we took representative urban load curves of urban centers like Delhi, Chandigarh, and Pondicherry and added urban and rural loads in line with population growth estimates for the year 2022. Fig. 3 shows the projected load curves for the model.

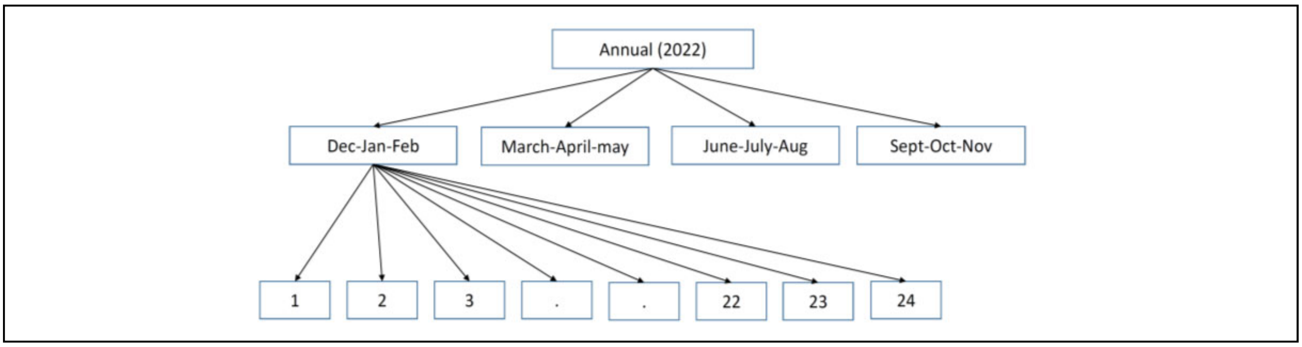

Figure 2 Timeslice allocation in the model

Constraints

1. Demand satisfaction

All the national electricity demand from each sector should be satisfied by electricity generated from all technologies.

2. Capacity use and availability factor

Electricity generation from each technology is in line with the availability factor.

3. Minimum stable generation levels

Electricity generated from each technology cannot go below the minimum stable generation level constraint.

4. Ramp rates

The ramp-up and ramp-down rates of all electricity generation technologies cannot exceed the maximum ramp rate constraint.

5. Minimum online and offline times

The time between subsequent start-up and shut-down cannot be less than minimum online time. Similarly, the time between subsequent shut-down and start-up cannot be less than minimum offline time. The detailed constraints and their formulations can be found at Panos and Lehtila (2016)[9]. The methodology is adopted from our previously conducted study (Kumar et al, Unpublished) [10].

Timeslices and load curves

The study timeframe is divided into four different seasons of 3 months which nearly coincide with India's seasons. Each season has a representative 24-hour load duration curve for representing a typical day. Fig. 2 illustrates the timeslice level in the model.

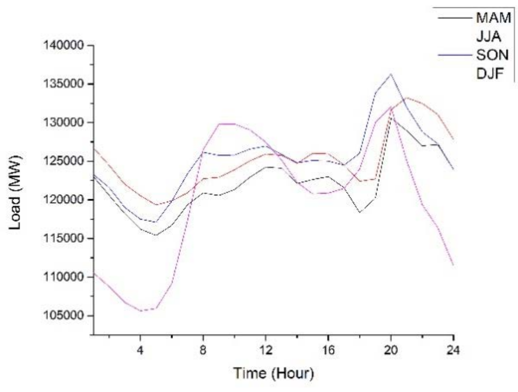

Figure 3Projected load curves for India for the year 2022

Table 1Capacity mix for base year (2018) and target year (2022)[2]

Technology	Base year (GW)	Capacity for 2022 (GW)
Coal	197.1	266
CCS	-	1
Gas	24.8	34
Nuclear	6.7	12
Hydro	45.2	61
Solar PV	21.6	59
Solar CSP	-	4
Distributed solar	-	36
Onshore Wind	34	62
Offshore Wind	-	2
Bio Energy	8.8	18
Diesel	0.8	-

Data and Sources

In order to represent power purchase agreements, the allocated capacity of power plants is taken from Merit India website (Merit, 2019)[12]. From the allocated capacity, the older units are assumed to be covered under power purchase agreements. For this analysis, we assume the partially allocated coal and gas units to have perfect allocation. The capacity for year 2022 was assumed to be in line with NITI Aayog's National Energy Policy targets for 2022 which consists of additional 100GW of solar and 60GW wind. Table 1 summarizes the capacity for year 2018 and capacity targets for 2022. The fixed and variable cost of electricity production are calculated in line with CERC norms (CERC, 2014; CERC, 2015)[13][14].

The power plant operational characteristics are assumed in line with Phadke et al (2016)[8] and Palchak et al. (2018)[15]. The cost of coal, gas and oil are assumed in line with prices in 2018. The cost of coal transport is assumed in line with railway freight charges. Solar and wind availability factors are assumed in line with Staffell and Pfenninger (2016)[16] and NREL (2019)[17]. Hydro availability factors are assumed in line with estimates of Phadke et al. (2016)[8].

minimizing scenarios. This higher cost of electricity is attributed to higher utilization of new coal thermal power plants and capacity charges from older power plants tied under minimum offtake guarantee. The cost of operations from coal and gas thermal plants increases by 63-56 % under minimizing strategy. Nearly 82-84 percent of the coal thermal capacity tied under power purchase agreements remain unutilized in emission minimizing operations.

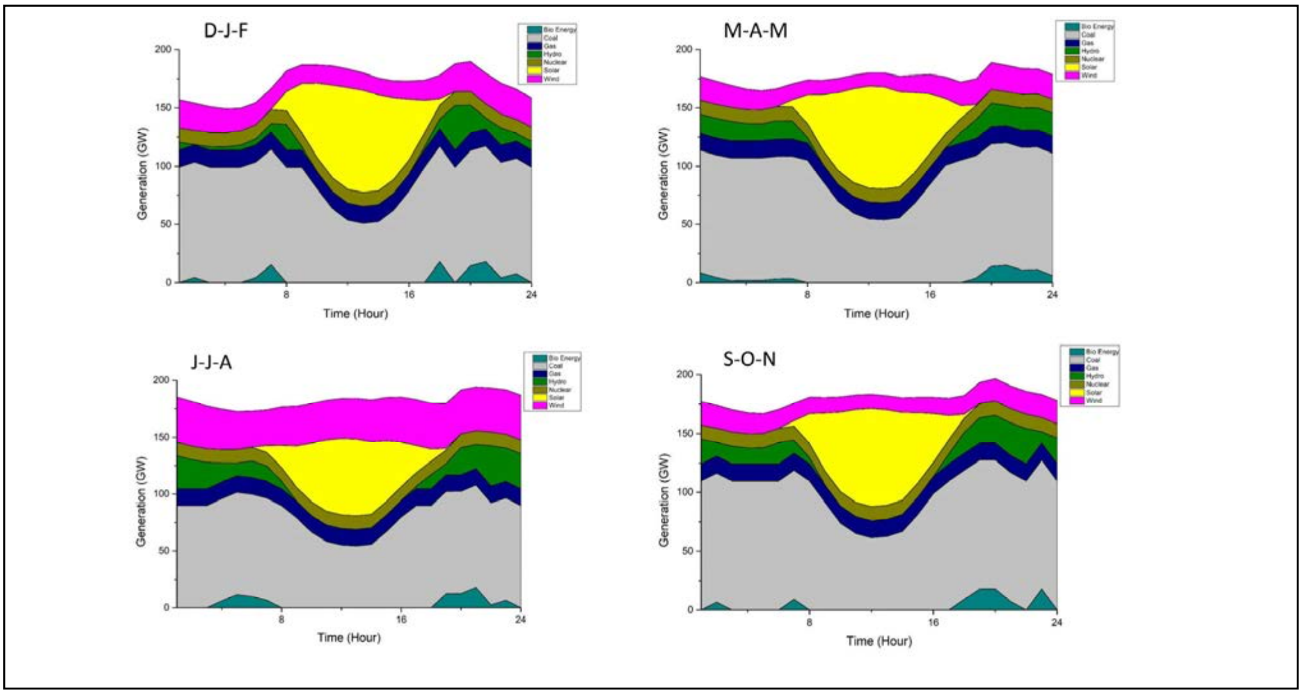

Figure 4 Electricity dispatch in both scenarios (cost and emission minimization)

III. RESULTS

On analysis of both the scenarios, it is found that coal thermal plants contribute 45-55 percent of electricity in both the scenarios. However increased penetration of renewables increases the variability in grid. The average ramp up rate increases from 2.2-5.6 GW/hr in load curve to 7.8-9.8 GW/hr. In addition, the average ramp down decreases from 2.3-3.8 GW/hr to 5.3-8.1 GW/hr. Fig. 4 shows the electricity dispatch in all days of analysis.

Table 2 Capacity operation summary in cost and emission minimization scenarios

Plant types		CM	EM
Base year Inventory (2018)	Active capacity(GW)	111.95	40.81
	Active units	312	75
	Inactive capacity(GW)	85.22	156.36
	Inactive units	308	545
Future inventory (2018-2022)	Active capacity(GW)	0	69.8
	Inactive capacity(GW)	69.8	0

The average age of operating coal thermal in cost minimizing scenario is 11.8 years. In contrast, the average age of coal thermal units decreases to 3.8 years in emission minimizing scenario. This is due to the fact that younger coal thermal units have higher efficiency and lower emission factors. Nearly 80 units operating in cost minimizing (baseline) scenario are older than 25 years. In contrast, all units operating in emission minimizing scenario are younger than 25 years. Table 2 summarizes the operations of existing and future inventory.

We observe that emissions can be reduced by 16-23 percent in the emission minimizing strategy with 36-39 %increase in the cost of electricity. The cost of electricity from coal thermal portfolio also increases by 71-79 %in the emission

Acknowledgement

The authors would like to thank Department of Science and Technology (GOI) for grant support towards Interdisciplinary Programme in Climate Studies at Indian Institute of Technology Bombay.

References

[1]Ecofys. International comparison of fossil power efficiency and CO2 intensity - Update 2015. Utrecht: ECOFYS Netherlands B.V.; 2018.

[2]NITI Aayog National Energy Policy 2017

[3]MOEF. moef.nic.in Ministry Of Environment, Forest and Climate Change 2019.

[4]Mishra M, Khare N, Agrawal A. Scenario analysis of the CO2 emissions reduction potential through clean coal technology in India's power sector: 2014–2050. Energy Strategy Reviews 2015;7:29-38

[5]Shukla P, Dhar S, Mahapatra D. Low-carbon society scenarios for India. Climate Policy 2008;8;S156.

[6]Massetti E. Carbon tax scenarios for China and India: exploring politically feasible mitigation goals. International Environmental Agreements: Politics, Law And Economics 2011;11:209-227.

[7]de la Rue du Can, S., Khandekar, A., Abhyankar, N., Phadke, A., Khanna, N., Fridley, D. and Zhou, N. (2019). Modeling India's energy future using a bottom-up approach. *Applied Energy*, 238, pp.1108-1125.

[8]Phadke A, Abhyankar N, Deshmukh R. Techno-Economic Assessment of Integrating 175GW of Renewable Energy into the Indian Grid by 2022. Lawrence Berkeley National Laboratory; 2016.

[9]Panos E, Lehtilä A. Dispatching and unit commitment features in TIMES. 2016.

[10]Kumar P, Banerjee R, Mishra T. Trade-offs in cost and emissions in Indian Power Sector. Unpublished.

[11]POSOCO. Electricity Demand Pattern Analysis Volume I. Power System Operation Corporation Ltd; 2016.

[12]Merit. Meritindia.in. Ministry of Power. 2019.

[13]CERC. Central Electricity Regulatory Commission (Terms and Conditions for Tariff Determination from Renewable Energy Sources) (Third Amendment) Regulations. New Delhi: Central Electricity Regulatory Commission (Government of India); 2015.

[14]CERC. Central Electricity Regulatory Commission (Terms and Conditions of Tariff) Regulations. New Delhi: Central Electricity Regulatory Commission (Government of India): 2014.

[15]Palchak D, Cochran J, Deshmukh R, Ehlen A, Soonee S, Narasimhan S et al. Greening the Grid: Pathways to Integrate 175 Gigawatts of Renewable Energy into India's Electric Grid, Vol. 1. National Study. 2018.

[16]Staffell I, Pfenninger S. Using bias-corrected reanalysis to simulate current and future wind power output. Energy 2016;114:1224-1239.

[17]NREL. www.nrel.gov. National Renewable Energy Laboratory. 2019