


DISCUSSION PAPER

COAL TRANSITION IN INDIA

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COAL TRANSITION IN INDIA

1. Introduction

The provision of secure, affordable and sustainable energy is one of the major challenges for the fast-growing economy of India. Historically, countries' economic development has been characterized by:

- The transition away from low productivity agriculture towards high productivity industry, and to a lesser extent services.[1]
- The transition away from a low energy consumption, "biomass-and-muscle"-based energy system, to a high energy consumption, fossil fuel-based energy system.
- The process of urbanisation and infrastructure development, allowing much faster and larger exchanges of goods, services, people and ideas.

All of these processes entail large increases in energy consumption. India is still on the cusp of this strong growth in energy demand, with its per capita consumption being just 38% of the world average. India's energy supply is heavily reliant on fossil-based sources, notably coal. Traditionally, coal has been the most abundant and cost-effective resource. However, a number of factors are now driving increased uncertainty around the role of coal in the future energy mix. Local environmental damage, notably air pollution, has become a pressing social and political concern. Global climate change has been accepted as a policy priority, and India is committed to playing a proactive role in international efforts to address it, consistent with India's responsibilities and capacities. Technological innovation is rapidly changing the relative prices between different energy sources, notably between coal and renewables in power generation.

This paper discusses the possibilities of energy transition in India with particular reference to the implications for the coal sector.

1 This being said, there is a lively debate among economists as to whether the traditional development pathway of a transition out of agriculture into industry is being weakened by global macroeconomic and technological developments, as a result of which late-mover developing countries may see a higher importance of the services sector at an earlier stage of development.

2. Overview of the Coal Sector in India

2.1 Introduction to Indian Economy

India is the second most populous country in the world with 1.3 billion people in 2017, and its population is projected to increase to 1.5 billion by 2030. The Indian economy is one of the fastest growing major economies of the world. Over the last seven years the GDP growth rate has averaged 7.3%, and is projected to be in the order of 7.9% over the coming five years.[2] India is still a low-income country with high levels of material deprivation for large shares of its population. GDP per capita was around 6500 USD2011 at Purchasing Power Parity (PPP), which is 2.3 times lower than that of China at about 15 200 USD2011 PPP.[3] A few indicators below give a sense of India's relatively low level of development, and the requirement to grow its economy:

- Human development index: 28.5% lower than the global average
- Child malnutrition: 38% higher than the world average.[4]
- Energy consumption per capita: 62% lower than the world average

At the same time, India is the 3rd largest energy consumer in the world in absolute terms, but ranks 47th in the world in terms of per capita energy consumption. This indicates that there is a huge pent-up demand for energy in India, as its consumption levels progressively converge towards those of higher income countries.[5]

India's share in world fossil fuel resources is relatively low. In 2017, India contributed only 0.9% of world crude oil production, and 0.8% of world natural gas production. India has only 0.3% of world proved oil reserves and 0.6% of world proved natural gas reserves. On the other hand, India is relatively better endowed with coal, with 9.4% of world proved reserves and 9.3% of world production. For this

2 (IMF, 2018)
3 Ibid.
4 Above two data points from (UNDP, 2018)
5 Without a doubt improved energy efficiency of technologies will lower demand, but also has the effect of lowering the relative price of energy consuming technologies. The effect is to allow greater access to energy services at lower income levels, but also a lower long-term equilibrium level of consumption.

reason, India's energy sector is preponderantly dependent on coal, and its import dependence of crude oil and natural gas is high today, and will rise even further in the future.[6]

The high import dependency on fuels is an important macroeconomic vulnerability for India. Since 1995, India's net energy imports have averaged about 4% of GDP, and have reached peaks of 7-8% of GDP a number of times (2008, 2011, 2012, 2013). During periods of high international energy prices or rupee weakness (the two are often correlated),[7] net energy imports can put significant pressure on the current account deficit, currency valuation, inflation, interest rates, and ultimately on Indian growth. Controlling this exposure is a crucial aspect of India's long-term development challenge.

2.2 Coal in the Indian Energy Sector

For the reasons outlined above, coal dominates India's energy consumption matrix, accounting for 56% of primary energy consumption.[8] The graph below displays India's primary energy consumption matrix in 2017. It should be noted that the graph displays the primary consumption of "commercial" fuels, i.e. those that are marketed commercially. It thus excludes traditional biomass collected by non-market labour (often women), for example for residential cooking, which is still a significant part of the Indian energy system. Renewables thus means modern renewables, such as wind, solar, and modern forms of biomass.

Coal also plays a crucial role in the production of electricity. Figure 2 below displays the electricity generation matrix for India in 2017. It can be seen that coal contributed the lion's share to electricity generation (76%), with hydro (9%) and renewables such as wind and solar (6%) also making a significant contribution. At the same time, wind and solar generation has grown very strongly, at a compound annual growth rate of 18.4% per year over the last 10 years (see Figure 3 below). This presages a potential future transition away from coal towards renewables in the Indian power sector. In the longer-term the future of coal in India will depend on the success of the transition to variable renewables, as discussed in this paper.

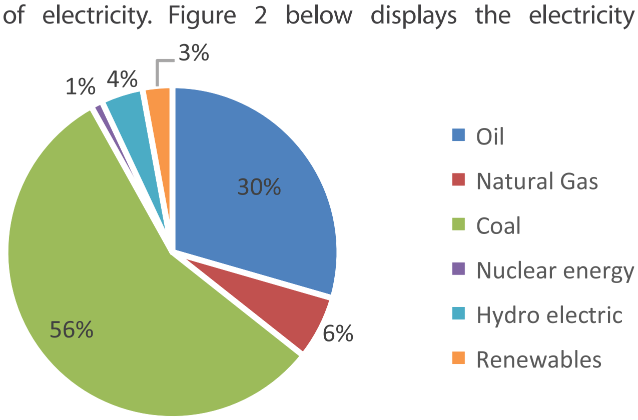

Figure 1: Primary Energy Consumption Matrix of Commercial Fuels, 2017, India
Source: Authors[9]

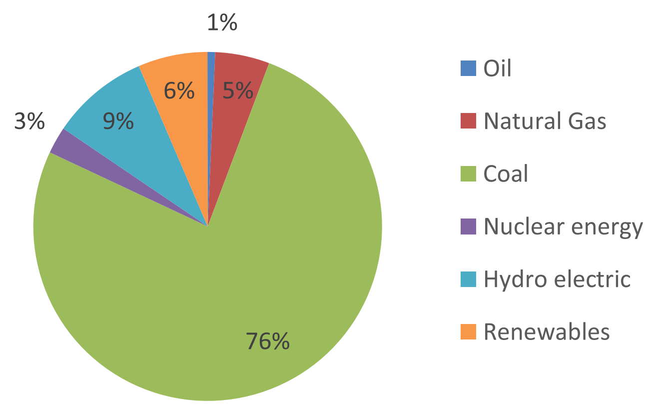

Figure 2: India's Electricity Generation Matrix, 2017

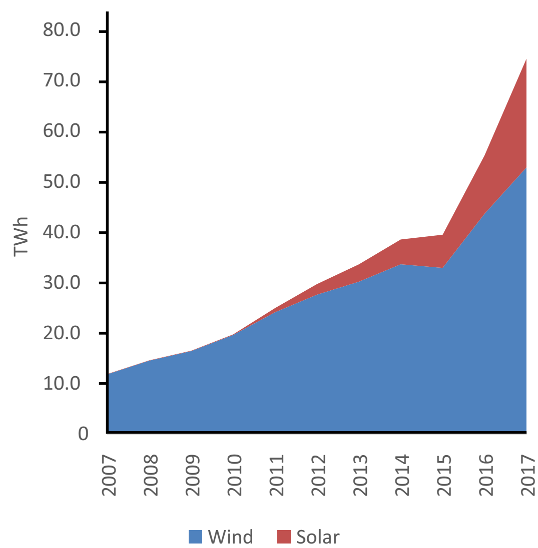

Figure 3: Growth of Wind and Solar Generation
Source: Authors[10]

Despite its large domestic resources, India is a net importer of coal, and its import dependency has grown in recent years. Import dependency on an energy basis was around 31% in 2017, having risen from about 12% in 2007.

6 (BP, 2018)

7 Since early 1987, changes in nominal international oil prices have explained about 30% of changes in the INR/USD nominal exchange rate.

8 (BP, 2018)

9 Data from (BP, 2018)

10 Data from (BP, 2018)

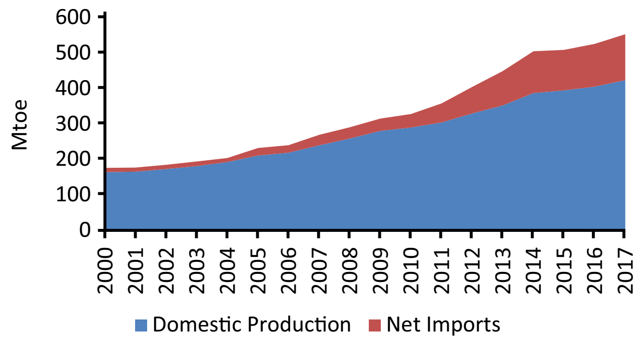

Figure 4: Domestic Production and Imports of Coal Fuels
Source: Authors[11]

Domestic production has been unable to keep up with the high rate of demand growth. Domestic coal is also often lower quality (notably higher impurities and lower energy content) versus those available on international markets.

Besides power generation, coal is also used directly in the industry sector, both as fuel in industry, and a reactant in the production of steel (coking coal). In 2017, India consumed 805 Mt of steam coal (largely for power production), of which 20% was imported. By contrast, India consumed 88.5 Mt of coking coal, of which 53% was imported.[12] India's high ash domestic coal is not suitable for coking coal, and India is therefore likely to continue to be reliant on imports to meet strongly growing demand for coking coal. Given the very low level of per capita steel consumption (about 1/3 the global level), India's demand for steel is expected to rise significantly in the coming years.

2.3 Coal in the Indian Economy

The Aggregate Level: Employment, Productivity, Wages and Economic Significance

Besides playing a crucial role in the energy sector, coal is traditionally considered as an important economic sector in the country. It provides employment to around 355,000 people, although there is significant uncertainty around these numbers and the actual number is likely to be somewhat higher (maybe in the order of 500,000 direct jobs).[13] As seen in the figure below, the employment of labour in this sector has been decreasing substantially, because of rapid improvements in labour productivity.[14]

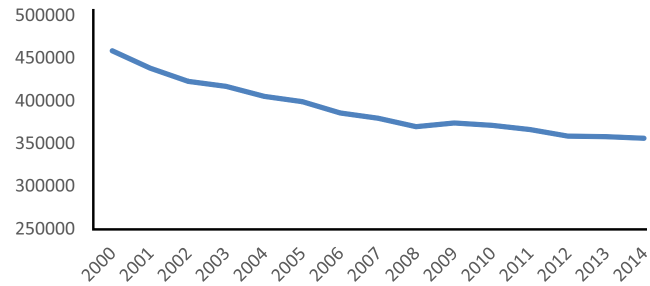

Figure 5: Employment in the Indian coal mining sector
Source: Authors[15]

It can be estimated that the labour productivity of the Indian coal mining sector improved by about 6.6% per year in the period 2000-14, as output grew by 4.9% per year and employment in the sector declined by 1.8% per year.[16] This is similar to the rate of labour productivity improvement seen in the period 1980-1995 in the UK, during which the Thatcher reforms disrupted the heavily unionized sector, ushering in rapid productivity improvements, but also lasting socio-economic damage to coal mining regions.[17] India's labour productivity of coal mining still has some way to fall, being about two times higher than the global average.[18]

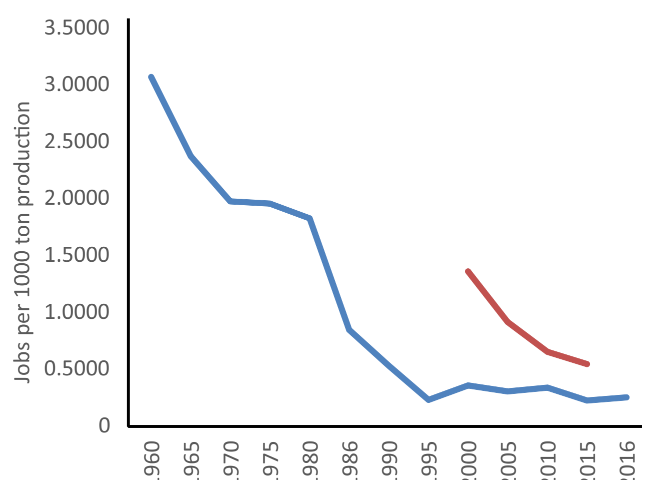

Figure 6: Labour Intensity of Coal Mining, Jobs per 1000 ton of production
Source: Authors[19]

In terms of value, the coal and lignite sector accounted for about 37% of the nominal value of gross output in the Indian mining sector, a figure that has shown a variable

[11] Data from (BP, 2018)
[12] (IEA, 2018)
[13] (CIL, 2018) claims that the coal sector employs 500,000 people directly and the same again indirectly.
[14] The assumption here is that if the 500,000 employment number from (CIL, 2018) is correct, then for back years employment would have been correspondingly higher. In other words, we consider here that productivity trend implied in the (MOSPI, 2018) is correct, albeit for a higher overall level of employment.
[15] Based on data from (MOSPI, 2018)
[16] Authors' calculations based on data from (MOSPI, 2018)
[17] (Fothergill, 2017)
[18] (Vishwanathan, Garg, & Tiwari, 2018)
[19] Based on data from (Fothergill, 2017; MOSPI, 2018)

trend over the last 15 years, but no absolute decline (it was 37% in 2000).[20] Given that the mining sector made up about 2% of the Indian economy, we can estimate that the coal sector accounts for about 0.7% of the Indian economy as of 2015.[21]

It is also useful to look at the issue of workers' wages in the coal sector. The flipside of the productivity improvements highlighted above should be growing wages. Between 2000 and 2014, nominal wages for coal mining grew from 204.82 Rupees/day to 416.74 Rupees/day. Adjusted for inflation, this amounts to a real wage growth of some 42% across the period. However, in the same period, the labour productivity of coal mining (tons/job) grew, as noted above, by 131%. This indicates that real wages grew at a significantly slower rate than labour productivity. The coal sector is not alone here: in recent decades, labour productivity growth has been much faster than wage growth in the industry and manufacturing sectors.[22] Figure 7 illustrates this dynamic. The bars show each sector's daily wage rate in 2014, while the line plots real sectoral wage growth against an estimation of real sectoral labour productivity growth in the period 2000-14. A negative number indicates that real wage growth was proportionately less than productivity growth; a positive number indicates than real wage growth was proportionately more than real labour productivity growth in the period 2000-14. It can be seen that the majority of sectors (15 out of 17), labour productivity grew significantly faster than wages. This gap between labour productivity growth and real wage growth was relatively smaller in the coal mining sector: 11 out of the 17 sectors had a gap between labour productivity growth and wage growth that was larger than that of coal.

The above analysis shows that despite being dangerous and dirty, coal mining is relatively "good" employment in India, with positive real wage growth; a delta between real wage growth versus labour productivity growth that is large but still smaller than most other industrial sectors; and a relatively high level of remuneration relative to other sectors. Nonetheless, the coal sector accounts for a small section of the overall Indian economy and labour market (in the order of 0.8% of total employment, consistent with the coal mining sector contributing 0.7% to the total Indian economy).

Coal in State and Regional Economies

However, while coal is not a significant economic sector for the country as a whole, it is highly significant for certain states, and more particularly for certain districts within those states. Coal is a major source of revenue and employment generation in resource rich states like Jharkhand, Chhattisgarh and Odisha. The table below

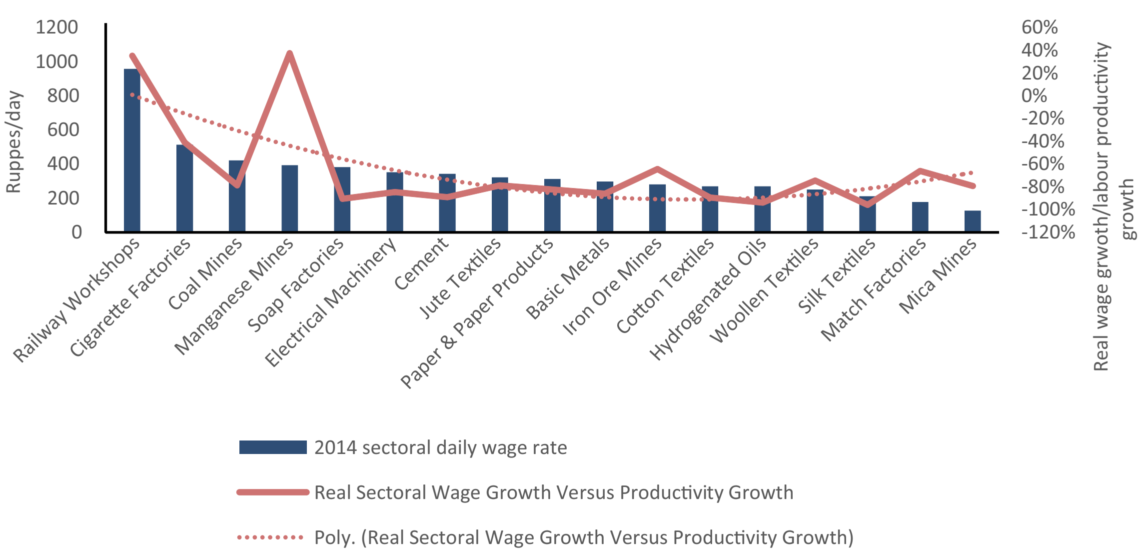

Figure 7: Sectoral wages in 2014 (left axis), and real wage growth versus real productivity growth 2000-14 (right axis)
Source: Authors[23]

[20] (MOSPI, 2018)
[21] Authors calculations based on (RBI, 2018; MOSPI, 2018)
[22] (Basole, A et al, 2018)

[23] Based on data from (RBI, 2018; RBI, 2018; IndiaStat, 2018). It should be noted that the analysis in the figure represents an approximation, as the labour productivity data available is more sectorally aggregated than the wage data available.

shows different states' shares in the monetary value of coal output in India. It can be seen that a handful of states dominate the production of coal, notably Jharkhand, Madhya Pradesh, Chhattisgarh, Andhra Pradesh, Odisha, and Maharashtra. We can attempt to gain a sense of how important the coal mining sector is to the economy of these states by combining data on the share of coal mining in the mining sector of these states (column B) and the share of the mining sector in the overall state economy (column C). The result (column D) shows that the coal sector made up an estimated 3-10% of the economy of these states. The estimates here are rough, given the need to combine statistics on the *output* value of the coal and mining sector (columns A & B), with data on the *value added* of the mining sector in the total state economy (column C). Nonetheless, the results give a sense of the order of magnitude of the coal sector's contribution to the state economy of these coal-rich states. It should be noted that the figures shown in the table below date from 2009-10, the most recent year of state-wise monetary coal output data that we could find. Given that in the intervening period, other sectors of the economy grew faster than the mining sector, the above-quoted figure of 3-10% of state output is likely to be less today.

Even within these states, coal production is further concentrated within certain districts. Sub-state level statistics are hard to come by, and are non-harmonized across different states' districts. But we can get a sense of the district-level concentration of the coal economy from what data is available. The table below presents data for the district of Dhanbad in Jharkhand, known as the coal capital of India. As can be seen, Dhanbad district alone is estimated to contribute 41% of Jharkhand state's mining sector value added (which in turn is estimated in to be 91% from coal – see the table above). Likewise, the mining and quarrying sector (i.e. coal mining) comprised 26% of Dhanbad district's economy. Dhanbad's GDP/capita is also some 46% higher than that of the state of Jharkhand as a whole, which is in turn a relatively poor state. The numbers here for Dhanbad are likely to be representative of other major coal mining districts in other states, for which comparable statistics are not available. This again emphasizes two important points. Firstly, coal mining is concentrated within certain specific districts of major coal producing states. Secondly, the coal sector has a relatively higher level of value added and wages compared to other sectors.

Table 2: Importance of Coal to the District of Dhanbad

District Share in State Value Added from Mining and Quarrying	Mining and Quarrying in District Value Added	District Domestic Product/Capita Compared to Domestic Product/Capita of Jharkhand
41%	26%	146%

Source: (DistrictsofIndia, 2018)

Coal in India's Current Account

As noted above, India is a structurally resource poor country relative to its huge population size, necessitating the import of fuels and other primary resources. Since 1995, India's net energy imports have averaged about 4%

Table 1: Importance of Coal to the State Economy

States	State Share in the All-India Value of Coal Output (A)	Share of Coal of the Value of the Output of the State's Mining Sector (B)	Share of Mining in the State's Economy (C)	Estimated Share of Coal Mining in the State's Economy (D = B*C)
Jharkhand	22%	91%	11%	10%
Madhya Pradesh	16%	78%	4%	3%
Chhattisgarh	15%	66%	13%	9%
Andhra Pradesh	13%	43%	4%	2%
Odisha	11%	38%	12%	4%
Maharashtra	10%	83%	5%	4%

Source: Authors[24]

[24] Based on data from the (RBI, 2018; IndiaStat, 2018). Note: data is for 2009-10, the most recent year of state-wise coal output value that we could find

of GDP, and has reached peaks of 7-8% of GDP a number of times (2008, 2011, 2012, 2013). This is a macro-economic concern. However, how important is the coal sector here? Over the same period, India's net coal imports averaged to about 0.5% of GDP, indicating that coal was a not insignificant contributor to India's current account deficit.[25] The table below provides another perspective. It shows the importance of coal within the overall goods trade deficit of India in the fiscal year 2017-18. Overall, net coal imports contributed 14% of India's goods trade deficit, compared to the 65% contribution of crude oil imports. Within coal imports, the contribution of steam coal (largely for power generation) and coking coal (for steel production) was roughly equal. Thus, roughly half of India's coal imports can be considered structural, given that steel production will increase significantly in the coming years and there is small scope for domestic substitution of coking coal imports. The share of coking coal in India's coal imports is likely to rise in coming years, as coking coal imports rise on the back of growing steel production.

Table *3*: Coal in India's Current Account 2017-18

	Trillion Rupees	Billion USD	% Share of Total
Total Goods Trade Deficit	-7.28	-109	100%
Coal Trade Deficit	-0.99	-15	14%
Of which steam coal	-0.48	-7	7%
Of which coking coal	-0.41	-6	6%
Crude Oil Trade Deficit	-4.74	-71	65%

Source: Authors based on data from (DoC, MoCI, 2018)

2.4 Conclusion to this Section

The above sections introduced the role of coal in the Indian economy and energy sector. Three key messages stood out from the analysis.

- Firstly, the Indian energy sector is dominated by coal, and power production even more so, due to the historical lower cost and high availability of domestic coal resources.
- Secondly, the coal sector is fairly insignificant in the Indian economy in aggregate. For an economy undergoing massive industrial, urbanization, and demographic transition, the labour market implications of any prospective transition in the coal sector are likely to be insignificant. Put in simple terms, in aggregate the coal sector is too small and the Indian economy so huge and changing so quickly, that coal sector transition would be a drop in the heaving ocean of economic change that India is undergoing.[26] Moreover, the labour productivity of Indian coal mining has been improving fairly rapidly, but still has a long way to go, being about half of the world average. Thus, even production increases (which we would expect in the coming 10-15 years - see below) would not necessarily create significant new jobs, as labour productivity would continue to improve, potentially faster than production growth. Indeed, labour productivity would need to improve significantly if domestic coal is to be economically competitive compared to imported coal.
- Thirdly, coal has high economic significance at the state level, and especially the district level within states. Here, it can provide in the order of 25% of economic output, a significant share of state fiscal revenues, and a large share of comparatively well-paid employment.

3. Coal Transition in India: Drivers and Prospects

In the following sections we provide an analysis of the prospects for coal sector transition in India in the coming 10-15 years.

3.1 Policy Overview

The overarching objectives of Indian energy policy are to provide access and affordability, given the large number of Indians still lacking access to modern forms of energy and the importance of energy in fuelling industrialization, urbanisation and infrastructure development. However, in recent years, environmental concerns have risen up the ranks of policy priorities. This has been due to the worsening of environmental challenges such as local air pollution and water scarcity, as well as increasing cognizance of the threats posed by global climate change to Indian sustainable development. But it has also been driven by the increasing economic competitiveness of alternatives to fossils, notably in the power sector.

[25] Above calculations based on data from Enerdata and UNCTAD.

[26] For an authoritative analysis of the jobs-creation challenge that India faces, see (Basole, A et al, 2018)

The following policy objectives summarize the high-level thrust of Indian energy policy as it relates to the issue of coal sector transition:

- The Government of India aims to achieve 175 GW of renewable energy generation capacity by 2022, which would drive up the share of RE in electricity generation, excluding large hydro, from the current level of 7% to about 20% within the space of a few years. This is one of the most ambitious renewable energy programs anywhere in the world.
- The National Electricity Plan prepared by the Central Electricity Authority under the Ministry of Power targets 275 GW of renewable capacity by FY2026-27, and a total share of non-fossil fuel capacity of 57.2%.[27]
- According to the National Electricity Plan, a net increase in coal fired power generation capacity of some 21% by 2027 should occur, taking the installed capacity from 197 GW today to around 238 GW. According to the document, this is required to meet rising demand, but more particularly to provide peaking and load-following power to compensate for variable renewables. This growth rate of installed coal capacity would represent a significant slowdown compared to the pace seen over the last 10 years.
- Under the Paris Agreement, the Government of India proposed to reduce the GHG emissions intensity of India's GDP by 33-35% by 2030 and raise the non-fossil fuel power generation capacity to 40% (which would likely be significantly overachieved if the objectives of the National Electricity Plan are achieved).
- The government had set the target of achieving 1000 Mt of domestic coal production by 2020, in order to meet demand and reduce imports. However, this has been pushed back to the mid-2020s in view of challenges meeting the target and reduced demand, due in part to climate and renewable energy policies but also lower than projected economic growth in recent years.
- The government has implemented the Perform Achieve and Trade scheme (PAT), which aims to improve the energy efficiency of large industrial consumers, such as iron and steel, cement and power generation. India's energy efficiency in large industrial facilities is already close to world class, and on PPP terms its energy intensity is below the G20 average.
- The Ministry of Environment and Forests has released new, stringent norms for emissions of local air pollutants (NOx, SOx, and Particulate Matter) from coal fired power plants, and targeted 2017 for their implementation. However, in the face of widespread non-compliance and requests from the Ministry of Power, the implementation of these norms has been pushed back to 2022. The implementation of these norms is expected to raise the cost of coal-fired electricity by some 0.2-0.3 R/kWh.

The general thrust of these policies is to accelerate the transition to a power system based on a high share of renewables, and reduce the environmental footprint of coal, while balancing the objective of meeting demand growth and affordability. The table below provides an overview of the key capacity targets for the electricity sector as per the National Electricity Plan.

Table 4: Electricity Capacity Targets According to the National Electricity Plan

Technology	2017-2018		2021-2022		2026-2027	
	MW	% of Total Capacity	MW	% of Total Capacity	MW	% of Total Capacity
Coal	197172	57%	217283	45%	238131	38%
Gas	24897	7%	24897	5%	24897	4%
Diesel	838	0%	838	0%	838	0%
Nuclear	6780	2%	10080	2%	16880	3%
Hydro	45293	13%	51301	11%	63301	10%
Solar	21651	6%	100000	21%	150000	24%
Wind	34046	10%	60000	13%	100000	16%
Small Hydro	4486	1%	5000	1%	8000	1%
Bio Mass	8839	3%	10000	2%	17000	3%
Total installed capacity	344002	100%	479399	100%	619047	100%

Source: Authors[28]

3.2 Economic Considerations in the Context of Coal Sector Transition

LCOE of Different Generation Technologies in the Indian Context

A major driver of coal transition has been the increasing cost-effectiveness of alternative sources of power generation, notably wind and solar. The table below displays the projected trajectory of levelized costs of electricity (LCOE) for different generation technologies in

[27] (CEA, 2018, p. 5.16)

[28] Based on (CEA, 2018)

India to 2030. It can be seen that renewables (wind and solar) are estimated to be the cheapest sources of new generation already today, beating even pit-head coal (plants located at the mine mouth, negating transport costs, which currently account for just 17% of installed coal capacity). Secondly, coal-fired generation is projected to lose competitiveness versus renewables throughout the projection period, due to its rising costs. Coal costs increase due to increases in capital costs for pollution abatement technologies and improved efficiencies, as well as inflation in the cost of coal, driven notably by transport costs (this is why the trajectory for pithead and non-pithead coal diverges). The current capacity-weighted average tariff today, including both variable and fixed costs, of the existing coal fleet is in the order of 3.70 R/kWh.

Even if we take fixed costs as given,[30] there is a substantial share of the existing fleet whose variable costs are above 2.5 - 3 R/kWh, and therefore would be susceptible to replacement by cheaper renewables. The Figure 8 displays the supply curve for the existing 197 GW of coal capacity, considering only their per unit variable costs, not the per unit fixed costs required to recover the capital investment and generate a return on investment. It can be seen that roughly half the existing capacity has a variable cost that is in the order of RE costs at 2.50 – 3.00 R/kWh. In other words, it should be economic to immediately replace between one quarter and one half of the existing coal fleet with cheaper renewables, even if outstanding fixed costs are still honoured.

Cost Components of Coal and Sensitivity to Alternative Assumptions

The above analysis has shown that coal is estimated to be losing economic competitiveness versus renewables on an LCOE-basis, due notably to the rising cost of coal. Table 6 displays the components of the cost of coal to the power sector over the last seven years. It reveals the importance of regulated items such as taxes and duties in driving the significant price increase seen. Likewise, there is an important role played by coal transportation

Table 5: LCOE of Different Generation Technologies in India (R/kWh)

Results					Summary of Key Assumptions		
	2017	2022	2025	2030	Starting investment cost (R Cr/MW)	Capital Cost Learning Rate (%/yr)	Fuel Price Escalation (%/yr)
Solar PV Ground Mounted	2.87	2.58	2.42	2.30	3.50	-2.10%	n/a
Wind Onshore	2.85	2.75	2.69	2.58	4.50	-1.00%	n/a
Solar PV Rooftop	6.76	6.03	5.64	5.34	6.50	-2.10%	n/a
Small Hydro	3.88	3.88	3.88	3.88	5.04	n/a	n/a
Biomass Power	5.68	6.58	7.39	9.02	5.59	n/a	5.00%
Nuclear	3.92	3.93	3.96	4.02	18.02*	n/a	2.00%
Large Hydro	4.81	4.81	4.81	4.81	12.00	n/a	n/a
Natural Gas Combined Cycle	5.10	5.71	6.24	7.26	4.20	n/a	4.00%#
Pit Head Super Critical Coal	3.64	3.97	4.26	4.82	6.60	n/a	4.00%
Non-Pit Head Super Critical Coal	4.97	5.53	6.01	6.95	6.60	n/a	4.00%

*Source: TERI analysis and modelling. N.B. The above calculations use the accepted formula for calculating LCOE[29] (required tariff to meet equity rate of return), not the CERC tariff formula. Common across all technologies is the assumption of 12% WACC, and 33% corporate tax rate, straight line depreciation. *Includes insurance and decommissioning. #Costs of gas based generation are assuming a 75-25% split between pooled domestic gas and LNG.*

[29] see (Comello, Glenk, & Reichelstein, 2017)

[30] The Indian coal fleet is financed on the basis of long-term power purchase agreements (PPA), which comprise a variable component calculated on a per kWh of production basis and a fixed cost component which is independent of generation.

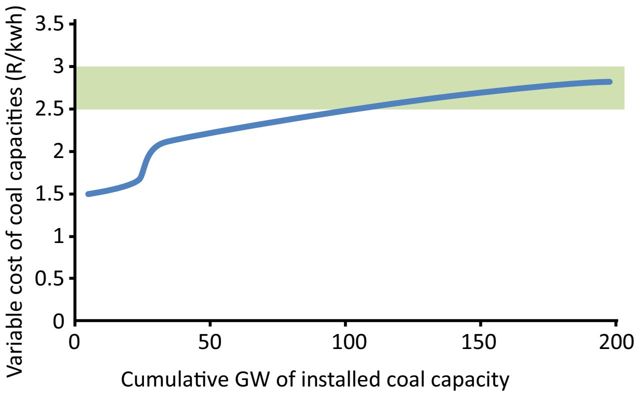

Figure 8: Supply curve for variable costs of existing coal generation versus RE tariff (green zone)

Source: TERI analysis

cost inflation, which composed about 40% of the final price displayed.[31] The base price has grown in nominal terms by about 4.50%/yr, which is somewhat lower than the growth in the wholesale price index (WPI) in the same period (4.90%). However, consistent with above-inflation growth of other price components, the WPI item "non-coking coal" has grown faster than the growth in the wholesale price level (5.80% versus 4.90%), indicating a real growth in the cost of coal since 2010.

Table 6: Coal Cost and Its Components

		2010	2017	CAGR
Base Price	R/ton	560	760	4.50%
Taxes and Duties	R/ton	202	645	18.00%
Coal Cost	R/ton	847	1541	8.90%
Coal Transportation	R/ton	513	819	6.90%
Taxes and Duties on Transportation	R/ton	44.24	194.58	23.60%

Source: Authors[32]

At the same time, the rail freight price index (of which coal transportation composes a 45% weight) grew by 7.7% per year from 2010 to 2017, substantially above the all-commodity WPI growth rate quoted above of 4.9%. Thus, real cost inflation in the rail freight sector appears to be a significant and potentially structural driver of the increased cost of coal. There are a number of potential drivers of this cost inflation. One is the prevalent cross-subsidy from freight transportation to passenger transport (similar to the industry-residential cross-subsidy in electricity prices). There is some evidence of this in the slightly slower growth in the passenger rail transport price index of 6.4% in the same period; at the same time, this price growth rate was still substantially above the all-Commodity price index growth rate. One can also hypothesize as follows. Inflation occurs when (money) demand outstrips (real) supply. In a highly densely populated, democratic, federal country, where incomes and hence demand for freight and passenger transport are increasingly rapidly, it may be *structurally extremely challenging for the supply of infrastructure-intensive transport services to keep pace with demand*. It may thus be that cost inflation in rail transport is a structural phenomenon affecting the competitiveness of coal power.[33]

In the above analysis, we assumed a relatively low escalation rate for coal fuel price of 4.0%, substantially less than the historical growth rate over the recent period, and less than the rail freight and coal price indices' growth discussed above. Thus, it would seem that the uncertainty regarding coal price escalations would be biased on the upside, which would further reduce the competitiveness of coal vis-à-vis renewables. However, even if actual fuel price growth were less, it would not substantially change the picture of relative prices seen in Table 5 above.

Considering the Grid Integration Costs of Renewables

One should be at pains to stress that comparing technologies on an LCOE basis is only one perspective, given that the variability of renewables introduces further costs to the system (so-called grid integration costs). The scale and drivers of these costs have not been thoroughly studied in India, and there is an urgent need to do so. Generally speaking, they are determined by the degree of correlation between the temporal profile of variable RE production, on the one hand, and the temporal profile of electricity demand, on the other. Other system characteristics, such as the capital intensity of the existing fleet and its flexibility are also significant determinants. Finally, grid integration costs increase with increasing penetration of variable renewables.

The grid integration costs of renewables in India are likely to be significant given the importance of solar in the renewables mix. Solar's output is concentrated around

[31] Clearly this depends on the distance of the plant from the mine mouth. The figure quoted here would be consistent with about 500 km of transportation.

[32] Based on data from (CERC, 2018)

[33] Above analysis based on WPI data from (OEA,DIPP, 2018).

midday, and thus requires significant capacities to be online at night to compensate for its absence of output (or more advanced grid integration options such as storage and demand response). Because they are not required to produce during the day, the capacity utilization factor of these capacities will be less, *mechanically raising their per unit cost*. The international literature on the grid integration costs of solar suggest that these costs increase more rapidly with increasing penetration than is the case for wind. This is because of the temporal concentration of solar's output around midday: each marginal unit of supply is temporally correlated with all previous units of supply. Marginal solar output comes at a time when it is less and less needed by the grid, i.e. it is of declining marginal value (alternatively put, each marginal unit lowers proportionately the capacity utilization factor of the capacities required at night to meet demand, raising their per unit cost. The two perspectives – declining marginal value of solar output, or increasing per unit cost of the required residual capacities – are expressions of the same phenomenon).

International estimates suggest that at penetration rates of 15%, grid integration costs could increase the cost of solar by about 30-50%.[34] India would be likely to hit this level of penetration during the mid- to late 2020s. This would equate to raising the cost of solar from 2.42 R/kWh (estimated solar LCOE in 2025) to 3.15-3.63 R/kWh. It should be noted that this price is still less than the estimated LCOE for pit-head coal in 2025 (4.26 R/kWh). Importantly, the international literature suggests that there are avenues to reduce this "grid integration" increment, notably the flexibilization of the existing fleet, grid interconnection, storage and demand response.

This problematic is conceptualised in the graphs below, which show a simplified framework of demand and supply curves. In the left-hand panel, the demand curve D is shown to be declining steeply, i.e. there is declining marginal value on any marginal unit supplied. This is because electricity cannot be stored, nor demand easily shifted in time on a large scale. Thus, any supply surplus to requirement is of little value, and any supply deficit of requirement has a huge opportunity cost (demand not being met). It can be seen that as solar supply increases from S1 to S2, the equilibrium price falls sharply from P1 to P2. The left-hand panel approximates a short-run equilibrium, in which little has been done to flexibilize the grid through storage, demand response and demand side management, or greater flexibility from the dispatchable fleet. In the right-hand panel, the demand curve is shown to be declining less steeply, and hence the drop in market value from P1 to P2 as solar output decreases from S1 to S2 is less severe. This approximates a longer run equilibrium, in which flexibilization of the power system means that the decrease in the marginal value of solar output is much less steep (here approximated by the slope of the demand curve).

The framework allows us to clearly see that increasing solar output will have (steeply) increasing grid integration costs (or, the other side of the medal, increasing solar

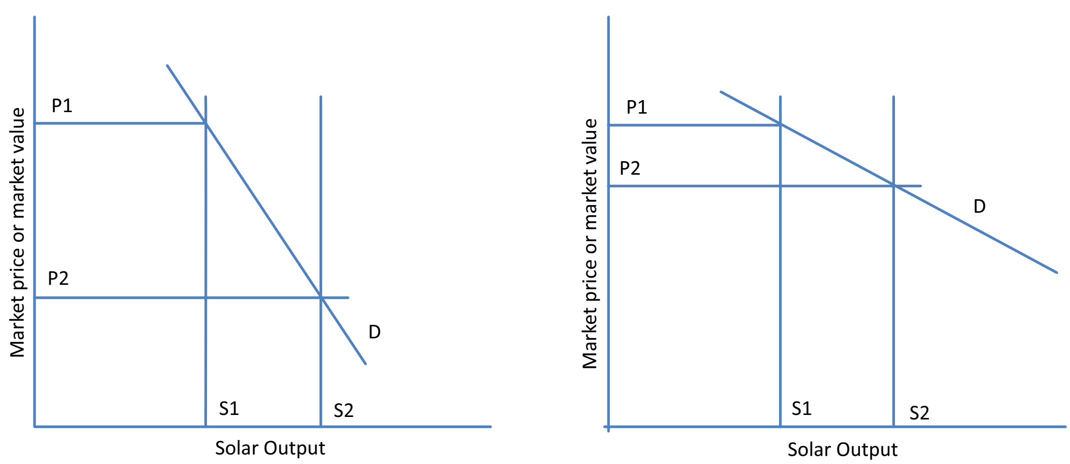

Figure 9: Conceptualization of the marginal value of solar output in short (left) and long-term equilibrium (right)
Source: TERI

[34] (Hirth, 2013)

output will have – steeply - decreasing market value), until large-scale flexibilization of the power system occurs through storage, demand response, flexibilization of the dispatchable fleet, and large-scale grid interconnection.

To get a sense of the challenges of grid integration, the figure below shows the operation of the Indian electricity generation fleet on an average demand day in winter and summer in the year 2030, under a high renewables scenario. One can see the stresses that the daily cycling of solar energy imposes on the system, with the coal fleet required to cycle on average from a plant load factor (PLF) of around 40-50% to 70-80% from midday to night. This is theoretically possible, but would require a high degree of flexibility and pan-India coordination in the operation of the dispatchable fleet (coal, gas, hydro). The modelling below considers a "business as usual" scenario for flexibility, i.e. it excludes flexibility options such as battery storage and demand response which are not yet available at large scale in the Indian power system.

The above discussion leads to two main conclusions. Firstly, the transition underway in the power sector is driven in part by the increasing economic competitiveness of renewables, *on an LCOE basis*. Renewables are already cheaper than all new coal, and are cheaper than a significant share of the variable costs of the existing coal fleet.

However, this analysis excludes the system costs of RE. This leads to the second conclusion. Although the grid integration costs of renewables have not been studied with the necessary granularity in the Indian context, several conclusions can be drawn from the analysis above. Firstly, the grid integration costs of renewables can be significant, and increase with penetrations. Secondly, even with sharply increasing grid integration costs, estimated from the international literature, at the penetrations likely to be seen in the 2020s, renewables are still projected to be cheaper than coal including pithead coal. Thirdly, grid integration costs can be reduced through adaptations in the operation and capital stock of the system, notably the introduction of flexibility options like demand response and storage.

We can therefore conclude that the speed of coal transition in India's power sector will depend on the speed, cost and scale of the introduction of these flexibility options. The importance of solar in the Indian renewable energy mix places particular importance on options to smooth the daily cycling of output, notably demand response (to shift demand to midday) and storage (to transfer energy to the evening).

Can Storage Solve the Solar Grid Integration Challenge?

The table below shows estimated costs for solar plus different durations of battery storage, namely 3 and 6 hour storage. Both options are expensive today, but by 2030, solar plus 3 hour storage would be competitive with our estimate of non-pithead coal. It would certainly be competitive with non-pithead coal operating at part-load, i.e. as a load following resource largely operating at night. By contrast, solar plus six hours of storage would still be relatively expensive by 2030.

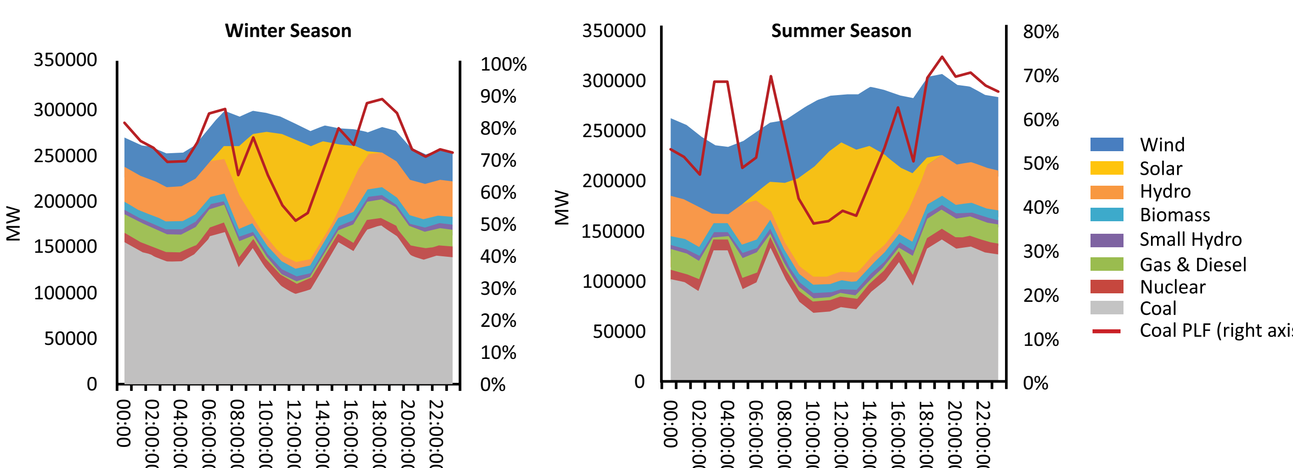

Figure 10: Daily Cycling on an All-India Basis Imposed by High Shares of Solar, 2030 High RE Scenario
Source: TERI analysis and modelling

Table 7: Costs of different solar plus different durations of energy storage (R/kWh)

	2017	2022	2025	2030	Storage Investment Cost Assumption	Solar Investment Cost Assumption
Solar Plus 3 Hours of Storage	13.62	10.32	8.11	6.34	35000 INR/kWh falling to < 10000 INR/kWh by 2030	3.5 Cr/MW declining 2% per year
Solar Plus 6 Hours of Storage	23.87	17.35	12.91	9.37		
Lithium Ion Storage	29.29	21.66	16.39	12.20		n.a. Assumed cost of charging electricity at 2.5 R/kWh

Source: authors

This highlights a couple of important points. Battery storage for daily energy shifting remains a relatively expensive option. Storage becomes an attractive option when it has multiple revenue streams, including frequency response. Thus, storage by itself is unlikely to completely solve the problem of solar's cyclical daily output: after three hours of storage have passed, other capacities would be required for the rest of the night. However, even a few hours of storage at reasonable cost could significantly reduce the operational challenge of grid integration. We can therefore conclude two things. Firstly, solar plus storage can greatly facilitate the grid integration of solar, reducing the operational strains arising from surplus energy production at midday and rapid ramping requirements for residual capacities at sunset. Secondly, however, solar plus storage is unlikely to cost-effectively solve the issue of bulk energy supply at night, at least on the timeframe to 2030.

There are thus no silver bullets for grid integration, and all options will need to be expeditiously deployed to enable high levels of renewables to be deployed by 2030 (flexible operation of the thermal fleet, grid interconnection, storage, demand response, all enabled by reforms to electricity markets to create the requisite incentives). This is a huge challenge in an ambitious timeframe.

3.3 Conclusion to this Section

Three points can be concluded from the above discussion:

- Renewables are the most competitive electricity generation technology in India today, and their competitiveness will only increase in the future.
- Even with a significant cost increment to take into account grid integration costs, renewables remain highly competitive against alternative sources of generation, at the levels of penetration that we are likely to see in the 2020s.
- The technical challenge of grid integration is likely to be significant, and will require wholesale reforms to infrastructure, capital stock, market and incentives, and the operation of the power system.

4. Projections: Looking Forward

4.1 Coal Demand

In this section we present some projections for coal demand to 2030, differentiating between steam coal for power generation and coking coal demand. The projections are based on the following assumptions:

- A baseline demand scenario of electricity demand growing at about 6% per year, to reach some 2040 TWh of grid consumption by 2030. Captive power consumption[35] is estimated at 389 TWh, from today's level of 137 TWh. This scenario is consistent with India's long-run GDP growth being slightly above 7% per year, and the elasticity of electricity demand to GDP being slightly below 1, as it has been historically.[36]
- Three supply scenarios are shown below. In the Current Trajectory Scenario (CTS) coal capacity continues to grow in the 2020s, while RE capacities also grow strongly albeit slightly below government targets for 2022 and 2027, and by extrapolation for 2030. In the Current Policy Scenario (CPS), coal capacities grow as per the government targets and policies to 238 GW by 2027, and RE capacities grow likewise to 275 GW by 2027. In the high RE scenario (HRES), there is no further addition of coal capacity beyond the currently under construction pipeline, and RE capacities hit and then overachieve government targets for 2022 and 2027 respectively.
- Coal demand for coking and industrial use is projected econometrically based on regressions of industrial value added and steel production.

[35] Industrial own generation in the manufacturing facility.

[36] This would imply that India would follow a less energy intensive development path than peers such as China or Vietnam, where the elasticity of electricity demand to GDP growth has been greater than 1 for periods of one to two decades during the energy intensive phase of industrialization and urbanisation.

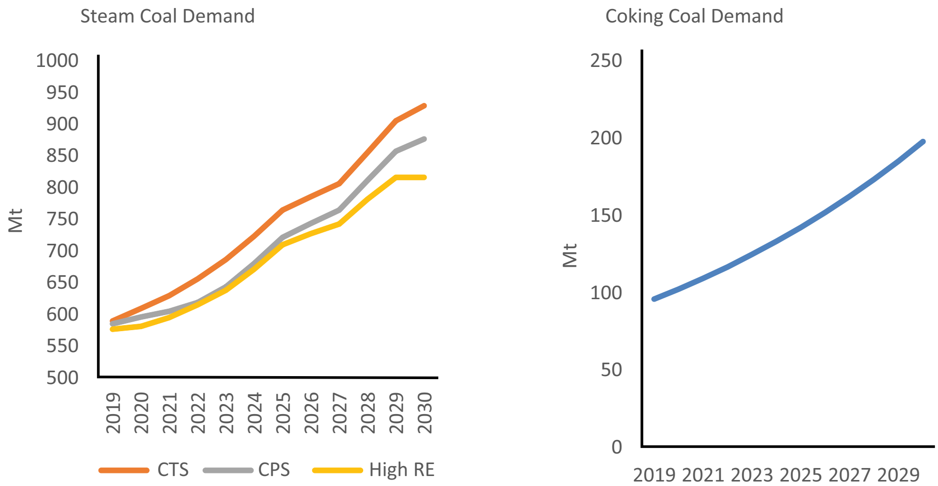

Figure 12: Projected steam coal demand for grid consumption, and coking coal demand

Source: TERI analysis and modelling

The figure below displays the results of the demand projections.

Steam coal demand for grid power consumption increases in the three scenarios to between 816-929 Mt by 2030. In the high RE scenario it is seen to peak and decline from about 2028 onwards, whereas in the other scenarios it is on an increasing trajectory to 2030. It should be noted that this does not necessarily mean a commensurate increase in capacity for coal power, as increasing demand can also come from an increasing plant load factor of the existing fleet (PLF). Coking coal demand increases strongly with growing steel demand, reaching almost 200 Mt by 2030. Captive power could add another ca. 242 Mt of steam coal demand by 2030 (up from ca. 110 Mt today). Thus, total steam coal demand would be in the order of 1058-1171 Mt by 2030. It is likely that this could be met largely through domestic production. Projections of cement and steel production suggest that industrial coal demand (ex. coking coal) could reach 298 Mt by 2030, from 105 Mt today. The table below summarizes these figures. These projections fall within but at the lower end of recent projections from the industry, which also don't differentiate between different drivers of coal demand.[37]

Several conclusions can be drawn from the above analysis. Firstly, it is possible that steam coal demand for grid power generation could peak in the late 2020s under an aggressive RE scenario. Secondly, however, much analysis of India's electricity demand and supply position overlooks captive power which is today predominantly based on coal: demand for captive power could add another 30% to steam coal demand if demand growth for captive power is met from coal. While the economics would suggest a large potential to shift this captive power to open-access based renewables, there is a question of the ability of the grid to absorb further shares of renewables beyond what is seen in grid-based power (as discussed above). In the high RE scenario, installed capacity of variable renewables reaches 390 GW by 2030, as against a peak hourly demand of ca. 360 GW. Integrating this amount of RE would be a significant challenge for the Indian power grid. Finally, the growth of coal demand from industry is often overlooked: final consumption in steel and cement, the two biggest coal consuming industry sectors, could reach as much as 25-28% of demand for steam coal. Below we make some recommendations arising from these conclusions for India's coal sector transition.

Table 8: Projected coal demand in 2030 for different segments (Mt)

Steam Coal Demand for Grid Power	Steam Coal for Captive Power	Coking Coal	Final Consumption in Steel and Cement	Total Steam Coal	Steam Coal Plus Industrial Final Consumption
816-929	242	198	298	1058-1171	1356-1469

Source: TERI analysis and modelling

[37] (CIL, 2018)

Employment

In this section, we develop some broad-brush scenarios for employment in the coal mining sector, based on the following assumptions. Firstly, we assume that coking coal demand growth will largely be met from imports. Secondly, we assume for the rest of coal demand, the import share remains around 20% across the projection period. Thirdly, we show results based on base year data for two datapoints of current coal mining employment.[38] Fourthly, we provide two scenarios for labour productivity improvements, namely 3% per year or 5% per year. As mentioned above, the CAGR of labour productivity improvements can be estimated from MOSPI data at 6.6% per year. However, in the last 5 years this has slowed to 3.9% percent per year. For this reason, we chose two figures which represent a potential upper and lower bound. The figure below displays the results.

The results show that the gap between labour productivity growth and output growth could narrow compared to the historical period. In scenarios with lower labour productivity growth, employment actually starts to increase in the early 2020s, as the output growth rate finally exceeds the labour productivity growth rate. On the other hand, in scenarios of stronger labour productivity growth, employment continues to decline. On balance, it seems possible that output growth will outstrip labour productivity growth some time towards the latter half of the 2020s, leading to small increases in employment thereafter. However, even in a scenario of modest labour productivity growth, as output growth slows in the late 2020s, employment starts to peak and then decline.

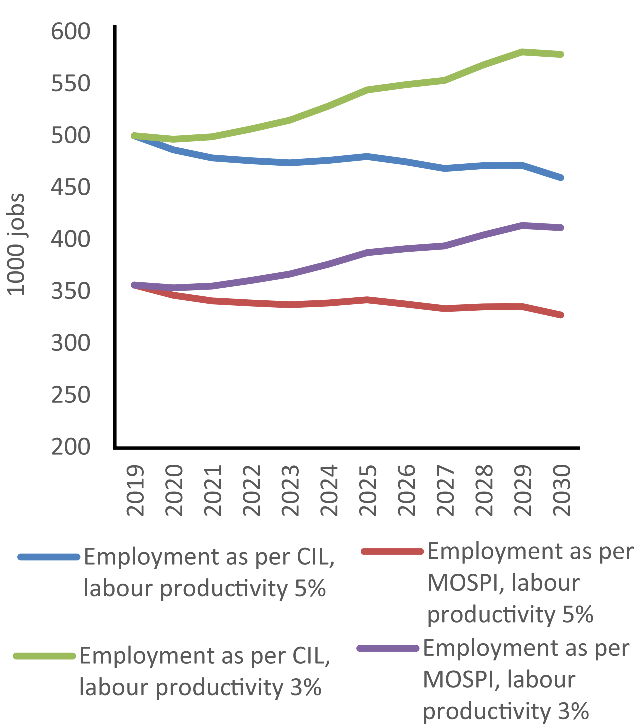

Figure 12: Coal mining direct employment scenario
Source: TERI analysis and modelling

We need to put this in perspective, however. The six coal-rich states of Andhra Pradesh, Chhattisgarh, Jharkhand, Madhya Pradesh, Maharashtra, and Odisha are projected to have labour market new entrants in the order of 45 million between now and 2030, or 24 million if we focus only on male new entrants given today's (lamentable) low labour force participation rate of women in the Indian economy.[39] By contrast, employment creation or decline in the coal mining sector is estimated to be between + 79 thousand to – 40 thousand by 2030 compared to today's level in the figure above. Thus, even in coal rich states, and even assuming the rate of labour productivity falls below the rate of output growth, job creation in the coal sector is projected to be insignificant (three orders of magnitude less) compared to the job creation requirement. In contrast to more stagnant developed economies and their more stagnant coal dependent regions, the dynamism of India's demographics and economic growth create aggregate labour market transitions which absolutely dwarf the possible employment transition in the coal sector. The "just transition" in the coal sector will therefore be determined by the success of these macro-transitions.

5. Conclusion

- **On an LCOE basis, renewables are now significantly cheaper than new coal, and cheaper than the variable costs of one half to one quarter of the existing installed coal capacity.** From an economic perspective, it would make sense to substitute new renewables for existing coal, even if sunk capital costs were treated as given (as is the case with current contract structure based on a two-part tariff). There is thus considerable opportunity to lower power costs to the economy through continued growth of renewables.
- **Even with a significant cost increment to take into account grid integration costs, renewables**

[38] From (CIL, 2018; MOSPI, 2018)

[39] TERI calculations based on data from (MHRD, 2018). We take new entrants as population members <= 17 years old, > 10 years old as of 2016.

remain highly competitive against alternative sources of generation. Our estimates, based on international meta-reviews, suggest that the grid integration cost of renewables would not reverse the relative competitiveness of renewables over coal, at the levels of penetration we are likely to see in the 2020s. However, grid integration is likely to be a significant technical challenge. The scale and speed of the transition in the coal power sector will depend on the effectiveness of these efforts to flexibilize the Indian grid. Given the importance of solar, particular importance needs to be given to storage and demand response.

- **The rate of electricity demand growth poses an additional challenge to coal sector transition.** On average between now and 2030, about 100 TWh of electricity demand will be added each year. Meeting this only from wind and solar would require annual additions in the order of 40-45GW each year between now and 2030.[40] This is challenging from the perspective of supply chain growth, land-acquisition, financing, and evacuation. At the same time, the financing, infrastructure and socio-economic conditions for coal, hydro, or gas to fill in any slack appear equally challenging.
- **The labour market impacts of coal transition do not seem to pose a challenge.** Firstly, in the Indian context, we are not talking of an abrupt decline in coal consumption, but rather a mid-term scenario of foregone growth, peak and decline. By 2030, in an aggressive renewables scenario, steam coal demand for grid power could peak. This gives time to prepare for transition, including by controlling the expansion of production and guiding new entrants away from the coal mining labour force. Secondly, India's labour market transition is so vast as to make the coal sector-specific transition a drop in the ocean.
- **Coal demand in the industry sector – captive power and final industrial consumption – are often overlooked.** Coal demand for final industry consumption is projected to grow several percentage points faster than steam coal demand, while captive power from coal could also grow significantly. More focus could be put on providing substitutes to industrial coal use, in particular biomass and electrification for industries than can further electrify industrial production.

[40] Assuming a combined wind and solar capacity factor of 25-28%.

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