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The Renewable Energy Transition and The Economics of Banning Coal Based Electricity Generation in India

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Table of Content

Research Context

Current State of Indian Electricity Generation Sector

Indian electricity is dominated by coal

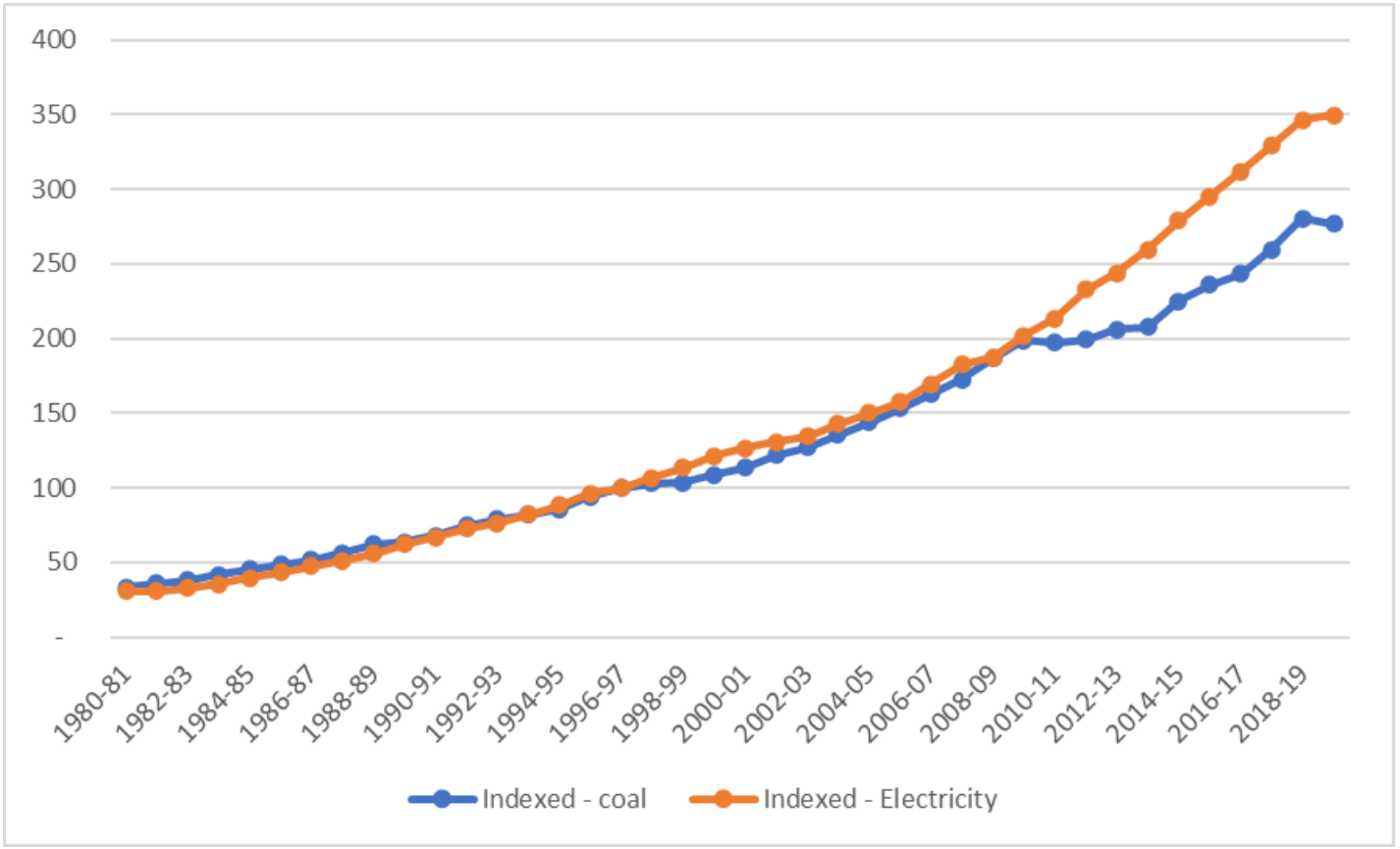
- Indian electricity systems are challenged by
  - Energy security and resource constraints – coal versus green energy resources
  - Development imperatives – access to affordable electricity for its population
  - Climate change risks

- While coal has been the mainstay of power generation sector in India, the trends indicate lower capacity utilization of existing coal power plants and lower present and projected capacity additions in coal based electricity generation.

- India has committed to net zero targets by 2070

Electricity sector reforms have made and impact

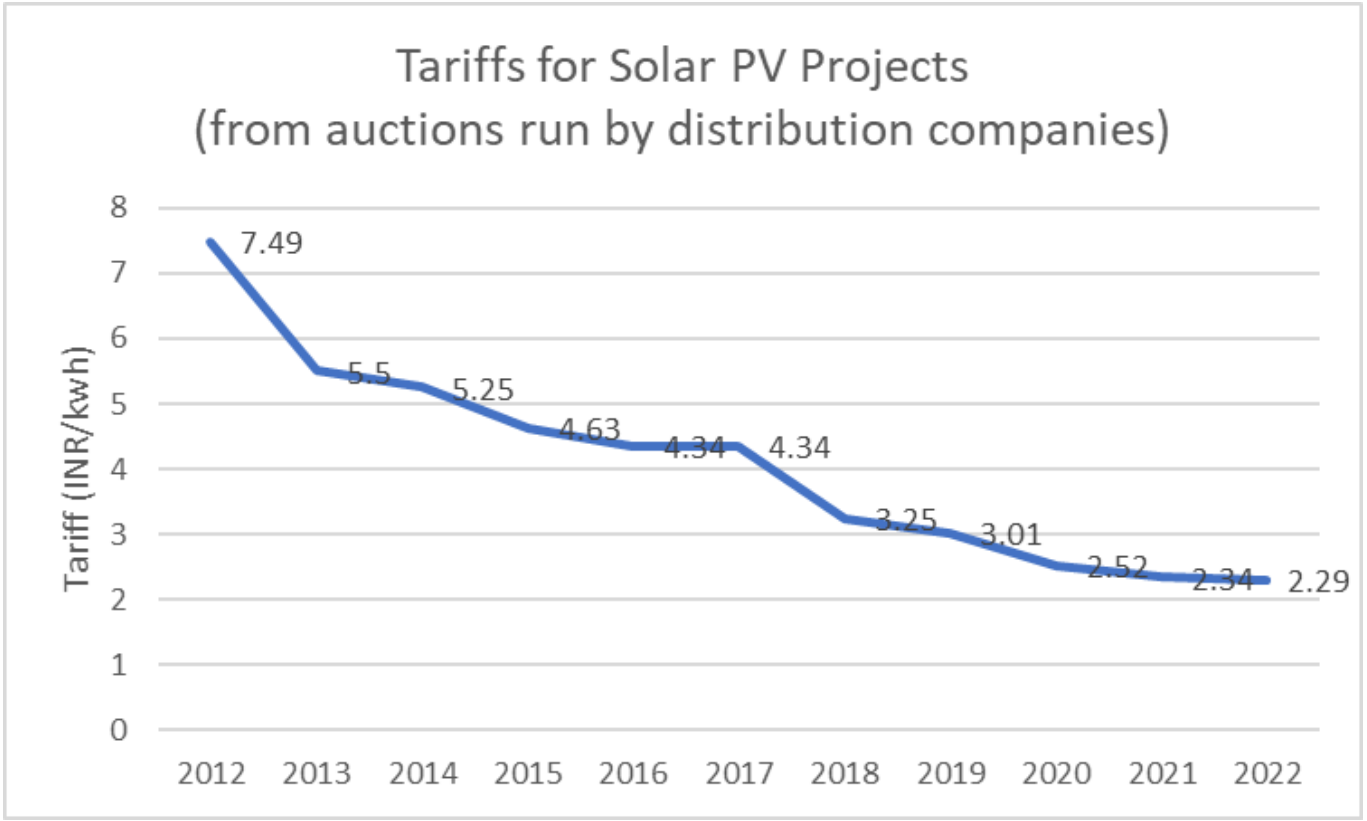
- Competitiveness of technologies – aggregation of capital costs and operating costs – has impacted choice of investments
  - Private sector participation
  - Competitive procurement



Source: Ministry of Power, Ministry of Finance, Government of India

Renewable electricity tariffs have been declining

- Falling tariffs of solar PV and wind power electricity have been ascribed to:
  - Economies of scale
  - Learning by doing – project construction and maintenance practices
  - Technological innovation



Source: ICF Consulting, JMK Research

Research Questions

Which way is Indian Electricity Generation Sector headed to?

Research Questions

- In the business as usual case of electricity generation sector in India, will the decarbonization occur in the timeframe that India has committed itself to?

- By how many years will implementation of social cost of carbon hasten the process of electricity transition from coal based to renewable generation in India?

- How much deadweight loss of economic efficiency result if there is implemented a ban on coal based power?

Theory and Model

How do we set out to answer the research questions?

Dynamic Model

- Static models are not well suited to study the transition, since the objective function is for only one particular time instant.
- Dynamic model accounts for:
  - Declining tariffs from renewable electricity systems over time
  - Generation costs are rising from coal based power plants
  - Increasing substitutability of RE and coal based electricity generation with costs of storage declining
- The model captures investment behavior of market participants

Optimization Model

- Planner's problem to determine the production of gasoline and electric vehicles to maximize discounted benefits net of production and usage cost.

$$\max_{y,\,x} \int_0^{\infty} e^{-rt}\left(U(Y, X) - c_y y - c_x x - \delta_y Y - \delta_x X\right) dt$$

subject to constraints (initial steady-state)

$$\dot{Y} = -aY + y; \qquad Y(0) = Y^{ss};$$

$$\dot{X} = -bX + x; \qquad X(0) = X^{ss};$$

$$y \geq 0; \qquad x \geq 0.$$

- *U(G, X) – Benefit in Dollars of installed capacities*
- *c_y – Construction Cost of Coal based power plants*
- *c_x - Construction Cost of RE based power plants*
- *y(t) – Production of Gasoline Vehicles at time t*
- *x(t) – Production of Electric Vehicles at time t*
- *δ_y – O&M Cost of Coal based power plants per unit*
- *δ_x – O&M Cost of RE based power plants per unit*
- *Y(t) – Installed Capacity of Coal Plants at time t*
- *X(t) – Installed Capacity of RE Plants at time t*
- *a, b – Coal and RE plant Retirement Rates*
- *Y^{ss} , X^{ss}– Current Coal and RE Power Installed Capacities*

Model - First Best

- First best solution is defined as the one with costs of carbon abatement are imposed on sources of carbon emission
- O&M costs of coal based plants, therefore, will include costs of carbon abatement
- Writing Hamiltonian and Kuhn-Tucker conditions, and then using the first order conditions, we get:

$$U_Y = (a + r)\, c_y + \delta_y$$

$$U_x = (b + r)\, c_x + \delta_x - \dot{c}_x$$

Where, $\dot{c}_x$ is the opportunity cost of investing in RE power plant when it may be more expensive to do so

Model – Business as Usual (BAU)

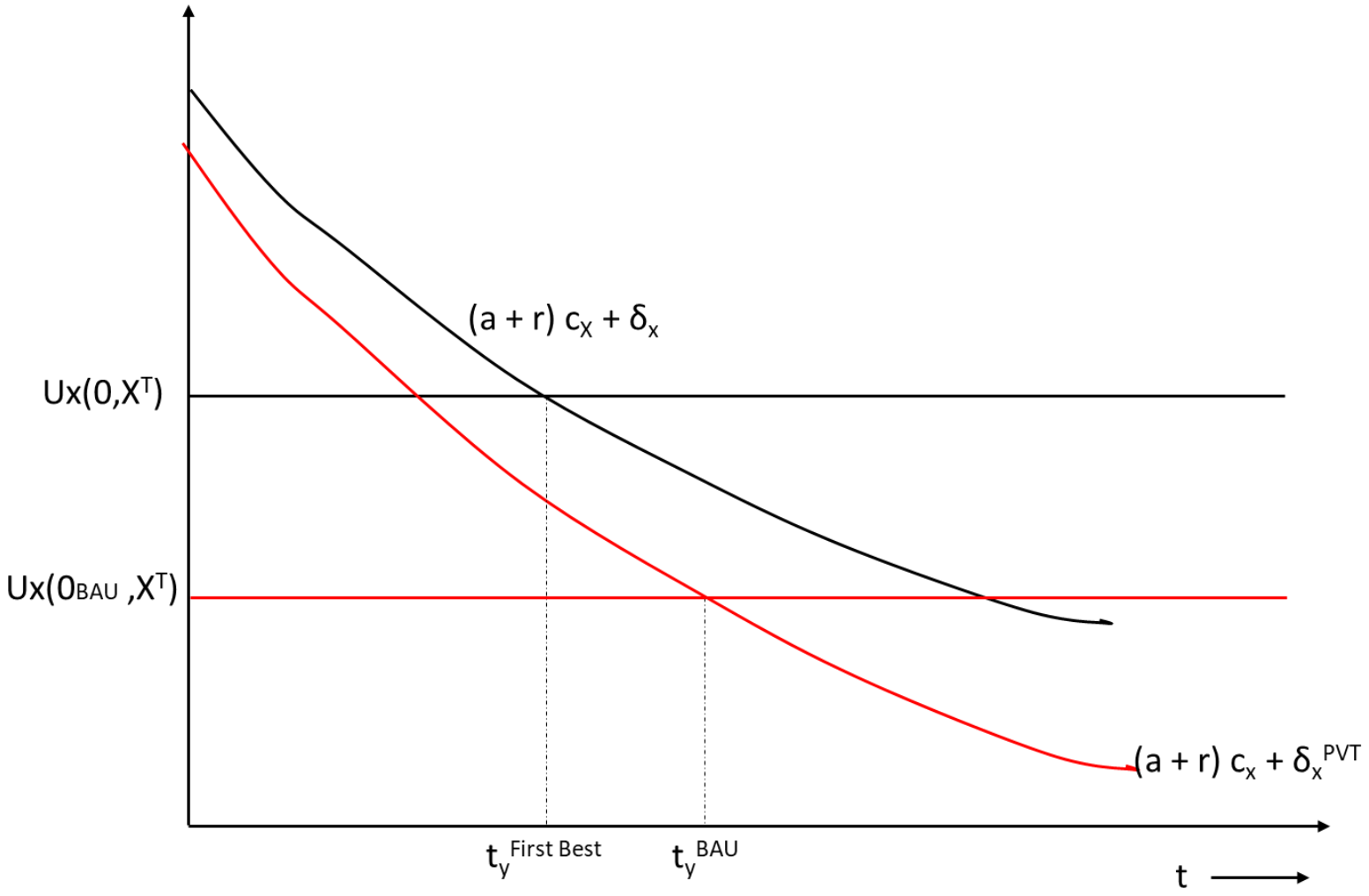
- Under BAU, all externalities are ignored, and no market policies are there to correct them. Therefore, the optimal control problem is:

$$\max_{y,\,x} \int_0^{\infty} e^{-rt}\left(U(Y,X) - c_y y - c_x x - \delta_{y\,PVT} Y - \delta_{x\,PVT} X\right) dt$$

δ_g^{pvt} – *Private O&M Cost of coal power plant*
δ_x^{pvt} – *Private O&M Cost of RE plant*

- We can use the BAU and First Best models to compute change in transition times if social costs of carbon are imposed
- The area under the curve of BAU following an imposed ban on coal based power can give us indication of dead weight loss

Transition Time – BAU and First Best



Model Calibration

Based on the Current State of Indian Electricity Generation

Model Calibration

Calibration is based on observed values from 2000 to 2020

The O&M costs δy and δx are comprise externality costs – based on the assumption that carbon is priced at US$ 45/t CO_2

- The O&M costs with social costs of carbon have an added component

No externality costs in BAU

Utility Function

The final calibration step involves specifying a functional form for the benefit function U (Y, X) .

The functional form must satisfy:
1. concavity assumption;
2. ideally be parsimonious with parameters; and
3. functional form to admit corner solutions with only RE plants at some point of time

$U(Y, X) = A \ln(Y + \eta X + \gamma \eta Y X)$ Where: A , γ , and η are parameters to be calibrated

This function nests both linear and convex indifference curves, and the parameters η can be interpreted as the relative preference for electric vehicles and γ determine the degree of substitutability.

Calibrated Values

Parameter	Value	Description
δy^{PVT}	1.80 INR/kwh	Private coal based power O&M cost
δy	4.81 INR/kwh	Coal based power O&M cost including externalities
δx	0.20 INR/kwh	Renewable electricity O&M cost
Cy	1.40 INR/kwh	Construction cost of coal based power plant
Cx	2.20 INR/kwh	Construction cost of renewable electricity plant
Y^{2020}	204.07 GW	Installed capacity of coal based power in 2020
X^{2020}	142.11 GW	Installed capacity of renewable electricity in 2020
ε_{ypx}	1	Cross price elasticity
a	0.029	Coal based power plant retirement rate
b	0.083	Renewable electricity plant retirement rate
r	0.12	Interest rate
η	0.51	Preference of renewable electricity

Calibrated Time Functions

Parameter	Functional form	Data Used
δy^{PVT}	0.49 + 0.02t	Coal prices from Coal India Limited, 2012 to 2020
δy	2.4 + 0.02t	Constant spread over δy^{PVT} (with social cost of carbon at US$ 45 per tonne)
δx	Constant	Renewable electricity O&M cost at 2020 level
Cy	Constant	Ministry of Power Annual Report 2012-2021
Cx	2.2 x (1 + $exp^{-1.5t}$)	Ministry of Power Annual Report 2012-2021
Y	- 0.01 – 0.016t	Ministry of Power Annual Report 2012-2021
X	0.06 + 0.006t	Ministry of Power Annual Report 2012-2021
Y	1.4 + 0.04t	Ministry of Power Annual Report 2012-2021
X	0.3 + 0.03t	Ministry of Power Annual Report 2012-2021
ε_{ypx}	Constant	Cross price elasticity assumed to be equal to 1
a	Constant	Coal based power plant retirement rate
b	Constant	Renewable electricity plant retirement rate
r	Constant	Prime lending rate of Indian bank – State Bank of India
η	Constant	Ministry of Power Annual Report 2012-2021

Additional assumptions

- Tariffs for RE power have reached an asymptotic levels and are held constant in our model
- No shadow price of coal is added to the operating costs – India has large coal reserves and does not foresee resource exhaustion in the time period under study
- Gas based power plants have low installed capacity and low capacity utilization – India does not seem to have a transition pathway through natural gas route

Results and conclusions

First Best and BAU Comparison and Deadweight Losses

RE Transition – BAU and First Best Case

In the simultaneous solution, if ty < ∞ , then the transition time ty is the solution to

$$Cy = \int_{ty}^{\infty} e^{-(a+r)(\tau - ty)} [(U_Y(Y(\tau), X(\tau)) - \delta_y)] \, d\tau$$

Case	**t_y - In years from 2020**
BAU	36.1
First best case	2.8

The first best case solution is quick due to high cost of carbon imposed – ty will be higher with lower costs of carbon

Even with zero cost of carbon, RE transition is likely to be manifested by 2056.

Deadweight Loss – Ban on Coal Based Power

The calibrated model is used for comparing welfare loss in case a ban on coal based power is implemented before 2056 when the coal based power is estimated to be phased in business as usual case. This is done by computing difference in integrals of net benefit for BAU and ban imposed on coal based power capacity addition.

For the purpose of computation, three cases of ban are assumed to be imposed in years 2030, 2040 and 2050. The results are presented in the table below:

Ban imposed in year	Deadweight loss (INR per unit)	Deadweight loss (INR billion)	Deadweight loss (% of current GDP)
2030	8.34	15,329	10.4%
2040	2.79	5,153	3.5%
2050	0.56	1,034	0.7%

Policy Implications

What do these results imply?

Policy Implication

Calibration of the Indian electricity generation market shows that the transition may not take long in the business as usual case, even while given that costs of carbon are not included in coal-based electricity generation.

However, in both cases, the dynamic model may suggest if the electricity transition from coal to renewable sources is likely to occur much before the committed time frame for net zero.

Policy implication may be to keep minimal interventions –

- To keep battery minerals and other RE inputs accessible
- To not subsidize coal mining and logistics

References

Standing on the shoulders of giants

Key references

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Thank you.

Questions and Comments?